Creating a more sustainable disposable diaper without compromising on user experience.

TU Delft

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Integrated Product Design
MSc. Graduation

Towards a renewable, partly reusable disposable diaper system.

MSc. Graduation Thesis
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ABSTRACT

Context

In a society where sustainability is becoming more and more relevant, disposable single use diapers are still used by 95% of parents. Every baby uses approximately 4000 diapers in their first 2,5 years of life. This is close to 160 kilos of material that is used once and then discarded. As the use of disposable diapers only increases with the increasing number of births yearly worldwide, the amount of material needed to sustain the diaper market is enormous. The Future Diaper Project initiated this research with as the main goal to develop a more sustainable disposable diaper. Can disposable diapers be designed to have lower environmental impact, reduced material use and be made renewable? To prevent the design of unusable futuristic designs an extra focus was placed on user experience. Currently disposable diapers can be named as the essence of convenience, low effort and easy disposal. Can a new diaper both be more sustainable while preserving this user experience? This project proposes a new concept to revolutionize the future of the disposable diaper market.

Approach

The main approach of this project lies in the classic double diamond model, consisting of research & analysis (discover), define, conceptualization (develop) and deliver (embodiment and final product). The research and analysis phase allowed the creation of a clear vision, list of requirements and provided a strong foundation for ideation. Through extensive desk research, talking with parents, observation and analysis of impacts through creating a diaper model (Excel) with the material database of Granta Edupack (previously CES). With a clear path ahead created by the analysis, ideation of concepts was started, generating various ideas that could reduce diaper impact. Emphasis lied on embodiment to validate concepts, as well as analyzing impact with the previously created diaper impact model. Implementing low-fidelity prototypes combined with the numerical approach of the model proved to deliver time efficient insights and results.

Results

The result of this project is a user-tested, new diaper system, that potentially reduces the CO_2 emission with 63% and the water use with 18%. The product combines three approaches of making a diaper more sustainable: reusing parts, reducing material use and changing the material composition to biobased materials. The final concept reuses parts of the diaper that most often do not get dirty in use. It combines this with separating day and night capacity of absorbency. The final step taken in this concept is the material composition, which is changed to be almost completely biobased. By being both reusable as well as disposable the diaper stays close to the convenience level parents of today count on, giving them an alternative that is more sustainable without having to compromise on convenience. The end result is a biobased and reusable and disposable diaper system stripped of all unnecessary material, that reduces environmental impact without compromising the user experience.

CONTENTS

LIST OF ABBREVIATIONS

AD layer - Acquisition Distribution layer
CO_2 - Carbon dioxide
CO_2-eq - Carbon dioxide-equivalent
EoL - End-of-life
FDP - the Future Diaper Project
LoR - List of Requirements
Low-fi - Low fidelity
PE - Polyethylene
PLA - Poly lactic acid, a biobased polymer that can be used in some applications instead of fossil-based plastics.
PP - Polypropylene
NIR sorting - Near InfraRed sorting
SAP - Super Absorbent Polymer
Starch based SAP - Biobased variant of SAP made from starch

CHAPTER 1

THE PROJECT

This project started in collaboration with the Future Diaper project. In this chapter, the main vision of this organization is explained. Out of this vision seamlessly follows the project brief and assignment.

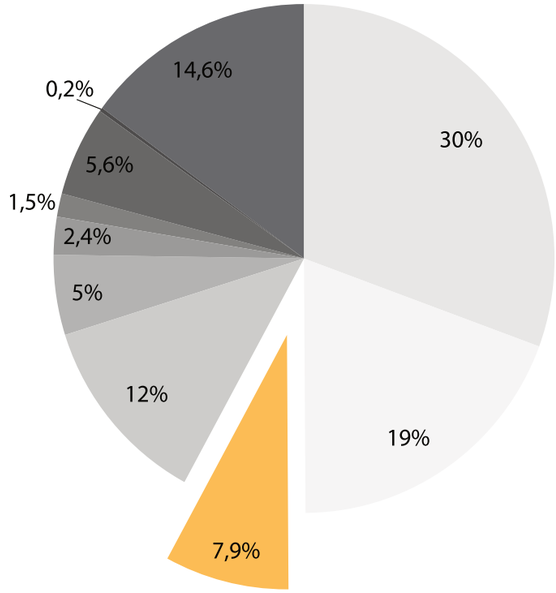
First needs to be established why a project in the department of sustainable design engineering was chosen.

THE PROBLEM

In a continuously growing society, the ever-increasing demand for materials keeps putting a bigger strain on the environment. This causes the amount of waste generated to grow, which can contaminate air, water and soil. On top of that it can also cause extra CO_2 and methane to enter the atmosphere which adds to the global warming.

It is expected that the consumption of materials will double in the coming 40 years, while the amount of trash will increase with 70% towards 2050. (OECD, 2018) Consumers, legislators and designers need to be made aware of changes that have to be made in both their behavior as in products they use or design, in order to create a circular economy. (Afvalpreventieprogramma, 2021)

The sustainable qualities of products provide added value to customers, increasing the market value simultaneously with its sustainability. (Eurobarometer, 2009): 'Slightly more than 8 in 10 EU citizens feel that a product's impact on the environment is an important element when deciding which products to buy.' However, it should be noted that on the other hand the consumer is not willing to buy an inferior product just because it is a product with a lower impact. 'Only a minority [of consumers] rate environmental impact as more important than a product's quality or price'. (Meyer, 2001)



19% Paper and cardboard

30% Biodegradable waste

12% Plastics

5% Glass

2,4% Ferrous waste

1,5% Non-ferrous waste

5,6% Textiles

0,2% Small chemical waste

14,6% Other

7,9% Diaper material

Figure 01) The waste distribution in the Netherlands 2019 (Rijkswaterstaat Afvalmonitor)

To reduce our trash problem, we first need to know what it is consisting of. A little over 30 percent consists of organic waste, making up the biggest waste stream.

Second biggest is paper and cardboard, which is separately collected from the municipal waste.

As the third biggest waste stream we find baby diapers to make up a 7.9 percent of our waste stream. (Rijkswaterstaat afvalmonitor 2019) Each year it accounts for 160 million kilograms of used diaper waste in the Netherlands alone. This huge amount of trash consists 75% out of urine and feces, but this still makes up 40 million kilograms of single use diaper material. (RIVM 2016) They are not separately collected on a national scale at this time as there is no viable way to recycle them. This represents an important loss of material resources as well as a source of environmental pollution.

MY OWN VISION

As a designer I feel the need to design to improve products on all aspects. I value simple thoughtful designed products over flashy new gadgets.

We live in a society where it has become a trend to buy a product and throw it away in the same day, even if it was meant to last. With this throwaway mentality we lack products that last or products that are designed to be disposable. (Hellmann & Luedicke, 2018)

We need to move beyond this throwaway mentality by designing products with full awareness of their lifespan. Design needs to promote ways of consumption which spare resources. Informed design where the designer bridges the gap between knowledge and use case. Designers need to be aware of the cost of the materials that go into a product and their durability. Then it is the designer's duty to design the product in such a way that it justifies its material choice and quantity over the use period. Designing a bike that reduces material consumption can only be beneficial when the bike lasts as long, or longer, as a normal bike.
Not only material consumption, but also the end-of-life of the product needs to be well considered. A designer needs to be knowledgeable in where the product goes when it reaches the end of its service life. A clear choice needs to be made in the design process on whether there are recycling options, composting possibilities and the cost of incineration. We cannot naively suppose that everything gets recycled to its full extent, possibilities and infrastructures need to be analyzed before placing a product on the market. (Cooper, 2016)

It is my vision to contribute to this, by gaining a deep knowledge and understanding of the impact a design can make both environmentally and to the user. Next to this I choose to work on projects that focus on creating more sustainable products. I want to utilize my design skills to make products that function, while being more sustainable.

THE COMPANY

This project is done in collaboration with The Future Diaper project, a non-profit organization that is committed to making changes to the diaper market by making diaper usage more sustainable. Through collaboration with universities, manufacturers and researchers, they support research into diaper use and design. The focus of research is aimed at making both the disposable diaper as well as diaper use more sustainable. Concepts and ideas that follow out of these research projects set a path for the future.

Next to this non-profit organization the Future Diaper Project has started a commercial venture, Toddy, that takes the first step towards their mission focus areas. A product service that delivers a chosen number of disposable diapers, that is used in combination with washable diapers. The disposables from Toddy are already partly bio-based, to use the littlest amount of fossil-based plastic. Toddy's main goal is to, with its customers, set small steps into a more sustainable direction, with possibilities available now. Small steps with large amounts of people instead of big radical steps with only a small amount of people, to make the largest impact possible.

The Future Diaper Project works towards more sustainable diapers to reduce material use and waste. Their ultimate goal is to get rid of diaper waste in 2030. Their current three main focus areas are to guide the progress into the right direction. These directions are:

1 *Shortening the time period diapers are used, through earlier potty training.*

Currently children use on average 4000 diapers before they are potty trained. (Environment Agency, 2004) (Mendoza et al., 2019) In the last 40 years the age at which children stop wearing diapers has increased 1,5 years on average. (Bakker & Wyndaele, 2000) (Future Diaper Project) The onset of potty training has been delayed significantly, as well as potty training methods that have changed. Maturity signals that are indicators for starting potty training, are missed but also have changed. A method where potty training is adapted to the child need is more popular now (Blum et al., 2004; Choby & George, 2008). Diapers have changed over these decades, as well as parents work schedules. Are there ways in which we can bring down the potty trained age to be able to save on materials?

2 *Reducing material consumption through reducing the use of disposable diapers.*

Can we convince parents to use less disposable diapers by using washable diapers? The washable diapers have been developing and have evolved from a cotton towel that has to be folded and is leaking constantly to a preformed solution that is more foolproof. Can new methods or services be designed so more parents start using cloth diapers?

3 *Decrease disposable diaper impact through rematerializing and redesigning.*

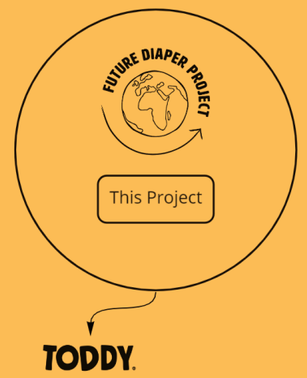
The current disposable diaper consists out of a mix of fossil-based plastics that cannot be used in a meaningful way in a recycling process. Can we design a diaper that allows for a better end-of-life scenario? Can the diaper be redesigned so it uses less material?

CONCLUSIONS

My graduation project will focus on the third mission statement. Through exploring new possibilities of making disposable diapers more sustainable, I am going to show new directions the diaper market could go into.

All new concepts need to decrease the disposable diaper impact through rematerializing and redesigning the form of the disposable diaper or the way we use the it.

The main outcome is going to set an example of new possibilities that would be viable on the disposable diaper market. The Future Diaper Project could start a venture in which they develop the concept further into production, but this is not the goal of this project. The project will convince and call the diaper market to action, through showing viable, more sustainable concepts. It should stand as a vision towards sustainability, and a guiding-line for the FDP to strive for a truly sustainable diaper.



PROJECT GOAL

In this master graduation project, the focus will be on the disposable diaper. Even though washable cloth diapers use less material than these disposable diapers, there is an impact shift with the use of the cloth diapers. When laundering cloth diapers, a lot of water and energy is used to wash them clean. Also, detergent and the way the diapers are dried after washing has a possible impact, especially when using a tumble dryer. A recent UN report (UNEP, 2021) gives more insight into the difference in impact between disposable diapers and reusable cloth diapers. If all impact categories are taken into account, there is no clear better diapering method.

Almost all parents that choose to use washable diapers also step out to using disposable diapers from time to time (88 percent). (Pocock et al., 2005) There could be various reasons for using disposables on occasion as going on holiday, at daycare, when tended to by grandparents and during nights. Both the leak free nature of disposable diapers as well as their convenience takes priority on occasion. This shows that even if the market would move towards reusable diapers more, there would always be a need for disposable diapers.

This project will focus on making their impact smaller. All aspects of the diaper will be involved, but the center of energy will be on material composition and decreasing material use. Reducing the amount of fossil based material used, while enabling recycling and decreasing waste.

A redesign of the current diaper will be performed, with the consumer needs up front. Because a more sustainable product that does not deliver a comparable quality and function to its less sustainable counterpart, is non-desirable for consumers. A diaper that is both more sustainable without compromising on function and experience, is the ultimate goal.

ASSIGNMENT

The end goal of this project is to have a viable concept that has a smaller impact than the current disposable diaper. Through looking at possibilities for recycling, rematerializing and redesigning the disposable diaper, new ideas will be explored to make it more sustainable. In all concepts impact, end-of-life as well as user experience will be evaluated through prototyping and testing.

The main aim is to investigate and explore new design possibilities for the disposable diaper.

“To design a more sustainable disposable diaper, without compromising on user experience.”

THE APPROACH

For this graduation project of 6 months, a rendition of the classic double diamond approach to design will be used as a foundation to structure the process and planning. As the diaper is a complicated product consisting of various materials and functions, first an extensive desk research into materials and their environmental impacts needs to be completed, to create a diaper material model (in Excel with the use of Granta Edupack). This model can later be adjusted to evaluate concepts. Talking with parents is also an important part of this phase, to get an understanding of their current diaper choice as well as their frustrations and concerns. Potential new materials as well as differentiating products on the current diaper market will also be evaluated.

After the analysis and research phase, a clear understanding of the problem will be gained. It will serve as a stepping stone to define the vision and the list of requirements. The vision will need to reflect the FDP's company goals to set a clear path for conceptualization. The list of requirements will later be used as a method of evaluation of concepts.

The third phase will be focused on ideation and the creation of various concepts. Multiple ideation methods will be used to gather ideas. These ideas will all be low-fi prototyped, analyzed, or otherwise evaluated for viability. When possible and safe, real babies will be involved in trying on new concepts and testing ideas. At the end of this phase, a list of concepts will be available to possibly pick from, or combine from to create the final concept.

The final phase will be focused on picking or combining concepts to develop the final concept. This concept will reflect the most viable idea that fits best with the vision and list of requirements. In this phase better prototypes will be built, (long-term) (user) tests will be done.

At the end of the project a future vision will be given together with recommendations to the FDP, so they can be built further on the progress made in this graduation project to create a more sustainable diaper.

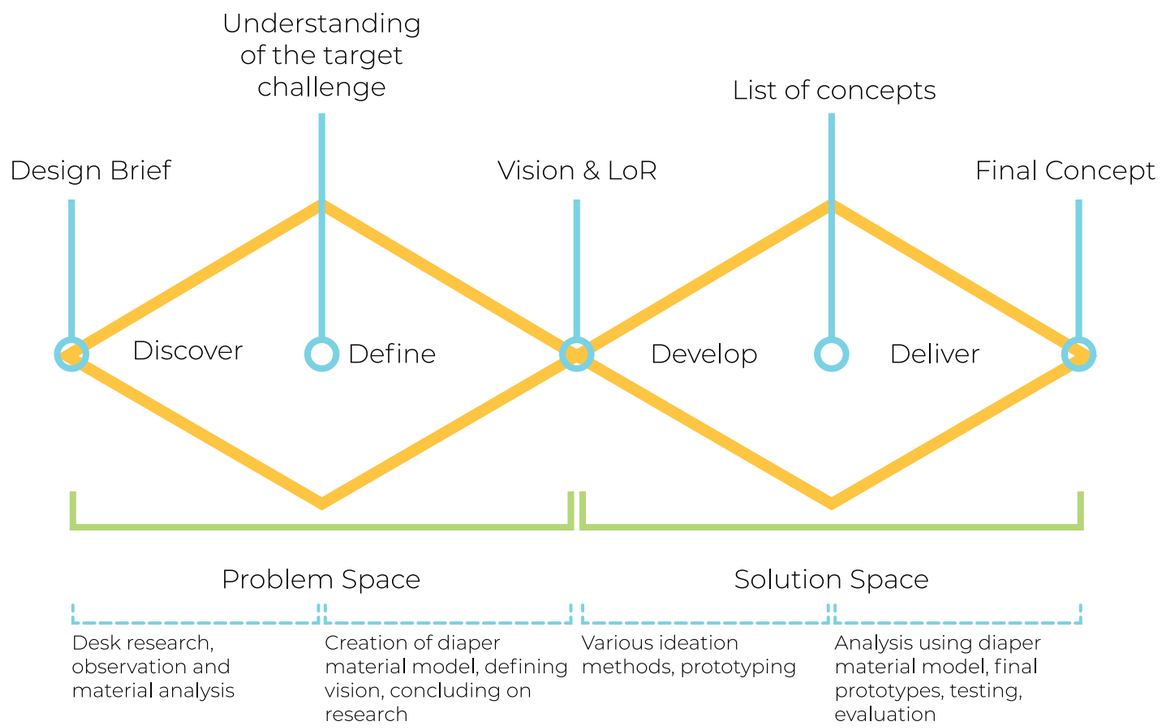


Figure 02) The envisioned process for this project. A classic double diamond structure edited slightly to fit the development of a future diaper. At midterm the development phase should be started, at the graduation presentation the final concept should be defined, analysed and tested. The double diamond is my own rendition based on the classic double diamond by UK Design Council, 2019.

CHAPTER 2

THE DIAPER

In order to redesign the diaper to be more sustainable, a clear understanding of the current diaper and its parts is required. A history was put together through the use of literature to be able to see how the diaper came to be. Through taking apart multiple diapers from various brands and looking at previous literature, a physical analysis was created. Also, current end-of-life possibilities are explored. The goal of this chapter is to get a proper understanding of parts and functionalities of the current diaper.

DIAPER HISTORY

By looking into the history of development of the diaper, the goal is to find patterns and drivers for new concepts, that can tell us what is important in the design of a future diaper.

Diapers existed already in ancient times, as historical documentation suggests, mothers used to wrap their babies in milkweed leaf, animal skins or moss to prevent disease and protect them from the elements. In warmer climates diapers were not used at all. In Aboriginal clans, moss and animal skin was used to absorb the urine, while in South America similarly dried plants were used in old cloth. In China mothers learned to feel peristaltic movement, to then hold their baby over a pot or even out a window. (Krafchik, 2016)

In the second half of the 16th century, two different styles came to exist in the greater Europe region. Babies were either wearing long gowns so they could go anywhere, or were wearing linen cloths. These styles later became more and more popular all over the world. Diapering practices in Europe did not change significantly until industrial revolution around 1820. In this period the middle class started to buy furniture. They did not want their infants to destroy their new possessions, which evolved into more strategic wrapping and folding of cloth to protect furniture, clothing and carpet. Towards the late 19th century safety pins became more popular to secure the cloth diapers, but often these diapers leaked. (Levin, 1970) These diapers were gathered in bins for washing. The cloths that were kept in these bins were often a source for bacteria and smells. Towards the early 20th century plastic pants came on the market to provide a more leak proof experience.

Figure 03) Jan Miense Molenaer, 1637

In the 20th century the first disposable diapers, or then called destroyable babies' napkins, were invented. Both paper diapers as well as the first two-part systems were brought to market. The system Paddi was one of these and consisted out of a disposable pad combined with a plastic garment with snaps. Initially parachutes were used to create the garments. Paddi was patented and brought to shops all over the UK. (PADDI the First Disposable Nappy Diaper, 2014)

After the second world war the movement of women wanting more freedom increased the demand for disposable diapers. They wanted more time for work and travel, and the washable diaper did not meet their wishes. (Smithsonian Lemelson Center, 2000) During the 1950s this demand was met with the development of disposable diapers by multiple players. (Procter & Gamble, J&J Kendall, Parke-Davis, Playtex) P&G invented what would later be named Pampers, which came to market in 1961. (No. 2464: Engineering Diapers, 2016)

In the coming decades the disposable diaper industry exploded and became extremely competitive. Innovations were made to improve function in terms of fit and containment. The last mayor diaper innovation was the invention of super-absorbents, or SAP, which reduced the amount of fluff needed, and improved the ability of the diaper to hold liquid. (P&G 2014)

The composition of diapers has changed significantly in the last 20 years, and technical improvements have enabled the production of lighter and smaller diapers. This is mostly caused by using less fluff and more SAP to create a more compact absorbent core. (Torrijos er al., 2014) (Juarez and Garcia, 1989)

CONCLUSION

You may ask yourself how the knowledge of the history of diaper development can benefit the design of a future diaper. By analyzing this history, there are patterns to be found. It can be concluded that all diaper development thus far has been driven by the desire for convenience. It originated in protecting the baby, as we can see in the earliest versions of a diaper, to prevent disease. All further development of this original idea is driven by the need for convenience. People wanted the ease of use; they wanted the process to be cleaner and most of all less work. This must be an important driver in designing new concepts for diapers.

DIAPER FUNCTION

The functions of a diaper can be put into 3 main categories. These functionality groups are all of vital importance for the overall performance of the diaper, but making the division allows us to take a step back and get a clear overview of the diaper first, before diving into the different parts.

* *Absorbtion*

The most vital function of a diaper is to absorb the urine and feces produced by a baby. The vital qualities are the absorbing speed and liquid retention quantity. The speed is important as the baby is going to excrete urine in multiple peaks throughout the day. When the absorption speed is not high enough the diaper would leak. Retention is important for the lifetime of the diaper. The lower the retention quantity of a diaper, the quicker it is full and needs a change.

* *Fit*

The fit is key to making a diaper work correctly. When a diaper is ill fitted, it is prone to leaking or can cause skin marks on the baby. A good fitted diaper helps with containment, especially when the fit is flexible. Not only does it prevent gaping when the baby moves around, it ensures that all babies fit the diaper. As babies come in a lot of shapes and sizes, a resizable mechanism is key to making a diaper wearable and fitted correctly.

* *Containment*

This category consists out of all parts of the diaper that are needed for the containment of the baby's feces and urine. They also keep other elements in place, like the fitting mechanism, to ensure containment. This category is the one in constant contact with the baby's skin, therefore it has critical limitations, on which will be elaborated on further in Chapter 3 User.

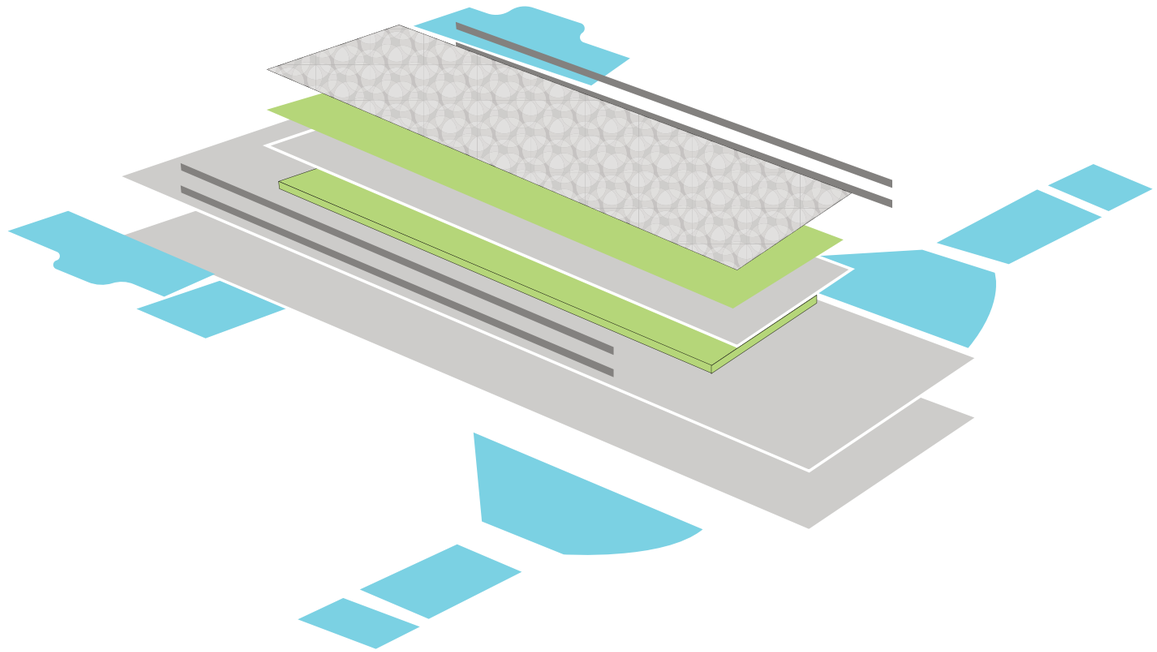


Figure 04) Diaper content in function groups. Gray: Containment, Blue: Fit, Green: Absorbtion.

DIAPER PARTS

Current diapers differ slightly over different brands and models, but are to a large extent the same. The average diaper is a layered construction consisting out of a top sheet, acquisition distribution layer (AD layer), core wrap, absorbent core, containment flaps with elastic, back sheet, leg cuff and fasteners. (EDANA 2019) These parts will be discussed one by one to develop a clear understanding of how this seemingly simple product is build up. From the bottom to the top, or from the outside of the diaper to the layer that touches the baby, all parts will be described.

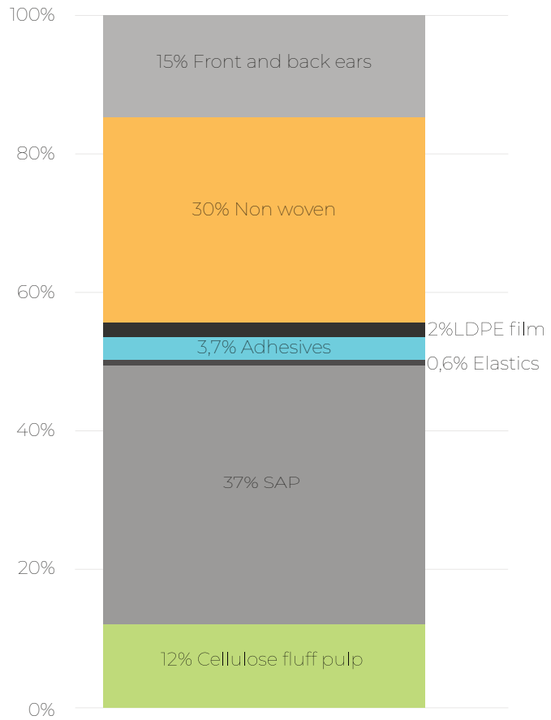


Figure 05) The composition of a diaper. Averaged out from both own weighing as well as EDANA, 2019

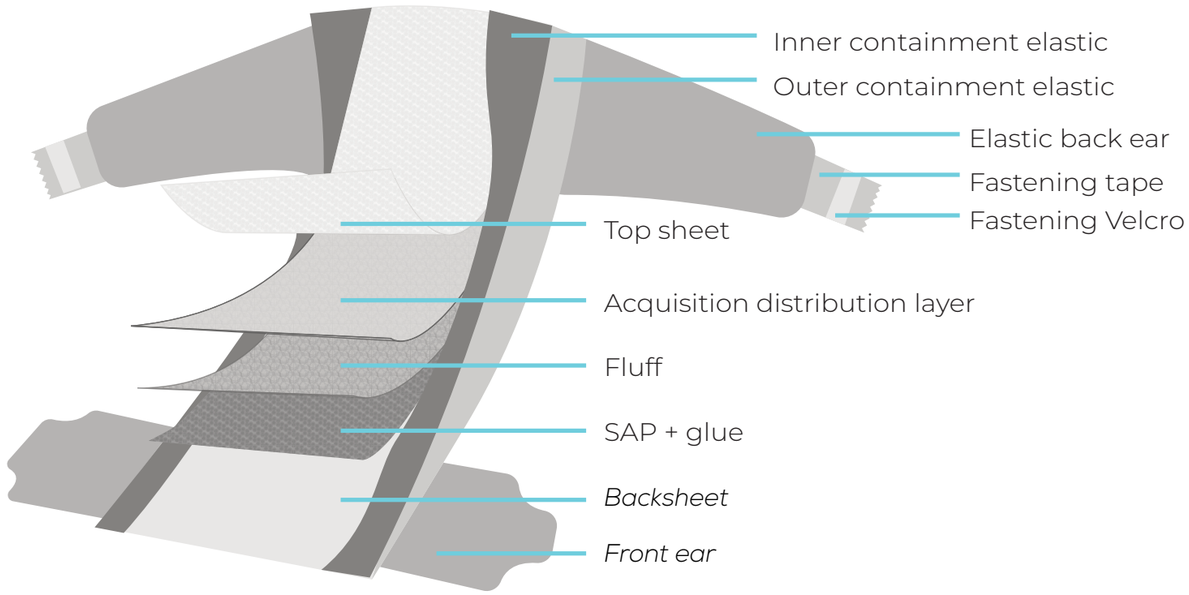


Figure 06) Diaper parts:
Inner and outer containment elastic, made from elastane wrapped in non-woven.
Elastic back ear, made from elastane film sandwiched in between two layers of non-woven material.
Fastening tape, made from non-woven material, with attached to it a fastening Velcro.
Top sheet, made from soft non-woven material, often containing lotion products.
AD Layer, made from a plastic fiber mesh, shaped wide to tight to utilize capillary action.
Fluff, a quick absorbing layer that is made from organic fibers, most often from wood.
SAP layer, which absorbs urine and transforms into a gel. It is made from sodium polyacrylate crystals. These crystals are held in place on the back sheet or to an extra non-woven layer with glue.
The back sheet is made from a layer of plastic film with a layer of non-woven on top.
The front ears are made from a non-elastic non-woven.

The main outside structure of the disposable diaper is made out of a non-woven fabric. Non-woven are made out of Polypropylene (PP) and make up most of the structural elements. (The back and front ears, outside structure, core wrap and the cover of the elastics) The non-woven material is built out of plastic fibers, that are molten and entangled together. The main benefit of this material is that it is light, soft to the touch but never loses structural integrity when wet. This material is also porous and not watertight, which is why, to contain all urine and feces in the diaper, the back sheet serves to keep all the moisture inside the absorbent core. This back sheet is made out of a polyethylene film. (PE) The film and non-woven layers are bonded together through heat and heat activated glue.

Located on top of the film is the absorbent core, which is the part that facilitates the absorption functionality in the diaper. The main component of this core is Super Absorbent Polymer or SAP, which is most often sodium polyacrylate. (RIVM 2016, Mendoza et al., 2019) This is a polymer which can absorb liquid worth up to 100 times its own weight. (Bachra et al., 2020) (Wambui et al., 2014) When still dry, SAPs look like transparent crystals. These are glued into formation to the core wrap. When in use, the crystals absorb the liquid, causing them to swell up and form a gel. This gel is highly durable and does not leak its moisture under pressure. (Helmes et al., 2014) The average diaper has enough SAP to absorb up to 450 milliliters of urine, (EDANA, n.d.) which is way over the amount of urine a baby produces. (More on this in Chapter 3, Baby output) This over dimensioning of the diaper is to reduce leaks even when the diaper was not changed within the regular timeframe. The SAP doesn't have the absorption capacity that is as quick as is needed for the diaper to not leak. Therefore fluff, mostly fabricated out of natural fibers (bamboo or wood pulp) (EDANA, 2019) is needed to be able to obtain all the liquid and capture it in the absorbent core.

The function of the SAP is optimized by use of the acquisition and distribution (AD) layer made out of a non-woven mesh layer. This AD layer which is in between the top sheet and the absorbent core facilitates the fast intake and distribution over the SAP and fluff layers. It prevents centralized wetness, that could cause leaks. These non-woven mesh layers utilize capillary principles to draw moisture away from the baby, toward the absorbent core. The dry environment this provides against the baby's skin is vital, as it prevents rashes and irritation. (Adam, 2008)

The top layer of the diaper is made out of a on one side hydrophobic material, and a hydrophilic on the other. This two-sided material is key to keeping the skin of the baby dry. It is the part that has the most contact with the baby and in some brands even contains a lotion product on it to care for the baby's skin. This top layer is important to prevent diaper rashes, as the layers underneath are harsh to the skin and will not repel moisture.

The diaper as a whole has one important issue to overcome that has not been explained so far. The top layer, AD and absorbent core work together to prevent a phenomenon called rewetting. When a diaper is in use a baby moves around and pressure points shift over the diaper. When these pressure points shift, there is a risk of the diaper's already captured moisture to return to the surface of the diaper. This could result in the diaper leaking, or causing an even more humid environment for the baby's skin, which could in turn cause heavy diaper rashes. These rashes will be further discussed in the next chapter about the User.

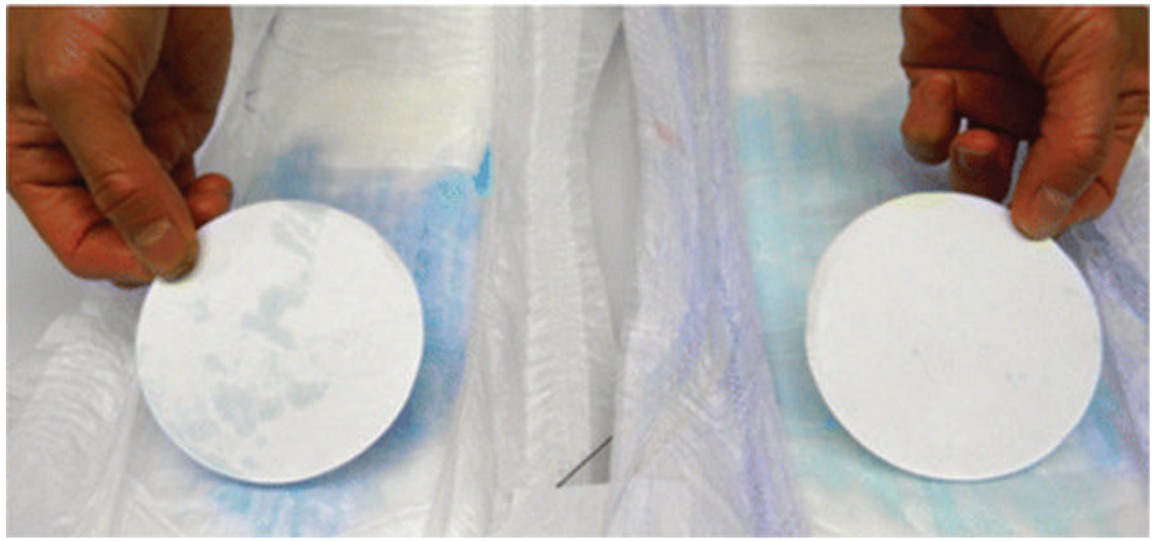


Figure 07) Rewetting comparison. (Helmes et al., 2014) As most diapers differ in composition, they also have different retention qualities. In the image can be seen that the retention of the diaper on the left is much lower than the diaper on the right. The rewetting value is therefore higher on the left, which will increase the risk of diaper dermatitis.

END-OF-LIFE

In our current way of living, diapers get thrown away together with all other non-separatable municipal waste. This waste stream is brought to an incineration plant, where it is destroyed by fire, recovering energy. What is left is called fly ash and ground ash, which are both used in building applications like cement filler.

The diaper waste does not consist out of only diapers. The weight of used diapers can primarily be allotted to urine. (EDANA, 2007) (Colón et al., 2011) The urine per diaper will always be an estimated and averaged number (see chapter 3, baby output), but will contribute 75% of the weight of the diaper waste.

Table 01) The contents of a diapers when disposed. (Colón et al., 2011)

Material	Weight (kg)	Weight percentage
Non organic material	0.027	12,74%
Fluff, organic pulp	0.014	6,60%
Feaces	0.010	4,72%
Urine	0.161	75,37%

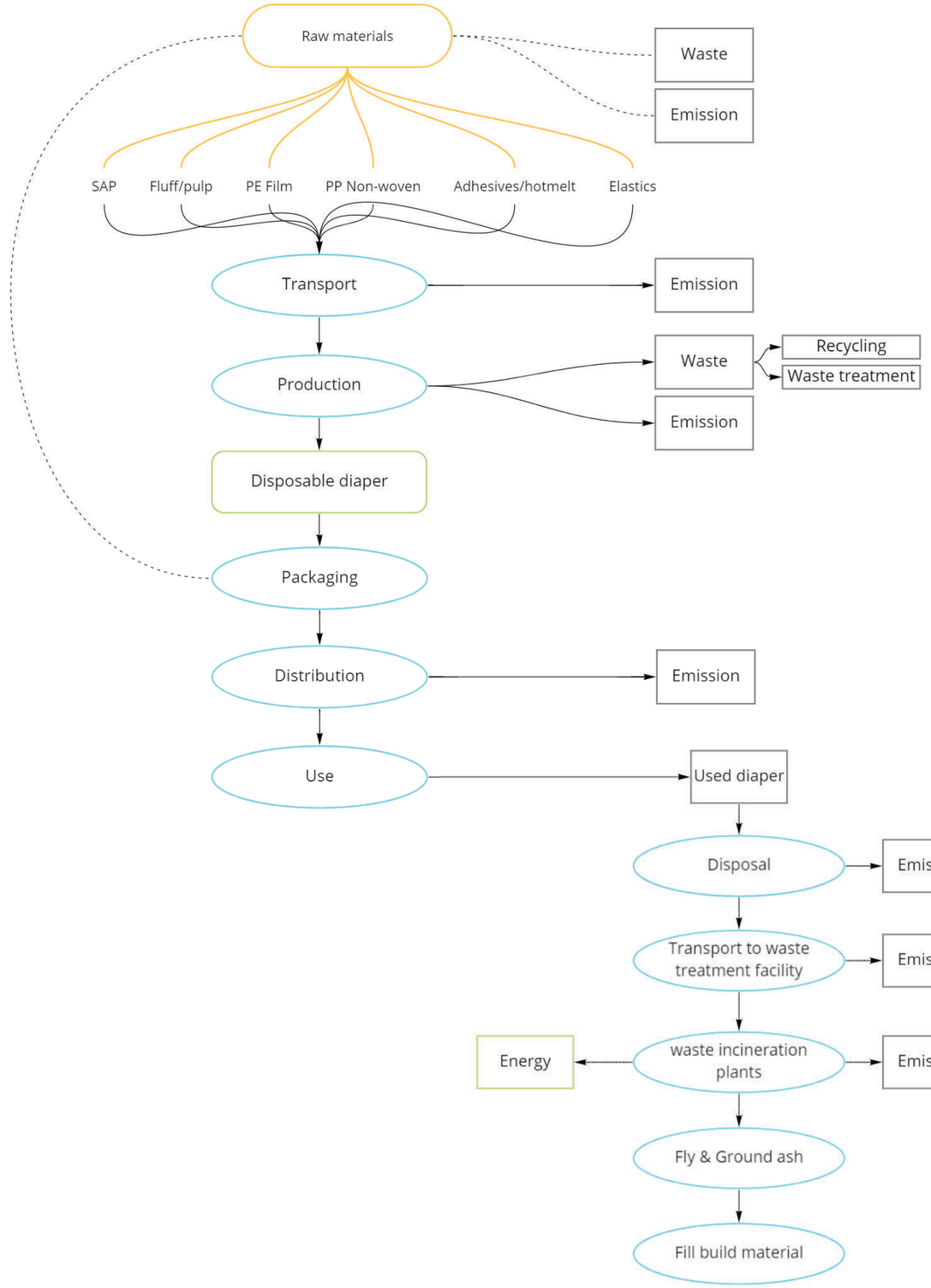


Figure 08) The production and incineration of a diaper.

An alternative to incineration is currently up and running by ARN, which uses a technology called thermal pressure hydrolysis (TPH). (CE Delft, 2021) In this waste management system the diapers get collected separately, after which they are shredded and heated with steam up to 250 degrees Celsius. In the tank in which this process takes place, the organic materials, consisting of both the fluff and excrement, hydrolyze, and return to simple molecular components, while the plastics melt, stick together and float to the top. This plastic component is then granulized and can be used for various products. The remaining hydrolyzed slurry goes into a digester, which will generate biogas over time. The left-over slurry that comes out of the digester is incinerated with energy recovery. This could be used as a fertilizer, but there is currently no market for diaper compost. There are concerns about pathogens and medicine traces. (Spijker et al., 2016)

Currently the output of plastic granulate is of low quality, as it is a mixed waste stream. To be able to recycle this plastic valuably, a market has to be found for the recycled granulate. As the end product can suffer from differing quality, lower mechanical properties and still be almost as expensive as virgin plastic, it is not always an attractive option for manufacturers. (Green Chem, 2020)

Recycling plastics is thus an option to reduce overall plastic waste production, and save on loss of material. The downside of this is the reduced quality of the recycled granulate. (CE Delft, 2021) (Green Chem, 2020) After a few cycles of recycling, plastic also reduces in quality, it simply reaches the end of the service life. Therefore, the process of recycling always generates waste when the material is at the end of its multi-recycling cycle. Therefore, an alternative method is needed to accommodate for this waste stream.

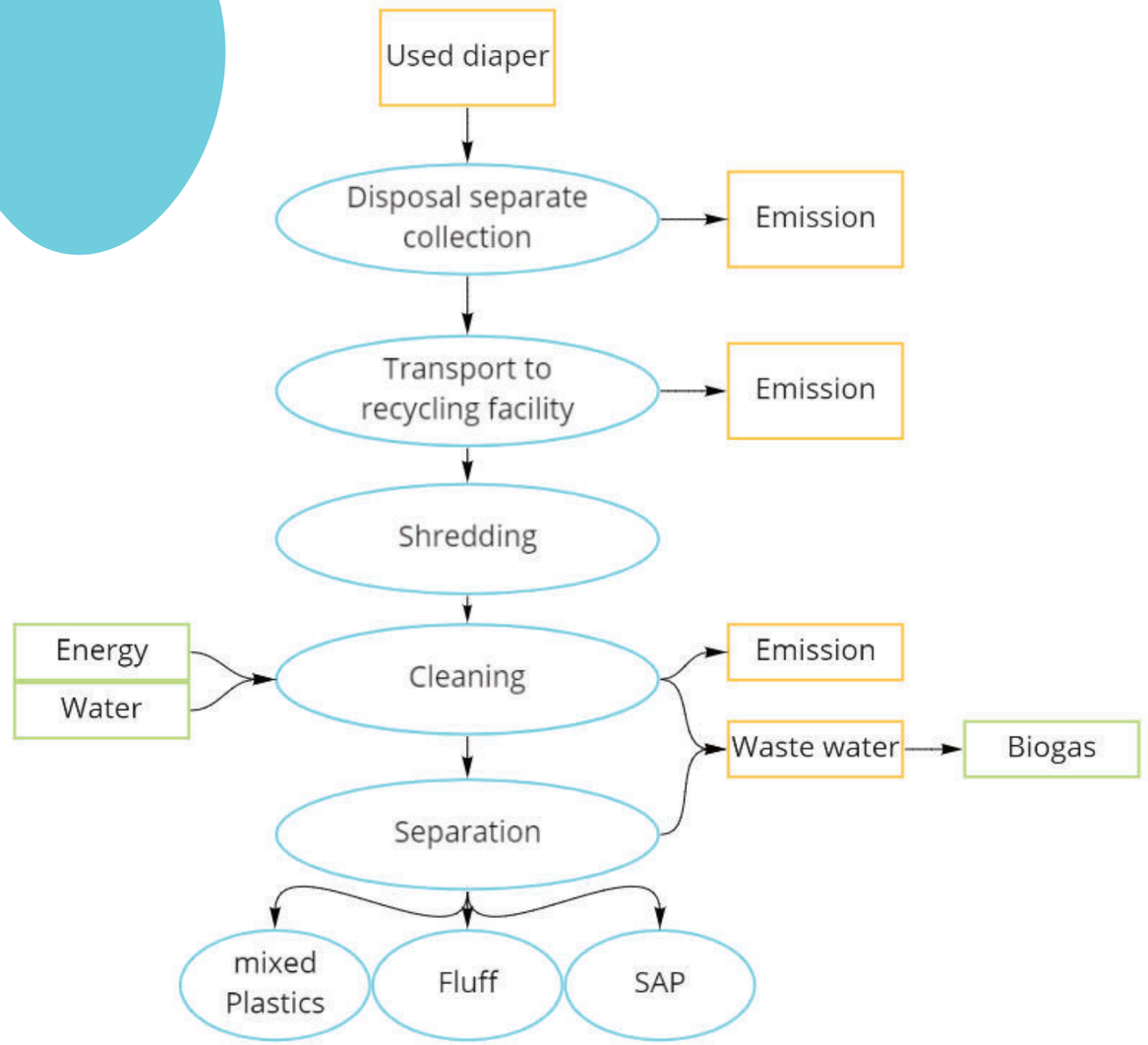


Figure 09) The recycling and digesting process of a disposable diaper at ARN.

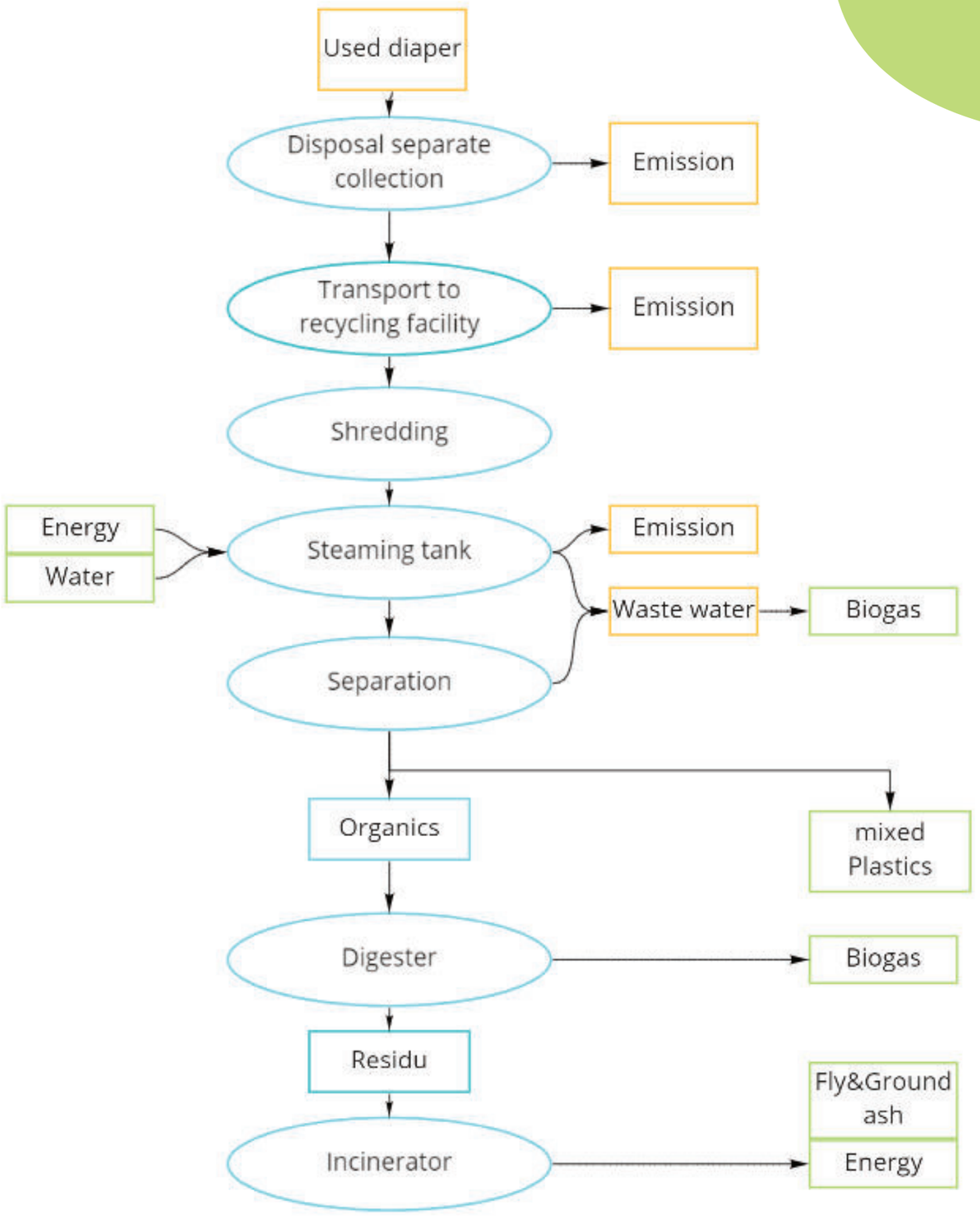


Figure 10) The recycling process of a disposable diaper at Fater in Italy.

The only other waste treatment plant that has proven to work is in Italy, which uses another method to mostly separate waste streams instead of pressurizing them in tanks. The shredded diapers are sterilized in an autoclave and separated through differences in density. (Arena et al., 2016)

However, there are some problems with the remaining streams. It is hard to separate the fluff and SAP particles. (Kim and Cho 2017) Also, the plastic waste stream is again not clean enough to create high quality plastic. In Italy, there is also an issue with legislation, which for this waste treatment plant has the consequence of not being allowed to sell the resulting materials as new materials. Through legislation recycled diaper material will always be considered waste.

CONCLUSION

As currently almost all diapers are incinerated, we suffer a tremendous loss of fossil-based plastic. The new methods currently available for recycling and digesting are not full solutions for this problem. Also, any new method will most likely deal with the same issues that the current plants deal with. For this project this displays that new concepts could be developed that solve recycling issues as per example the separation of the materials. It also shows that diapers are currently not designed to have any end-of-life other than incineration or landfilling. Are there new opportunities to be found in the design of the diaper in order to better the end-of-life? Can materials be switched out for others to improve impacts?

CURRENT IMPACT

To be able to compare future concepts to the current scenario, an inventory needs to be done of current impacts. Most important are material impacts and quantities, as they can be guiding factors for new concepts. In this chapter the impact of a disposable diaper is quantified to investigate the size of the worldwide problem.

To begin this investigation, the impact of a single disposable diaper was quantified by weighing the different parts. Through using the EDANA (global non-woven association) composition datasheet the material type was determined. In the GRANTA database the impact per material type was looked up to be able to create a material graph.

This graph assesses the water use and CO_2 footprint of the production of the materials and the combustion CO_2 that is released when incinerated. The production of the materials has a contributing factor of approximately 80% in the disposable diaper. (Mendoza et al. 2019)

The end-of-life scenario also impacts the final footprint of the diaper. Recycling a single use diaper will cause a lower impact environmentally compared to incinerating or landfilling. (Arena et al. 2016) The main benefits of recycling are lower non-renewable resource depletion and decreased emission. (UNEP et al., 2021) The same material is pointed to as the main beneficial sort to recycle: Plastics. After recycling the next best end-of-life scenario is incineration with energy recovery. ((UNEP et al., 2021; GRANTA database) Especially when diapers are co-incinerated with other municipal waste with energy recovery, the method comes close to recycling. The similar results from these two methods are due to the extra need for sterilization with steam. (Arena et al. 2016) Currently the infrastructure for recycling diapers and collecting them separate from municipal waste is not in place. With any system comes contamination of the waste stream, as both human as well as system sorting will never be perfect. (Itsubo et al. 2020)

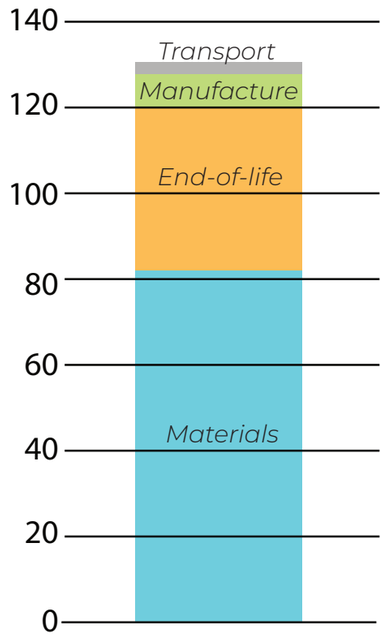


Figure 11) Total GWP per 1000 diapers in kg CO_2 (adapted from Mendoza et al. 2019)

Table 02) Impact of materials and incineration of 1 diaper

Component	Material type	Weight per diaper in kg	Production Water usage per diaper in liter	Production CO_2 Footprint per diaper in kg	Incineration Footprint per diaper
Fluff pulp	Wood fiber (pine)	0,005	3,500	0,002	0,009
SAP	Sodium Acrylate	0,0151	0,605	0,055	0,012
Elastics	PUR	0,0003	0,025	0,001	0,001
Adhesives	SBS	0,0015	0,219	0,005	0,005
Plastic film	LDPE	0,0009	0,064	0,002	0,003
Non-woven	PP	0,012	0,470	0,035	0,038
Tape	PP	0,006	0,235	0,018	0,019
Total		0,04	5,119	0,1168	0,086

From the study (Mendoza et al. 2019) it can be gathered that the manufacturing of 1 diaper costs 12 kJ. The manufacturing of diapers contributes less than 2% of its total impacts. For this project that means that the manufacturing impact is not going to be evaluated as it is such a small percentage. (UNEP et al., 2021)

Transportation emission can be split into multiple categories: Raw material transportation, Production waste transportation, final product transportation and end-of-life waste transportation. The two greatest categories are the raw materials and the final product transportation impacts. Even though the disposed diapers are much heavier per unit, due to urine and feces, the distance to the nearest waste treatment plant is much shorter as they are local compared to a factory. However, just as the by manufacturing created emission the impact of the transport is negligible compared to material production and end-of-life. See figure 11 (Cordella et al. 2015) This concludes that the main impact of the diaper is thus due to its material composition, weight and the way it is disposed.

CONCLUSION

The main take away for this project here are the areas that should be focussed on. The manufacturing and transport of the disposable diaper have minimal impact on the total global warming potential. It is much more valuable to reduce the impact of the primary materials and the end-of-life. This is thus where the key focus of the ideation will lie.

REUSABLE DIAPERS

Disposable diapers are currently used all over the world. There is lots of speculation about if reusable or washable diapers are better for the environment. In a report from the UN, we can find a clearer unbiased answer. (UNEP et al., 2021) Through an LCA study the use of single use diapers is compared to washable diapers.

The conclusion consists of a few main points: The impact of single use diapers and washable diapers are comparable, but the impact is in different times of their lifecycle. The reusable diapers perform better in terms of material use, but cost more water and energy during the use period. The disposable diapers cost more material and have more impact in the end-of-life, but don't use water or energy during use. (UN Environment Program, 2021)

A difference can be made during the use of washable cloth diapers in choosing water temperature of the laundry cycle and line drying instead of tumble drying. (TEST Survey Environmental Agency UK)

The main two reasons that parents choose to use cloth diapers is to save money and to waste less material/ generate less trash. Currently a small 5% of parents with children using diapers are using cloth diapers. (NDBN, 2019; Pocock et al., 2005) Of these parents, 88 percent also say that they use disposables from time to time. The main two reasons to step out from the washable diaper are 1; during night time, to prevent leaking during this longer period of using 1 diaper, and 2; when away from home.

The fact that parents are stepping out from washable diapers, is very interesting to this project. This means that there will always be a market for disposable diapers, not only for their convenience factor, but also in a hybrid use with both cloth diapers as well as disposable diapers.

Photo from babylist

CONCLUSIONS & REQUIREMENTS

- The main three functions of a diaper are containment, fit and absorption.

- The fit of a diaper is key to containment. Elastics allow for movement of the baby while providing the same level of reliability. A flexible fitting mechanism will allow a diaper to be adjusted to each individual baby, with less sizes.

- A diaper has a certain retention quantity, which is dependent on the amount of fluff and SAP it contains. This quantity is most often a lot more than what it holds when the diaper is changed.

- A diaper is built by hot melting a lot of different materials together, both organic as inorganic. This makes it a difficult product to recycle. Especially the plastic in diapers has a high potential for it to be recycled. Also, pathogen contamination is a consumer worry in the composting or recycling of diaper products. That is why almost all diapers are currently incinerated or landfilled.

- Throughout history the key driver of diaper development and innovation has been convenience. Over the years diapers have evolved to not leak, not soil any furniture or belongings, and users have been able to increasingly trust the functionality.

P.3 - The diaper can hold normal consistency bowel movements within the product. (1 in 40 can leak due to consistency of stool)

M.2 - The diaper must use less material (in weight) in use than a normal disposable diaper.

S.1 - The diaper is durable enough to hold up in between changes.

S.2 - The diaper cannot tear when the baby is moving.

E.1 - The diaper should fit all babies in between 0 and 36 months, through multiple sizes and a flexible closing mechanism.

E.2 - The diaper must allow for the material to stretch around the waist to allow for breathing and movements.

U.1 - The diaper must be easy and convenient in use and therefore not require extra items to launder, more than once a week.

CHAPTER 3

THE USER

After getting an in depth understanding of the current diaper, a deep dive into the user is needed. The user of the diaper is mainly the baby, but the parent is the decision maker. Both their needs need to be addressed in order to create a successful new product. In this chapter the way we use disposable diapers and in what quantities will be talked about.

Through both literature as well as observation of diaper changes, the main needs and current pains are concluded. The main goal of this chapter is to get a deeper understanding of the user, next to the understanding of the disposable diaper we already gained. During ideation the user needs need to be addressed as well as building the new disposable diaper.

CURRENT DIAPER USE

This project is focused on creating a more sustainable disposable diaper as there is a persistent large user base for them, one that will most likely never go away completely, as said in the previous chapter, even with the use of washable diapers disposable diapers are used from time to time. With the average amount of births per year slowly increasing, by approximately 1% per year, (World Demographics 2020 (Population, Age, Sex, Trends) - Worldometer, n.d.) the demand for diapers of any kind will keep increasing. This accounts to a total of 140 million babies every year. Multiple diapers are used daily for a prolonged period of time, without the ability for the user to reuse to reduce their disposable diaper consumption. On average a child uses 4.16 disposable diapers every day. (Environment Agency, 2004) This accounts for the difference between the amount of diaper changes on an infant and on an older child, but assumes that all children over the age of 2.5 years old do not use diapers anymore. Of the used diapers, approximately 2 of them contained a bowel movement daily.

Changing manual from kidsit.com

If we calculate this further into the child's full diapering lifetime, the total number of diapers is (4.16*365*2.5) 3796. As stated in the previous chapter a clean diaper weighs 0,04 kilograms, bringing the material usage per child in disposable diapers to (0,04Kg*3796) 152 Kg. However, these numbers can be specified more by looking at the amount of diaper changes per baby's age. In the next chapter the baby's production of urine and their bowel movements will be compared to this diaper use.

The insight into the current amount of diapers that are used every day will be important later when designing concepts. Knowing average numbers will help in the design of a disposable diaper, and in calculating impacts over a day of use or over a diapering life-time.

BABY URINE PRODUCTION

A diaper's absorption does not necessarily reflect the amount of urine a baby produces. Urine production can be different for every baby and even from day to day. There are however numbers for average hourly urine production. Through accessing the documents of the NCLEX (National Council Licensure Examination), which is the national US examination for nursing, the average hourly production of urine per kg of body weight could be calculated. For this an average growth diagram was put together (TNO Groeidiagrammen) per sex and month of age. The graph will be leading for the absorption that is needed for a baby's diaper.

Next to the amount of urine that a baby produces there is the frequency of bowel movements. In the first few months when the baby is still on breastmilk or formula, the stool has a very soft consistency. It does not smell, as the baby does not eat solid foods yet. (Bom & Huber, 2006; Davisson, 2019) The frequency of diaper changes in this age group from birth to 6 months old, is mostly dependent on the routine. (Healthline, 2018) Except for special circumstances, as diarrhea, the diaper changes most often come in the same rhythm as the feedings. (Bom & Huber, 2006) In this age-group the average diaper amount used can differ between 12 to 7 diapers a day. (See figure 12)

After 6 months, most babies start will small bites of solid foods. From this moment on, the stool can smell and be present in bigger quantities, but also be less frequent and more solid.

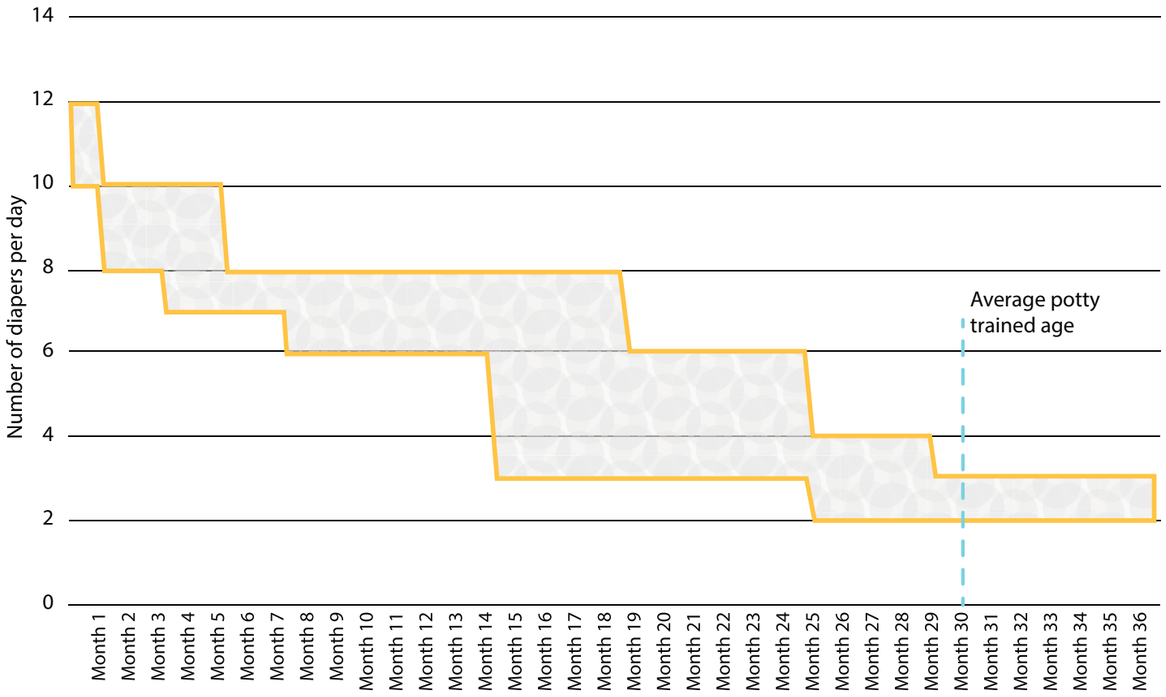


Figure 12) Estimated diaper use. With the average potty trained age of 30 months.

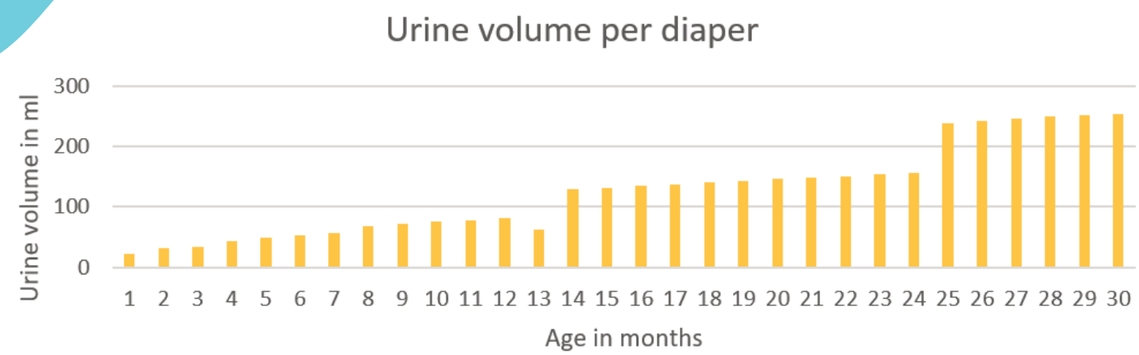


Figure 13) Urine volume per diaper per month of age.

Table 03) Urine volume per diaper and the absorption capacity per size

	Newborn	Size 1	Size 2	Size 3	Size 4
Months used for	0,5	3	4	10	12
Average urine volume per diaper in ml	23	33	50	104	198
Absorption capacity	120	145	181	429	875
Sources absorption capacity	(Shramko et al., 2013)	(Maso et al., 2019)			Own weighing

(Source: Healthline; Maso et al., 2019)

(Farrisi, 2003) From here on out, most diaper changes are the result of a bowel movement. Diaper changes from this age and on continue to be less frequent.

From figure 13 and table 03 we can see that there is a major disconnect in the absorption capacity and the average urine per diaper. There are two reasons for this; one, every diaper is made to be a night diaper, that can absorb up to twelve hours of sleep. The second reason is that all diapers contain a large margin of extra absorption capacity, to guarantee a leakproof experience. In this comparison, the least amount of diaper changes is used gathered from figure 12. This is to have the largest urine volume per diaper. When the diaper is changed more often, the urine volume per diaper decreases, which of course also works the other way around. However, this will not disprove that the absorption capacity is over-dimensioned.

CONCLUSION

The main conclusion that can be a very important take away for future stages of this project is, that the current diaper has a disconnect in absorption with the urine production. The night and day difference in required absorption will most definitely get a place in further ideation stages. It shows that there is material to be saved, while giving the consumer the same quality product. Can a diaper be made to fit the actual urine production needed? How much impact can a day and night diaper system make? And if you tell parents the day diaper is less absorbent, is that a reason for them to change the diaper more often (resulting in even more material consumption)?

PARENT'S NEEDS

Through both internet research on parenting websites, interviewing parents and reading various parental guidance books, it becomes clear that there are multiple main considerations that need to be addressed in the design of a new diaper. A parent will always want to deliver the best possible care they can to their newborn baby. A diaper is a baby care item that they will need to use thousands of, and when finding a brand they like, they tend to stick to it. (Pavithra et al., 2016) The four main categories of consideration identified are:

* Safety

Safety is the most important factor for choosing a diaper. Diapers that feel too rough or through their elastics leave skin marks have deterrent effects. Diapers are currently made to feel good through an extra layer of non-woven over the containment film. This makes them feel soft to the touch on the outside, while still being able to hold urine. Also, lotion ingredients are used in the top layer of the diaper to prevent skin rashes. (for more on this see chapter baby 's needs and restrictions)

Most mayor diaper brands currently carry different certifications on their product packaging to make them feel safe and better than competing brands. For example, there are multiple dermatology certifications that show skin safety. These markings can make a parent choose a brand and give them the comfort they need in knowing that they are using the best product they can.

* Convenience

As being a parent is hard enough, most parents opt for ease of use. Products that are machine washable are desirable over hand wash only, or single use over multiple use. If a product is not as easy to use or when it needs a lot of extra work in between uses it will not be as popular for parents. This can be concluded out of both the diaper history as well as it being very clear from interviews. Parents are afraid of hassle and just want a simple diaper solution.

* Cost

The cost of a diaper can be a deciding factor for the parent. Parents may be willing to spent more for a certain brand, but this does not mean that all parents have the financial means to do so. It can also be a deciding factor in choosing to use washable diapers over disposable diapers. However, as we saw in the previous chapter, 95 percent of the parents still use disposables for their low effort. The economic benefits outweigh the extra effort it costs to wash the cloth diapers.

Figure 14) Certifications and seals of dermatology safety.

Economic viability should be an important consideration factor as making a super sustainable diaper that is too expensive to sell to most parents is not a great concept. However, as this project is focused on creating new more sustainable solutions and not necessarily financial viability. Logical considerations should be made however, on the pricing of the diaper.

* Dependability

Being able to trust that a diaper is going to hold up over a certain period is key to diapering. In essence it is why we historically use diapers, to not make a mess, to not soil furniture and to not have to wash clothing and bedlinen on a daily basis. Being able to depend on a diaper for a parent is key. Parents that had experienced a certain diaper brand or model that leaked, makes them less likely to buy that brand again. (Pavithra et al., 2016) A parent needs to be able to trust the workings of the diaper as well as their ability to use it correctly.

CONCLUSION

When creating concepts for this project that are more sustainable, addressing the needs of the parents is vital to create a viable idea. These four deciding factors in choosing a diaper are going to be key in setting up requirements for new designs. Especially safety, convenience and dependability are most important, where cost in a concept for the Future Diaper Project is of lesser priority.

DIAPER INTERACTION

A diaper change is not as simple as it might seem. When looking at the, for parents, mundane activity, there are a lot of steps involved. The current disposable diaper is for example impossible to change with one hand, as the closing strips need to be pulled, to make sure the fit is right. While on a newborn this might be doable, especially on older children that can move on their own a diaper change can be a challenge. Although there is a learning curve, the addition of diaper pants to the diaper product line shows that an easier solution brings advantages, but also other problems. During observation it became clear that the diaper change can be more of a hassle than one might expect, which is certainly an aspect to be considered in the design of a new diaper.

Table 04) Steps in a diaper change.

Disposable diaper Interaction
Establish the need for a diaper change
Get baby to the changing table or place
Undress baby as needed for changing
Get new diaper ready
Release closing strips 2X
Wipe
Place wipe on top of diaper
Remove diaper from underneath baby
Close diaper with strips 2X
Place dirty diaper away from baby
Grab the new diaper
Place the new diaper underneath the baby
Close the diaper closing strips 2X
Redress baby
Get baby off changing table
Dispose of old diaper

Figure 15) Own photos of the struggle of a diaper change.

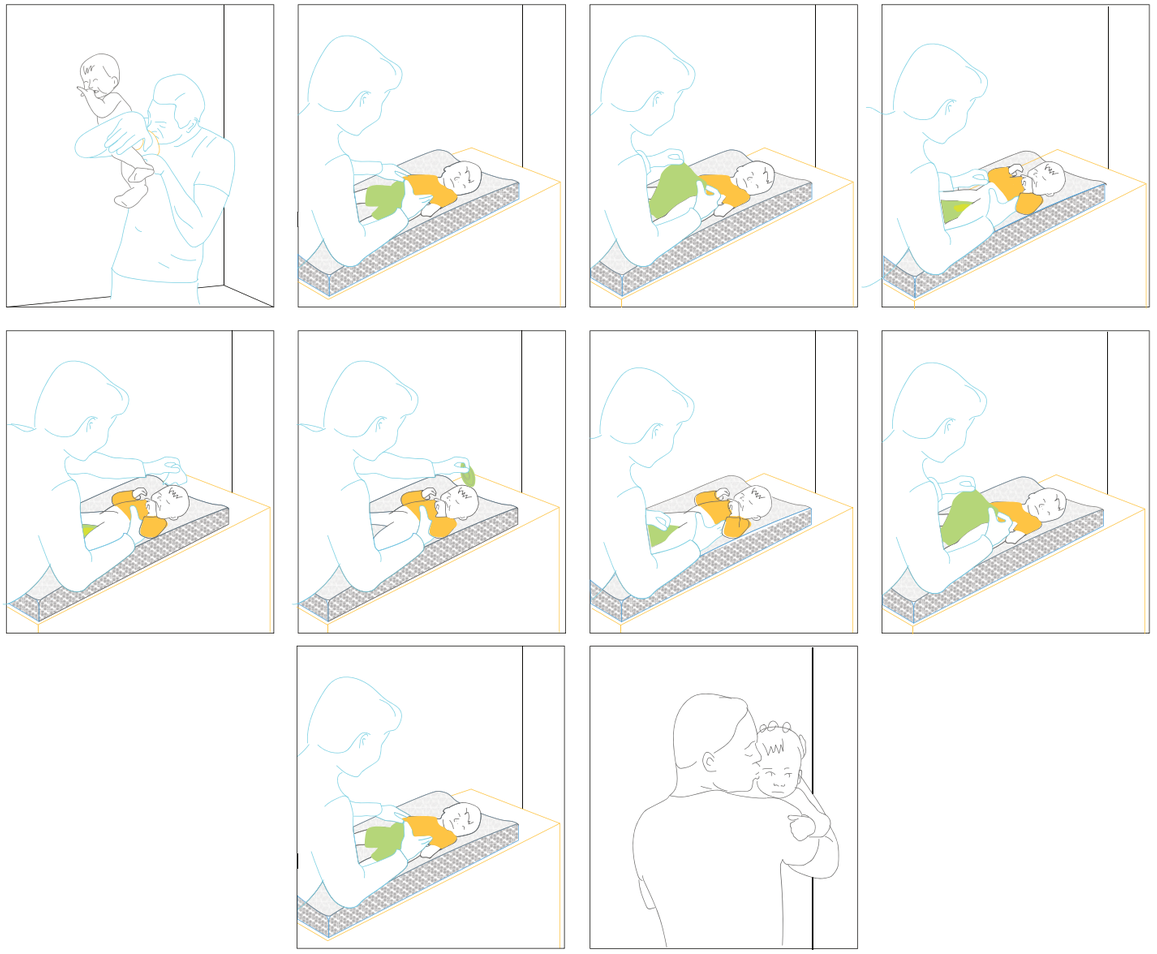


Figure 16) The diaper changing steps in drawings.

To be able to design for a new diaper the interaction process of changing the current disposable diaper had to be charted. There are clearly personal preferences and therefore differences, but overall the changing method for a disposable diaper is similar.

MATERIAL RESTRICTIONS

There are some special concerns for babies using diapers, as their skin is especially sensitive. As the diaper creates a closed off humid environment, the baby's skin is prone to develop diaper rash or diaper dermatitis. The top layer which is in contact with the skin frequently consists of hydrophobic polypropylene fibers. As this layer prevents a lot of rewetting, the skin is kept drier. However, the constant contact of the diaper with the skin can still cause skin problems.

As the baby's skin is so sensitive, the fit mechanism is also very important. A diaper that is fitted too tight can cause irritation. The elastics in the cuffs and waistband prevent leaks, but however may have adverse effects on the skin as it puts constant pressure on the skin.
Allergens should also be taken into account. Allergic contact dermatitis, or adverse allergic reactions to wearing a diaper can be caused by multiple factors. Materials that have rubber additives, glues or lotions contained within the diaper could all potentially cause an allergic reaction to the skin. Even some dies used in diapers have been known to cause adverse reactions in some infants. (Klunk et al., 2014). As a general rule of thumb, the materials currently used in the diaper, are safe to use in diapers. The materials touching the baby's skin are the ones most critical, so especially these materials should be tested.

In the design of a new more sustainable diaper, the baby can in no circumstance suffer under design changes. Applying potential allergen materials as well as more parts that add pressure need to be evaluated and analyzed closely.

CONCLUSION

This means that there are some restrictions for further concepts:

- No elastic can be used that is directly touching the skin.

- Parts that are used in the fitting mechanism, all need to have give to prevent pressure points and skin marks.

- The top layer of the diaper should be kept as dry as possible, to prevent rashes.

CONCLUSIONS & REQUIREMENTS

- On average a baby will spend 2.5 years in diapers in which he or she will use 4,16 diapers daily on average. This adds up to at least 3800 diapers per child, which compared to other sources is still a low number. The 3800 diapers add up to 152 kilos of raw material per child.

- For parents, safety, dependability, cost and convenience are most important. Parents look out for certifications and are sensitive to marketing. Diapers are an emotionally high impact product, as all parents want what is best for their baby.

- Babies have an extremely sensitive skin, which is prone to diaper rashes. These rashes can occur in a humid environment, especially when a diaper is prone to rewetting. When a diaper works well and is regularly changed, the skin is kept as dry as possible.

- A disposable baby diaper is a universal product, used by parents, grandparents and child care professionals.

P.1 - The diaper can hold the average urine production in between average changes plus a 10-15% margin.

P.2 - The diaper can hold the amount of urine with the weight of the child pressing on top of the core.

U.2 - The diaper has to be easy to dispose of and therefore must be designed so the product can be thrown away by itself in the general garbage can, it should not require prepacking it in a single-diaper trash bag.

U.3. - The diaper cannot require a user to touch the soiled part of the diaper.

Sa.1 - The diaper cannot contain allergen materials that touch the skin.

Sa.2 - The diaper cannot leave pressure marks on the baby's skin.

CHAPTER 4

THE MARKET

The diaper market is highly competitive. A few big players are currently active, dominating the main segment. Brands need to keep innovating to keep up with market demand. In this chapter we explore new diaper products that are significantly different from the current standard diaper.

After looking at different functionalities we look at benefits and potential downfalls. The market has not stood still, and some brands have come out with more sustainable products. Material reduction and using new materials are the key to these new products. In this chapter three diverse new developments will be explained and analyzed.

PAMPERS HYBRID

P&G recently came out with an alternative diaper solution which is a cross between washable and disposable diapers. The first major player on the disposable diaper market to come out with a hybrid system. This hybrid solution consists out of an outer, which functions as a washable cover. When in use the parent puts an insert into it, which will, in principle, catch all urine and poop. Pampers claims up to 12 hours protection from wetness while using 25 percent less material compared to their normal harmony diapers.

The cover pants consist out of two layers, a waterproof coated outside layer, and a soft microfleece water absorbent layer on the inside. The leg cuffs contain elastic, which is resizable. The closing mechanism is also size flexible and consists out of an array of buttons, that cover the front. This allows a parent to use the diaper over a range of normal diaper sizes.

There are other smaller companies with a similar product. GroVia for example has a hybrid system that can have washable as well as disposable inlays. The disposable inlays however do not contain a similar absorbent core as the Pampers diapers.

When comparing this hybrid solution to the current standard disposable diaper, a few aspects clearly have changed.

The parts that are reduced or removed are: one of the elastic containment flaps, the front and back tapes, non-woven parts that make the waistband. Paper is added to cover the glue strips that are located on the back of the inlay. The amount of SAP, fluff and film has remained the same in the inlays.

Table 05) Pampers hybrid overview

Company size	One of the top 3 leading companies on the diaper market segment.	Material savings (in weight)	25% (10 grams per diaper change)
Pamper Hybrid target customer	Targeting the current pampers customer that has more money to spend to be more sustainable.	Extra costs: (source Coolblue and Pocock 2005)	Laundry: 0,3 liters of water + 0,008 kWh electricity per diaper + detergent
Place of purchase	Currently available at both supermarkets as well as drugstores.	Convenience	Extra effort in laundry plus the need to bring both inlays and extra pants when going out.
Value proposition	Trusted Pampers no leak quality, while saving material.	Other benefits	Cute designs as well as a very soft feel of the diaper. Flexible fit, a baby will fit the outer as well as the same inlays from 6 months to 2,5 years old.
Unique Selling Point	Pampers absorbent core quality		

Figure 17) (top) The Pampers outer and inlay.
Figure 18) (bottom) the outer pants with snaps and soft fleece lining. (both from pampers.be)

POTENTIAL SAVINGS

A more critical statement needs to be made on the Pampers hybrid inlays. The pants are adjustable to the size of the baby, allowing the parent to use the pants from the age of 6 months up until 2,5 years old. Over this two year period both the same outer pants as well as the same inlay is used.

On the one hand this is beneficial for the user as choosing diaper size and switching from one size to another is eliminated. On the other hand, this means that the absorbent core will be over dimensioned for most users. A 2,5-year-old infant will need more absorption than a 6-month-old, but as they are using the same inlays, a lot of absorbent material is wasted. The Pampers Inlay can be compared to the average size 4 diaper, which is recommended in use starting at 11 kilos, which equals to on average 18 months old (TNO Groeidiagrammen).

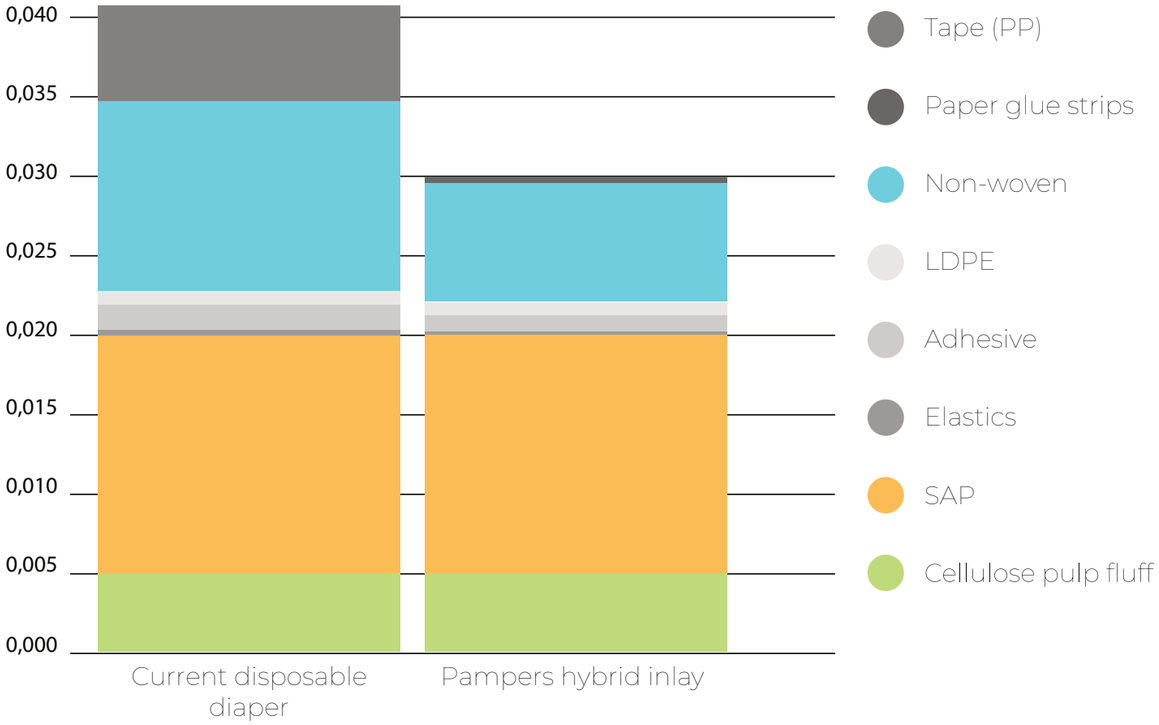


Figure 19) Material use of a normal disposable diaper (in size 4) and the Pampers hybrid inlays.

The inlays that are used in the Pampers hybrid diaper system have a watertight back film. This makes the inlay hold all urine and feces without it leaking through onto the soft fleece lining of the outer pants. This lining makes it however a pant that will require frequent washing, as it will get soiled easily.

Outer pants that are used in washable diaper systems are made watertight as washable inlays are not watertight. The outer pants in these systems do not have this soft fleece lining, making it a wipeable product. When soiled it will still require washing but this will be a lot less frequent as with a fleece lining.

For the user the feeling of the soft lining is very pleasant, but the lining will cause it to require more frequent laundering.

User reviews also show that the disposal of the inlays is not convenient. The inlays do not have a strip to close it after use. In the disposal of current diapers, the fit mechanism can be reused to roll and close the diaper before throwing it away. The inlay does not have such a strip, which is a missed design opportunity.

Figure 20) The inner lining of the Pampers Hybrid (pampers.be)

Figure 21) The inside of a washable diaper that can hold washable inlays does not have a full lining. Instead the lining is limited to where the outer diaper touches the skin. (Blümchen Stoffwindeln)

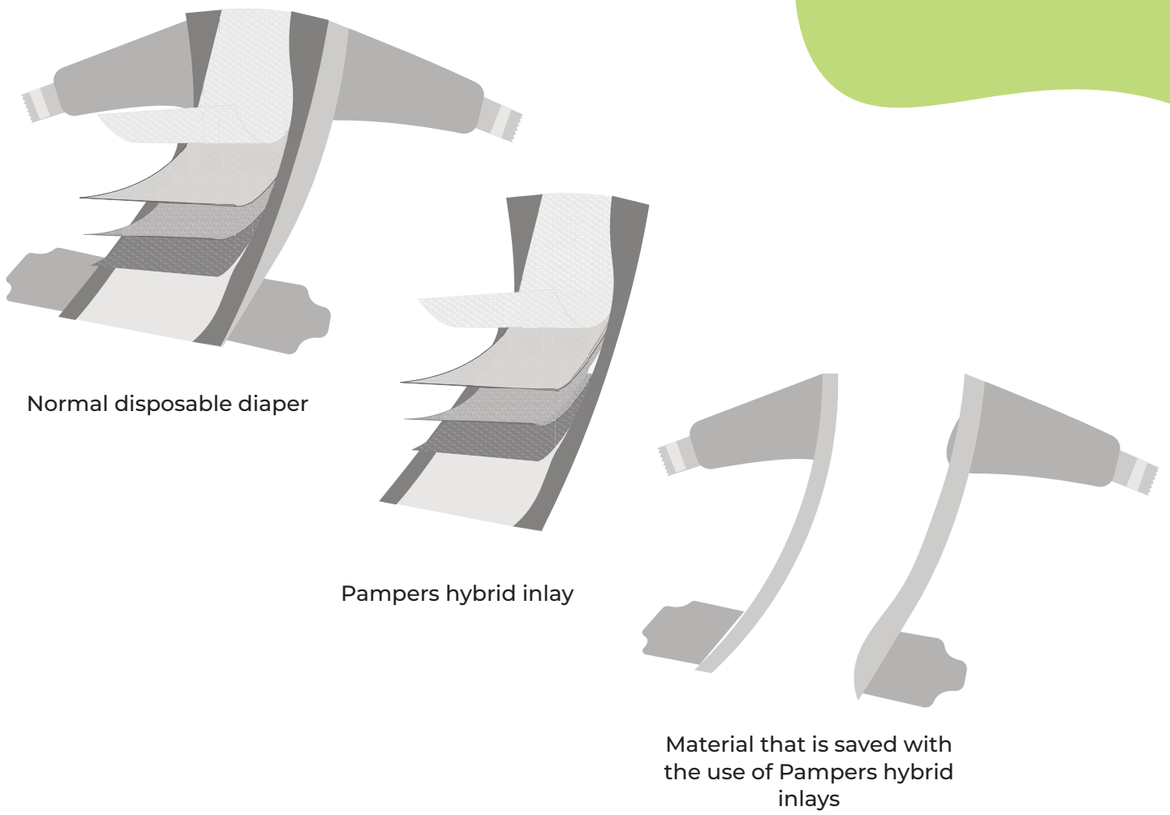


Figure 22) the 25 percent material savings consists mostly out of the front and back ears and one pair of the containment elastics. An addition of paper is however done to cover the glue strips.

Table 06) The impact of a normal disposable diaper build up from material impact as well as incineration as the end-of-life scenario. (source: Granta Edupack)

	H_2O use in liter (in production of materials and incineration)	kg CO_2 equivalent (in production of materials and incineration)
4 diapers used per day	20,48	0,81
Totals over 1 day	**20,48**	**0,81**

Table 07) The impact of a day of use of the Pampers Hybrid system. Material content of the inlays, incineration as the end-of-life and the laundry costs (including detergent) are included. (source: Granta Edupack, Coolblue and Pocock, 2005)

	H_2O use in liter (in laundry, production of materials and incineration)	kg CO_2 equivalent (in electricity, production of materials and incineration)
4 Inlays used per day	21,15	0,54
2 pairs of outer pants used, cost of laundry:	0,36	0,01
Totals over 1 day	**21,51**	**0,55**

A 5% increase in water use (by the addition of paper) and a 32% decrease in kg CO_2 equivalent through the reduction in material use.

CONCLUSION

The analysis of the Pamper hybrid product shows that a reusable outer definitely has emission benefits. The 25% material reduction of the fit mechanism is the main benefit factor. In the ideation phases a clear analysis should be done to see what parts can be made redundant or can be reused. To split the cleans and the uncleans and through that design a new diaper.

The need for laundry in the Pampers hybrid system is high, a parent would at least need two pants per day. When going for a day out of the house, a parent would need to bring a few extra pairs of these outer pants. Compared to just using the conventional disposable diapers, the convenience factor is lower. In the design of a new diaper system, this convenience level should be closely guarded, because when a product is not convenient in use, parents could opt out. When designing for the FDP the innovation is more important than the convenience, but the aim of this project is to design a product that finds the compromise between these factors.

The Pampers hybrid shows that this convenience is not completely worked out yet in for example the inlay disposal. A small design addition can make a big impact in the user's experience. An inconvenience may even cause the parent to use more material, in terms of disposable bags in this instance.

LITTLE AND BRAVE

BELT SYSTEM

The New Zealand based company Little & Brave is a much smaller player on the market and cannot be directly compared to P&G with the Pampers hybrid. But Little & Brave also has a hybrid product on the market that is significantly different from the current architype of the normal disposable diaper. Therefore, it is worth reviewing the product and its functionality to be able to apply this knowledge in later stages of the project.

A belt that snugly fits a baby around his or her waist, with an inlay folded under it. As the company has a focus on biobased and biodegradable products, the inlays are fully industrially compostable. They contain fossil-based SAP, bio-plastic and FSC certified fluff. No elastic, no glue to attach the inlay to the wrap. The liners are mostly biobased, only the SAPs are fossil-based. The company offers a service to pick up the used diapers as well as home deliver new clean diapers to the user. This ensures the inlays to be composted properly in a commercial set-up.

Table 08) Little & Brave wrap overview

Company size	Small, only selling products in New Zealand	Material savings (in weight)	Estimated 25% (10 grams per diaper change)
Little & Brave target customer	Targeting environmentally aware parent that wants to reduce trash creation.	Extra costs:	Some laundering is needed of the fabric wrap.
Place of purchase	Currently only available in New Zealand via their own website.	Convenience	The inlay has to be tightly fitted on the baby and in the wrap, this may cause a learning curve.
Value proposition	Industrially compostable inlays that are the best choice in terms of environment.	Other benefits	The company has a service that will pick up and compost the used inlays for you.
Unique Selling Point	No fossil-based plastics, made to be used with a fabric wrap that does not require frequent washing		

Both the wraps as the inlays come in multiple sizes, as the design without leg cuff elastic demands a very tight fit to prevent leaks. There are however non-woven material guards that should prevent leaks.

The main vision of the company is to provide the New Zealand consumer with the best eco-friendly diaper that will leave the littlest waste for future generations.

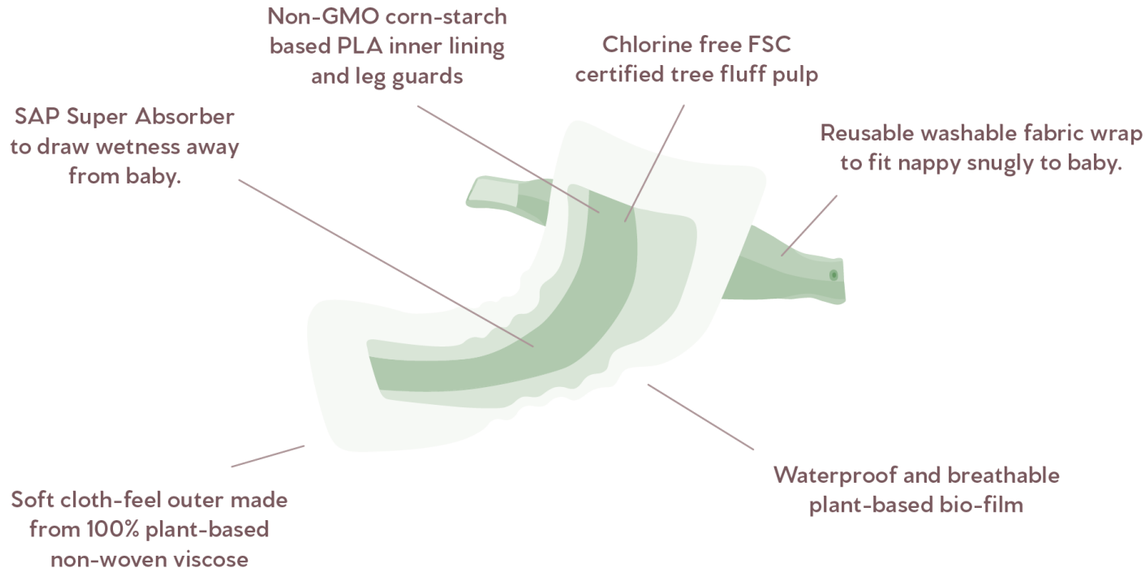


Figure 23) (bottom) The inlay that is used in the wrap. (from Little & Brave)
Figure 24) (top right) The Little and brave wrap in use. (from Little & Brave)

As there are no user reviews online for this product, it is hard to find out how well it works. The fact that there is no elastic on the inlay, seems to suggest that this diaper is very prone to leaking. This problem is comparable to the ageing elastics in washable diapers. When the elastic gets older, it may lose its stretch. Therefore, the leg cuffs aren't as tight as they need to be to prevent leaking. In an inlay that does not contain elastic, this probably is the biggest concern. However, the company probably made this choice to create a product that is fully compostable, as elastane is not compostable or biodegradable.

As the wrap is not going all the way in between the legs, there is a much smaller chance of the wrap getting soiled. Also, as it is a smaller product, washing it will cost less energy and water compared to the Pampers outer pants.

Especially the composting service guarantees that the inlays will get composted in the right way. This will reduce methane production, as other municipal waste goes to a landfill. (Taiwo, 2011)

This product is only available in New Zealand, and not within reach in the EU. As this product cannot be weighed out and analyzed a numerical analysis will not be presented. Efforts have been made to get a wrap and inlay pack send to the Netherlands but were unsuccessful.

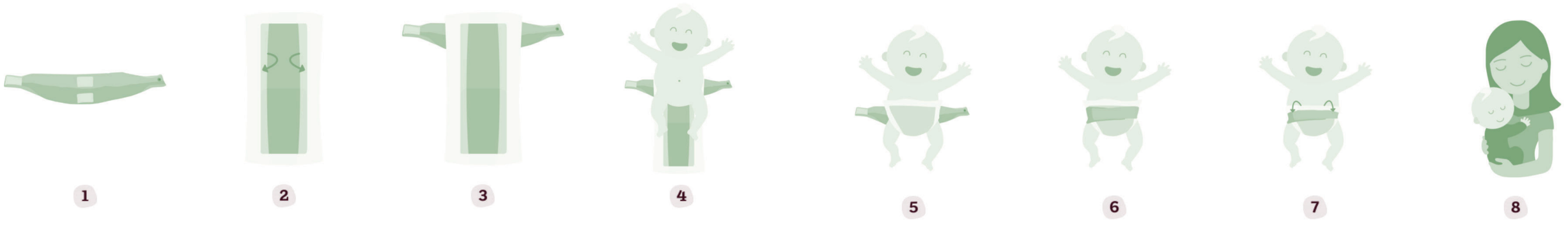
CONCLUSIONS

The Little & Brave diapering system shows that also small companies are trying to make a real difference in the impact of diapering. Trying to get on board eco aware parents with a system that aims to be the least impactful while still being disposable.

The diaper belt shows an architype significantly different than the normal disposable diaper. After a learning curve a parent will be able to use it, but they will need to be committed to keep using it, as the inlays can only be ordered online.

For this project it shows that there is a place for out of the box ideas that do not comply with the current architype. Possibilities for composting should be evaluated.

Figure 25) The instructions for use of the diaper belt. (source Little & Brave)



FAIRWINDEL

The company Fairwindel is currently producing almost 100% Biobased diapers. While keeping the same build of the classic disposable diaper, all parts (except the closing Velcro) are made out of biobased materials. Interestingly, the SAPs that are in current disposable diapers is replaced in this brand's product with a starch-based substance. All other eco-diapers or more sustainable diapers and inlays have thus far not gone without the fossil-based SAPs for 1 simple reason. The absorption quantity of these fossil-based granulates is of outstanding magnitude. When replacing the fossil-based for the starch-based SAP, the diaper does not absorb the same quantity. Therefore, the Fairwindel diaper is making a big controversial step towards fully biobased diapers, maybe compromising on absorption quantity, but delivering a more sustainable product to the market.

Although the absorbent core is fully biobased unlike any other diaper brands currently on the market, there is still a 15% fossil or non-biodegradable part of the diaper. For example, the elastics are not biodegradable and the Velcro and AD layer are currently not available in biobased and biodegradable material, simply as they are not produced by manufacturers yet.

In decomposition tests of this diaper performed by themselves in a non-industrial home hot compost, the result of 85% decomposition took 2,3 years. As said earlier, composting will have a lower methane production than landfill, but when a parent wants to compost all diapers used (around 4250 over 2,5 years) in their own home compost it most likely will not work logistically.

Table 09) Fairwindel diaper overview

Company size	Small, selling products mostly in Germany but can be shipped to the EU	Material savings (in weight)	Extra material is used as the diaper needs to be changed more often.
Fairwindel target customer	Targeting environmentally aware parent that has more to spend on diapers	Extra costs:	Extra cost from the need of more diapers.
Place of purchase	Currently only available via their own website.	Convenience	The diaper works exactly the same as a normal disposable diaper.
Value proposition	100% renewable raw materials and completely biologically decomposes	Other benefits	85% Compostable
Unique Selling Point	(Almost) Fully biobased diaper. (even the SAP)		

The Fairwindel has a lower absorbent capacity. Their company website indicates that the diaper needs to be changed every 4 hours, where a conventional disposable diaper can last overnight. This is confirmed by testing the diaper core with the core from a normal disposable diaper. Absorbency is lower, and it seems the gel that forms is less stable as well. When using the diapers on a baby this will increase the frequency of needed changes.

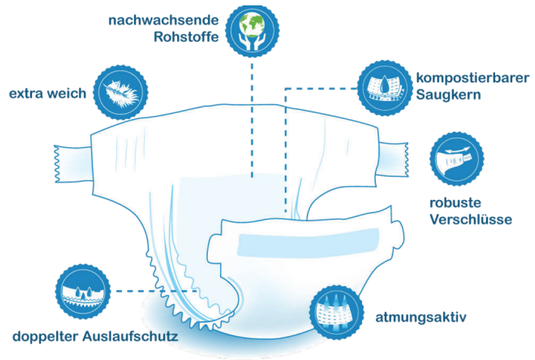


Figure 26) Fairwindel composition (fairwindel.de)

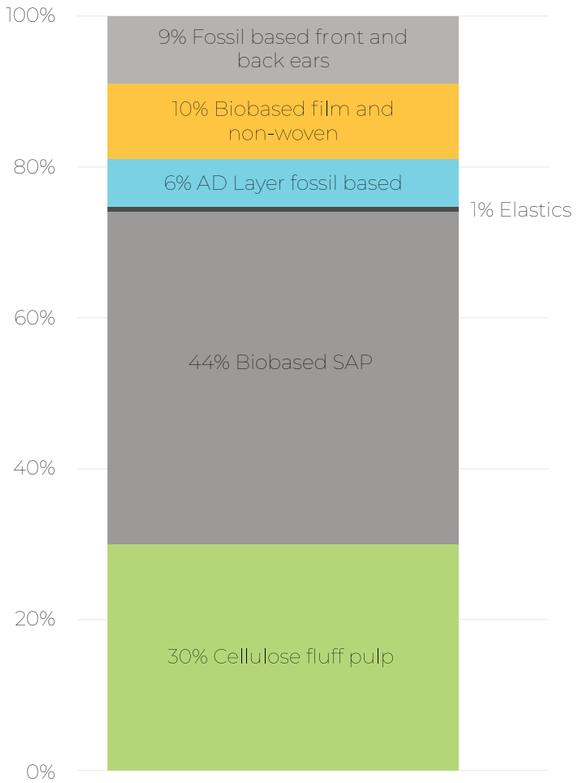


Figure 27) The composition of the Fairwindel

Figure 28) (top left) Fairwindel SAP and fossil-based SAP in dry form
Figure 29) (bottom right) Fairwindel SAP and fossil-based SAP in wet form

Table 10) The impact of a normal disposable diaper day of use build up from material impact as well as incineration as the end-of-life scenario. (source: Granta Edupack)

	H_2O use in liter (in laundry, production of materials and incineration)	kg CO_2 equivalent (in electricity, production of materials and incineration)
Per diaper	5,11	0,20
Totals over 1 day 4 diapers used per day	**20,48**	**0,81**

Table 11) The impact of a day of use of the Fairwindel diapers. Material content of the diapers, incineration as well as the end-of-life are included. (source: Granta Edupack)

	H_2O use in liter (in laundry, production of materials and incineration)	kg CO_2 equivalent (in electricity, production of materials and incineration)
Per diaper	4,37	0,13
Totals over 1 day 5 diapers used per day	**21,78**	**0,58**

A 6% increase in water use (by the use of biobased materials) and a 28% decrease in kg CO_2 equivalent. Of course the main benefit of the Fairwindel diaper is its renewable nature.

CONCLUSIONS

The Fairwindel shows that it is possible to create a diaper with a fully renewable absorbent core. It also displays that for small companies it is difficult to have manufacturers create small batches of biobased products. (This could be through incompatibility with machinery for example)
For this project it means that biobased materials should be explored, especially because innovating towards renewability is one of the main goals of the FDP. The decreased absorbency of the core with the use of biobased SAP should be further researched.

CONCLUSIONS & REQUIREMENTS

- Pampers has launched a hybrid product, featuring a washable pant with a disposable inlay. This saves 10 grams of non-woven material. This is 25% of the weight of the original diaper, but the design of this diaper requires washing of the outer pants. This causes more work for the parents. There is only 1 size of inlay for this product currently, which causes the use of it on younger babies for it to be severely over dimensioned.

- A fully biobased diaper has also been launched on the market by the German company Fairwindel. This product Is fully renewable, but has reduced absorbency.

F.2 - The diaper does not have to adhere to the standard diaper architype.

(other requirements do also partly have their origin in market research but were already named in previous chapter)

CHAPTER 5
FUTURE MATERIALS

This chapter dives deeper into future and current renewable materials. The benefits but also drawbacks of biobased materials are discussed. The goal of this chapter is to establish the need for these materials in a diaper product as well as conclude clearly when, how much and why it should or should not be used in a diaper product in the future. Also, the end-of-life of these materials will be compared to fossil-based plastics. Are there possibilities for recycling? And what are the environmental benefits and drawbacks on a large scale?

WHY BIOBASED?

Materials created from a natural renewable source are called biobased. They are by definition not ever sourced from fossil fuel. As they are from a biologically grown source, it should always be taken into consideration that no human food source is depleted for material needs.

Biobased materials are very beneficial to counteract fossil fuel depletion, as they are infinitely renewable (if production volumes allow to replenish resources) and in a lot of cases able to replace fossil-based materials. As diapers are extremely hard to recycle in a valuable way, when made out of renewable materials it could make it acceptable to use incineration as the end-of-life scenario for the diaper. (GRANTA) There is no major permanent loss of material and the emission created by incineration is later taken in by new biological sources to create new biobased materials, making it carbon neutral in a small circular system. However, as most vehicles and production facilities are not yet fully run-on renewable energy a small cost of fossil fuel persists.

Currently none of the biggest selling diaper companies on the market use biobased plastics or SAPs in their products. There could be multiple reasons for this. Availability is a big part, as well as existing machinery.
The availability of a biobased material is dependent on the capacity it is grown at. For example, corn-based bioplastics are obviously made from corn. This corn needs to be grown and can only provide a certain amount per square meter of farm land. For a large-scale rollout of disposable diapers, it should be considered that the material may not be available in those quantities. When using the resource for diapers there could be shortages somewhere else.

Currently it can also be challenging to produce a biobased diaper with the existing machinery and equipment. (Nealis, 2021) New materials can require different machines, which are extremely expensive. With time, new equipment will be available, lowering the initial costs of manufacturing new biobased diapers.

As fossil fuel is a limited resource, we should find a solution for our fossil-based products. For future generations, diapers will still be needed, which means new materials can have the potential to make the disposable diaper renewable and available for those that come after us.

Innovation plays a big part in this. With time, more and better material substitution will be possible for the current disposable diaper. The more widespread the new material is produced and used in diapers, the lower the cost will be. For this project both current and upcoming materials will be taken into account. The key in this is to ask what is possible now and what are aspects that can be changed in the future.

ALTERNATIVES

In this chapter all materials currently in the disposable diaper will be covered one by one. For each material current or future substitution possibilities will be weighed out.

NON-WOVENS & FILM

Some smaller diaper brands are already using biobased film and non-woven material for their diapers. Mostly made out of PLA or PHA, these materials function as well as a PE or PP variant. Some of these materials can even be composted as their end-of-life pathway. (Total-corbion, Natureworks, Ahlstrom-munksjo, ipp) PLA and PHA both cost more water compared to using PP and PE. (GRANTA) The most likely reason these materials are not yet used to replace the fossil-based plastics is their price. As they are not (yet) mainstream, they are more expensive as fossil-based plastics.

Figure 30) Non-woven material currently used for diapers (HCPE).

SAP

The superabsorber is one of the most important elements of the disposable diaper today. As it provides the dry comfort, we wish to protect the skin, a diaper cannot go without anymore. SAP is a fossil-based product made out of sodium polyacrylate. A biobased alternative is a processed starch molecule that can absorb significant amounts of urine. Currently the quantity it can absorb is lower than its fossil-based counterpart. This will cause the diaper either to last shorter, or leak earlier compared to a normal disposable. More changes will cost even more material. However, a lot of innovation is taking place, where a recent study (Capezza et al., 2020) shows the possibility of making a biobased SAP that has superior function over its fossil-based counterpart. This shows that currently it may not be possible to replace fossil-based SAP 1 to 1 with biobased SAP, but surely shows potential for it to be in the future.

Figure 31) Fossil-based SAP absorbing water.

ELASTICS

The elastics currently in disposable diapers pose the biggest challenge to replace. A biobased alternative would be to use natural rubber, of which still 40 percent of elastics is made of. (Kohjiya & Ikeda, 2021) Natural rubber is both biobased as well as biodegradable, but poses a great risk to the health of the baby. Rubber is an allergen, which can induce rashes or other allergic reactions. This is why it is currently not used in diapers. It also makes it a difficult product to replace, as a biobased alternative is available but unusable. There could be potential in covering the natural rubber with another material so it does not make any contact with the baby's skin. Other ways of making materials flexible or even show elastic behavior should be explored.

Figure 32) Synthetic elastics pulled from diapers.

ADHESIVES

Adhesives in the diaper are used in 2 ways. The first is to hold SAPs in place against the core wrap. The second use is a hotmelt to fuse different diaper layers together. In some diapers some of the glue has already been replaced by a process of ultrasonic bonding. (Fameccanica, 2018) Layers are then simply welded together, removing the need for glue. In some other diapers, the SAPs are sprayed on the fluff material, where it would sit in between the core wrap (Mendoza, 2019). Glueless diapers have already appeared on the market, reducing the footprint by 32%. (Mendoza, 2019) Also, biobased adhesives have been developed, as polycaprolactone (PCL). (Granta) However, no clear environmental impact information can be found in the database or other sources. For this project the impact of the fossil-based adhesive is assumed to have the same impact as a biobased one. It is also assumed that glue is used. When in a further stage a concept is further developed and glue can be gone without, the impact will only be lower.

Figure 33) SAP granulate held together with adhesive.

POTENTIAL SAVINGS/COSTS

First we will look at a simplified footprint of all materials and their replacement. In the coming pages other aspects will be considered, but for now the focus lies on footprint in water and carbon dioxide from production of the material and emission from incineration.

Table 12) Current materials used and other biobased options for those parts. (GRANTA)

	Water usage production of material	CO_2 emission in production of material	CO_2 emission of incineration of material
Unit	L/kg	CO_2 kg/kg	CO_2 kg/kg
Fluff			
Pine	700	0,38	1,81
Bamboo	700	1,06	1,74
Non-wovens & Film			
PP	39,2	2,92	3,14
PE	58,2	1,86	3,14
PLA	20,8	2,28	1,85
PHA	200	0,9	2,05
SAP			
Sodium Acrylate	40	3,63	0,81
Starch based SAP	42	0,88	1,85

Not only currently non-biobased elements can be substituted. The fluff currently in diapers is mostly made out of wood fiber. Small brands have shown that bamboo can also be used as a source for this fiber, a much faster growing plant.

As can be seen in the table on the left, the emission of most biobased materials is lower in total (emission of production plus emission of incineration) compared to their fossil-based counterparts. However, water use is also higher in some cases. Especially PHA has a high-water cost per kilo of material created. This is because it is created in an activated-sludge reactor, which needs inflow of water. (Tarrahi et al., 2020) In further concepts this needs to be taken into account in order to weigh out these differences.

The most important benefit of replacing fossil-based materials with biobased materials is of course their renewability. The main question is, can a renewable product cost more water? Can renewability justify higher emission?

COSTS OF BIOBASED

A material, especially a biobased material does not only have an emission cost that can be expressed in water and carbon dioxide. Change of land use is one of the most important factors.

Land use

As biobased materials need to be grown in some way, every kg of material requires a certain amount of land to be produced. A product can only be made if there is both enough land as well as if that land is viable as farmland.

Table 13) Land use for PLA and PHA (Brizga et al., 2020)

	Land use square meter of crops per kg of plastic
PLA	0,75
PHA	1,25

Table 14) Calculation for worldwide biobased plstic in diapers, land use.

Worldwide diaper sales in kg 8168000000 (statista)			
Average weight per diaper in kg 0,033 (Spijker et al., 2016)	Total diapers used yearly 247515000000		
	Average plastic quantity in diapers in kg 0,01 (Spijker et al., 2016)	Total plastic used yearly in diapers in kg 2475151515	
		Land use m^2/kg plastic PLA 0,75 PHA 1,2	Total land needed in km^2 PLA: 1856 PHA: 3093

To be able to make all future diapers biobased, a calculation needs to be made to see if that is even a possibility. As can be seen in the table at the bottom of this page, a total extra of 1856 km^2 is needed for PLA and 3093 km^2 in PHA. To give these numbers some frame of reference, it would be a 0,017% and 0,028% increase in the worlds agricultural land respectively. (Our world in data 2019) The estimate is that currently 55% of arable land is still unused. (SAGE) This would make it possible to make all diapers biobased.

However, not all diapers will get replaced by biobased diapers at once, but this calculation shows that it would be a viable option that should not take away from the world's food supply, or increase food prices due to higher demand.

If the same calculation is performed with biobased SAP (0,15 square meter land per kg (Brizga et al., 2020)) another 0,004% increase would be needed.

Next to increased land use, there are other factors that need to be considered.

When more crops are grown, it results in greater amounts of pollutants, owing to the fertilizers and pesticides released onto the fields. More crops grown can also deplete farmland from minerals.

Biobased materials are currently still being transported as well as produced in facilities and vehicles that are not yet fueled by energy from natural sources. This causes fully biobased products to still have a fossil fuel-based footprint, making them not completely renewable.

For all comparisons in this report, incineration is used as the end-of-life pathway. Currently not all municipal waste is incinerated. 15% of non-recyclable waste is landfilled (CBS, 2014). When some biobased plastics get landfilled, they start biodegrading, causing methane to be released, a greenhouse gas more harmful than carbon dioxide.

Even though there are also negative aspects to biobased plastics, while creating the diaper of the future, it is expected that bioplastics are going to play a very important role. Disposable diapers consist fully of single use materials that are extremely hard to recycle in a valuable way. As fossil-based plastics are an ending resource, using an infinite resource as biobased plastics will be the way of the future. However, in any future scenario, there are two paths that need to be taken, recompositing of the materials as well as reduction of the used materials as much as possible. This will reduce pressure put on the environment, food sources and makes materials available for other products.

New technologies and innovation in the field of biobased materials and crop growing will significantly improve the efficiently at which biobased materials can be produced. More efficient crops (more yield per square meter) will decrease the amount of land needed for the production of the bioplastics, leaving more land for food production. New innovations in production of materials can increase the yield of plastics per input. As bioplastics compete with primary food sources now, ideally this would shift to being able to use parts of plants that are not used for food, and are a by-product that is not used.

In this project efforts will be made to create a diaper that used biobased materials. As it is a project to design the diaper of the future, fossil fuel use needs to be minimized where possible. Next to this, the material usage of diapers in general needs to be reduced as much as possible, to put the least amount of strain on the environment and current food sources.

RECYCLING

An important question that still needs answering is if there is potential in recycling used diapers. As can be read in the chapter the Diaper, current composting and digesting efforts to recycle used diapers use completely separate facilities, that may not be viable currently (Knowaste).

Can a new material composition (with potentially a new design) influence the potential for recycling? Is there value in recycling biobased materials?

When separately collected or sorted by a sorting system, there is a potential for biobased plastic to be recycled. PLA for example, can be either remelted or repolymerized to create new products. There are some concerns with getting a clean waste stream to be able to get an uncontaminated recycled PLA. Any form of contamination will cause a less desirable end product as mechanical properties can be compromised and the product quality will be inconsistent.

With any human based sorting there will be a margin of error, this can be both wrong products as well as contaminated products (food residue in packaging). In recycling facilities, a computer-based sorting system, that makes use of NIR (Near infrared sorting), uses a spectrum of infrared light to identity materials. This type of system can identify PLA in the municipal waste stream, therefore not requiring the consumer to sort or a separate collection system. (CE Delft, 2021) However, in systems like this, there is still an error margin up to 10 percent in tests done in similar systems. (CE Delft, 2021; KNOTEN WEIMAR, 2017)

Also, contamination of the diaper waste with baby's excrement can decrease the quality of the end product. This can be concluded out of tests completed with food packaging. Food traces found in the waste stream affect the recycling yield and quality (Total Corbion, 2017) Most remains, including fat traces can be removed from the waste stream through washing the plastics with warm water and friction, but this is an expensive process that may even break down the bioplastics. (CE Delft, 2021)

With diaper waste there are some concerns with pathogen contamination. As previously mentioned, diapers should be sterilized with steam as there is a risk for pathogen contamination. (Arena et al., 2016)

In conclusion, with the introduction of biobased plastics, recycling would still be a viable way to reduce material usage. However, ways of sorting currently may not be able to produce a valuable end product or it may cost more to recycle then to grow and create new biobased plastics. Especially with the mixed material nature of the diaper, a rigorous redesign would need to be done to make material separatable and preferably a separate collection stream would need to be set up for that particular diaper to ensure beneficial recycling. When a diaper is (almost) fully biobased, it might be the best option to incinerate as the end-of-life pathway.

For this project this means that the focus will not be on recycling, but will be on reducing material usage and improve on the materials that are used.

CONCLUSIONS & REQUIREMENTS

- Biobased materials are able to replace all fossil-based materials in the current disposable diaper. This would potentially make the diaper fully renewable. However, starch-based SAPs have reduced absorbency, which will require more SAP or more diaper changes. (increased material use)

- Some biobased materials cost more water to produce than the fossil-based materials that they are replacing. Another risk of using biobased materials is that they could use up a potential food source.

- Biobased materials are renewable, and when incinerated, the CO_2 that is released is part of a short circular system and can be capture with the growth of new plants. When the biobased material is incinerated there will not occur a permanent loss of materials.

- The diaper of the future should both reduce material use, as well as apply biobased materials as much as possible to make this single-use product as renewable as is viable.

M.1 - The diaper should contain more than 85% renewable materials.

EoL.1 - The diaper must have smaller emission when incinerated compared to a current disposable diaper.

EoL.2 - The diaper must create less waste compared to a current disposable diaper.

CHAPTER 6
DESIGN VISION

This is where it all comes together. All previous chapters come together in one coherent design vision. This vision will be the point of departure for the second phase of this project, the ideation and conceptualization.
The vision for this project will be based on the company, the FDP and previous findings. On the foundation of this vision a set of main requirements will be constructed. These requirements will become the evaluation criteria of concepts.

DESIGN VISION

A clear product vision is needed before moving further into ideating and creating concepts. The vision is the aim that is supposed to be reached within the product. For this project the main aim is to make the diaper more sustainable, without compromising on the user experience. Going into the ideation phase this one main goal is going to be somewhat more specific, to have guidance in choosing and evaluating ideas.

To design the disposable **diaper of the future**, that aims for **100% renewability**, **lowers the environmental impact** and **displays new possibilities** for future diaper innovation.

For the FDP it is important to explore new ideas and possibilities in diaper innovation now and set out on a path for the future. With a concept thus comes a certain timeframe but also a roadmap. What are innovations that could be implemented in products now, what can be done within a certain timeframe (max 5 years) and what concepts need more time to be able to be a viable product. This 6 month project will in no way, shape or form deliver a product that is ready for manufacturing. It will however deliver a proven concept that, with its roadmap, can lead to as much environmental savings as possible and therefore be the diaper of the future.

Important to explain further from this vision is the aim for 100% renewability. As this is one of the FDP's main goals, it is key to making the diaper of the future. There are however limitations to this renewability, as can be read in previous chapters. That is why again, a future perspective will be of upmost importance. All concepts will be evaluated for possible substitutions of materials, but next to this it will be the aim to reduce the overall material consumption, through reuse and minimalization.

PROGRAM OF REQUIREMENTS

Performance
P.1 - The diaper can hold the average urine production in between average changes plus a 10-15% margin.

P.2 - The diaper can hold the amount of urine with the weight of the child pressing on top of the core.

P.3 - The diaper can hold normal consistency bowel movements within the product. (1 in 40 can leak due to consistency of stool)

Material
M.1 - The diaper should contain more than 85% renewable materials.

M.2 - The diaper must use less material (in weight) in use than a normal disposable diaper.

Form
F.1 - The diaper must be able to pack flat so it can be transported efficiently.

F.2 - The diaper does not have to adhere to the standard diaper architype.

Structural
S.1 - The diaper is durable enough to hold up in between changes.

S.2 - The diaper cannot tear when the baby is moving.

Ergonomic
E.1 - The diaper should fit all babies in between 0 and 36 months, through multiple sizes and a flexible closing mechanism.

E.2 - The diaper must allow for the material to stretch around the waist to allow for breathing and movements.

Use
U.1 - The diaper must be easy and convenient in use and therefore not require extra items to launder, more than once a week.

U.2 - The diaper has to be easy to dispose of and therefore must be designed so the product can be thrown away by itself in the general garbage can, it should not require prepacking it in a single-diaper trash bag.

U.3. - The diaper cannot require a user to touch the soiled part of the diaper

Safety
Sa.1 - The diaper cannot contain allergen materials that touch the skin.

Sa.2 - The diaper cannot leave pressure marks on the baby's skin.

End-of-life
EoL.1 - The diaper must have smaller emission when incinerated compared to a normal disposable diaper.

EoL.2 - The diaper must create less waste.

CHAPTER 7
IDEATION

With the design vision and the list of requirements under my belt I went into the ideation phase. Through using multiple ideation methods together with peers and individually a list of ideas was established. These ideas were then combined into multiple concepts that were elaborated on to be able to assess their viability with the list of requirements.

STRATEGIES

Low-fi prototyping

First through extracting parts from current disposable diapers, a low fi prototyping, trial and error based minimalization of materials was performed. The idea of this type of ideation is to simply cut and paste to create new ideas. By touching and feeling the product it can sometimes be much more clear what design aspects are. Also, simple materials as elastic and pins were used to mimic ideas.

Through peeling apart, the multi-layered structure, it was found that there are certain parts that have the potential to be removed as it is a part currently doubled. Also, multiple alterations were found to be possible for the mechanism. Not only would it be possible to replace the closing mechanism with something more durable that can be reused, there are also possibilities to tie it instead of use Velcro, as well as change the interaction of the change, by instead of closing back to front the absorbent core can be tucked under an elastic belt. New ways of wearing a diaper were explored on a doll. This gained me a feel for the diaper, its possibilities and gave a clear impression of what parts have the potential to be reused.

Figure 34) Photos from ideation strategy low-fi prototyping

SCAMPER

In a second method I have involved other students. Using a SCAMPER graph, ideas were put on post-its using the MIRO platform. The SCAMPER method asks 7 different questions to provoke creativity and out of the box ideas, which is very useful in the case of this project, as the diaper might be an already overengineered product. By using this method, I was able to dig deeper into design possibilities. Working with other students helped me by having new perspectives on the problem, which for me as a designer is beneficial.

As the diaper is a product almost over engineered, it was very hard to see a possible design space that would be viable. The main effect of this ideation method was breaking open the ideation space. Through asking various questions that weren't necessarily straight to the point in terms of making a diaper more sustainable, they opened up a new ideation space. Most useful ideas that came out of this ideation were replacing and reusing certain parts of the diaper. Seeing current mechanisms in a different light will help future efforts to reduce material use.

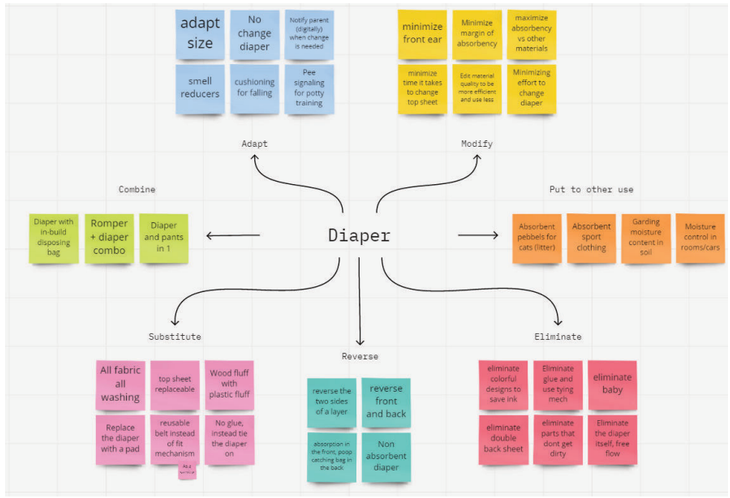


Figure 35) The filled out SCAMPER graph.

Substitute

Combine

Adapt

Modify

Put to other use

Eliminate

Reverse

Ideas

Substitute materials to renewable materials.

A romper that combines function with the diaper.

Diaper of which only the core is changed and thrown away.

Mono material diaper

All diapers can resize however much needed to provide any amount of absorbency needed.

Ladder of R

A third method to generate ideas was inspired by the ladder of Rs.

The levels of circularity inspired category focused ideation, where every level had its own design possibilities. By putting the current disposable diaper as the main subject and asking questions as: How do we Refuse to use more diapers? Multiple ideas were put on paper, which were very sustainability and circularity focused. Even though using this model of level of circularity is not an official ideation method, I would highly recommend this strategy to any designer facing a design problem concerning sustainability. This method showed the importance of reducing materials in the design of the diaper. It also showed that using biobased materials could benefit the impact of a diaper as a second aspect.

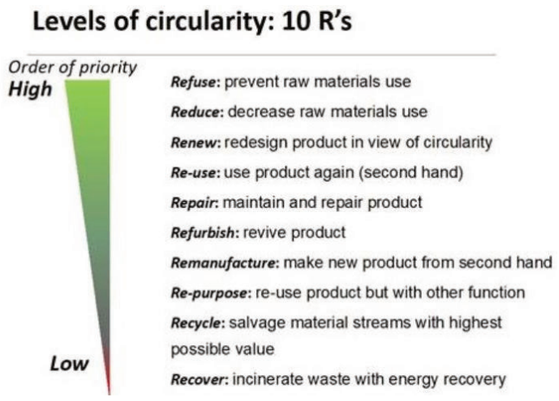
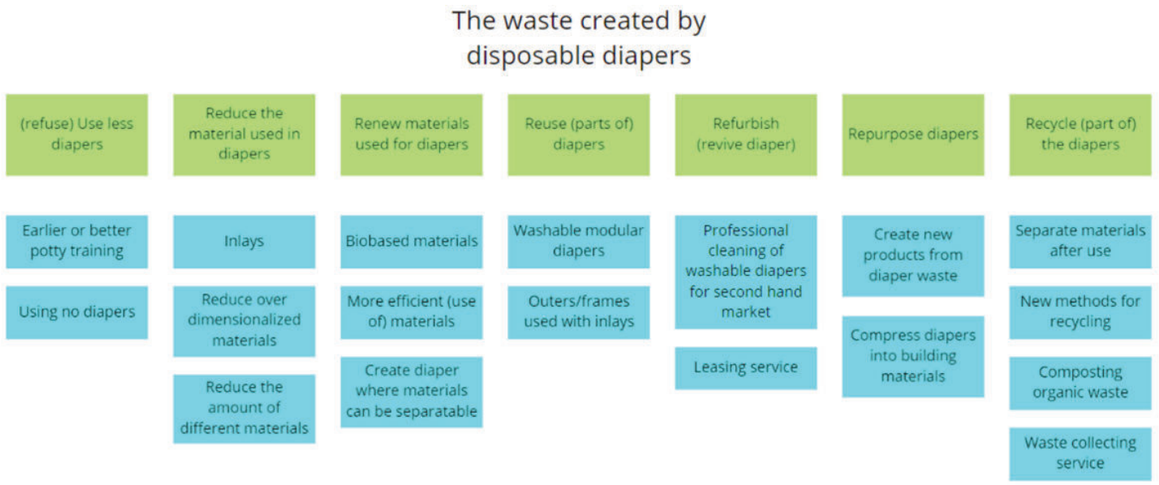


Figure 36) The levels of circularity divided into 10 Rs



CAFCR

The last method used in this ideation phase was a way to establish end user needs and goals. Even though a requirement list was put together, the values of parent's values were not listed with the purpose of finding new solution spaces. Using the CAFCR model (Muller 2011) and thereby architectural reasoning, a method which is usually used for system design, a clear view on user priorities is formed. By conducting interviews with both mothers and fathers with children currently in diapers, a framework of needs and priorities is established. From this way of thinking, new ideas to improve user experience came to light.

From these first two phases, the rest of the phases were completed (appendix). From this reasoning the importance of ease of use for the parent became apparent. Aspects like clean and easy disposal had priority over environmental friendliness. This brought a string of reasoning to this project that hadn't been considered earlier. Parents do not want to nor have the time to spend extra time on diapers. They want a highly safe and dependable product, that is easy in use.

This method brought to light some extra aspects to consider in the design. Indicators that notify a parent when a diaper change is needed, or methods that help in clean disposal are not required for a well-functioning product, but would provide a pleasant user experience.

The customer objectives can be defined in terms of key drivers. 4 Customer objectives were identified (in order of importance):

- **Safety** for their baby
- **Dependability** for themselves (to not have any leakages, saving them in cleanup)
- **Ease of use** for both themselves and their baby. They don't want to spent a lot of extra time or effort, as well as they don't want to get their hands dirty.
- **Environment** for themselves, to not have an enormous footprint, to be able to feel content with the diaper choice.

Application (How is the product used);

The application view is used to establish the way the consumer is achieving his or her objectives. The main objectives of using diapers are:

- Keeping the urine and feaces contained within the diaper.
- Single use or with reusable parts of the diaper, as long as it does not require a lot of extra work.
- Disposal is clean, with a clear conscience.

Ideas

Add inbuild method of disposal (closing strip/bag)

Indicators for when a diaper is full rather than wet

Diaper that communicates it's footprint to make a parent aware of the costs of diapering.

CONCEPT DIRECTIONS

After gathering all ideas, they clearly can be put into 3 main categories. These categories will be the points of departure for generating concepts. Concepts could be an elaboration on one of the ideas, or combine multiple. The main goal of the categorization is to work towards multiple end goals and most ideally combine these directions to make the best future diaper possible.

The timeline of the concepts is dependent on what innovation is needed to make it work. For every concept the time needed for it to be effective will be indicated. A concept could for example not lower the environmental impact now, but could do so with a better biobased material that is expected to become available within 5 years.

Move toward 100% biobased diaper

Can a diaper be fully renewable? Currently the maximum share of biobased materials is 85%, this means that there is still a 15% share to go, as well as that the 85% diaper still has some functionality problems due to the biobased material's qualities.

Minimize material use of each diaper

Can parts of diapers be made redundant? Can the material be reduced in some parts? Can the disconnect between absorption and urine production be minimized?

Reuse parts of the diaper

Not all parts of a diaper get dirty in every use. Can parts be reused? Can a diaper be replaced with one or more reusable washable parts?

LIST OF CONCEPTS

- **Fully biobased diaper**
- **Flushable diaper**
- **Night and day diaper**
- **Frame diaper**
- **Romper diaper**
- **Disposable reusable diaper**

These concepts will be explained and further elaborated on in the coming chapters. During this concepting phase, the list of requirements and the vision were closely watched and used to guide the development.

All concepts were worked out to a point where the diaper could either be low-fi prototyped and tested on a doll (for the reuse direction) or to where a clear material analysis could be done to see how the environmental impact had changed.

Move toward 100% biobased diaper

Fully biobased diaper

A fully renewable diaper.

What are possibilities in making a diaper 100% biobased? Can parts be omitted to achieve this? Can mechanisms be changed?

To be able to design a 100% biobased diaper, we need to understand why currently diapers are not fully biobased. Certain parts can't be manufactured in the same form in a biobased material simply because there is no alternative material.

Currently the elastic in a diaper is hard to replace. The elastic is located in the leg cuffs as well as in the back ears. They are essential for both fit and containment. Therefore, they should either be replaced by a material with similar elastic qualities or be redesigned. In the exploration of this concept both these routes were taken, to maximize the possibility of finding new solutions.

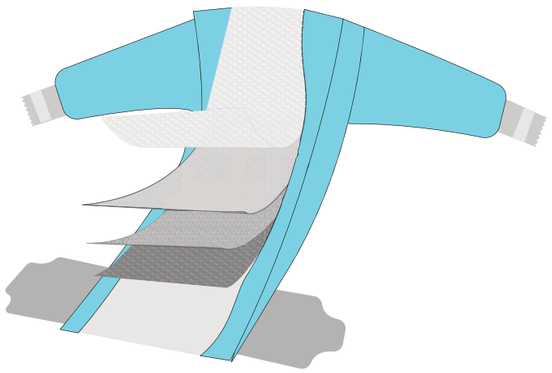


Figure 37) Diaper parts currently containing elastic are marked blue.

Material changes that can already be done include the SAP, non-woven and film. They can already be replaced as they all have a viable alternative on the market.

The fluff of the current disposable diaper is made from organic fibers, mostly out of fast-growing trees. (EDANA) Bamboo is a fast-growing plant that can also be used in the fluff. Even though not the main goal of this concept, it is important to incorporate changes in the material composition, in this case to prevent deforestation.

Most biobased materials cost more water, as they need to be grown. This will cause this concept to have higher water costs compared to a fossil-based disposable diaper.

Table 15) Current materials used and other biobased options for those parts. (GRANTA)

	Water usage production of material	CO_2 emission in production of material	CO_2 emission of incineration of material
Unit	L/kg	CO_2 kg/kg	CO_2 kg/kg
Fluff			
Pine	700	0,38	1,81
Bamboo	700	1,06	1,74
Non-wovens & Film			
PP	39,2	2,92	3,14
PE	58,2	1,86	3,14
PLA	20,8	2,28	1,85
PHA	200	0,9	2,05
SAP			
Sodium Acrylate	40	3,63	0,81
Starch based SAP	42	0,88	1,85

For this concept low-fi prototyping was used to find possibilities to omit the elastics. Can a non-elastic material be transformed into an elastic one?

Inspiration was taken from the way wood can be cut into a lasercutter to create flexible wood, named kerfing. Through adding slits in certain patterns, flexibility and even stretch can be achieved. I applied the same patterns to paper and non-woven material with the use of both a plotter and doing it by hand. The main goal of this exercise was to prove that elastic could be replaced with other materials, to achieve the 100% biobased diaper.

Figure 38) Tests done with paper and non-woven to create elastic material.

Elastic behavior was achieved with both paper as well as non-woven. The paper proved prone to tearing, but the non-woven behaved as intended.

A new sheet of non-woven material was cut into the shape of the back ears, and slits were placed in a similar manner as with the small tests. The newly created elastic ears were glued to a store-bought disposable diaper to test if the mechanism would work. The leg cuff elastics were also replaced with strips of non-woven, treated with the kerfing pattern.

A doll was used to test the new mechanism. The new elastic material worked as intended, it behaved similarly as the elastic in current diapers. However, the material is somewhat fragile, making the new ears prone to tearing. For the leg cuffs there was one main problem. The inner leg cuffs are currently used as containment, which a piece of material with holes in it will obviously not be able to do.

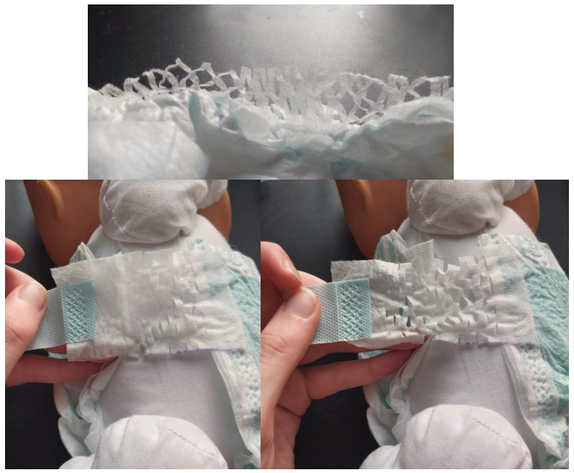


Figure 39) A prototype of a diaper without elastic, with the non-woven material.

This new way to achieve a fully biobased diaper shows that both material innovation as well as new design have a place in making a diaper more sustainable.
However, the elastics only make up a 0,6 percent of the weight of the current diaper. Other concepts will be worked out as well to explore other possibly more impactful design changes that can be made.

Move toward 100% biobased diaper

Flushable diaper

A diaper that rapidly biodegrades and can be flushed in the toilet.

Are there new possibilities in the end-of-life design of the disposable diaper when it is biobased?

The availability of bioplastics for the production of a diaper creates even more possibilities for the end-of-life. Especially PHA (Poly-hydroxy-alkenoate) is a promising material to use, as small particles of this material can degrade within 30 days in the sewer. (Dilkes-Hoffman et al., 2019) As PHA is a material created from sewer sludge flushing a used diaper through the toilet makes it truly circular. The biodegraded material can be the carbon source for new PHA material.

The main advantage of flushing the diaper instead of throwing it away is that this end-of-life path generates less waste. As 75% of diaper waste consists of urine and feaces, which for adults go into the sewer anyway, depositing of this 75% would be a good reduction of waste created. Especially for the urine, which has a high water content, it can impact the amount of energy can be recovered in an incineration process. From water no energy can be recovered during incineration, it only takes up heat for it to evaporate. (Rijkswaterstaat wvl, 2021) Disposing of the main water content would therefore be beneficial.

Figure 40) A diaper blender to be used before flushing.

However interesting the idea of flushing a diaper through the toilet may be, a diaper is not necessarily biodegradable when it is biobased.

Most beneficial would be to flush all water containing parts of the diaper. The absorbent core contains all urine and thus water in its absorbent gel. This gel, made of SAP can be made from biobased materials, but is not yet manufacturable in a way that it would be biodegradable at the same rate as the PHA. The quickest biodegrading SAP has only been tested in soil, and took 21 days to degrade for 67 percent. (Chen et al., 2022) For a flushable diaper concept it means that currently there is no viable SAP to use in its composition.

Next to the speed of biodegrading of the SAP, there is also a more practical problem that came to light during elaborating on this concept. Concerns are:

- Sewer blockages caused by not yet degraded materials.

- Eutrophication of sewage water caused by the addition of a lot of extra material to the stream.

- Fossil-based diapers that are wrongly shredded and flushed by unknowing user. This will cause a lot of plastic particles to get into the environment.

This concept is not yet viable and problems will remain for the foreseeable future. Comparing incineration of a biobased diaper with flushing the diaper, there is a big benefit to incineration, as energy can be recovered during the incineration. When flushing the diaper this is not a possibility.

All the concerns combined made this concept unviable and therefore not continued on to elaborate it further.

Minimize material use of each diaper

Night and day diaper

A diaper which has different capacities for day and night.

Reducing the absorbency content during the day will save on material. As diapers are designed for both day and night use there is always a part of the full capacity that is not used during the day.

Through analysis of the current disposable diaper and the output of the average baby, it became clear that there is a disconnect in current designs. Current diapers over dimension the absorbent capacity to make the diaper adequate for both daytime as overnight use. As can be seen in the User chapter, the diaper changing frequency during the day is higher compared to the night. As children get older, they start using 1 diaper overnight instead of waking up for a feeding and change at night.

As stated in the chapter User, the overall average of diapers used daily is 4,16. When a child is wearing only one during the night, it means that there are 3,16 left over during the day. For a 12- to 24-month-old (which is most likely when a child needs 4 diapers a day and sleeps through the night) 11 - 14 hours of sleep per day is advised. (Sleepfoundation) This means during the day a diaper is worn for a minimum of 4,1 hours. The diapers that are used during the day have the same absorption capacity as the ones used for 11 hours. However, urine production during the night is lower, the ration day/night is 1,9. (Vulliamy, 1965) This means that a night diaper of 11 hours has the same urine volume as a day diaper of 5,8 hours. This means there is an over dimensioning of 1,7 hours, or 41 percent of the absorption capacity.

In the design of a more sustainable diaper, separating day and night use will be key, as it is a very simple and straightforward way to cut back on material use. The concept will be easy to explain to parents and easy to apply in their day-to-day setting.

By reducing the amount of SAP with 41% the content list of the day-diaper can be created.

Table 16) (Right page top table)
The impact of a normal disposable diaper day of use build up from material impact as well as incineration as the end-of-life scenario. (source: Granta Edupack)

Table 17) (Right page bottom table)
The impact of a day night system disposable diaper day of use build up from material impact as well as incineration as the end-of-life scenario. (source: Granta Edupack)

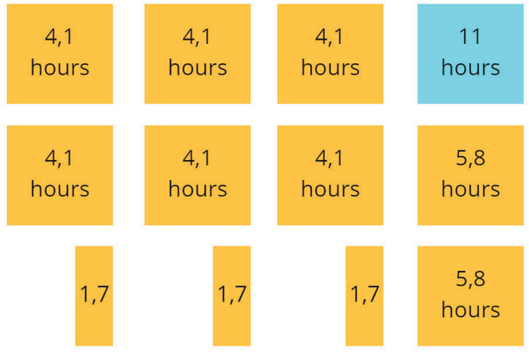


Figure 41) The over dimensioning of diapers.

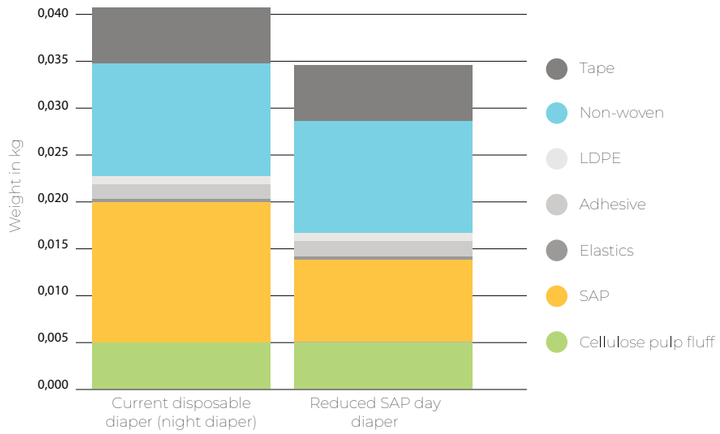


Figure 42) A night diaper, with the same material composition as a the current disposable diaper and a day diaper, with the same composition except for the SAP, which is reduced by 41 percent.

	H_2O use in liter (in production of materials and incineration)	kg CO_2 equivalent (in production of materials and incineration)
Per diaper	5,11	0,20
Totals over 1 day 4,16 diapers used per day	**21,30**	**0,84**

	H_2O use in liter (in production of materials and incineration)	kg CO_2 equivalent (in production of materials and incineration)
1 Day diaper	4,87	0,18
1 Night diaper	5,12	0,20
Totals over 1 day With the use of 3,16 day diapers and 1 night diaper	**20,51**	**0,76**

A 9,5 percent decrease of CO_2 equivalent as well as a 4 percent decrease in water use.

This concept achieves a more sustainable diaper through material reduction. By dividing day and night use, redundant capacity can be removed from the day diaper material composition.

When a child uses more than 4,16 diapers per day, the benefits compared to the current disposable diapers will only increase.

This concept shows that diapers during day and night can be designed differently. The resulting concept would be easy to implement as it is simple to understand and execute for parents.

Reuse parts of the diaper

Frame diaper

A reusable, rinsable, elastic frame in which a diaper inlay can be placed.

As the elastics in diapers are hard to replace with a renewable alternative, a reusable elastic structure might me the solution.

Through analyzing differentiating products currently on the market, we see a problem with the belt system. (chapter Market) As the elastics in both washable diapers as well as disposable diapers are key to the containment function, in any belt system, they are required to be in the inlay. To minimize material use in the inlay, a reusable elastic frame can be designed in order to guarantee the same level of containment, without single use elastics.

When designing the frame in which the inlay will be placed, a new opportunity came to light. Some elastic materials do not need laundering, but can be rinsed when needed. For example, silicon elastics could be used to create a frame, which then would not necessarily need any laundering or washing. A wipe when a messy diaper comes along would be sufficient.

This concept was low-fi prototyped with the use of a doll. Multiple configurations as well as materials were put together, to figure out the best solutions.

Figure 43) Pictures of low-fi explorations of the frame. It was most important to find the right attachment points to be able to place an inlay.

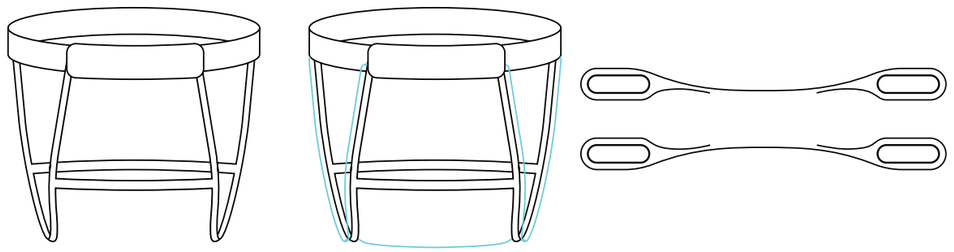


Figure 44) An elastic frame (in black first picture) with the inlay (in blue in the second picture) possibilities for inlay placement over the frame (third picture)

Figure 45) A new way of opening a diaper: Front opening, so an inlay can be placed inside without taking the whole frame off.

While handling the material during the explorations it became clear that solely elastic on the baby's skin was not safe. It would cause irritation because of its non-slip and non-absorbent nature. As can be read in the chapter User, the baby's skin is very sensitive, which forced the concept into two other directions:

- The inlay must cover all the frame so it does not touch the skin.
OR
- The 'belt' part around the waist can be made from fabric. (As can be seen in violet in the figures)

In the first direction the inlay has to cover the frame completely, without having containment elastics itself. The inlay will have to stick out above the frame (for example on the belly and back) this will create a system prone to leaking, as the non-woven will absorb liquid as well as let it through with movement.

Figure 46) Placing an inlay in between the skin and the frame will make the diaper prone to leaking. In the illustration the blue lines mark the path, in between skin and inlay.

In the second scenario the frame essentially becomes an extension of the earlier discussed Little and Brave belt system.

During the ideation for this concept a new closing mechanism was invented. A way of closing the diaper with one flap that comes to the front and a belt that remains closed at all times. This way of building the mechanism could support the use of diaper inlays, as the frame itself does not have to be taken off completely. Ideally this process would be as easy as open, wipe, place a new inlay and close. With this closing mechanism, a parent would even be able to close the diaper with one hand (compared to the need for two with the current disposable diaper closing strips).

The potential material savings of this concept are the same as with the Pampers Hybrid product, minus the impact of the elastics and the need for laundering. However, with the frame diaper there will be costs in rinsing or wiping, on top of the material costs of the inlay.

In the scenario in which the belt would be made out of fabric, there would also be laundering costs, making this concept even closer to the Pamper Hybrid environmental costs.

With the low-fi prototypes, inlays were placed into the frame, this was more complicated than expected, as the frame is flexible, where the inlay cannot stretch. The difficulty in this interaction may not be worth the savings in environmental costs it is achieving.

Romper diaper

An adjusted romper where an inlay can be placed in.

Can a piece of clothing that a baby already wears function as an inlay holder?

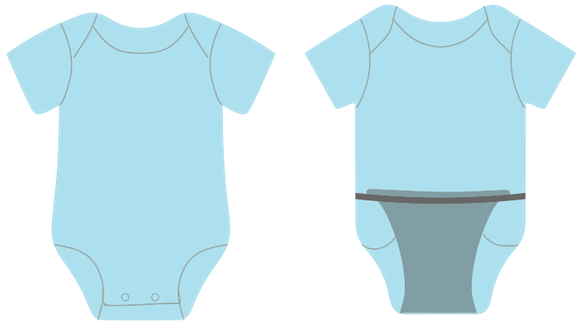


Figure 47) A romper adjusted for use with an inlay. A higher closure and a belt modeled into the romper.

All babies, especially in colder climates like the Netherlands wear rompers. Because babies already wear them on a daily basis, it would be the perfect candidate to function as an inlay holder. It would not introduce extra laundry work for the parent.

In order to fit an inlay properly into a romper, adjustments to the current romper design need to be made in order to make it function as intended.

First of all, in order to provide the same containment and fit as the current disposable diaper, the romper needs elastics build in. Especially to provide containment around the legs, elastic needs to be implemented in the leg seams.

The second adjustment to provide this containment has to be around the waistline. This could be made of elastic, but could also be an integrated belt in the romper. In order to make the inlay fit in a convenient way into the romper, the closing placement should be shifted up, to be able to open the romper without loosening the inlay from the romper.

The success of this concept hinges on the effectiveness of the inlay. If the inlay leaks, a parent would have to undress the whole baby in order to dress them with a new clean romper. In this case a pair of underpants that hold the inlay would be easier in use. Also, when a romper gets dirty, the cost of laundering an extra romper is higher than washing a pair of extra underpants.

While evaluating benefits and drawbacks for this concept however, the front closing mechanism (similar as in the frame diaper) appeared as an easy way to use inlays without having to take the outer system off completely every time. That is why prototypes were made of this mechanism, to explore the interaction further.

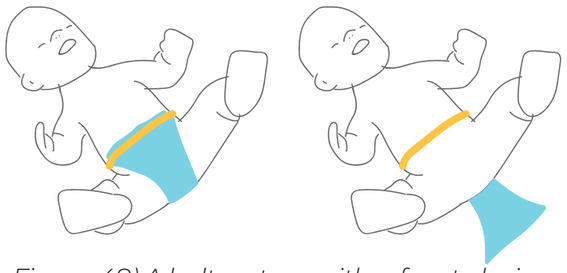


Figure 48) A belt system with a front closing flap. Easier placement of the inlay, without having to take the outer off.

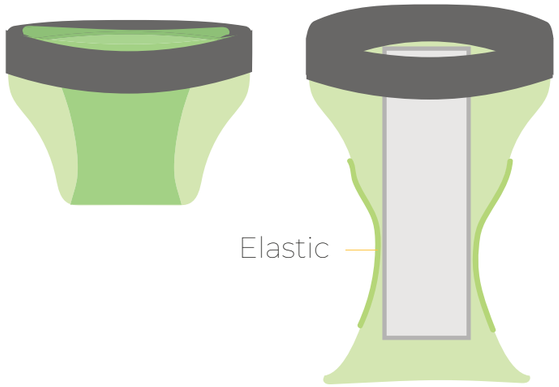


Figure 49) The front closing belt system.

Figure 50) The belt system prototyped for a doll. An elastic belt under which the front flap closes. The flap also contains elastic.

Through testing this system on a small scale (on the doll) it was deemed viable. The interaction could be completed with one hand, the front flap closed tightly against the skin and the leg containment elastics laid flat against the skin, to ensure a leak-proof diaper.

The elastic belt in the prototype was a closed circle. This band had to be maneuvered over the legs in order to get it to sit in the desired place on the hips. Even easier would be to make the belt able to open and close so it could just be slid under the baby.

This new mechanism was made in baby-size, to be able to test it on a real baby. A belt, that closed under which the front flap could close. This prototype was made out of cotton.

This prototype was also tested with a Pampers Hybrid inlay to get a more

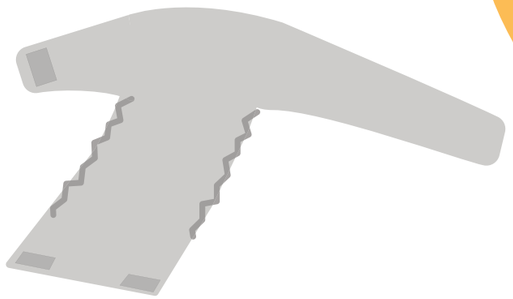


Figure 51) A belt that opens, with front flap.

Figure 52) The belt system prototyped for a real baby. A belt that opens and closes, with a separate flap.

realistic feel of changing the diaper. The overall experience of opening and closing the diaper to place inlays was pleasant. The belt stayed in place when opening and closing the flap. The placement of glue on the Pampers hybrid inlay is on the back edge. This way the baby's body weight leans on it when trying to change it. A lower placement of glue would be beneficial. This concept would be an iteration on the existing Pampers Hybrid concept, as it is a washable outer used with inlays. During the development of this concept a new approach came to light: that this thin outer, could possibly be made disposable.

Reuse parts of the diaper

Disposable reusable diaper

A reusable outer diaper used with inlays, that can be disposed of instead of laundered.

Disposal is the ultimate convenience, can a reusable diaper outer be made to be reusable and disposable?

A thin reusable outer that holds inlays and when dirty or broken can be disposed of. This would be ideal for parents that currently use and like using disposable diapers, for their convenience, but are willing to take small steps to more sustainable diapering.

The mechanism that was explored in the previous concepts was made from a non-woven diaper material, to prototype a disposable outer.

Figure 53) A non-woven prototype of the new mechanism.

This structure was not as durable as it was intended. Using glue on the material made it stiff and unsuitable for a diaper. Sewing it with a machine or by hand caused it to rip, due to the holes that were poked by the needle. It was concluded that making a diaper from non-woven material was too hard to prototype with the means I had access to.

New ways of prototyping were explored, of which the most successful was the utilization of diapers to make prototypes. In an almost Frankenstein fashion prototypes of a disposable outer were made, to be able to test the durability and shaping. As the main goal of this project is making the disposable diaper more sustainable, it was not a requirement to make all prototyped parts myself. The overall quality of this outer diaper improved, making it possible to try it out on a real baby.

Figure 54) The previously ideated belt system, created with a disposable diaper with the absorbent core removed.

Figure 55) The disposable prototype tried on on a real baby.

Trying the new disposable outer on a baby proved the mechanism worked, even on a disposable outer, which is much less sturdy than sewn cotton. The disposable outer performed well, the baby was wearing the outer over the romper for a few hours to test if any tears or other problems would arise, but no issues came to light.

When placing the Pampers Hybrid inlay into the disposable diaper outer, and removing it after it was clear that the glue on the inlay was meant for it to stick on fabric. The glue was too harsh for the more delicate non-woven of the disposable outer. Less harsh glue should be used for inlays meant for this system.

Combining best of both convenience as well as reusing for sustainability purposes, the reusable-disposable outer diaper introduces reuse of material that otherwise would be single use. A small amount of extra

Table 18 & 19) A normal diaper divided into an inlay (left) and an outer (right)

	Amount of material in g
Cellulose pulp	5,0
SAP	15,1
Adhesive	1,5
Non-woven	7,0
Film	0,3

	Amount of material in g
Non-Woven	7,0
Elastics	0,3
Tape	2,0
Film	0,6

effort is needed, but no big steps like laundering diapers or the need for bringing a few extra washable outers is needed. The disposable outer can be folded to a tiny square, similar to a menstrual pad, which makes it a small item to bring along, compared to washable outers.

In the table at the bottom of this page can be seen that the use of the reusable-disposable outers in combination with inlays can save 21% in kg CO_2 equivalent. This is when a child uses 4 inlays every day. Especially during the first 6 months, a baby uses more than these 4, which makes this concept even more beneficial. The more the outer is reused, the more environmental savings are made. If the user scenario becomes that the outer is only reused once instead of multiple times, this system will still be desired over a normal disposable diaper.

	H_2O use in liter (in production of materials and incineration)	kg CO_2 equivalent (in production of materials and incineration)
1 Reuseable outer	0,492	0,130
1 Inlay	4,600	0,060
Totals over 1 day Use of 4 inlays and 2 outers	**19,26**	**0,64**

Table 20) The environmental impact of the reusable disposable diaper in material cost and incineration as the end-of-life. 6% water is saved as wel as 21% on kg CO_2 equivalent compared to the use of normal disposable diapers. (source: Granta Edupack)

CONCEPTS & LOR & VISION

To be able to take next steps in concept development all concepts (still in early stages) needed to be evaluated with both vision as well as the LoR. Most viable and fitting concepts can then be taken into further development stages.

Fully biobased diaper

As per the vision set for this project is to aim for a 100% biobased disposable diaper, this is a very important concept that shows that there are certainly steps that can be taken. However, as in the chapter Materials can be read, a lot of innovations in the field of biobased elastics and SAPs are still researched and not available for diaper production just yet. As this project is setting a vision for the diaper of the future, this is a concept that will be worked further on in coming chapters.

Flushable diaper

The flushable diaper is the concept most distanced from current reality. Even though it would propose a whole new method of disposal, it is not viable, as not all diaper materials are flushable and future innovation will unlikely make this a reality.

Night and day diaper

The night and day diaper concept shows that some diaper improvements can be made without compromising anything in functionality or user experience. This separation will be used in further concepts, at least as an addition to make more impact where possible.

Frame diaper

Even though the interaction and hassle this concept brought to the interaction, a new way of opening and closing a diaper was an innovative idea that supports changing an inlay. A new way of putting hybrid diapers on the market, setting them apart with a new closing mechanism. The new mechanism will be further developed to be combined with another concept with inlays.

Romper diaper

Through calculating what extra laundry would be generated through using the romper as the holder of the inlay, this concept was deemed unviable. This concept was however used to further explore the new closing mechanism. This new closing mechanism supports using inlays and leaving (thus reusing) the outer. A future concept would not require this mechanism to fulfil the vision, but it would support it.

Disposable reusable diaper

The disposable reusable diaper proposes a significantly differentiating concept. It delivers both the convenience of disposal as well as material savings that are tangible and clear to understand for the parent. It is a concept that could be combined with others, to further increase savings. It clearly sets a path for future diaper development, where it is a lower impact disposable diaper that does not require extra user effort and therefore would be a viable concept for an actual product, not just a concept.

"To design the disposable **diaper of the future**, that aims for **100% renewability**, **lowers the environmental impact** and **displays new possibilities** for future diaper innovation."

COMBINING DIRECTIONS

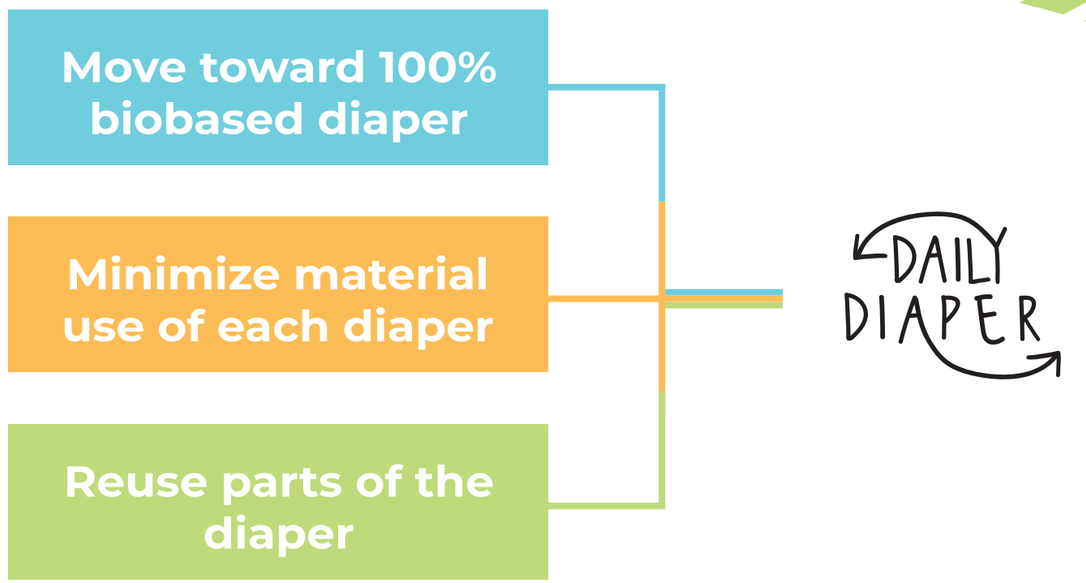
During development of the concepts explained on the previous pages, it became clear that there was great potential in combining directions. A diaper that is made more sustainable in all three directions, to make the greatest decrease possible on the cost of diapering.

For the ultimate concept, a reusable disposable diapering system will be combined with flexible inlays, made out of biobased materials.

This will result in a concept that adheres to the set vision best, as it uses concepts from all three design directions. This concept will be elaborated on through prototyping, calculations on the environmental impact, scenarios and user testing.

The new concept will be called the Daily Diaper. This name stems from the reusable and disposable outer, which will hold up over the whole day. This system will be a more sustainable disposable diaper experience.

"A fully biobased reusable and disposable diaper system stripped of all unnecessary material."



CHAPTER 8
CONCEPT

The daily diaper. A reusable outer, that can be disposed of when dirty or broken. Replaceable inlays that come in multiple sizes and absorbency capacities. No laundering needed, so providing the parent with the same convenience as a normal disposable diaper, while saving on materials. The materials that are used are made to be as renewable as possible. A smaller footprint for a pleasurable user experience.

THE DAILY DIAPER

To further establish the concept of the Daily Diaper, this chapter will dive into all aspects in detail. The material composition, the inlays with different absorbencies and the physical shape of both the inlay as the outer diaper. Also, the environmental impact will be analyzed and compared to the current disposable diaper.

In this chapter will also be decided what components need further testing. User scenarios will be walked through to find potential problems fast. The proposed tests will be completed in the next chapter, the goal of this chapter is to show the concept, its benefits and question design choices made that need further testing.

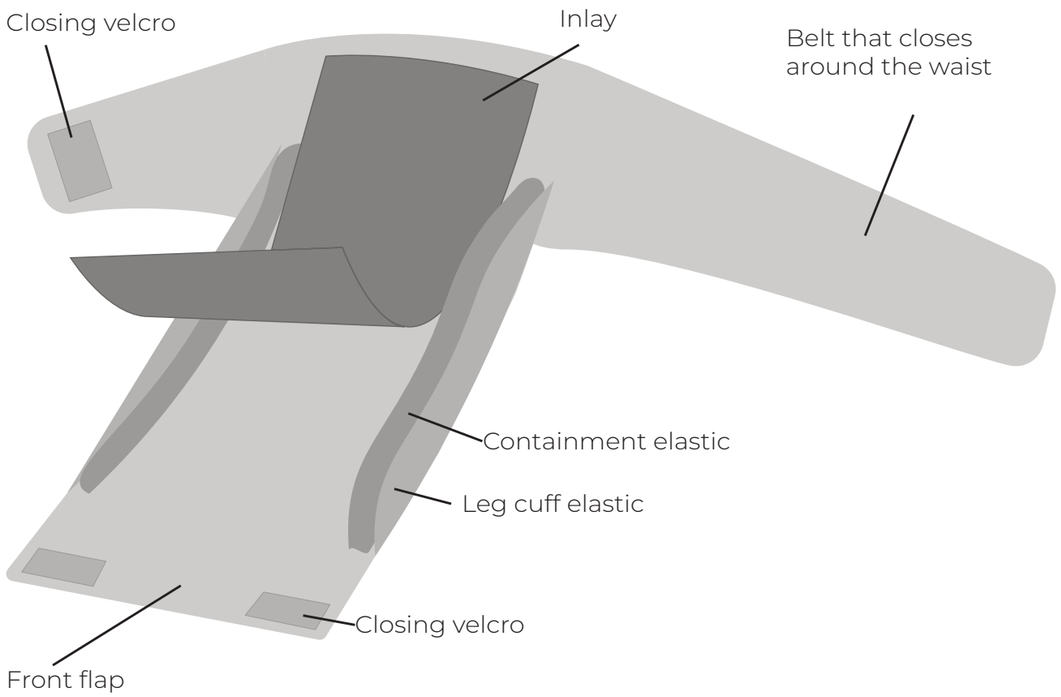


Figure 56) The Daily Diaper

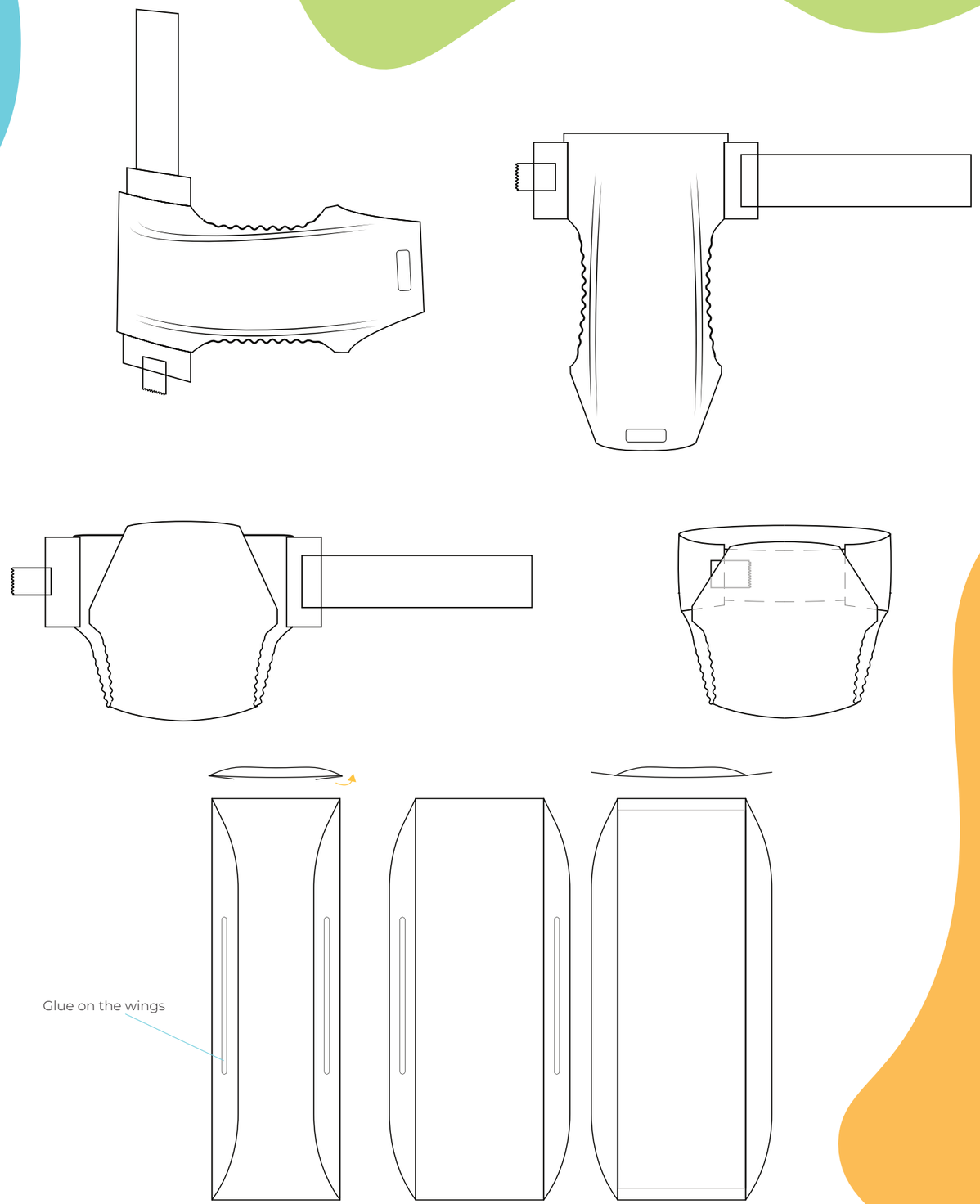


Figure 57) The daily diaper illustrated (top) Outer, (bottom) Inlay.

COMPOSITION

When aiming for a fully biobased diaper, the material composition of the current disposable diaper needs to change. In material composition the two biggest changes are that the Daily Diaper consists out of more than 99% biobased material as well as the split between day and night use diapers.

As discussed in the chapter Materials, the starch-based SAPs currently available are not as absorbent as fossil-based SAPs. However, with the new innovations in mind, the same amount of biobased SAP will be used as fossil-based SAP that would be required. In the chapter (Future vision) will be a step-by-step plan to slowly make this future diaper project a reality.

This material composition will be for a comparable diaper size 4 to 5 (depending on brand). As this is the same as the Pampers Hybrid inlay, it will be easiest to compare.

The Daily Diaper inlays will be used in sets of 2 kinds: The use of a night inlay for overnight, and a day inlay for during the day. The day-inlay will have a 41 percent reduction of absorbency, as this is overcapacity that is only needed at night (see concept Day-Night diaper) The outer is designed to hold the elastics, to make the inlay fully biobased and renewable where the outer will only contain 1% non-biobased material, the elastics.

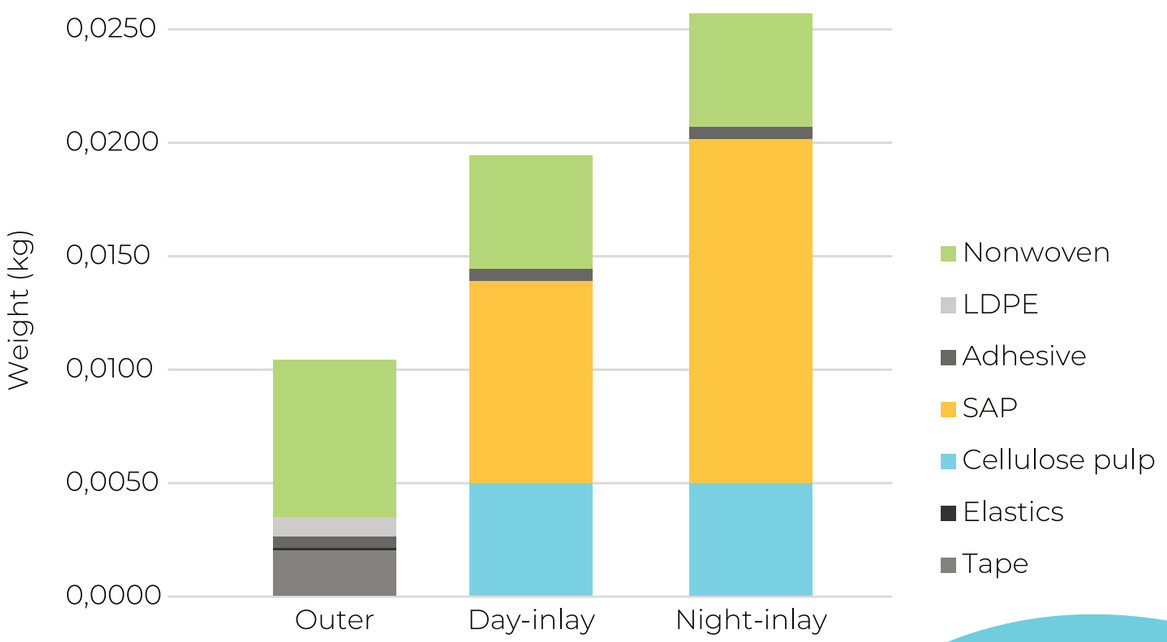


Figure 58) The Daily Diaper contents.

IMPACT & WEIGHT PER MATERIAL TYPE

Table 21) The Night-inlay composition and impact.

			Impact from production		Incineration
Component	Weight (kg)	Material used as source	Water use in liter	CO_2 foot-print in kg	Combustion CO_2 in kg
Cellulose pulp	0,0050	Pine	3,500	0,002	0,009
SAP	0,0151	Cornstarch SAP	0,636	0,013	0,028
Adhesive	0,0005	PUR	0,073	0,002	0,002
Film	0,0001	PLA	0,002	0,000	0,001
Non-woven	0,0050	PLA	0,104	0,011	0,009
Total	0,0257		4,313	0,028	0,0479

Table 22) The Day-inlay composition and impact.

			Impact from production		Incineration
Component	Weight (kg)	Material used as source	Water use in liter	CO_2 foot-print in kg	Combustion CO_2 in kg
Cellulose pulp	0,0050	Pine	3,500	0,002	0,009
SAP	0,0151	Cornstarch SAP	0,375	0,008	0,017
Adhesive	0,0005	PUR	0,073	0,002	0,002
Film	0,0001	PLA	0,002	0,000	0,001
Non-woven	0,0050	PLA	0,104	0,011	0,009
Total	0,0257		4,313	0,028	0,0479

Table 23) The outer pants composition and impact.

			Impact from production		Incineration
Component	Weight (kg)	Material used as source	Water use in liter	CO_2 foot-print in kg	Combustion CO_2 in kg
Non-woven	0,007	PLA	0,146	0,016	0,013
Elastics	0,0001	PUR	0,010	0,000	0,000
Adhesive	0,0005	SPS	0,073	0,002	0,002
Film	0,0009	PLA	0,018	0,002	0,002
Tape	0,0009	PLA	0,042	0,005	0,004
Total	0,0257		0,288	0,024	0,020

Main source used: GRANTA Edupack, with addition of Vercalsteren 2012 for the impact of starch based SAP.

INLAY CAPACITY

Current disposable diapers come in a range of sizes. Normally they go from a newborn size or 0 to a size 6 for when a child is 2,5 years old. They come in extra-large sizes for children that are potty trained at a later age as well as in tiny sizes for preemies, but these special sizes will not be taken into account in this project.

The Daily Diaper system uses inlays for the absorbency. The great benefit of the inlays is that a parent can easily size up or down, when necessary, without being dependent on if the diaper fits the body size. The inlays for the Daily Diaper will use a gradient sizing system. A system where inlays with multiple absorbency capacities fit into the same outer. This way a parent can size up for over-night use, as well as size down for day use if for example when a child has a higher-than-average frequency of bowel movements.

The inlays will fit lengthwise, as the biggest size will be the exact length from middle front (belly button) to middle back (top of diaper on the back). The smaller sizes have a little less length, but this is space that will almost never gets soiled. This can be compared to the Pampers Hybrid inlay, which also do not stretch the whole length from front to back.

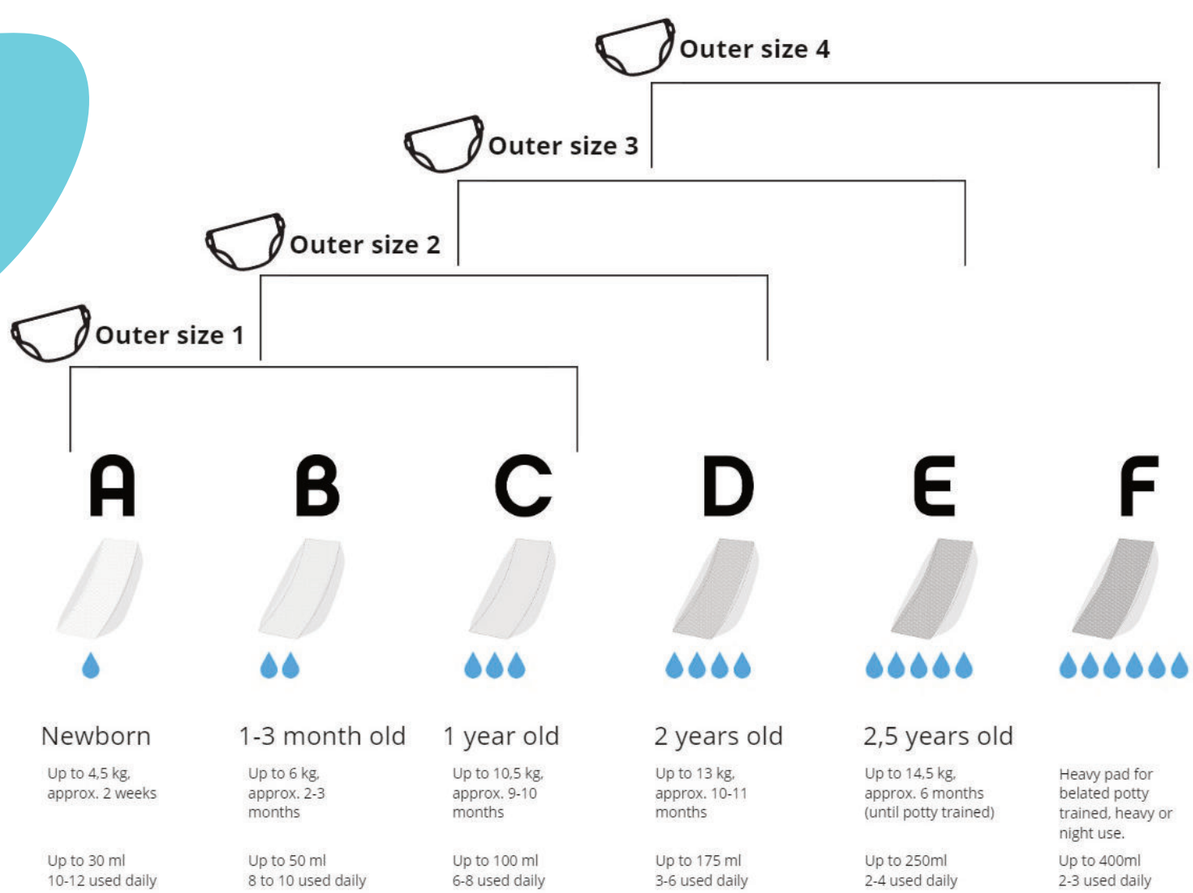
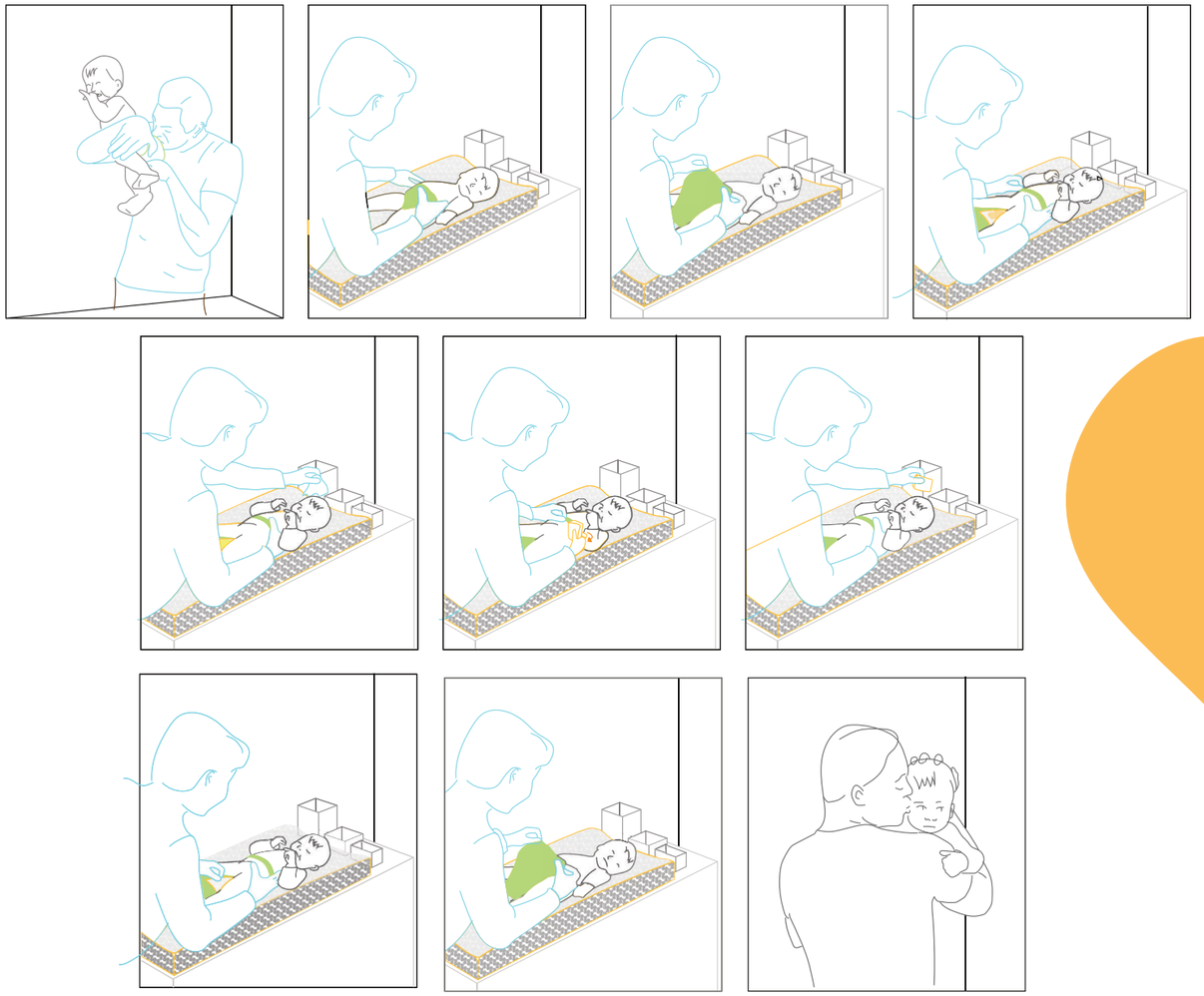


Figure 59) The Inlay gradient.

CHANGING THE DIAPER

With the change of the mechanism, changing a diaper is also significantly different. Therefore, there was a need to show the intended interaction in detail, to make the new mechanism clear to understand. In the figure below we can see a regular diaper change, where the outer is not changed, only the inlay. From top to bottom left to right:
1) The need for a diaper change is established.
2) The child is placed on the changing station.
3) The front flap is opened.
4) The parent checks for leakage of the inlay onto the outer, if it had leaked a new outer would be put on.
5) The outer has not been leaked on, so a wipe is grabbed to clean up the baby. The wipe is then placed on top of the inlay.
6) The inlay is pulled off the outer, then folded in half. The inlay is placed away from the baby.
7) A new inlay is grabbed.
8) The inlay is placed under the baby in the right position.
9)The front flap is closed.
10) Time for baby cuddles.

Figure 60) The new changing process.



END-OF-LIFE

The Daily Diaper is mostly created out of biobased material, only 1% of the composition of the outer is fossil-based, which are the elastics. As concluded in the chapter Materials, a diaper currently is too hard to recycle in a valuable way, where if biobased materials are used, incineration might be the best route for the end-of-life scenario. The Daily Diaper therefore is intended for disposal with municipal waste, to be incinerated.

On this spread a comparison of the impact of production of the materials as well as the end-of-life can be seen for the normal disposable diaper and the Daily Diaper. To be able to compare in a fair way, 1 day of use will be used as the baseline for both diapers, where 4,16 diapers (the average) are used, where in the Daily Diaper 1 outer is used with 1 night inlay and 3,16-day inlays.

Table 24) (top) The impact in production of materials and the emission of incineration of a day in the use of current disposable diapers. (GRANTA Edupack used for calculations)

Table 25) (bottom) The impact in production of materials and the emission of incineration of a day in the use of the Daily Diaper. (GRANTA Edupack used for calculations)

	H_2O use in liter (in production of materials and incineration)	kg CO_2 equivalent (in production of materials and incineration)
Per diaper	5,11	0,20
Totals over 1 day, 4,16 diapers used per day	**21,30**	**0,84**

	H_2O use in liter (in production of materials and incineration)	kg CO_2 equivalent (in production of materials and incineration)
1 Night inlay	4,31	0,08
3,16 Day inlays	12,80	0,19
1 Outer	5,11	0,04
Totals over 1 day, 4,16 diapers used per day	**17,40**	**0,31**

A total of **18%** reduction on water use is achieved through the design of the Daily Diaper. This is calculated with the average amount of diapers used, in earlier ages of the child where it uses more than 4,16 diapers per day the water savings will be even higher. This will also differ per child, on the amount of night vs day inlays they use and how many times they reuse the outer.

A grand total of **63%** kg CO_2 emission savings is achieved through reuse, reduction and the use of biobased materials. Again this will depend on the use, but on average, this will be the emission reduction.

FUTURE POTENTIAL

There can be made a distinction in inlay and outer for the end-of-life scenario of the Daily Diaper. Ultimately, the outer has great potential for recycling, as it only consists out of 2 materials, elastics and non-woven, of which 99% of the weight is made up out of a biobased non-woven material. In future iterations adjustments could be made to create elastics that can be torn off to separate it or are loosely encased in non-woven material so they can be separated in the recycling facility. There is a potential for a recycling service to be set up for the separate collection of the outers from customers of the Daily Diaper, when there are enough users to make this viable. The outers could then be recycled into new outers or other products, due to the low material contamination. However, getting the Daily Diaper to the market should be priority now for the FDP. The recycling service could always be started later, but for now the bigger impact savings can be made with the incineration of the whole product after its use life.

USE SCENARIOS

The new closing (and changing mechanism) of the Daily Diaper, supports easier changing with inlays. For the diaper change two different scenarios are envisioned. One using the new mechanism as intended and one variable way, where preparation is key.

As with any diaper, there would be a phase of adjustment from one system to another. Also, a new method could work better for some parents. However, these are the two easiest envisioned methods.

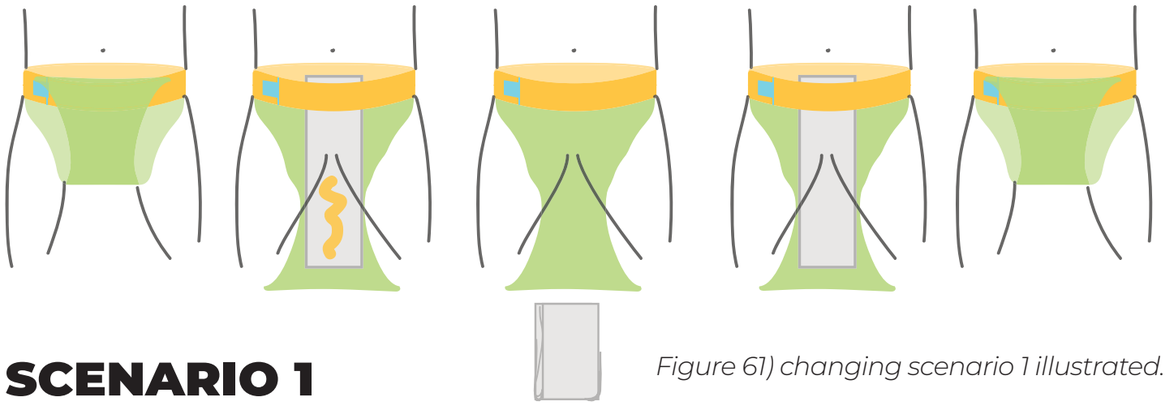


Figure 61) changing scenario 1 illustrated.

SCENARIO 1

In this first changing scenario, the parent changes the inlay while the baby still has the outer on. Especially in a quick change, without a lot of poop to wipe, this is an easy method.
From left to right: 1) Opening the front flap of the diaper. 2) Wipe the baby. 3) Lift baby's weight off the inlay and remove it. 4) Add new inlay under the baby. 5) Close the front flap.

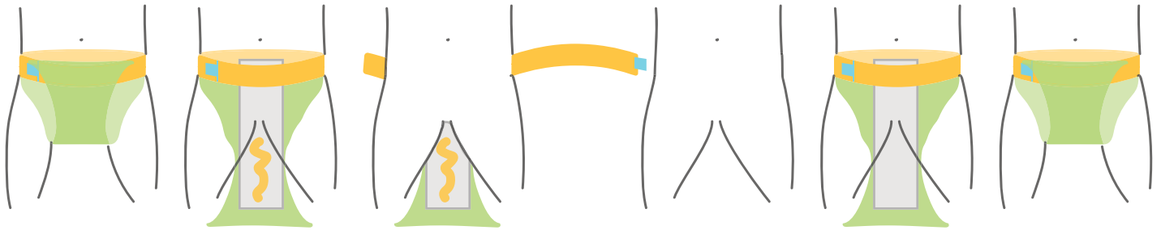


Figure 62) changing scenario 2 illustrated.

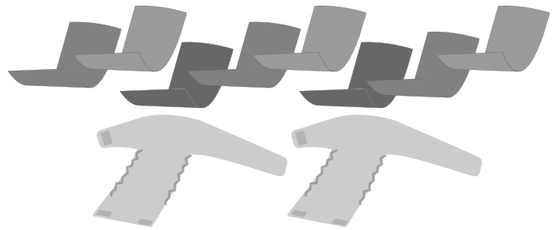
SCENARIO 2

The second scenario would be needed when there is a lot to wipe. In these circumstances it may be easier to have a new outer ready with an inlay already in there. Then during the diaper change, the whole outer+ inlay will be removed and after the change can be separated and reused.
From left to right: 1) Opening the front flap of the diaper. 2) Establish need for removing the whole diaper & wipe. 3) Open belt 4) Remove the diaper and inlay. 5) Put new outer's belt around the waist. 6) Close the front flap. *(7) remove the dirty inlay from the outer, the outer can be reused in a future change)*

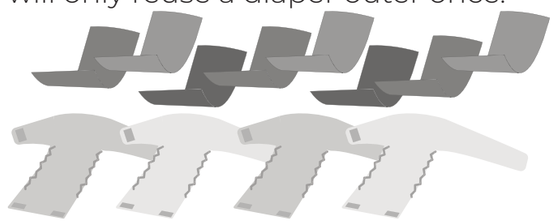
There is however more that comes to the Daily Diaper that should be pre-imagined, to justify the concept as a viable one. The frequency of changing and the frequency of reusing are important for this, as the concept will only be viable, when it actually lowers the environmental impact of diapering.

For this purpose, four varied use scenarios will be calculated through. To sketch a realistic range of possibilities of savings.

1) A newborn baby that needs 8 changes a day, that has no fully liquid bowel movements, of which the parent will reuse the outer to its maximum capacity.

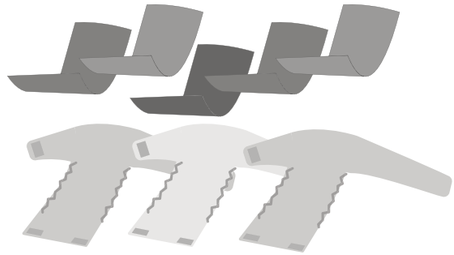


2) A newborn baby that needs 8 changes a day, of which the parent will only reuse a diaper outer once.



3) A 1-year-old baby that needs 5 changes per day, of which the parent will reuse the outer to its maximum capacity.

4) A 1-year-old baby that needs 5 changes a day, of which the parent will only reuse a diaper outer once.



Scenario 1 and 2 will be compared as the babies are the same age, meaning that the material use and impact of the inlays is the same. the same goes for 3 and 4. For scenario 1 and 2 only day-inlays will be used. For the 1-year-old in scenario 3 and 4 (sleeping through the night) 4 day and 1 night inlay is used.

Table 26) Comparison of scenario 1 and 2 (biobased and day-inlays) and normal disposable size 1 diaper. (GRANTA Edupack)

	H_2O use in liter (in production of materials and incineration)	kg CO_2 equivalent (in production of materials and incineration)
8 Normal disposable	30,72	1,215
Scenario 1	24,74	0,42
Scenario 2	25,18	0,49

Table 27) Comparison of scenario 3 and 4 (biobased, day- and night inlays) and normal disposable size 5 diaper. (GRANTA Edupack)

	H_2O use in liter (in production of materials and incineration)	kg CO_2 equivalent (in production of materials and incineration)
5 Normal disposable	40,96	1,62
Scenario 3	20,81	0,36
Scenario 4	21,38	0,45

What can be concluded from both the scenarios, is that however often the outer is reused, with the reduction of the inlay for day use, the overall impact will be reduced. We can clearly see that the more the outer is reused, the lower the impact will be.

CHAPTER 9
TESTING

To prove a concept is viable, one has to test the prototypes on usability and functionality. Diaper prototypes are hard to test, as it would not be safe for a baby to be exposed to glues or other prototyping materials. Especially in diapers this is a problem, as the baby's skin is extremely sensitive, combined with the fact that a baby wears a diaper 24/7. Therefore, the testing of the prototype was divided into multiple tests. First the functionality of the prototype was tested without real babies. After the kinks were all worked out of the prototype, a bigger quantity of prototypes was made to test with real parents and their baby.

TESTING THE CLOSURE

The closure of the Daily Diaper needs to be evaluated in 3 phases. First the durability of the Velcro as the Daily Diaper reuses this part. Second test will be to evaluate the grip of the Velcro in the setting of amoving body. The third test will evaluate the closure of the diaper close to the skin.

As the same type of closure Velcro is used in the Daily Diaper as in the current disposable diapers, it is a part that needs to be tested. Especially because in the Daily Diaper the closure is opened and closed multiple times. The durability of the Velcro after opening and closing a few times needs to be evaluated, will it still be capable of staying shut even though the baby is moving?

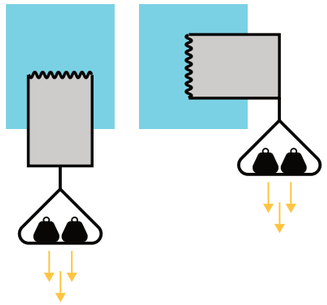


Figure 63) Test set up to test the force that can be applied before a diaper Velcro looses grip

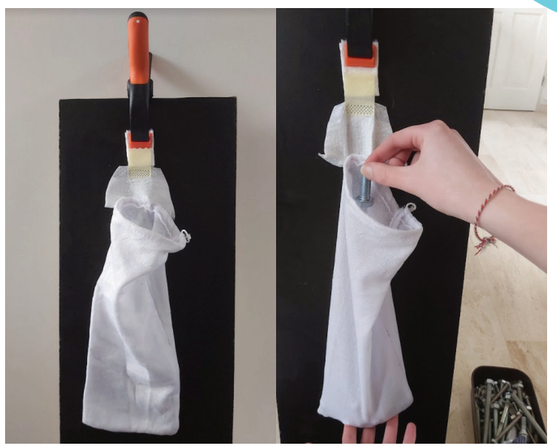


Figure 64) Test set up. Adding metal screws one by one as weight.

The main conclusion that can be made from these tests is that there is a decline in hold in the Velcro, caused by non-woven fibers that are picked up in the hooks. However, the estimated maximum of opening and closing that is needed during the use of the Daily Diaper outer is 5. The cline in between the 0 and 5 times opened and closed is minimal, only 290 grams of difference. This should not cause any problems in further development or use of the Daily Diaper.

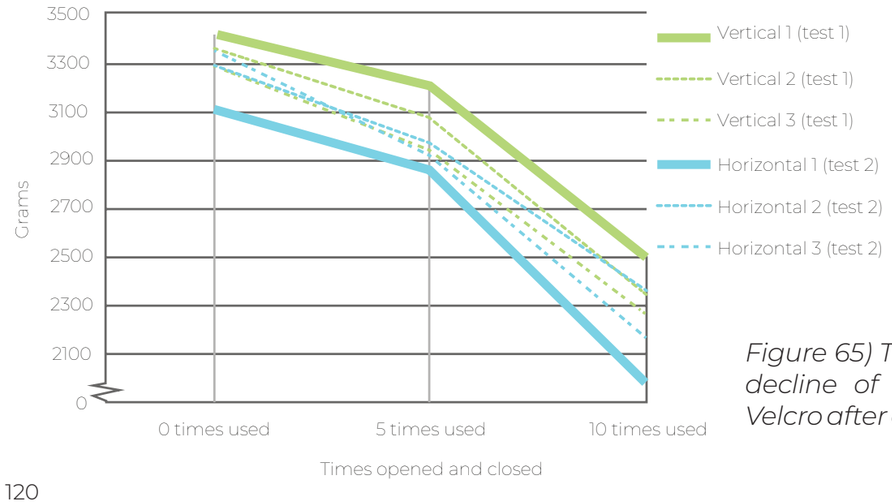


Figure 65) The test results of the decline of hold of the diaper Velcro after opening and closing.

It was established that the grip of the Velcro after multiple uses still has enough grip to hold. By introducing a new closing mechanism into the diaper, the mechanism itself should also be tested.

The test set up will be a series of movements, combined with the repetition of closing and opening the diaper. This way the ability for the diaper not tearing or deforming will be tested, as well as the permanence of the closing strips.

The test set-up is a baby mimicking form that is larger than the average baby. The over-sized nature of the baby form is important to stretch the daily diaper outer to its limits. When moving around the form, the movement of the baby is simulated. Also, movements that cannot be performed by a baby will be mimicked to test for potential points of failure of the outer diaper or the closing mechanism.

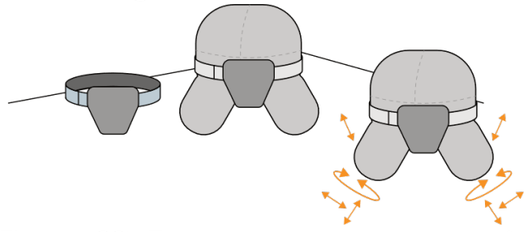


Figure 66) The proposed test set-up for evaluating closure strength.

Figure 67) The test was performed with both a bag of oranges (to test movement) as well as inflating a balloon little by little (to test stretch)

The new closing mechanism did not show any unexpected results. It remained closed even under the pressure of the inflating balloon, as well as it holding up to the movement of the bag of oranges. The outer diaper does not show signs of deterioration when stretched or moved. In these tests the new closing mechanism does not seem to impact the function of the diaper.

The last test for the new mechanism to be performed before user testing would be trying it on a real baby for a short period. This test would be more of a fitting, where potential gaps in between the skin and the diaper could be spotted. This is where leaks will happen, that is why current disposable diapers have a good seal in between skin and diaper.

The diaper outer performed well during the test. One critical area was found, in between the legs and front flap. There is a little gaping happening here, due to the angle the flap is shaped.

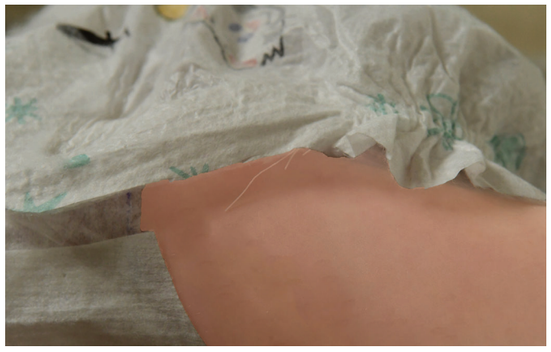


Figure 68) The gap at the front flap.

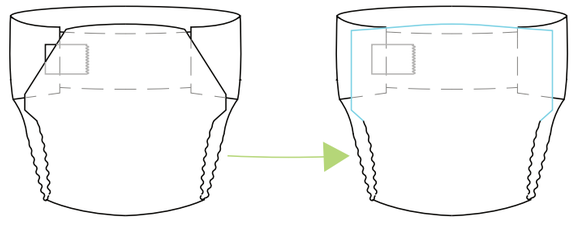


Figure 69) Adjustment to the Daily Diaper.

The one adjustment that needs to be made before creating prototypes for a usertest is the shape of the front flap. This flap is currently shaped more like an A with two edges sloping towards the middle. This needs to be more of an U or even a V shape, where the closing Velcro is on the corners, closing the gaps found during testing.

TESTING THE INLAY

The Daily Diaper concept was designed with no elastics in the inlay. As this is different than current products, tests with the inlay were needed to confirm the need for elastics for containment. Current disposable diapers have 2 pairs of elastic on them around the legs. The first question that needed to be asked was, are elastics around the leg cuffs necessary for containment?

The elastics in the cuffs are currently in all disposable diapers. Also, washable diapers have elastics around the legs. By looking through parenting forums, it was found that cloth diapers actually start leaking when the elastic is worn out. This happens over time, especially when wearing the cloth diaper and washing it over and over. On these parenting blogs multiple tips are given to either repair or replace the elastic, as it is such an essential part in the diaper. When cutting the elastic around the legs off a disposable diaper, it loses all its form. This shows that elastic is a requirement for the fit of the diaper.

The next question that needed to be answered was where to place the elastic for the leg cuffs. Can both elastics be in the outer diaper, and therefore be reused? Or do they need to be single use, on the inlay to provide the containment needed to keep the outer clean?

To test this, 3 different types of inlays were created. One with one pair of the elastics similar to the Pampers Hybrid. This inlay is expected to work best, as it is almost exactly the same as a current disposable when placed into a Daily Diaper outer which in this test case would have the other elastic in it.

The second inlay would have no elastic in it, instead the elastic containment flap would be in the Daily Diaper outer. The wings of this inlay will have a small amount of glue on them, to hold them in place, on the elastic containment flaps of the outer.

The third inlay would be made without elastics or wings. It is expected that this inlay will perform the least in terms of containment, as there is nothing in the inlay that will prevent spillage onto the outer. The elastics will all be located in the Daily Diaper outer.

Figure 70) The inlays used in the test. From top to bottom: 1- inlay with elastics

2- inlay with wings

3- Inlay without elastics or wings

A Daily Diaper outer with either 1 or two elastics (depending on what inlay is used) will be put on a bag of oranges. A mixture of water, flour and paint will be made to simulate somewhat soft baby feces. The inlays will be placed in the outer one by one, after which the bag will be moved around. Also, some pressure will be put on the bag, to simulate a baby's weight.

After this test is performed, the outer will be taken off the bag, after which the inlay will be removed. Then the outer diaper is inspected for leaks of the blue mixture. In essence all diapers leak at some point, but if an inlay leaks in a simple test like this, the chance of reusing the outer will be low.

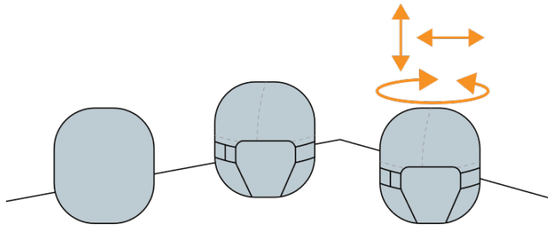


Figure 71) The test set-up.

Figure 72) The real life test set-up.

As expected, the inlay with containment elastics did not show any leakage. The blue mixture stayed in the inlay, moisture was absorbed and what was left stayed within the boundaries of the inlay, even when the bag was rigorously moved around.

The second inlay, the inlay with wings also performed well. Because the wings were stuck to the elastics, they worked in the same way as the first inlay. Through uneven absorption or more aggressive movements, one of the wings had some blue marks. This however is not a problem, as that is what they are meant for. As long as the outer stays clean, it can be reused.

The third test showed the importance of the containment elastics. With only some slight movements, the blue mixture already spilled over the edge onto the elastics on the outer. The mixture also got under the inlay, which would make it completely impossible to reuse the outer. This inlay would be the only one out of the three that is actually unusable in a Daily Diaper system.

Figure 73) The results of the inlay test. Top left inlay with elastic, no leaks. Top right inlay with wings, no leaks. Bottom left, inlay without wings or elastics, leakage.

This test proved that there is a need for containment measures in the inlay, not just the outer diaper.

The test also showed that elastics can actually be reused as they can be placed in the outer diaper, instead of in the inlay. Wings can provide containment, when placed on top of the elastics. This removed the need for elastics in the inlay, reducing the percentage of non-biobased parts used and reducing the material weight of the inlay.

USER TESTING

To truly test the prototype of the Daily Diaper, a test running over multiple days needed to be completed. A parent couple was recruited for this test. They both have extensive experience with diapering, as they have multiple children, of which 1 is currently still in diapering age. A one-year-old baby will be the main test subject. The parents will be given a live demonstration of how the daily diaper works before the test starts. Then they will be left with the testing set. (Estimated to last 3 days) After the 3 days of testing, they will be interviewed about their experiences.

The test is performed for three main reasons. First the overall end goal is to have parents experience the Daily Diaper system, with inlays and reusable disposable outers. As this is a new way of diapering, not like cloth diapers or hybrid systems, it was important to have parents experience the new system, to see if they understood it as well as thought it was a convenient experience.

The durability of the outer will also be tested, as the parents will be instructed to reuse the outers as much as possible, until they are broken or soiled. It is estimated that the outers should hold up over 12 hours (half a day) at least. This will also depend on how many changes are performed per day. The more changes, the more outers you will need, as they could get soiled.

The third goal of the test is to see how well the new closing mechanism works compared to the current closing mechanism used in disposable diapers. As there was chosen for a new mechanism that should make the use of inlays easier, this should be tested in a real-life setting. Therefore, the parents will be supplied with disposable outers of which half had the new and the other half had the old mechanism. Questions that need to be asked include: Where there any leaks due to the new mechanism? Did you as a parent experience the new or the old mechanism as easier to change?

The parents were supplied with a kit containing:
- 1 full bag of Pampers Hybrid inlays
- 4 outers with the new closing mechanism
- 3 outers with the old closing mechanism
- a notebook and pen for notes during the experiment

Figure 74) The test kit.

As safety is always the priority, the test was performed with store-bought products. It was chosen to use Pamper Hybrid inlays as they would be clean, skin safe as well as contain no prototyping materials. These inlays are different from the inlays chosen for this concept, however with the available prototyping materials and means it was not possible to make a safe self-made inlay. The outers were made out of store-bought diapers, of which the absorbent core was removed. The only part edited of these was the mechanism. The belt system was hand sewn onto the outer diapers, to stay away from using potentially harmful glue.

Even though the testing inlays are different from the ones intended for this concept, it is expected that the test will still give a clear impression of how the system works as well as the changing process be very similar. Previous tests performed show that the inlay with wings held up as well as the one with elastics, so the difference should be minimal.

The overall testing experience of the parents was positive. There were no critical leaks, or product failures or breaks. However, there were some notes that should be considered for adjustment.

First of all, the method of disposal of the inlays. The parents noted already on the first day of testing that there was some inconvenience with the disposal of the inlay. As the inlay had no closing mechanism on it, after use the inlay had to be disposed of in a small diaper trash bag, to keep it closed.

Figure 75) The difficulty of keeping the inlay closed for disposal.

The second note was the way the outer with the new mechanism fit their baby. The belt, which in the prototypes was made the length of the landing strip normally on the front of the diaper. This length was in particular for this baby a bit small. The belt could be quite tight around his belly. The belt should be made a little bit longer, to have the margin in size for the different shapes and sizes of babies.

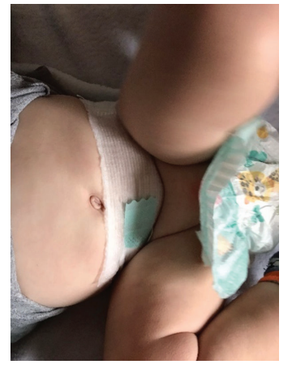


Figure 76) The belt was somewhat tight around the belly. Some extra margin in space would be needed to fit universally.

An insecurity that arose during the testing phase was the placement of the inlay in the outer. This inlay needs to be placed in a certain location to be most efficient, but there were no indicators in the outer to show where the back edge of the inlay needed to be placed. This should be an easy adjustment for future prototypes.

The final problem arising from the test was with the combination of the Pampers Hybrid inlay and the outer. They did not fit perfectly together; the outer was a little too small for the length of the inlay. This is an error that can be blamed upon the use of an inlay that is not made for use in the outer specifically.

In the after interview some questions were also asked about the experience with the new system, their awareness of the impact of the diaper and the new system and of course their preference for the new and the old closing system.

When asked, the parents rated the overall experience as pleasurable, they were very aware of what exactly they were saving through reuse (the outer) as they were physically reusing it. They felt in charge of when they would reuse and when they would dispose.

When asked about if they would be okay with using two different inlays, one for use during the day and one for the night, they said that that would be an easy adjustment, as they are home most days at bedtime. However, when going out or on holiday, it would be an extra item to bring.

The new closing mechanism was experienced as a convenient way of changing the diaper, but for their baby they liked the old mechanism more, simply because the belt was experienced as too tight. The new mechanism was especially good in use as their baby never lays still during a change (or at other times). It freed a hand at most times to hold the baby still.

The outer diaper was reused a maximum of 5 changes until it broke. A tear formed in the outer film, by pulling out the Pampers inlay. It was noted that the glue that is used to place the inlay was very strong, maybe stronger than needed. This is a logical observation as in the Pampers Hybrid system, the glue needs to grab onto a fabric instead of a film. The amount and strength of this glue is going to be different in the Daily Diaper inlays, as the strength is simply not needed and will only reduce the number of times the outer can be reused.

CONCLUSIONS

Even though the overall experience of the parents was positive there are some design changes that need to happen before further user testing would be done by the FDP.

Lengthening the closing mechanism belt would be the first. The flexibility of the outer is the key to making a universal diaper. Adding a few extra centimeters will of course increase material use, but on the other hand increase the potential user group. This extra length does not weigh more than 0,1 grams and is therefore not expected to influence the savings the Daily Diaper makes significantly.

The need for a better fitted inlay surfaced during the test. As neither the inlay nor the outer was produced to be used as a Daily Diaper, as they were made from adjusting existing diapers, not everything fit perfectly. In the next steps of making the Daily Diaper production ready, the inlay needs to be adjusted per size to fit in the outers indicated in the chapter Inlay Capacity.

As the parents indicate that they would like to use the Daily Diaper again, the experiment can be deemed successful. The adjustments will be made and can be found on the right page. For the FDP future steps can be taken to further develop the new mechanism, but these parents did not deem it a requirement for the diaper with inlays to work.

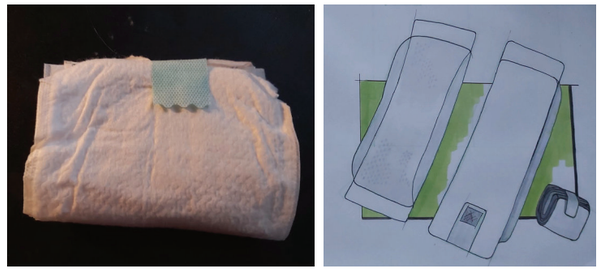


Figure 77) The proposed solution for the disposal of the inlay. It can be folded once or twice, then closed with the closing tape. During tests with imitation stool, the inlay with wings did not leak when folded.

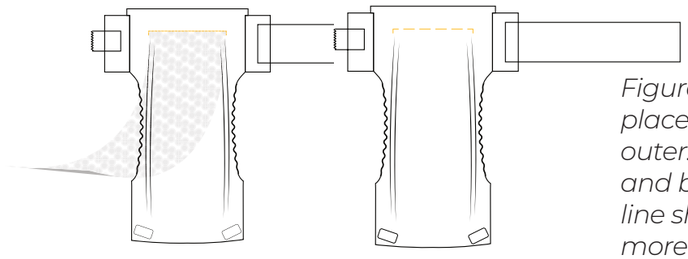


Figure 78) The proposed solution for the placement indicator on the daily diaper outer. Most diapers already have designs and brands printed on them, an indicator line should be possible to give the parent more confidence in placement of the inlay.

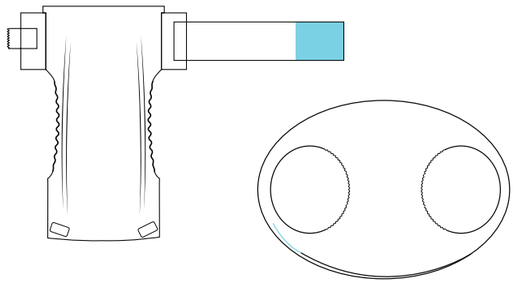


Figure 79) The proposed solution for the shortage of length of the belt. by making the belt a little bit longer, a more universal fit can be achieved, for babies that do not need the extra length, it does not cause any inconvenience, as it will simply tuck in the diaper outer. In the figure left top view spread out diaper, on the right top view of the diaper when worn (from the baby's head looking into the diaper).

Figure 80) Inlay length should be fitted to the size of outer diaper it belongs in. As all outers can fit 3 different inlays, the biggest inlay should be just a centimeter shorter than the perimeter of the outer, from belly button to middle of the back.

CHAPTER 10
EVALUATION

After testing the Daily Diaper, an evaluation is needed to conclude it. How does it fit within the list of requirements and the design vision? What are recommendations for the FDP to further develop this project? What would development of the Daily Diaper look like if production had to be started as soon as possible? And what are steps to make the diaper more sustainable now and what can be done in the future?

EVALUATION

Performance

P.1 - The diaper can hold the average urine production in between average changes plus a 10-15% margin.

P.1: The diaper absorbency in essence has not been reduced in the Daily Diaper. Only the day-night difference has been removed. This means that this requirement has been fulfilled.

P.2 - The diaper can hold the amount of urine with the weight of the child pressing on top of the core.

P.2: This requirement could not be tested as the biobased inlay could not be prototyped. However, the design of the diaper core was not changed, so no concerns are raised as long as there is enough SAP.

P.3 - The diaper can hold normal consistency bowel movements within the product. (1 in 40 can leak due to consistency of stool)

P.3: The ability for the inlay to hold stool under pressure and not leak onto the outer is an even stricter test for this requirement (requirement asks for not leaking out of the outer), in this test no problems presented itself. Further testing is needed to see the percentage of leaks, conducting the same tests on a big number of diapers.

Material

M.1 - The diaper should contain more than 85% renewable materials.

M.1: Working towards a fully renewable diaper, there have been alternatives found for every part of the diaper except for the elastics. Further ideation could be done to elaborate on the non-woven kerfing to achieve elasticity, but for this project the percentage of elastic (smaller than 0,5% in 1 day of Daily Diaper use) was too small and bigger impacts could be made with design changes. This requirement has been met.

M.2 - The diaper must use less material (in weight) in use than a normal disposable diaper.

M.2: The Daily Diaper uses less material through the reuse of the outer as well as by differentiating in day and night inlays. However, further research is needed to see how much biobased SAP is needed to the replace fossil-based SAP. This is going to depend on the efficiency of the starch-based SAP (which is still innovated on) and will determine the overall material weight. With the use of fossil-based SAP the requirement is met.

Form

F.1 - The diaper must be able to pack flat so it can be transported efficiently.

F.2 - The diaper does not have to adhere to the standard diaper architype.

F.1 & F.2: The Daily Diaper packs flat and requires less transport of material overall through material reduction. The Daily Diaper does not adhere to the current diaper architype and this has not caused any problems in user testing.

Structural

S.1 - The diaper is durable enough to hold up in between changes.

S.2 - The diaper cannot tear when the baby is moving.

S.1 & S.2- The Daily Diaper hold up well in the user test. Even though the prototypes for this test were handmade and the Pampers inlays had heavy glue, the outer held up for 5 changes. This meets the requirements.

Ergonomic

E.1 - The diaper should fit all babies in between 0 and 36 months, through multiple sizes and a flexible closing mechanism.

E.1 By adjusting the length of the belt after the user testing was completed, the outer should have an even bigger range that it could fit. That combined with the different sizes will allow all babies to fit into a Daily Diaper.

E.2 - The diaper must allow for the material to stretch around the waist to allow for breathing and movements.

E.2 The Daily Diaper has the same stretch on the closing mechanism as the current diapers. This requirement is met.

Use

U.1 - The diaper must be easy and convenient in use and therefore not require extra items to launder, more than once a week.

U.1 The Daily Diaper does not require any extra laundering, this requirement is met.

U.2 - The diaper has to be easy to dispose of and therefore must be designed so the product can be thrown away by itself in the general garbage can, it should not require prepacking it in a single-diaper trash bag.

U.2 The Daily Diaper inlays have a closing strip which allows for easy disposal. After this strip is closed the inlay can be disposed of as is. The outers can be folded and closed with the closing mechanism as one would normally do with a normal disposable diaper.

U.3. - The diaper cannot require a user to touch the soiled part of the diaper

U.3 The Daily Diaper does not require the user to touch any of the soiled parts, except for when the child would have a very liquid bowel movement. This is also the case with current disposable diapers and should not be a dealbreaker.

Safety

Sa.1 - The diaper cannot contain allergen materials that touch the skin.

Sa.2 - The diaper cannot leave pressure marks on the baby's skin.

Sa.1 & Sa. 2 The Daily Diaper does not contain skin contacting allergens and with the extra length on the belt does not leave any marks.

End-of-life

EoL.1 - The diaper must have smaller emission when incinerated compared to a normal disposable diaper.

EoL.1 The Daily Diaper has a smaller footprint in CO_2 equivalent. With the material reduction, the water use is also lower than the current disposable diaper, even though the materials by themselves cost more water to produce as they are biobased.

EoL.2 - The diaper must create less waste.

EoL.2 Through the reuse of the outer as well as the reduction of the day-absorbent core, the Daily Diaper generates less waste in its day-to-day use. This requirement has been met.

USER INTEREST

To be able to claim that the Daily Diaper is actually as convenient as a current disposable diaper I would need a large group of parents to test with. As this did not fit in the timeframe of this project, instead a user gauging was completed. In a public place that a lot of parents frequently visit, parents were asked if they would be willing to answer a few questions about a gradation project.

The overall goal was to see if parents would be willing to try the Daily Diaper (the reusable outer with inlays as biobased is not yet available). They would not need to actually use the prototype, it would just be based on the explanation of the new system and the environmental benefits. The explanation would be practiced beforehand, to be able to sell the product to its full potential.

The location that was chosen (with permission of the owner) was in a Dutch pancake restaurant in front of the baby changing station next to the entrance. Parents that walked by were asked if they would have a minute to spare for some questions. If they gave their permission something along the lines of this pitch was given (in Dutch):

"I like the strap that stays on the belly. I can just slide a new inlay in"

"I am willing to try this out, but I am not sure it will work for my child as he pees too much for current disposable diapers"

"I can't believe this is not already the current product"

"Thats nice, I can reuse this when it is not dirty"

"So there is no laundering? I can reuse it and throw it away?"

"For my graduation project, I developed a new disposable diaper. Currently a child uses around 4000 diapers in their diapering lifetime. This makes up of 160 kilograms of material that is only used once before it is disposed of. Within this material there is a lot of fossil-based plastic, which is not renewable.
This (showing the prototype) is the Daily Diaper, a reusable outer diaper that can be worn with an absorbent disposable inlay in it. In opens in a new way (demonstrating) from the front so only the inlay can be changed in an easy manner. This outer is then reusable by putting in a new inlay. The inlay (showing an inlay prototype) will come in a day and night thickness, for babies that sleep through the night. When the outer diaper gets dirty, it can be disposed of just like the current disposable diaper. This would save 63 percent on carbon dioxide emission.

Thank you for listening to my explanation, would you as a parent be interested in trying out the Daily Diaper?
Why would/why wouldn't you?"
Further follow up questions would be asked based on their answer.

RESULTS

23 parents were willing to give their opinion on the Daily Diaper.

91%

21 parents would be willing to try the Daily Diaper with their child.

9%

2 parents were not interested in trying out the Daily Diaper.

1 parent was currently using washable diapers, and was happy with their choice to do so.

1 parent did not understand the concept. When further explained, the parent was still not interested as he tought it was going to be more work.

70%

16 parents were interested in buying the diaper in the store to try it out at least once. They were not yet fully convinced about either the new mechanism or the decreased capacity for diapers during the day, but would be willing to try the product.

21%

5 parents were interested in using the Daily Diaper right away. They would be willing to use the new diaper for environmental reasons, and unless the product had critical errors (e.g. a lot of leaking) they thought they would be willing to permanently switch to the Daily Diaper.

CONCLUSION

The main takeaway from these user interviews is that there is significant interest from parents to reduce their diapering footprint. Especially the way the Daily Diaper is fully disposable was found a positive aspect. Parents were not willing to give up the convenience they were used to, but when explained there would be no laundering, just disposal when needed of the outer most of them were on board. It should be noted that the largest group of parents were willing to try the system out, but were not sure if they would give up the use of the normal disposable diaper. This could be because they were shown a prototype, but also shows that with the introduction of a new system comes doubt. The product should have an incredibly clear explanation in the marketing and advertisement to convince parents to try it out.

TARGET GROUP

Based on the results of the user interest interviews that were conducted, a target group can be described. First an analysis on the people interviewed needs to be completed. Who were the people interviewed, in what way were or weren't they willing to try the Daily Diaper and what questions did they ask?

First of all, the restaurant, a Dutch pancake restaurant located in a small town, has a general demographic of visitors that are Caucasian and have extra money to spend to go to a restaurant. The parents asked either had children (which were estimated under 6 years old) or were coming by to use the baby changing station. This means some of the interviewed parents did not have any children in diapering-age anymore.

The people that consented to be interviewed were interested in talking about disposable diapers with a student developing a new more sustainable diaper. This in itself suggest something about the difference between the people that were interviewed and the ones that declined. Of course, people are coming to a restaurant to enjoy themselves and do not necessarily want to spent time on a student asking questions, but parents that were interviewed showed understanding of the environmental costs of current diapers and they seemed to be aware of the amount of waste generated and material is used by using disposable diapers.

Questions were asked in the direction of: if there was a need for laundering, if it would be extra work and if special disposal was needed. As the Daily Diaper stays somewhat close to the disposal concept of the current diaper, after demonstrating the prototype of the outer parents were enthusiastic. They could reduce their footprint without having to put in extra work. This shows that they are (or feel) busy in their current lifestyle and that they do not have (or want to spend) on a more sustainable diaper.

The main target group that can be defined out of the interviews is a parent couple that is average to high educated, have a busy work life and have some form of awareness of the impact of their disposable diaper use and are interested in trying new products to decrease their footprint.

To illustrate this more, a persona of this parent couple is made. Meet Lana and Rick, both aged 31. They have an almost 3-year-old daughter Sophie, which only recently was potty trained completely. They have another baby on the way, due in 3 months and are now looking into what products they want to use for their brand-new baby.

During the diapering-age of their first baby, they tried to use washable diapers, but due to both their busy work schedules Sophie spends time at both daycare and her grandparents, which prefer not to use washable diapers. On top of this Rick and Lana like to go out on day and weekend trips, on which it frustrates them they need to bring many bulky washable diapers, as well as sit in the carried back with them while they are soiled and smelly. It also leaves Lana with a 3 extra laundry cycles in a regular week, which after a few months is not something she is willing to put extra time in anymore, so after 3 months they decided to switch to disposable diapers completely. However, they were not completely content with this choice either, as they felt that they were generating a lot of trash with their diaper use.

The Daily Diaper is a product Lana came across online, which for her ticked all the boxes in what she wished for in a diaper. While communicating with Rick, they came to the conclusion that this would for them be the perfect middle of the road solution, still disposable, but at the same time reusable to reduce their footprint. It removes the need for them to carry around multiple washable diapers, but instead they can bring the more compact inlays. They are comforted by the fact that it would be the best possible disposable diaper to provide them the convenience they need in both their lifestyle.

Source: Babystraatje

FUTURE VISION

For the Daily Diaper a sustainable evolution would be reccomended. As there are steps that can be taken now, that will already significantly improve the footprint of disposable diapers, it has a potential to be on the market as soon as possible, even if the full vision (100% renewable) is not yet reached.

Sustainable evolution

NOW

2022

Even though future innovation will be the key to making the diaper more sustainable, there are already a lot of possibilities that can make the disposable diaper more environmentally friendly and to have it use less material.

A reusable disposable outer can already be realized. As this would require similar production equipment as the current diapers, this would be a viable product now.

Inlays with different thicknesses is a similar product to produce as the absorbent core in the current disposable diaper. Precise quantities of the needed SAP would still need to be confirmed.

As can be seen in the Fairwindel example, there are already a lot of possibilities with biobased materials. Especially the nonwoven and films can already be viably replaced with a biobased variant.

NEXT

IN 3 YEARS

In the near future a lot of innovation into biobased materials will be completed. Newly researched starch-based SAPs are already on their way to be as good in terms of absorbency as their fossil-based counterpart. (Capezza et al., 2020) When the starch-based SAPs can valuably replace the fossil-based ones, this can also be applied to the Daily Diaper.

Applying this to the Daily Diaper will make it up to 99% renewable, where only the elastic has no viable biobased alternative yet.

LATER

IN 5+ YEARS

In a more future perspective, there will definitely be more innovation done to create renewable elastics.

When a certain percentage of people are using the Daily Diaper, it will also be a viable business idea to start a recycling service for the outers. As they are only biobased plastic and a small amount of elastic, there is a potential for recycling the plastic here, when enough diapers can be collected.

RECOMMENDATIONS

The final concept design of the Daily Diaper should serve as a starting point to the development of the diaper of the future. It is a future vision that shows that there are 3 directions to go into to make the diaper more sustainable. This section will highlight aspects that are recommended to continue on in further development.

Manufacturing

During this project, designing new innovative concepts had the priority. As the disposable diaper has had the same architype over the last decades, it was important to break the mold and look for new possibilities to make the diaper more sustainable. Even though I am confident the concept designed can be manufactured because its essence is so close to the current disposable diaper, (separated absorbent core and outer) manufacturers should be contacted to get input in further design iterations. As there is a possibility diaper-making machines (that are extremely expensive) need to be adjusted or rebuild to make the Daily Diaper, so further design should be done in cooperation with a manufacturer, that is interested in producing this product.

Testing

The key of making the Daily Diaper a reality is to create a functioning prototype and then do a large(r) user test. Ideally with at least 25 children, but more would be even better. This would be the group generating valuable insights into further development and show if the product is understood. The insights from this user test will be valuable to product development as well as in setting up a marketing strategy. The product understanding especially is an important factor to focus on, as the Daily Diaper is fully disposable, consumers need to understand that disposal is okay for this product. Especially with a fully renewable product, disposal with household waste for incineration would be de desired path. This needs to be communicated in a way the user understands.

Renewability

The first priority in the development of a more sustainable diaper, is taking steps that are already possible early. As can be read in the future vision, a sustainable evolution can be started. Working towards the most sustainable fully renewable diaper should not stop the progress that can already be made. Night and Day inlays, combined with a reusable disposable outer, can already save an incredible amount environmentally speaking. Renewability should and will always remain the FDP's main end goal for the disposable diaper, but there are steps that can be taken now that will set the tune for their future growth and set them on the path that aligns with their vision. When the first steps are done further innovation in biobased materials should be applied to the then existing product, iterating when the main product is already on the market, making it more sustainable step by step.

Target group

Before starting any of the previous recommendations named on this page it is important to evaluate the target group. From the user interest interviews it became clear that there is interest in the Daily Diaper. However, in a survey setting more insights will be gathered into who exactly are interested and why people that are not interested have their standpoint. Understanding the size of the target group will determine the potential market size and therefore the viability of the project. Even though the small test performed in this project showed that there is a market, bigger and more research would be the first priority.

ROADMAP

As the goal of this project was to set out a new direction for future diaper design, creating a product that would be able to hit the market within a year was never the goal. However, with the focus on user experience and by staying close to the convenience of the disposable diaper, the Daily Diaper would be a product that could (at least partly) already be launched. The readiness of certain aspects of the Daily Diaper concept needs to be evaluated. After this evaluation, the product potentially launching on the market should be explained to the potential customers. Who would be willing to use the Daily Diaper, who would be at least willing to try it out and which parents are not interested? Asking these questions to a big group of people will make the FDP able to make further decisions on the development of the product. As the progress the Daily Diaper makes on reducing the environmental impact as well as the positive reviews so far, the investment of doing a big user study measuring potential customer base would be justifiable. When the user study delivers positive results, great, then fund can be assembled for starting manufacturing of sample batches. If the results of the user study are negative, the FDP will at least not lose money by putting an unwanted product on the market. However, with the results of the user gauging done with the prototype, it is not expected a big user study will deliver significantly different results.

If the product development would be started today, what would be the steps to be taken? Of course, this is only a projection of steps that could be taken, in no way shape or form would the figure be set in stone.

After a positive outcome of the user study, the first item on the agenda would be the final design of the outer that needs to be decided on, sizes need to be determined. So far outer sizes based on Pampers sizes were used. The inlay capacity also needs to be finalized to reflect the day-night gradient system.

With this finalized design, manufacturers should be approached. As a company as the FDP is depending on manufacturers to produce their new diaper, they should be involved with the final steps of the design process to make sure the product is manufacturable. When a prototype is rolled out that is deemed successful, the prototypes for user testing can be produced.

The main aim of the large(r) scale user testing is finding problems in an early stage of the development. With 25 babies that should be in all different ages in between 0 and 2,5 years, a month of testing should be completed. During this test parents would be asked to write down daily annoyances, problems and even photograph them. During the month of testing critical failures of the product can be found, aspects that later can be re-envisioned before final production.

The test group can also be a valuable source of information to gauge product understanding. FDP would be able to gain precious input for marketing strategies, instructions that are needed and market positioning.

If a quicker launch would be preferred, a Daily Diaper could be produced that does not contain the new mechanism, but the classic one, expected to make manufacturing easier as this is an architype already existing.

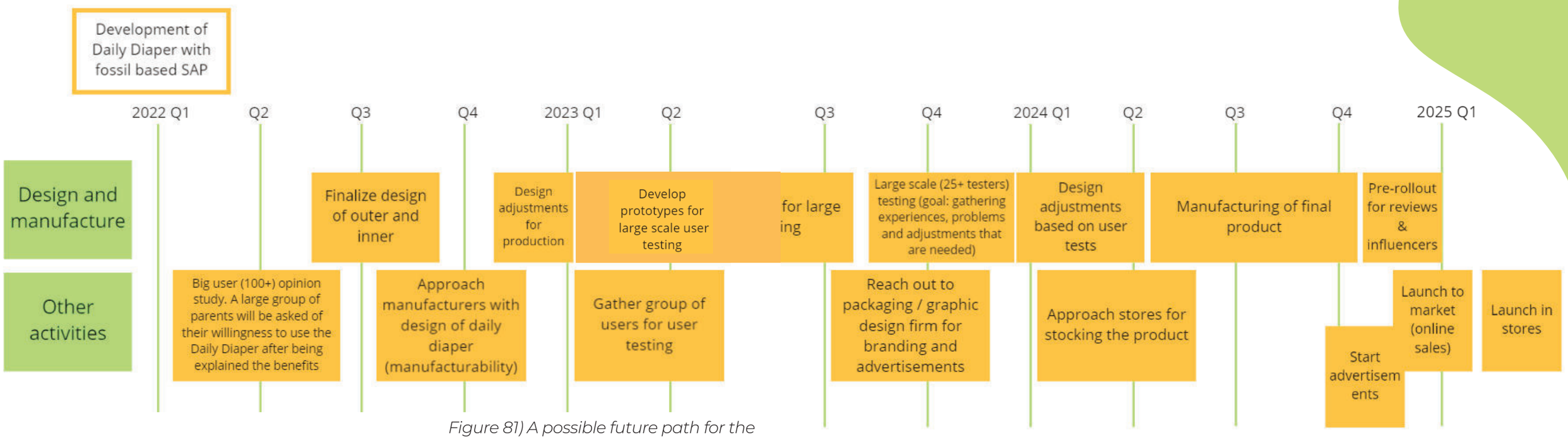


Figure 81) A possible future path for the Daily Diaper

CHAPTER 11
REFLECTION

For a designer, self reflection is one of the most important tools to learn from mistakes and also from successes. In the coming chapter I will reflect on the progress made during this project, planning and gained skills and knowledge. What is it in this project that will make me a better designer?

PERSONAL REFLECTION

As a designer I run not knowing when to stop. During this project I learned that I should build in moments of reflection and documentation of made choices, record why they were made on the basis of what knowledge. During previous projects and my internship, my time efficiency was always appreciated, motivating me to work even harder. In the graduation project I began with the same approach, working on making decisions, sometimes not opening up to other possibilities. Through coaching sessions with both Professors as well as the weekly meeting with the company mentor I kept receiving questions on decisions I had made. I had written a lot of decisions as if they were set in stone, where the essence of being a designer lies in making decisions without all the required information, thus bridging the gap. Towards the end of the project the realization hit that if I had reflected more in the beginning stages of the project and had taken the time to write down the design vision that was only in my head up until then, my coaches would have had a much easier time coaching me.

The main takeaway for me is that when looking for a future job after graduation, I want to work under experienced designers, to learn from their process how I can adjust mine to be clearer for outsiders. During my Bachelors and Masters degrees I was taught or self-taught all the skills and tools I need to be a successful designer. I learned about the designing process and how to look for solutions where there may not seem to be any. I learned how to be efficient and show great results in limited amounts of time. However, making a process understandable for someone who did not partake and explain how careful considerations were made is an aspect I still need to grow in. I am going to take steps in future projects to create clear visions, visualize choices and paths taken to present a clear considered concept.

I chose this project as I wanted to pull myself out of my comfort zone. In the 6 months before the graduation project, I had worked in a packaging company where I would design functional packaging as boxes, bottles and actuators. Most of my time was spend 3D modeling and printing prototypes. While I really enjoyed such a practical approach to design, I had missed going more in depth especially on sustainability aspect. (The aspect that is only beginning to start making an appearance in the packaging industry.) This project gave me the opportunity to both work on prototypes as well as designing a much more in-depth product. Throughout this project I have worked with calculations of environmental impact with an Excel sheet I had built through using the GRANTA (previously CES) database. The sheets I built provided clear reasoning throughout most decision-making steps in the project. While I really enjoyed the clarity it gave me in evaluating concepts, I noticed that I have more passion for fast paced projects, as well as hand on working with prototyping and 3D modeling. I had the chance for embodiment in this project, but for a diaper 3D modeling was not part of it as it would have had no purpose for this soft product. After graduation I will be looking for a career in designing physical products, as for example toys, appliances or furniture. In these industries I feel like I can apply my knowledge of user interaction design as well as my skills in prototyping and 3D modeling.

Throughout this project I focused on the disposable diaper as a whole. In my opinion I have showed viable concepts that can be used to create more sustainable diapers. When I would need to suggest to a new student with the FDP how to approach a similar project, I would of course advise them to pull all the knowledge from my project and then take one of the concepts to start talking with manufacturers. My project was about showing new ways for the disposable diaper to go, where a next project should focus on developing a product to go on the market.

In terms of personal growth, I feel that I have achieved to further confirm my professional identity and methods of design. I have worked throughout this project on aspects that I had no deep knowledge of beforehand, I have used methods I had not used before and was able to plan and manage a 6-month project myself. Starting in my bachelors in Eindhoven I was taught how to self-direct my learning as well as how to teach myself new skills or knowledge if I do not yet have what is required. In this project I have continuously been able to apply this acquired skill, to broaden my overall knowledge as a designer.

CHAPTER 12
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CHAPTER 13
APPENDIX

A - Graduation Brief
B - Midterm Evaluation
C - User interviews and User Interest
D - Ideation CAFCR
E - Excel model for diaper calculations

APPENDIX A

DESIGN FOR our future

TU Delft

IDE Master Graduation

Project team, Procedural checks and personal Project brief

This document contains the agreements made between student and supervisory team about the student's IDE Master Graduation Project. This document can also include the involvement of an external organisation, however, it does not cover any legal employment relationship that the student and the client (might) agree upon. Next to that, this document facilitates the required procedural checks. In this document:

- The student defines the team, what he/she is going to do/deliver and how that will come about.
- SSC E&SA (Shared Service Center, Education & Student Affairs) reports on the student's registration and study progress.
- IDE's Board of Examiners confirms if the student is allowed to start the Graduation Project.

USE ADOBE ACROBAT READER TO OPEN, EDIT AND SAVE THIS DOCUMENT

Download again and reopen in case you tried other software, such as Preview (Mac) or a webbrowser.

STUDENT DATA & MASTER PROGRAMME

Save this form according the format "IDE Master Graduation Project Brief_familyname_firstname_studentnumber_dd-mm-yyyy".
Complete all blue parts of the form and include the approved Project Brief in your Graduation Report as Appendix 1 !

family name: Deuring
initials: E.K. given name: Evelien
student number: 5265630
street & no.:
zipcode & city:
country: Netherlands
phone:
email: e.k.deuring@student.tudelft.nl

Your master programme (only select the options that apply to you):

IDE master(s): ★ IPD | DfI | SPD
2nd non-IDE master:
individual programme: - - (give date of approval)
honours programme: Honours Programme Master
specialisation / annotation: Medisign
Tech. in Sustainable Design
Entrepeneurship

SUPERVISORY TEAM **

Fill in the required data for the supervisory team members. Please check the instructions on the right !

** chair: C. Bakker dept. / section: Circular Product Design
** mentor: R. Balkenende dept. / section: Circular Product Design
2nd mentor: G. Meijer
organisation: The Future Diaper Project
city: Delft country: The Netherlands

comments (optional): Conny is going to be the expert on circular design methods. Ruud is going to be the expert on materials.

Chair should request the IDE Board of Examiners for approval of a non-IDE mentor, including a motivation letter and c.v..

Second mentor only applies in case the assignment is hosted by an external organisation.

Ensure a heterogeneous team. In case you wish to include two team members from the same section, please explain why.

APPROVAL PROJECT BRIEF

To be filled in by the chair of the supervisory team.

chair C. Bakker date 23 - 09 - 2021 signature _____

CHECK STUDY PROGRESS

To be filled in by the SSC E&SA (Shared Service Center, Education & Student Affairs), after approval of the project brief by the Chair.
The study progress will be checked for a 2nd time just before the green light meeting.

Master electives no. of EC accumulated in total: _____ EC

Of which, taking the conditional requirements into account, can be part of the exam programme _____ EC

List of electives obtained before the third semester without approval of the BoE

★ YES all 1st year master courses passed

NO missing 1st year master courses are:

name _____ date - - signature _____

FORMAL APPROVAL GRADUATION PROJECT

To be filled in by the Board of Examiners of IDE TU Delft. Please check the supervisory team and study the parts of the brief marked **.
Next, please assess, (dis)approve and sign this Project Brief, by using the criteria below.

- Does the project fit within the (MSc)-programme of the student (taking into account, if described, the activities done next to the obligatory MSc specific courses)?
- Is the level of the project challenging enough for a MSc IDE graduating student?
- Is the project expected to be doable within 100 working days/20 weeks ?
- Does the composition of the supervisory team comply with the regulations and fit the assignment ?

Content: APPROVED NOT APPROVED

Procedure: APPROVED NOT APPROVED

comments

name _____ date - - signature _____

Initials & Name E.K. Deuring Student number 5265630

Title of Project Redesigning the disposable diaper to accommodate for recycling.

Redesigning the disposable diaper to accommodate for recycling. project title

Please state the title of your graduation project (above) and the start date and end date (below). Keep the title compact and simple. Do not use abbreviations. The remainder of this document allows you to define and clarify your graduation project.

start date 01 - 09 - 2021 31 - 01 - 2022 end date

INTRODUCTION **

Please describe, the context of your project, and address the main stakeholders (interests) within this context in a concise yet complete manner. Who are involved, what do they value and how do they currently operate within the given context? What are the main opportunities and limitations you are currently aware of (cultural- and social norms, resources (time, money,...), technology, ...).

7.9 percent of all trash created in the Netherlands consists of infant diapers. (afvalmonitor rijkswaterstaat 2019) Which is more than 160 million kilos in the Netherlands alone. (RIVM Briefrapport 2019-0111, J.P.A. Lijzen et al.) Compared to other waste streams, diapers are particularly hard to recycle, as they consist out of multiple materials, such as plastics and cellulose. When the diapers have been used they also contain pathogens and could contain medicinal residues.

To be able to recycle a diaper properly in a recycling facility a two things need to radically change. Of course the material content of the diaper is an important factor, because what materials and how these separate in recycling is key. But what we forget about is that even if a diaper is able to be recycled, it has to end up at the right facility. Therefore the second factor is the disposal process of the consumer. Diapers should be separated from the other waste streams in order for it to be processed. The exact way will be determined by the material types it is made up from, but the user experience should be incorporated to make sure efforts in the material part pay off.

As the use of a diaper is made so easy, I think there is mayor possibilities for creating a more pleasurable experience of changing the diaper and disposing of it. As the use of a diaper is made so easy, I think there is mayor possibilities for creating a more pleasurable experience of changing the diaper and disposing of it. The adjustments made to better sustainability should however never compromise the user experience.

This project will be conducted in corporation with The Future Diaper Project, a company devoted to make diapers more sustainable. Their aim is to reduce all diaper waste in 2030. As they too believe that the washable diaper is never going to replace the disposal diaper fully, they are interested in this project to make the disposable diaper more sustainable.

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introduction (continued): space for images

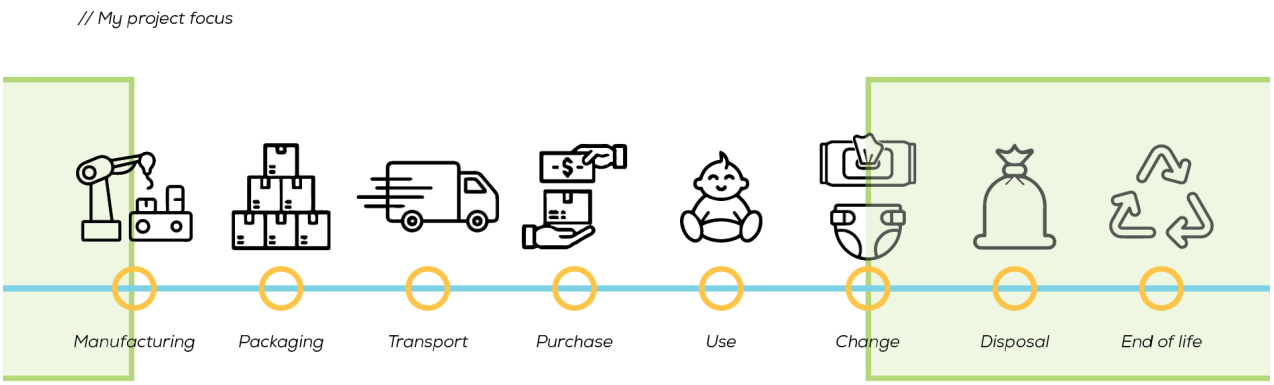


image / figure 1: The project focus areas.

TO PLACE YOUR IMAGE IN THIS AREA:
- **SAVE THIS DOCUMENT TO YOUR COMPUTER AND OPEN IT IN ADOBE READER**
- **CLICK AREA TO PLACE IMAGE / FIGURE**

PLEASE NOTE:
- **IMAGE WILL SCALE TO FIT AUTOMATICALLY**
- **NATIVE IMAGE RATIO IS 16:10**
- **IF YOU EXPERIENCE PROBLEMS IN UPLOADING, COVERT IMAGE TO PDF AND TRY AGAIN**

image / figure 2:

PROBLEM DEFINITION **

Limit and define the scope and solution space of your project to one that is manageable within one Master Graduation Project of 30 EC (= 20 full time weeks or 100 working days) and clearly indicate what issue(s) should be addressed in this project.

Currently diapers are mostly disposed of with the general trash, wrapped up with wipes and in a garbage bag. This mix of materials makes it hard to recycle. In this project I am going to accommodate for recycling in the consumer disposal process.

To be able to accommodate for recycling, the scope needs to cover both the material of the diaper and it's user disposal process. It will be a project focused on sustainability and user experience design.

The user experience is important because when the disposal process is optimized for the user (think no smells, clean experience, low effort) , collecting the diapers separately from other waste streams is more realizable.
From the other side, the composition of the diaper should be redesigned, as the multi-material structure it consists of currently is very hard to recycle.

ASSIGNMENT **

State in 2 or 3 sentences what you are going to research, design, create and / or generate, that will solve (part of) the issue(s) pointed out in "problem definition". Then illustrate this assignment by indicating what kind of solution you expect and / or aim to deliver, for instance: a product, a product-service combination, a strategy illustrated through product or product-service combination ideas, ... In case of a Specialisation and/or Annotation, make sure the assignment reflects this/these.

In this project I am going to redesign the end of life of the disposable baby diapers. The diapers composition needs to accommodate for recycling, as well as not lessen the experience of using it. The end product will be a diaper that is recyclable on a material level, but also integrates the user experience of this disposal proces.

This project process is going to be filled with prototyping, on an iterative approach. Throughout all steps of the design process there will be testing, to ensure a pleasurable consumer experience.

End product:

After a process of multiple prototypes, I will deliver a working experience prototype. This prototype will have optimal experience for disposal and have optimized end of life designed for it. It will not necessarily have all final materials, as some will most likely still be in development. Nevertheless, these materials will be explained in accompanying report.

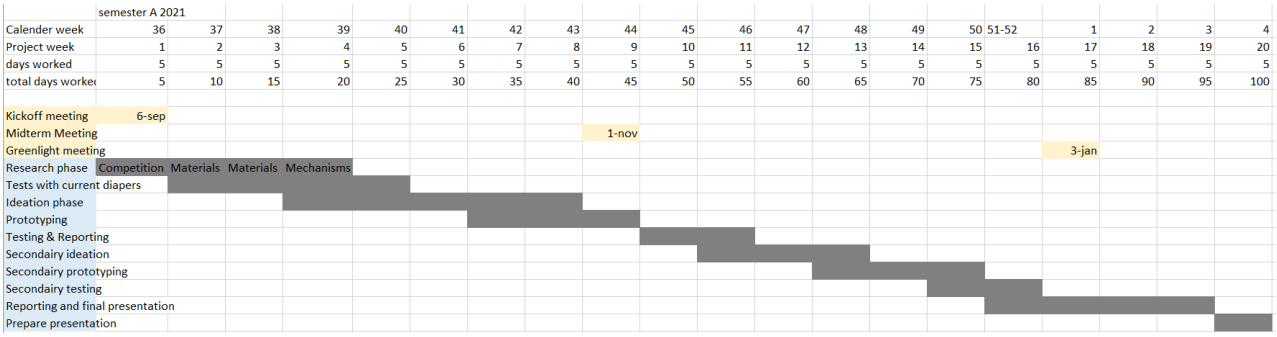
Initials & Name E.K. Deuring Student number 5265630

Title of Project Redesigning the disposable diaper to accommodate for recycling.

PLANNING AND APPROACH **

Include a Gantt Chart (replace the example below - more examples can be found in Manual 2) that shows the different phases of your project, deliverables you have in mind, meetings, and how you plan to spend your time. Please note that all activities should fit within the given net time of 30 EC = 20 full time weeks or 100 working days, and your planning should include a kick-off meeting, mid-term meeting, green light meeting and graduation ceremony. Illustrate your Gantt Chart by, for instance, explaining your approach, and please indicate periods of part-time activities and/or periods of not spending time on your graduation project, if any, for instance because of holidays or parallel activities.

start date 1 - 9 - 2021 31 - 1 - 2022 end date



This project needs a deep dive research phase into the different materials available. It will start with a week of mapping out the competition and other solutions out there. Then in the second week companies will be contacted for samples, so products can be compared. Also for new materials samples will be requested to be able to test. Simultaneously current diapers will be tested on to map out pains and gains of current products. Mechanisms will be the focus of the last week of research, to zoom in on the glue and elastic parts of current diapers, which are big obstacles in recycling currently. Simply testing the workings (and how it functions without certain parts) will be key to further develop a product.
Simultanuously to this researching and testing phase will be ideation, to get the first ideas on paper. Multiple ideation methods will be used to widen the scope of results. (Mindmapping, storyboarding, Challenging assumptions, sketching and low-fy prototypes. This period overlaps with prototyping models for a testing phase because it will allow an iterative approach.
Testing comes in after the first prototypes are finished, and a plan will be created based on the idea it is testing. Parents or future parents should be involved to gage their experience. Multiple subjects will be asked to test the prototypes in a moderated setting, after which they will share their experience through a questionnaire for and an interview. Participants are going to be found through my own connections and through the future diaper project.

This will be repeated in a secondary ideation, prototyping and testing phase, to be able to do improvements and go in deeper on certain issues.

Initials & Name E.K. Deuring Student number 5265630

Title of Project Redesigning the disposable diaper to accommodate for recycling.

MOTIVATION AND PERSONAL AMBITIONS

Explain why you set up this project, what competences you want to prove and learn. For example: acquired competences from your MSc programme, the elective semester, extra-curricular activities (etc.) and point out the competences you have yet developed. Optionally, describe which personal learning ambitions you explicitly want to address in this project, on top of the learning objectives of the Graduation Project, such as: in depth knowledge a on specific subject, broadening your competences or experimenting with a specific tool and/or methodology, ... Stick to no more than five ambitions.

I am a physical designer. I want to design products that are pleasurable to use as well as low impact. I love products that last me a lifetime and that age gracefully. In this project I found that I could apply my skills in prototyping (also in soft product design) as well as learn a lot about sustainability. My overall goal is to gain knowledge and experience in designing for a sustainable future. In previous course work I focused on experience design, which I accomplished through an iterative prototyping proces. In this project I see opportunities to apply this previous knowledge and learn in depth about materials simultaniously.

Objectives:

- Stick to an iterative (low-fy) prototyping design process (at least 8 prototypes at the end)

- Learn about the application and use of bioplastics. (use samples and aquire knowledge from manufacturers)

- Gain experience in designing for a sustainable future and prove a design is more sustainable. (do at least 2 LCA on concepts, also compare it to the current solution.)

- Create for the benefit of the user. (involve potential users at at least 3 stages.)

FINAL COMMENTS

In case your project brief needs final comments, please add any information you think is relevant.

Initials & Name E.K. Deuring Student number 5265630

Title of Project Redesigning the disposable diaper to accommodate for recycling.

APPENDIX B

The Midterm Evaluation Form

>> Complete the form to prepare for the midterm evaluation, and send it to your supervisors, at least 3 days prior to your midterm evaluation session. <<

Name student	Evelien Deuring
Student number	5265630
Name chair	Conny Bakker
Name mentor	Ruud Balkenende

Interim/In-between results

Short description of realised interim results:
Analysis phase completed, ideation phase 1 completed, concepts created and began prototyping.

Reaction on description interim results:
You are well on track and are confident about the next steps in your project. Make sure to critically reflect on your conclusions.

Reflection[1]

<take the course's learning objectives as starting point when reflecting on the topics below [2]>

Reflection on quality	*So far I have completed good quality work. All conclusions are based on sources and I have used multiple design methods and professionals input to reach them. I have had trouble however getting quality input from industry professionals. As the market is very competitive, information sharing is limited. I would also like to improve the quality of communication of concepts and ideas. I want to implement more quality sketches, which so far I haven't done.*	*Good that you have started report writing, it allows us to give you detailed feedback throughout your project.* *The diaper market is indeed competitive, and we realize that you have an assignment with a relatively narrow solution space. Given the difficulty to obtain company info, you might also check out patents on developments regarding diapers.*
Reflection on planning	*I have to have a good grip on my schedule, as I learned the hard way during earlier courses. So far, I am on track to finishing this project with a good result on the planned date. As of the midterm, I have however dealt with a week of illness, causing me to be slightly behind on prototyping. In the next weeks I will put in extra effort to catch up with this. I have a good chunk of report already written down, which will make creating the report in the final stages of the project much less time consuming, giving me more time to polish the end result.*	*A week of illness will (of course) lead to delays. This is a normal part of any project, so instead of pushing yourself extra hard to make up for lost time, we advise you to adjust your planning.*
Reflection on personal ambitions (if formulated in project brief)	*In the brief I set my goal to be iterative and so far I have been experimenting with available materials, but not with actual diaper materials. I am going to iterate more from now on, as I acquired materials to be able to create prototypes with.* *I have been learning tons about circularity, biobased materials and how they can be applied in an effective way. I have struggled with (and am still struggling) with finding reliable sources, and papers with reliable outcomes. Not all papers are reliable and I found that there is a lot of contradiction. In the future I will double check sources and conclusions before adding them to my report.*	*Your approach makes sense.* *Make a good plan for your user tests. What are you testing, with whom and why? What do you hope to learn? How will you record and analyse the user tests?* *For reliable papers first look into peer reviewed literature (search using Scopus or Google Scholar). Also carefully compare assumptions if results are contradictory.*

[1] A short indication of your thoughts and considerations with regard to the graduation project up till now.
[2] Learning objectives are to be found in the Course Manual, and in the IDE Study guide.

	User have up to this point not been heavily incorporated in the project. I understand now that creating a good more sustainable diaper may be more important than what a user may think about sustainability. I feel however that I should in later stages evaluate user experience.	
Reflection on supervision and/or project context	*The weekly meetings with the company supervisor have been very helpful. The interim coaching session, which I used as a think tank to generate ideas, and discuss the general concept I created were incredibly helpful to get the ideation phase started. I will continue in preparing meetings with a clear goal in mind.*	*Good to read that you have weekly company meetings – this is important.*

Decision supervisory team concerning progress graduation project at this moment		
X Continue	☐ **Adjust**	☐ **Discontinue**

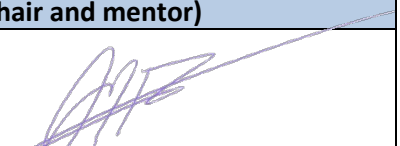
Substantiate the decision:
We are satisfied with your progress and your can-do attitude. Keep up the good work.

Adjustment of Project Brief: new arrangements

Proposal new arrangements based on this midterm evaluation:
n.a.

Final arrangements
<describe here the agreed on new arrangements, to be filled in during/after meeting>

Signatures (name, date and signature of student, chair and mentor)

 **Name student: Evelien Deuring** **Date: 2 nov 2021**	 **Name chair: Conny Bakker** **Date: 2 Nov 2021**	 **Name mentor:** **Date: 2 Nov 2021**

At the end of the Midterm Evaluation meeting: Please hand-in the filled-in form **on Brightspace,** upload to **'IDE Master Graduation Project'** organisation.

APPENDIX C

Parent interviews
An unscripted interview to better understand diaper usage and choice.
Parents interviewed came from my own circles and I am aware that they do not reflect society as a whole.
However, they will give me a good view and perspective on parenthood.
Parent 1
Uses exclusively disposable diapers
2 children, of which 1 still in diapers
Aware of the amount of trash/waste but has not found an as convenient alternative
Thinks they are using a lot of diapers (also due to late potty training, after the age of 32 months)
Diapers need to be thrown out every day due to smells
Washable diapers not an option due to not willing to put time in.

Parent 2
Has had 4 children, of which 1 has worn washable diapers
The upkeep of washing during day trips and moving houses was too much.
Disposable diapers proved to be incredibly convenient even though they were more expensive.
Did not care more about the environment than that it should be just as easy as possible.
"gehannes"

Parent 3
Has 2 children, both of which are still in diapers.
Fully using disposable diapers, but considered washable diapers at the start.
Decided that the time needed was not something they had to spare.
The couple did not want to have a bin of smelly diapers waiting to be washed, they rather wanted to be able to dispose.

Parent 4
Has 1 child, new parents
He sometimes had trouble with the baby moving during changes.
Is using disposable diapers and was not aware of an alternative like washable diapers.
When the concept of washable diapers was explained, he was not interested.
Disposables are easy, and that is why he uses them, he does not see the point in using something
that is less convenient just because it is better for the environment

Parent 5
Has 2 children, both still using disposable diapers.
Never considered disposable diapers, as he wanted to spend as little time as possible with the smelly diapers.
Had some awarity of material usage and waste creation, but did not really care.

Parent 6
Just had a baby, in disposable diapers.
This parent had just became aware of how many diapers they were actually going to need.
She was aware that this was going to create a lot of waste and use a lot of material.
She said she would further look into washable diapers at a later stage, when the baby was a little older.
For now disposables are a convenient option for her as parenting was already really stressful.

Parent 7
2 children, of which 1 is still in diapers
Not interested in washable diapers, simply because it wasnt perceived as convenient.
Disposable diapers are more leakproof and he needed reliability in diapers.

Parent 8
1 child, out of diapers for 4 years.
Aware of the impact of disposable diapers, but cared more about convenience.
With two busy work schedules, they did not want to spend time they had at home doing extra laundry.

User gauging with the prototype

around 50 people were asked if they wanted to talk about a new more sustainable diapers, 23 gave their permission.

	Parent 1	Parent 2	Parent 3	Parent 4	Parent 5
Interested	y	n	y	y	y
Why	Easy way to reduce impact	Was using washables	New product that is better	Reduce material use	Reduce material use
Estimation of awareness of environmental footprint (1-7)	6	7	3	7	5
comments	Was most interested in reducing material use. Really was into the reusing concept.	Did not want to switch to disposables as he was happy with current diaper choice	Thought it was a cool new concept. Would try it when it came out. Not sure he thought the reduced impact was important	Was very aware of the amount of material disposable diapers cost and was curious how the daily diaper reduced this.	Joined parent 4 in conversation. Agreed that it was a very interesting way to reduce, as she clearly understood what was being saved by reusing. The day night concept aslo resonated with her.
Use now or try from the store	Use it now	n	Use it from the store	Use it from the store	Use it now

	Parent 6	Parent 7	Parent 8	Parent 9	Parent 10
Interested	y	y	y	y	y
Why	Reduce overall footprint	Reduce overall footprint	Reduce material use	Reduce material use	Reduce overall footprint
Estimation of awareness of environmental footprint (1-7)	7	6	2	6	6
comments	Spoke about switching to vegetarianism to reduce footprint. Was curious how a new diaper could further reduce it.	Wife of parent 6, shared interest in reducing their footprint. They were sofar using disposals with a guilty concious, but were not willing to use washable diapers to reduce material use.	Clearly understood the reduction of material use by reusing the outer. Did not care much about the environment or his footprint, but was willing to try the diaper, as long as it gave him the same results as the current disposable.	An engineer, that was mostly interested in the new mechanism. He was very interested in the inner workings of the diaper, knew about the SAPs and was curious about biobased materials. He had also thought earlier about day and night differences of diapers. Biobased materials are awesome.	Wife of parent 9. Not an as technical view on the product, but still interested in the new diaper product. She said she wanted to reduce the pressure they were putting on the environment and said that she was watching pastic use.
Use now or try from the store	Use it now	Use it now	Use it from the store	Use it from the store	Use it from the store

	Parent 11	Parent 12	Parent 13	Parent 14	Parent 15
Interested	y	y	y	n	y
Why	Reduce material use	Reduce material use	reduce overall footprint	Did not understand the concept	Reduce material use
Estimation of awareness of environmental footprint (1-7)	5	5	4	2	5
comments	Reusal is cool, especially after that still being able to dispose of it. (had to explain twice that it is not washable but actually disposable)	Joined parent 11. Liked that there was a choice, dispose or reuse the outer	Thought the reduction of day diapers was smart, he said it would be a small adjustment.	Was not interested at all in a diaper product to reduce environmental impact.	REALLY liked the reuse of materials, she was a mother that was also really enthusiastic about reusable sandwich bags. Did not take the step to washable diapers as she read online that they may be as bad as disposables and she did not feel like extra laundry
Use now or try from the store	use it from the store	use it from the store	use it from the store	n	Use it now

	Parent 11	Parent 12	Parent 13	Parent 14	Parent 15
Interested	y	y	y	n	y
Why	Reduce material use	Reduce material use	reduce overall footprint	Did not understand the concept	Reduce material use
Estimation of awareness of environmental footprint (1-7)	5	5	4	2	5
comments	Reusal is cool, especially after that still being able to dispose of it. (had to explain twice that it is not washable but actually disposable)	Joined parent 11. Liked that there was a choice, dispose or reuse the outer. Very happy about biobased.	Thought the reduction of day diapers was smart, he said it would be a small adjustment.	Was not interested at all in a diaper product to reduce environmental impact.	REALLY liked the reuse of materials, she was a mother that was also really enthusiastic about reusable sandwich bags. Did not take the step to washable diapers as she read online that they may be as bad as disposables and she did not feel like extra laundry. loved biobased.
Use now or try from the store	use it from the store	use it from the store	use it from the store	n	Use it now

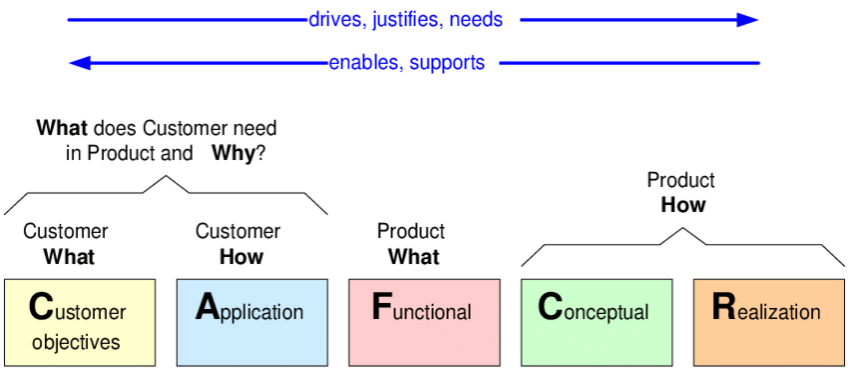
	Parent 11	Parent 12	Parent 13	Parent 14	Parent 15
Interested	y	y	y	y	y
Why	Unclear, but he liked the concept	reduce overall footprint	reduce overall footprint	reduce diaper use in general	reduce overall footprint
Estimation of awareness of environmental footprint (1-7)	0	5	6	2	5
comments	Said it was a nice concept. Also said he would use it, main reasons unclear.	She liked the reduction of day diapers. She was interested in trying to reduce her footprint.	Reusal and disposal was 'genius' middle of the road. Would like to use it when it comes out in the stores	Was aware of the cost and material use of diapers, and was most interested in reducing diaper use overall. This concept would be a first step he said.	was enthusiastic about both reuse as well as biobased materials.
Use now or try from the store	use it from the store	use it from the store	use it from the store	use it from the store	use it from the store

	Parent 16	Parent 17	Parent 18	Parent 19	Parent 20
Interested	y	y	y	y	y
Why	No clear reason, just liked it	Reduce footprint	Reduce footprint	reduce footprint	Reduce material use
Estimation of awareness of environmental footprint (1-7)	4	6	6	5	5
comments	Thought it was a cool new diaper after explaining it twice. Concept was not clear in 1 go.	Liked reusable outers, was already taking steps in life to reduce footprint	Joined parent 17, liked the concept of day and night as well, but was most enthusiastic about being able to decide when to reuse themselves.	Joined parent 17&18 in discussion. Did not get the concept at first, though a lot of extra work was involved. After more explaining the parent was enthusiastic.	Wanted to reduce plastic consumption. Reusable bags were named.
Use now or try from the store	use it from the store	use it from the store	use it from the store	use it from the store	use it from the store

	Parent 21	Parent 22	Parent 23
Interested	y	y	y
Why	Reduce footprint	Reduce material use	Reduce material use
Estimation of awareness of environmental footprint (1-7)	6	4	5
comments	Was really interested in how this product would come on the market, and when. Liked material changes to biobased and the night and day use. Said he would definetly want to see the outer inlay approach already in current diapers.	Liked that she could reuse. Also the renewability she thought was cool.	Joined parent 22. Was more aware of current impact their diapering habits had. Liked that this diaper would be a low effort step to a much more sustainable diaper.
Use now or try from the store	use it from the store	use it from the store	use it from the store

APPENDIX D

CAFCR Model for ideation



(Muller, 2019)

- **Customer Objectives (What does a consumer want);**

The customer objectives can be defined in terms of key drivers. For parents that need to use diapers for their baby's key drivers are in order of importance:

- Safety for their baby
- Dependability for themselves (to not have any leakages, saving them in cleanup)
- Ease of use for both themselves and their baby. They don't want to spent a lot of extra time or effort, as well as they don't want to get their hands dirty.
- Environment for themselves, to not have an enormous footprint, to be able to feel content with the diaper choice.

- **Application (How is the product used);**

The application view is used to establish the way the consumer is achieving his or her objectives. The main objectives of using diapers are:

- Keeping furniture and clothing clean.
- Single or multi use of the diaper, as long as it does not require a lot of extra work.
- Disposal is clean, with a clear conscience.

- **Functional (What does the product bring);**

The functional aspect is used to clarify the specifications needed to achieve the customer key drivers.

- The product keeps the moisture away from the baby's skin.
- The product does not cause rashes or allergic reactions.
- The product does not contain any parts that can cause suffixation.
- The diaper has a sufficient capacity comparable to the current disposable diapers
- The diaper requires little time and effort to put on, compared to a washable diaper.
- The product is less burdensome on the environment compared to current disposable diapers.
- The diaper does not leak.
- The diaper can be disposed in a clean way.

- **Conceptual (How does the product work);**

The conceptual aspect is specified to be able to understand how the product is able to achieve the specification stated under the functional aspects.

- The product uses wicking materials as a top layer.
- The product makes use of antiallergen materials, and does not use perfume.
- The product has no sharp, small or constricting parts.
- The product makes use of SAP to obtain a similar amount of liquid as a current disposable diaper.
- The diaper has a convenient donning system, allowing for quick diaper changing.
- The diaper has built in mechanisms to prevent leakage.
- The diaper has built in ways of clean disposal.
- The diaper uses reusable, recyclable or biobased and biodegradable materials.
- The diaper is quantitatively compared to current disposable diapers.

- **Realization (How is available technology used)**

The realization aspect is used to make the design parameters explicit, by for example determining budget, technologies limitations and margins. As these are mostly depended on what concept is chosen, it will not be elaborated on at this stage, except for a basic monetary restriction.

- The diaper must have a comparable price to current more sustainable options for diapers.
- The performance of the diaper should be evaluated. (Later stage)
- The ease of use of the diaper should be evaluated. (Later stage)

APPENDIX E

An Excel Model cannot be exported into a pdf in a valuable way. The model can be accessed and used through this qr code.