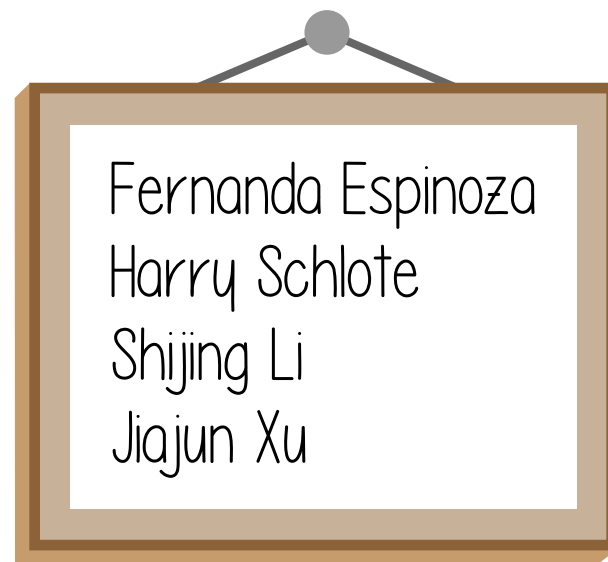
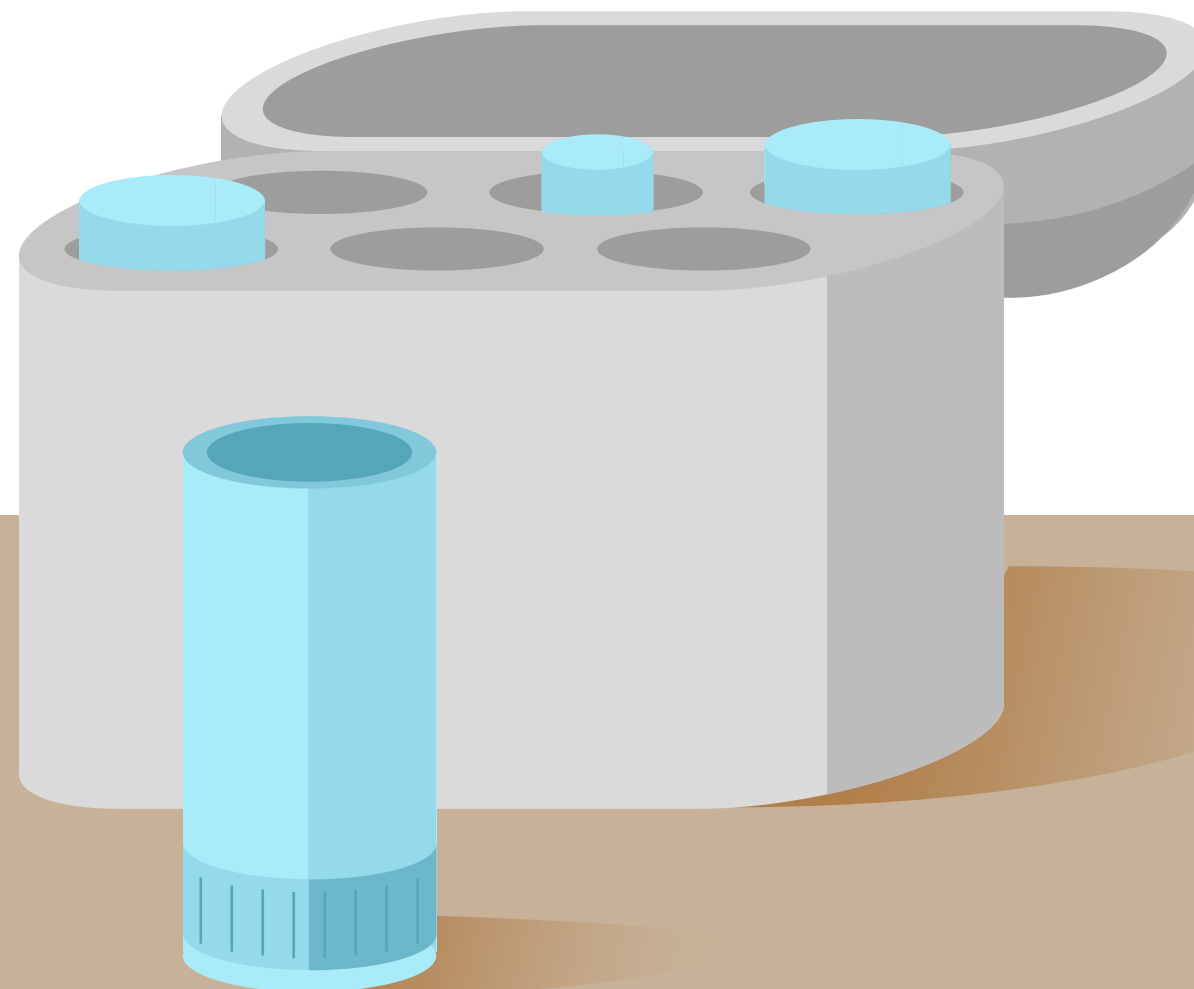




ARC
agricultural repeated cycle



background research

glue stick analysis

market

- UHU & Pritt sustainable options are **3 times more expensive**
- Increasing use of natural ingredients
- Decreasing use of PVA

user

- 35%** users say they don't own a glue stick even though they have some at home or school
- 1/3** of glue sticks are disposed because they dry out
- 93%** are disposed in general waste



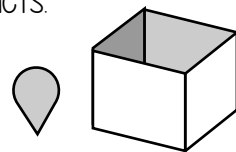
product

- Easy to disassemble due to lack of permanent joints or screws
- Packaging has the potential to be reused
- Product is based on a linear business model
- The casing and packaging contributed the most to its environmental impact
- The material made up **87%** of the embodied energy and **77%** of the carbon footprint

current PSS analysis

1 Writing instruments

The consumer takes the product to a Terracycle location and puts it in a box, where the box is then sent to Terracycle where they are separated by material composition, cleaned and melted into hard plastic that can be remoulded to make new recycled products.

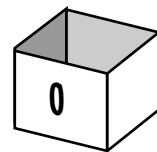


Product oriented PSS

This is something that adds onto the product by providing a revalorisation service to the resource of the product.

2 Zero-waste box

The consumer buys a zero-waste box, from 180 to 280 pounds, and fills it with empty glue sticks (or other glue containers) and then posts it for free to Terracycle so it gets sorted and melted into recycled plastic used for new products.



result oriented PSS

The service provided by the purchase of the box is the main purpose behind this PSS. The result is recycling the glue containers for 'free'.

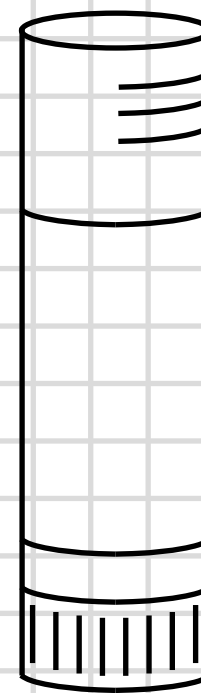
Terracycle is a product service system as a global recycling company for 'hard to recycle waste'.

Problems

Product level

- UHU & Pritt sustainable options are **3 times more expensive**
- There are no visible labels about the reuse or recyclability of the product or packaging.
- The glue is very likely to shorten the product lifetime due to its chemical properties.
- PVA is the most used material for the casing which is extremely harmful for the environment.

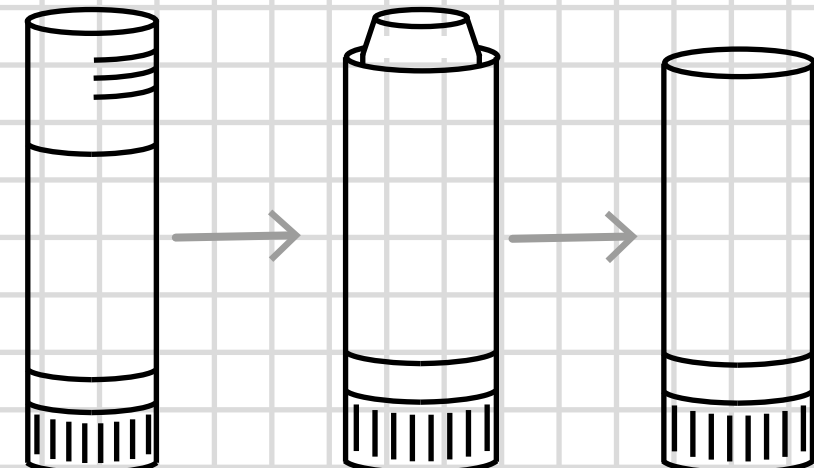
- social
- technical
- environmental
- economical



- Recycled plastic is **57 pounds** more per tonne
- Consumers need to be motivated enough to clean and recycle glue sticks.
- There are no requirements for labels about the recycling or sustainability of the product.
- There is not an existing infrastructure to deal with more sustainable materials like plant-based plastics.

system level

- Expensive prices of recycling schemes are a disincentive for consumers.
- No proper flow of information between manufacturers, brands and recycling companies.
- There are no legislations regarding the sustainability of materials in stationery.
- Recycling companies may have issues if the glue can't or isn't cleaned properly.
- Manufacturing processes may not be applicable to more sustainable materials.
- Reused plastics are more expensive than virgin materials disincentivising manufacturers.
- Consumers are likely to be careless with the product and shorten its lifetime.
- The transport for resources, materials and distribution pollutes the environment.



current system

A diagram of the current linear system of glue stick, and identifying potential and intervention points.

glue stick is sent to stationery shop

consumer buys glue stick

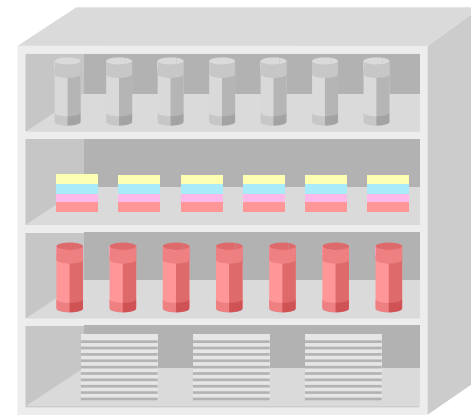
Packaging is thrown away

! our intervention
! Potential



The glue and casing have the potential to have the same manufacturer to avoid additional costs and transport.

glue stick is assembled



The glue stick has potential to reach very different types of consumers through e-commerce.



We decided to make the packaging from a biodegradable material, Paperfoam to decrease the amount of waste produced by the purchase of the product.

Paperfoam (9) is a UK company that makes packaging from potato starch and other natural fibers. Its packaging is able to biodegrade in soil after a week.



We chose to not let the lack of glue dictate the end of life of the product by providing a refillable system.



glue stick is used

The frequent use of glue sticks makes them have potential to be a successful reusable product.

glue stick becomes obsolete

the system of a PVA glue stick

This is the current system in place for glue sticks. It follows its production, manufacturing, purchase, use and finally disposal. We want to show where and how we are intervening this system.



end of life Potential

PVA can be easily recycled which gives the glue stick a very high potential for its end of life to recover some of the energy lost throughout this system. However, first social and Economical problems need to be overcome to make consumers willing and able to recycle their glue sticks.



glue stick is disposed

end



Our new material will be biodegradable to avoid the pollution caused by the glue stick ending up in a landfill.



We decided to change the material of the casing since it was the most significant component on the environmental impact of the glue stick. From PVA to a new Bio-plastic CL-PHA. (10)

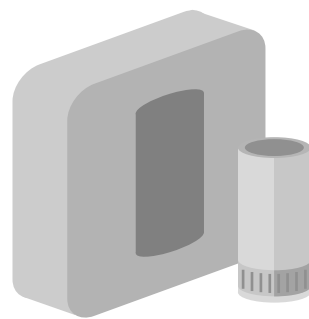
CL is a new type of PHA developed by Bio-On in Italy (13). It is made from agricultural waste and can biodegrade in soil or water in a few days.



The production of PVA requires chlorine gas which releases toxins into the atmosphere. It also has unethical implications when produced in China. We decided to intervene by replacing the main resource used for the glue stick from PVA to potatoes.

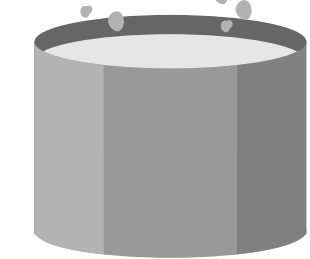


To completely avoid the use of PVA we will use a plant-based glue.



casing is made from PVA

glue is made from PVA



PVA is produced

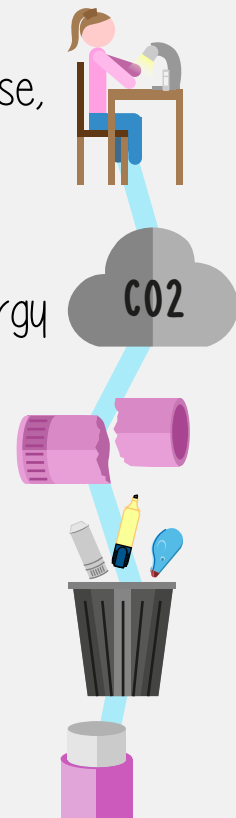
start

insights and specification

From the background research and current system, the insights can be curated and categorised in terms of product level and system. From these insights, the initial specification can be created that applies to most product in the stationary category.

Product level insights

- 1 Current products are intuitive for consumer to use, so no functionality changes should be made
- 2 Thermoplastics in the products are generally the component that contribute to more CO2 and energy
- 3 Generally difficult to disassemble, with hidden parts due to the casing on many products
- 4 Lack of ownership felt between the consumers and the products, which shortens lifecycle
- 5 Lack of quality such as moisture loss or tape breaking/unwinding leads to shorter lifecycle.



Specification

Ensure the product is easier to disassemble, so that user can dispose of it in a way to increase its end of life potential

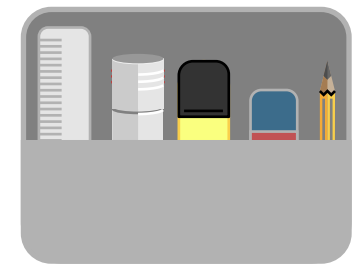
Make product feel more personal to user so there is more ownership and care taken over it.

Look to replace the thermoplastics in the product with an 'Eco' alternative

There must be clear information in the packaging and product to make the user aware of its sustainability and recyclability

Methods of sustainability

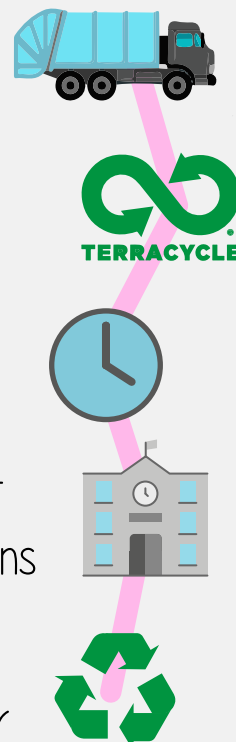
In design process, we will consider multiple specification points e.g. if we try to solve the disassembly issue, we will do this using non-thermoplastics (another spec point).



Also we will try to keep the system broad, so it can be applied to other stationary items.

System level insights

- 1 Clearly linear system, with virgin materials used in production and obsolete product going to landfill.
- 2 No current PSS schemes that are engaging enough to be widely used by consumers
- 3 The entire system has a quick cycle, from production to end of life in a few months
- 4 Large amount of stationary used in education, but no exclusive system schemes for these applications
- 5 Lack of sustainability in the whole system, from manufacturing to information on product for user



Specification

Make the system more engaging with consumers, making it more convenient or engaging and informative.

Make educational institutes a focal point to supply but also ensure the system is applicable to individuals or businesses.

Move from linear to circular system, by attempting to remove the landfill option, and by informing the user on the system.

Slow the cycle down, by making better quality product and/or making it refillable to extend product lifespan.

next steps

Now that specifications have been made for the product and system, the current system can be visualised and we can identify the points that relate to the specification and that will be changed in the new system.

Research can also be carried out into methods used to create the new system and a future scenario and time horizon can be stated.

new system level intervention

Now that the linear system has been analysed, the system can be redeveloped into the circular ones, with key points including resource flow, consumer journey, and energy flows being visualised. The **resource flow** can be seen with the key parts being illustrated in the diagram.

future scenario

Almost all consumers will be eco-aware due to the state of the world's climate and resources. The social trends incentivise companies to be more environmentally friendly so they offer refillable products and disposal services when products are obsolete. Consumers also want more personalised items due to higher emotional attachment and trade is idealised by consumers to be local, as it is thought to use less energy and be more environmental.

If ARC has a single factory to produce the packaging, glue and casing then no delivery is needed. However, if production is outsourced or produced in different locations then delivery between these places by lorry freight will be needed.

energy invested

To process the materials, and manufacture the product, this will require energy into the system.

The packaging is produced by combining starch, water and paper fibre, then injection mould. This has already been done by 'Paperfoam'.

energy invested

To grow the potatoes, and process them, including transport requires energy put into the system.

Potatoes are cleaned, washed, separated, crushed, dewatered, dried to make starch.

The CL PHA is produced by natural fermentation of farm waste by bacteria. This farm waste could be the same from the potato production, if both are local. This PHA is then injection moulded into the casings.

The agricultural waste is then used to make CL PHA, the bioplastic used to make the casing for the glue stick and replace thermoplastics.

The manufactured casings are then stored in a warehouse until a school places an order.

The school will purchase the service from ARC, depending on the number of students. These student can then gain access to the website to personalise their item.

The student can then choose their colour of product and graphic on it, and once all the students have chosen, the order will be processed and dispatched to the school.



energy invested

Delivery of the products to schools will use energy, as well as energy used by the online ordering system.

The personalised casings are then packed in boxes, made from the sustainable packaging and delivered to the school by courier.

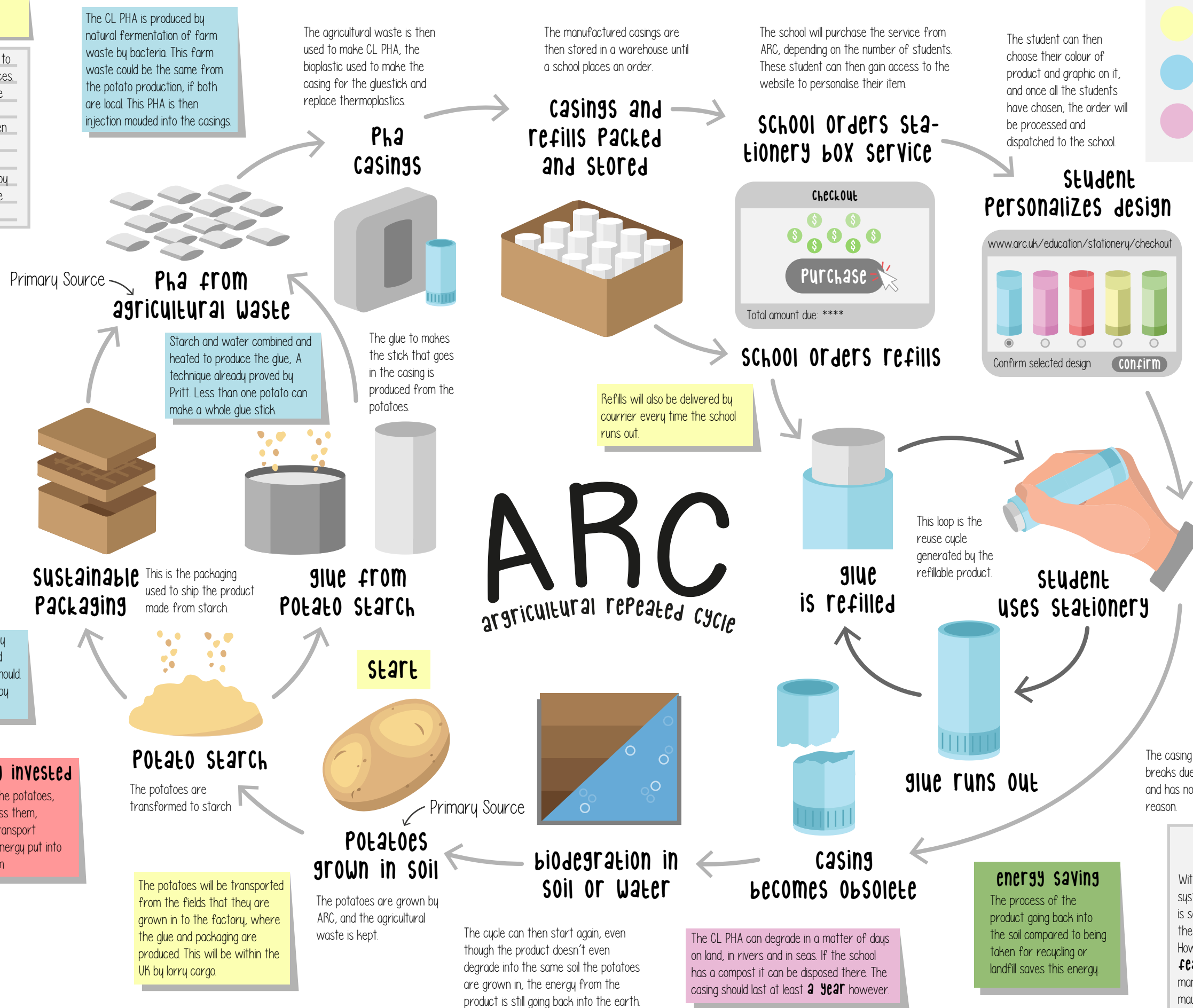
The glue stick are then personal to each child, and they will use their own whenever they need to.

Once the glue stick part runs out there is nothing left over, so the stick is simply replaced by the user and there is zero waste.

The casing should only become obsolete if it either breaks due to misuse, the student finishes school and has no need for it or for some other niche reason.

time horizon

With none of the interventions in the new system being unrealistic for this time period, it is sensible to suggest that the time horizon for the new system could be within a year. However, for the manufacturing and economical **feasibility** of the CL PHA and other manufacturing methods to be scaled, up this may be closer to 5 years.



Stakeholders on a consumer journey

1 school orders service innovation

- In this stage schools are our target consumer. They would be able to purchase stationery that their students need to use for school work. This lowers their costs as they buy a reusable product in bulk.
- ARC as the manufacturer would need to provide an online platform for schools and students to purchase glue sticks.

2 school orders refills

- The PSS offered by ARC also allows the school to purchase the individual glue sticks refills so they can store them and make the refill process faster and more convenient.
- Government needs to introduce legislation to limit the use of PVA in glue sticks so more sustainable options become more prominent.

3 student chooses design innovation

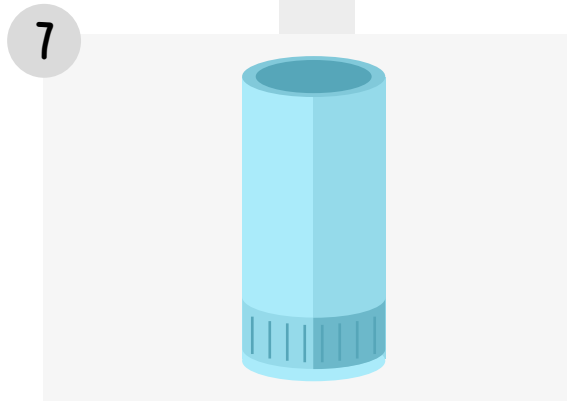
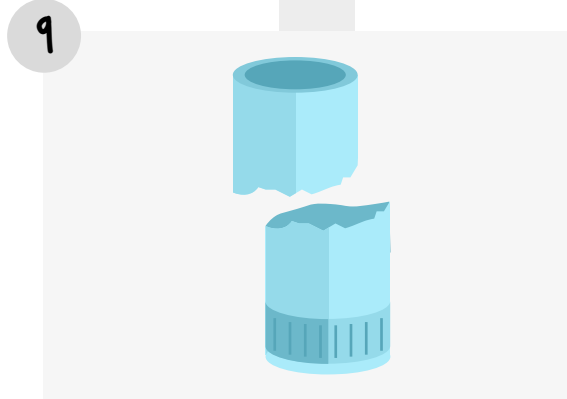
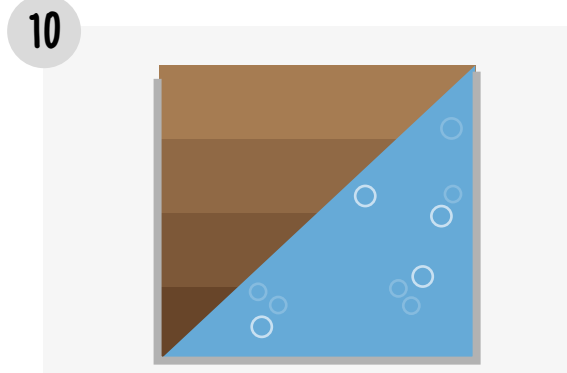
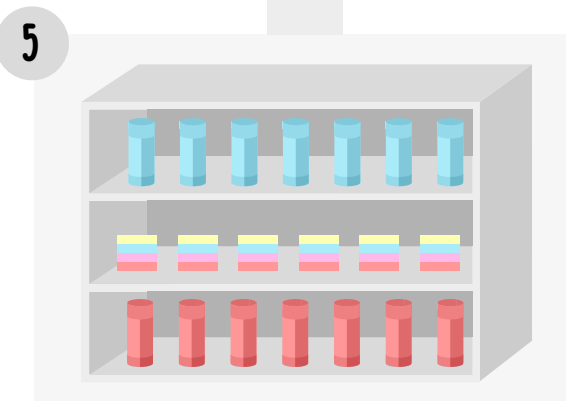
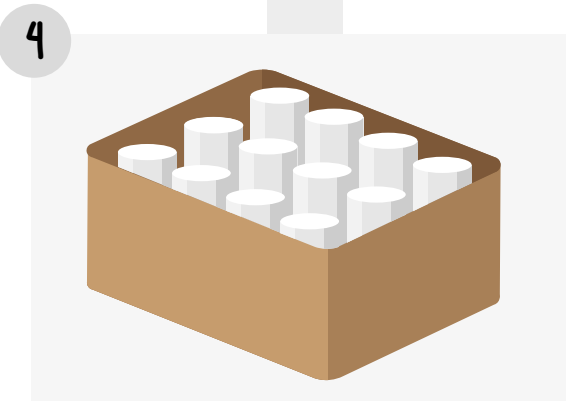
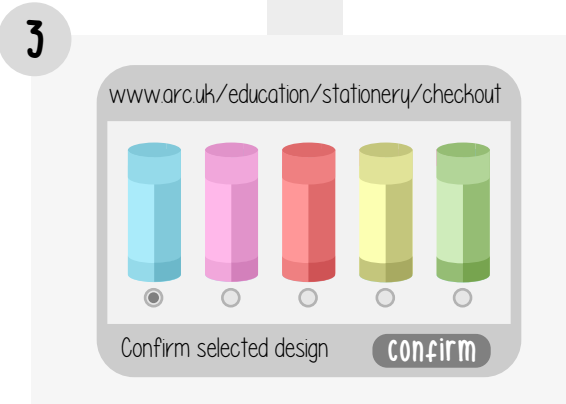
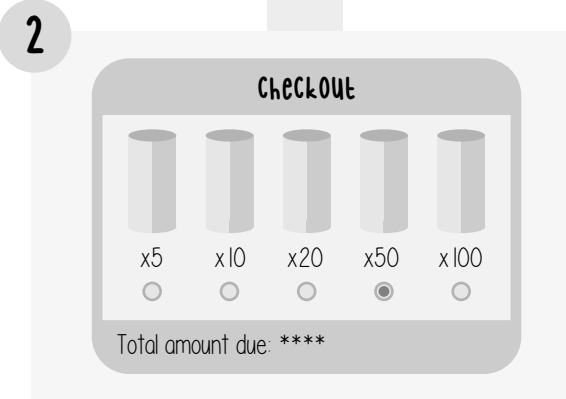
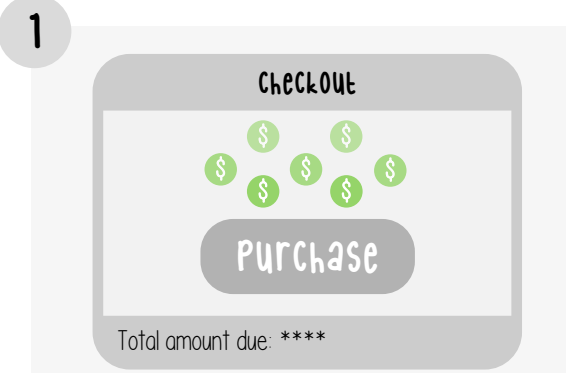
- Now the consumer are the students. They are granted access to ARC's webpage to personalize their glue stick casings. This allows them to differentiate their belongings and feel ownership.
- ARC needs to be able to manufacture the casing individually to fulfill each students' choice.

4 order is delivered feasible

- ARC needs to have good communication with the distributor to allow them to plan for the most efficient routes for delivery.
- The distributor used by ARC needs to be able to provide stability and protection for the glue sticks during transport to ensure their quality when delivered to the consumers.

5 refills are stored

- The consumer that initially receives the glue sticks is the school. This allows the school to properly organize the distribution to their students and the storage of refills that are not used immediately.



- consumer
- distributor
- manufacturer
- government

10 casing biodegrades sustainable

- The consumer that initially receives the glue sticks is the school. This allows the school to properly organize the distribution to their students.
- ARC needs to properly inform the school about the disposal of the glue sticks so they can teach the students.

9 casing is obsolete

- The government's emphasis on reducing waste will be put into practice as there will be no waste from the product until the outer casing breaks / is lost.

8 glue is refilled sustainable

- The action of refilling the glue will engage students with the idea of being zero waste and make them more conscious about the environment as they would not dispose of anything during this stage, in contrast to when they used other glue sticks.
- ARC needs to make sure that the casings are durable enough to sustain the use cycles for at least a year.

7 glue runs out

- The students will use the glue sticks at the same rate as before.
- ARC needs to make sure that the casings are durable enough to sustain the use cycles they will go through for at least a year.

6 student uses glue

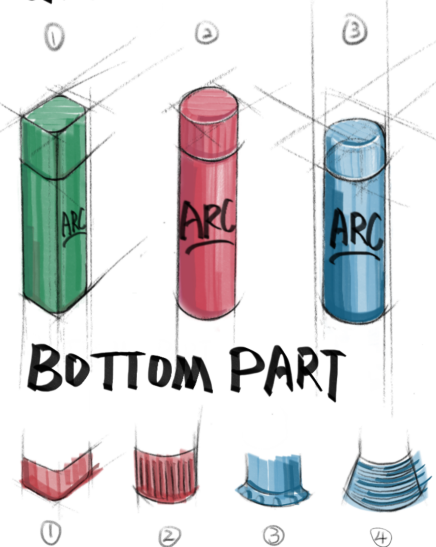
- Before students use the glue sticks, the school needs to give them proper instructions about the reuse system they would implement with the refillable glue sticks.
- Government would have legislation in place regarding the use of glue sticks in younger children to avoid toxic materials or small parts.
- ARC needs to ensure a high quality for their glue so they can fulfil the students' needs.

Product level intervention

This section illustrates how the product is manufactured, details on the materials used and how the separate parts work. The method of how the glue stick is actually refilled is detailed, with a combination of sketches and CAD models.

Casing design

GLUE STICK BODY

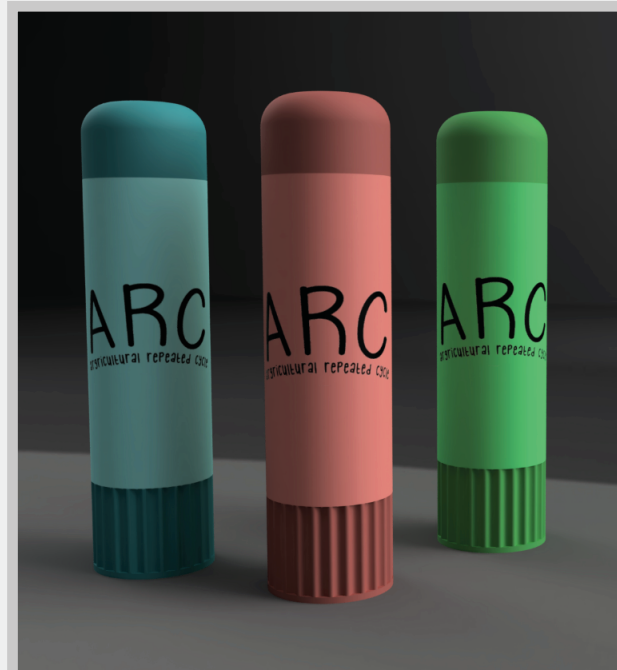


The casing is manufactured from CL PHA. This is different to normal PHA bioplastic in that the degradation time is much quicker.

The CL PHA can come in pellets which is a suitable form for injection moulding

The casing comes in the same form as current glue sticks, with an ergonomic textured bolt screw to twist the glue easier. The lid is also curved to fit our design style and for a softer aesthetic.

CAD Visualisation
of the Product

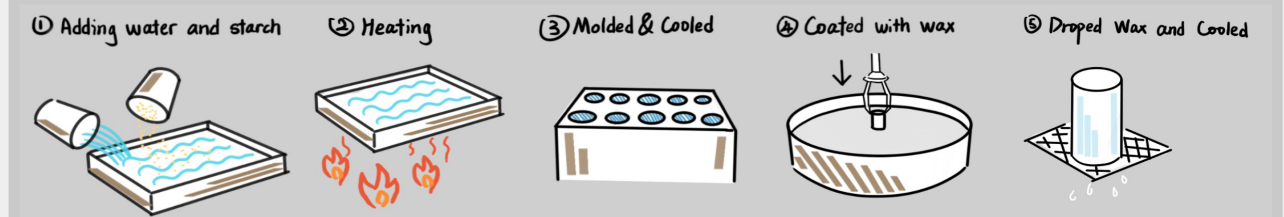
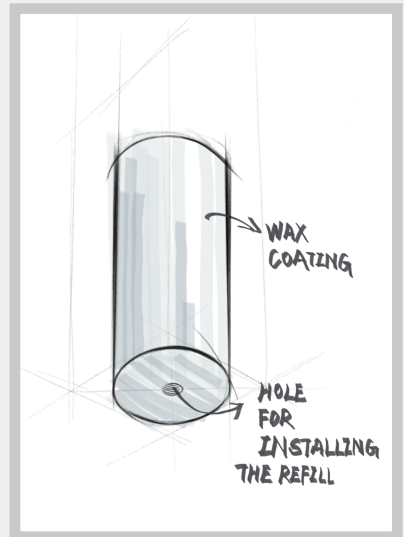


glue stick design

The sticks are made from the potato starch and water, as mentioned before and heated up. They are then cooled in a mould, so that the glue solidifies.

They are then quickly dipped in warm natural wax and then cooled again. Spray sealant wax was also explored but applications only include cars at the moment and did therefore not fit our future scenario.

The sticks have a small hole through the middle, slightly smaller than the bolt screw thread.



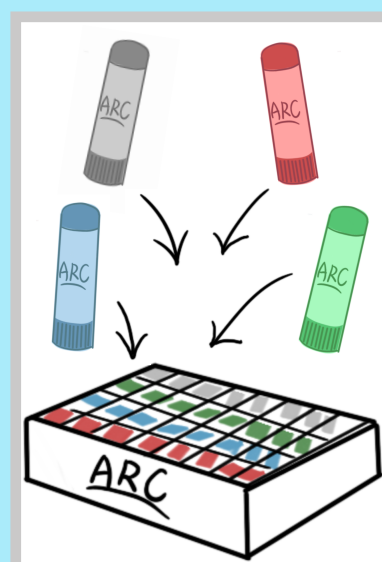
Packaging design

The packaging is used to store and transport the glue sticks as well as containing the glue sticks cases when they are delivered to the schools.

The packaging is made out of paperfoam as mentioned previously, as it is sustainable and utilises the same resource that makes the glue. It is also biodegradable and has very similar physical properties to existing packaging materials.

For the glue sticks, the packaging will be a standard size box, with square dividers to keep the sticks separate. They will not stick to the box due to the wax coating.

The casings will be in a similar style but slightly larger box again with dividers. They can come in multiple sizes depending on the order quantity.



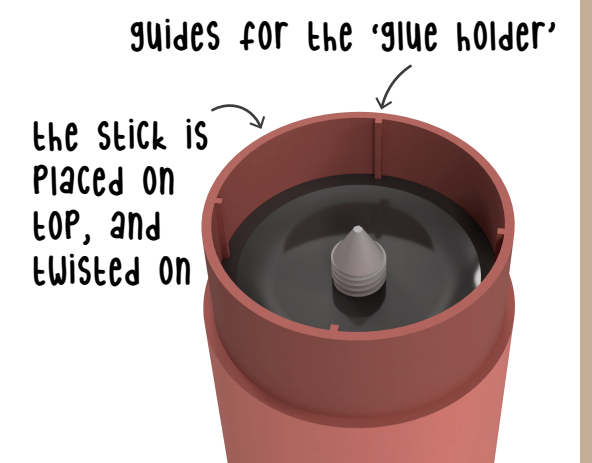
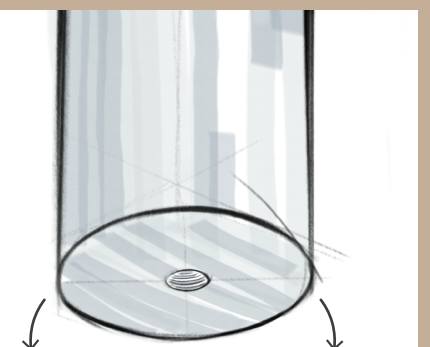
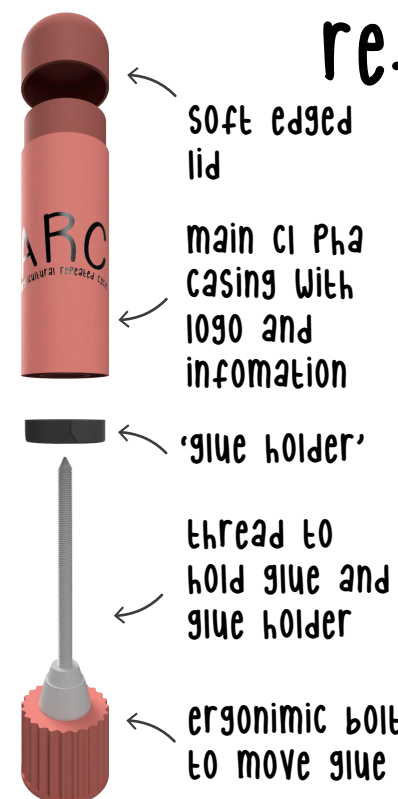
refill design and assembly

The refill system is designed to be simple and tidy.

Once the old glue stick has run out, a new one is taken out of the box, and then simply pushed into the bolt screw, and then the bolt is turned at the bottom of the stick to pull the glue onto it.

The grey component moves up and down the thread when the bolt is turned as it fixes to guides on the inside of the main tube. This helps the glue stick move up and down.

Due to the wax coating on the outside of the stick, while performing this refill the user's hands will not get sticky and there will be no mess, and no waste.



environmental + social impact

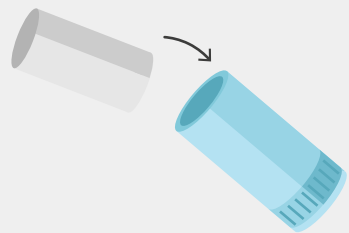
This new system and product has benefits socially and environmentally and these points are expanded on in this section. The new system aims to not only improve the sustainability of the stationary market but also change the way that consumers own glue sticks and stationary in general.

environmentally

natural disposal of the product means that no processes are used, so this **saves energy**.



The **refill** method means no waste after a glue stick is used, and then the **speed in the biodegradation** of the casing means that there is essentially **zero waste**.



The **sustainability footprint** is improved as a lot of the materials used to make the products are **linked** so the resources volume decreases. As well as these they are **natural resources** and given energy back to the earth at end of life.



The way that materials are sourced from the soil, and at the end of product life the product is disposed of in soil, it demonstrates the **improved circularity** of the product.

environmental impact

using CES eco audit tool
Analysis of the product was carried out with the new materials, assuming that the new glue stick will last around a year, and that an old one would last 3 months. We found the embodied energy and CO2 footprint per year:

before

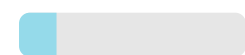
Embodied Energy - 9.92 MJ



CO2 Footprint - 0.44kg

after

Embodied Energy - 2.65 MJ



CO2 Footprint - 0.0594kg

You can see that energy has over 3x reduction and CO2 has over 7x reduction. These figures, as well as the fact that the end of life of the product will be more sustainable, shows the idea is feasible.

socially

(Highlighting sustainability, feasibility and innovation)

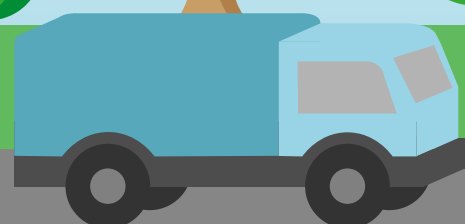
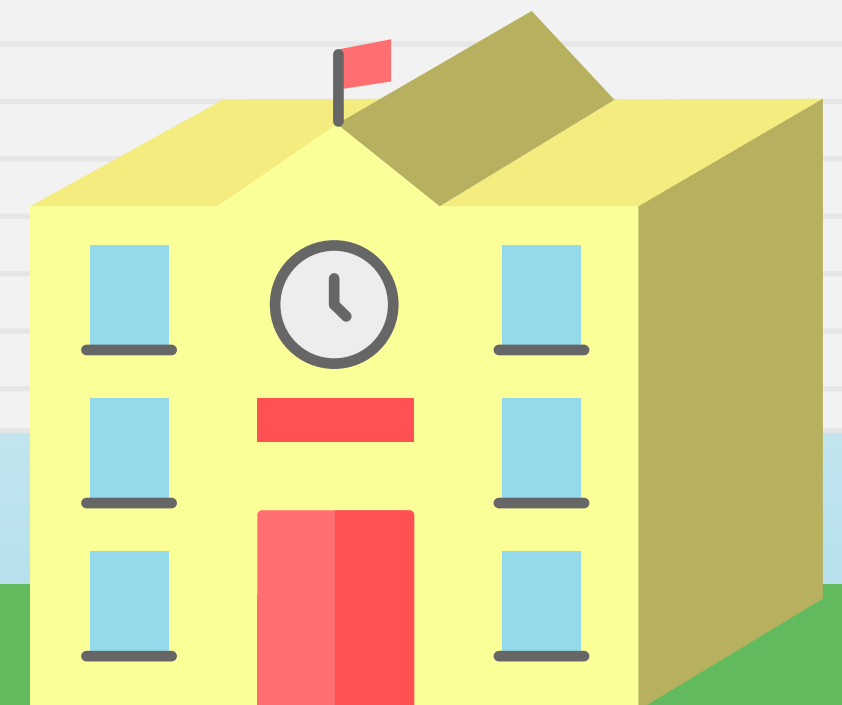
The product will teach children **ownership** and **care** and about **sustainability** if they are given an overview about the lifecycle of their product by their teachers. Previously glue sticks were shared in classroom, but this new system teaches them this important trait.

If Covid-19 is still present, this idea **improves hygiene** as items are not shared and therefore germs are less likely to spread.

All the **elements** in the system e.g. materials and form of transport **already exist** in the world and therefore the **intervention is feasible** as no drastic changes are needed to current infrastructure in the world.

costs for the product **shouldn't increase significantly**, disposal of the product is natural, the new materials will not be expensive and as the supply chain is linked and materials become more widely available, this will reduce costs and is **feasible**.

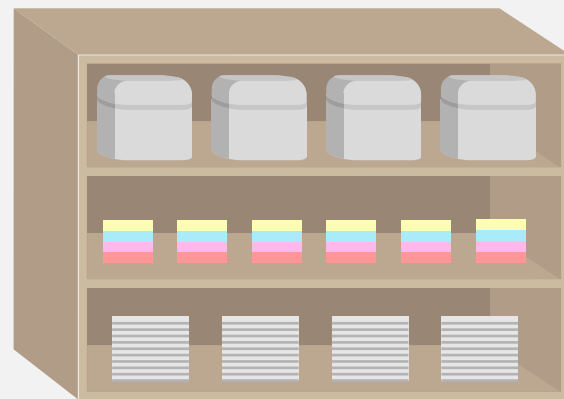
The intervention is **innovative** in the way that the students use stationary, and the complete circularity of the model, and therefore will hopefully be **recognised** and used.



the future of arc

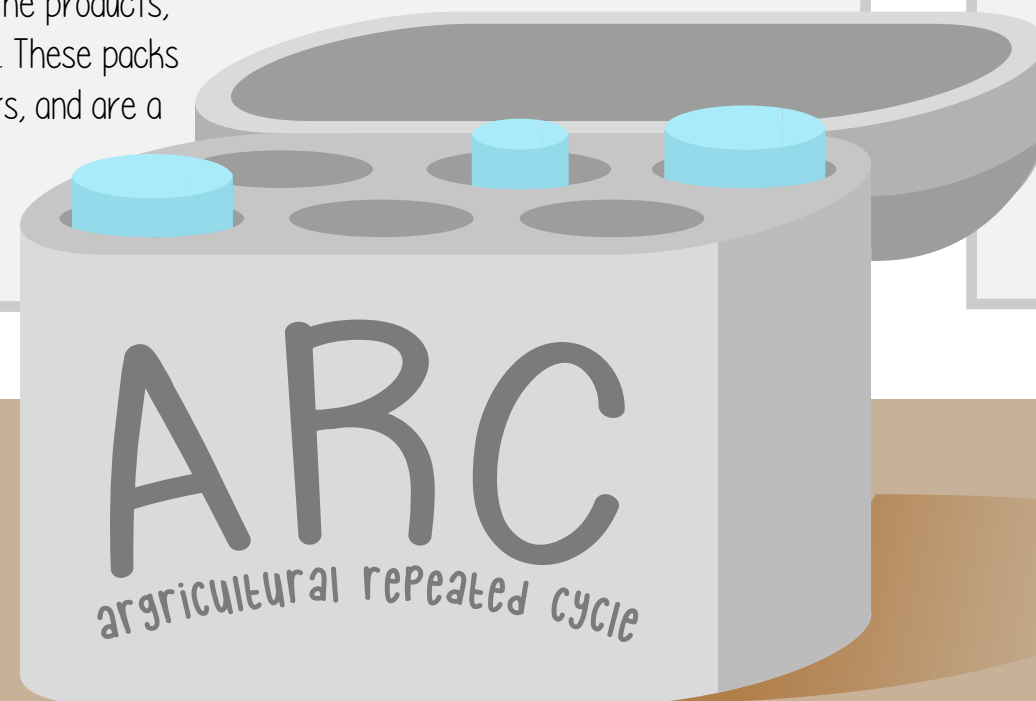
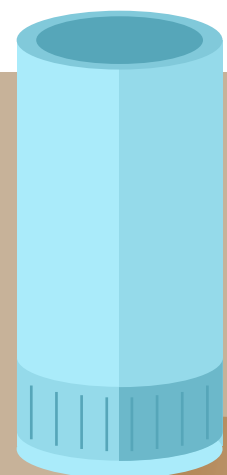
the stationery pack

The next step for ARC is to offer not only glue sticks but other refillable and reusable stationery products such as highlighters, pens, scissors, markers, mechanical pencils, etc. The idea would be for the consumer to have all these products with the same design on their outer casing giving it a consistent aesthetic generating a greater connection towards their stationery.

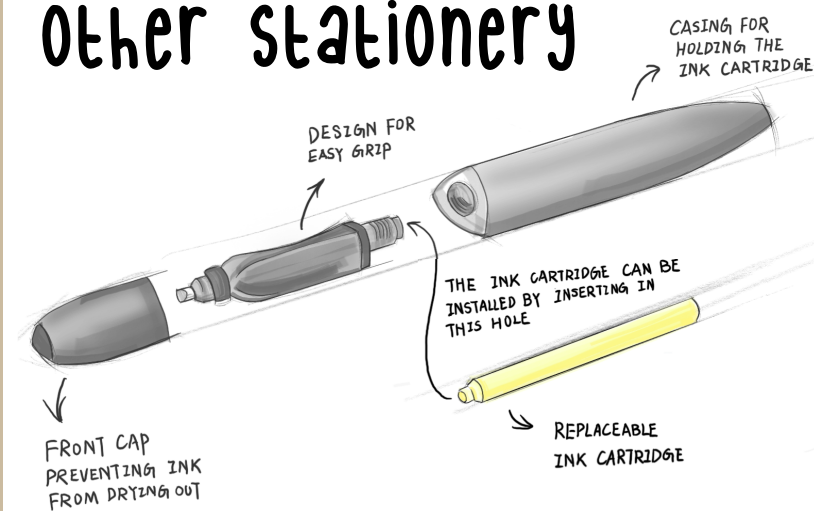


The other stationery and the pack would be made from the same material used for the glue stick casing, CL bioplastic. This ensures all products are sustainable and can be part of ARC's circular system. The pack also makes use of a living hinge and the stationery products are held inside by two sheets of CL bioplastic that have cutouts of the shape of products so they can easily slot in.

The matching aesthetic of these packs should again encourage the user to retain the products, and become more attached to them. These packs are also for home and business users, and are a way to neatly store the products. They will be a suitable size to fit in drawers.



other stationery



To apply the idea of a stationery pack in the future we would need to consider the design and manufacture of other stationery products. For example, this is a sketch of the refillable system for a highlighter ARC would offer in these packs. Further research should be made regarding the manufacture of the ink used so it can be part of ARC's circular system.

other consumers

To have a greater environmental and social impact ARC would expand its service and offer it to businesses and homes alongside schools and universities. This means that they would also extend the designs available for the casing of their stationery products since the consumers would now have very different needs and preferences regarding the aesthetic of the product. For example, businesses would prefer a more elegant and sleek design whereas students would prefer a fun colorful one.

When applied, the website through which the product is ordered will have clear different sections depending on the consumer.



key references

research

- 1 <http://www.madehow.com/Volume-5/Glue.html>
- 2 <https://www.beroeinc.com/category-intelligence/adhesives-market/>
- 3 <https://www.grandviewresearch.com/industry-analysis/stationery-products-market>
- 4 <https://www.uhu.com/en/more/sustainable-products>
- 5 <https://www.prittworld.co.uk/en/sustainability/packaging.html>
- 6 <https://www.prittworld.co.uk/en/about-pritt/production.html>
- 7 https://www.terracycle.com/en-GB/zero_waste_boxes/glue-sticks-and-bottles-en-gb
- 8 <https://sites.google.com/site/quatamagreenteam/elmer-s-glue-recycling-program>

new system

- 9 <https://www.paperfoam.com/>
- 10 <https://www.dezeen.com/2019/06/13/kartell-componibili-bioplastic-storage-unit/>
- 11 <https://www.ansys.com/products/materials/granta-edupack>
- 12 <https://www.cpsc.gov/Business--Manufacturing/Business-Education/Business-Guidance/Small-Parts-for-Toys-and-Childrens-Products>
- 13 <http://www.bio-on.it/what.php>