HORIZON-CL6-2021-CIRCBIO-01

Innovative solutions to over-packaging and single-use plastics, and related microplastic pollution (IA)

# BUDDIE-PACK

**Business-driven systemic solutions for sustainable plastic packaging reuse schemes in mass market applications**

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## Production of reusable packaging following sets of design rules

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D3.2: Production of reusable packaging following sets of design rules.

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# Acronym description

**CPET:** Semi-Crystalline Polyethylene Terephthalate

**DoE:** Design of Experiments

**GA:** Grant Agreement

**HDPE:** High-Density Polyethylene

**HIPS:** High-Impact Polystyrene

**OCA:** Oil Contact Angle

**PET:** Polyethylene Terephthalate

**PETG:** Polyethylene Terephthalate Glycol

**PLA:** Polylactic Acid

**PP:** Polypropylene

**PS:** Polystyrene

**SLA:** Stereolithography

**VSP:** Vacuum Skin Packaging

**WCA:** Water Contact Angle

**WP:** Work Package

**SUP:** Single-use Plastic

**PBT:** Polybutylene terephthalate

**PE:** Polyethylene

# Executive Summary

Manufacturing processes play a pivotal role in the development of reusable plastic packaging (RPP) systems. Ensuring that production methods align with the functional, aesthetic, and environmental requirements of reusable packaging is essential for the success of such systems. Deliverable 3.2 focuses on the manufacturing processes necessary to produce prototypes for six distinct BUDDIE-PACK use cases. The deliverable aims to define the processes, tooling, and results of producing sample prototypes for each type of packaging studied within the project.

As a foundational step, a detailed analysis of manufacturing processes was conducted. This analysis examined various techniques, including injection moulding for rigid packaging such as takeaway food trays and refillable bottles, blow extrusion for containers with complex shapes, flat sheet extrusion for thermoforming processes, and thermoforming itself for semi-rigid applications like catering trays and meat packaging. Each technique was adapted to optimise process efficiency, reduce waste, and meet the specific functional and aesthetic needs of the packaging use cases.

Complementing this analysis, the deliverable also provides a comprehensive review of the tooling and materials used in manufacturing. The tooling section highlights the characteristics and applications of steel and aluminium moulds, with surface modifications designed to improve properties such as scratch resistance, ease of cleaning, and visual appeal. Additionally, a thorough evaluation of materials was carried out, focusing on the sustainability and compatibility of options like recycled plastics and bioplastics with the requirements of reusable packaging.

The deliverable's most critical component is the production of prototypes for each BUDDIE-PACK use case. These prototypes demonstrate the feasibility of the selected manufacturing techniques and materials. The use cases include:

- Rigid takeaway food trays.
- Rigid refill bottles for personal care and loose goods.
- Rigid catering trays for ready meals in professional premises.
- Semi-rigid vacuum skin packs for meat distribution.
- Recyclable flexible Bag-in-Box® for home care loose goods.

Prototypes were evaluated to ensure they retained their expected functionality and aesthetic appeal while meeting reuse and recyclability standards. The insights gained from these prototypes serve as a practical framework for scaling up production and guiding future RPP development.

Deliverable 3.2 contributes significantly to the BUDDIE-PACK project by bridging material selection (Deliverable 3.1) and the practical implementation of manufacturing processes. The knowledge generated through this deliverable supports the project's broader goals of fostering sustainability and innovation in reusable packaging systems.

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# 1. Introduction

The **BUDDIE-PACK** project emerges as an innovative response to the environmental challenges posed by the excessive use of single-use plastics in the packaging sector. Within **BUDDIE-PACK, Work Package 3 (WP3) plays a crucial role, focusing on the development and manufacturing of the proposed reusable packaging solutions.** This work package addresses the technical aspects necessary to ensure that the packaging meets stringent criteria for sustainability, functionality, and durability. A key priority of WP3 is the selection of materials, including recycled plastics and advanced materials capable of meeting specific requirements such as food compatibility and resistance to multiple usage cycles, as demonstrated in deliverable 3.1: "Report on new functional material for reusable packaging". Moreover, WP3 explores the potential for integrating recycled materials into sensitive applications, promoting recycling technologies that ensure the safety and quality of the packaging. The work package also focuses on **optimising manufacturing processes** to guarantee that the proposed solutions are replicable and scalable in industrial contexts. Within WP3, **Task 3.2**, titled "**Manufacturing processes for reusable packaging"**, specifically addresses the validation of production processes that will bring the reusable packaging prototypes to fruition. **This task tackles several key aspects, such as identifying the most suitable manufacturing techniques for each use case, including injection moulding, blow extrusion, flat sheet extrusion, and thermoforming.** These technologies are carefully selected and adapted to meet the specific requirements of each type of packaging, ensuring not only its functionality but also its sustainability and economic viability. Task 3.2 also involves producing prototypes at various stages, from generic samples to final prototypes, allowing for the progressive evaluation of the suitability of the materials and processes employed. Additionally, this task includes validating the processability of the selected materials, ensuring they meet the required quality and sustainability standards.

This deliverable report, entitled "**Production of reusable packaging following sets of design rules**", focuses on detailing how the activities related to WP3, with particular emphasis on Task 3.2, have been developed and carried out. **The primary objective of this deliverable is to define the processes, tooling, and results associated with manufacturing prototypes of reusable packaging for each of the use cases studied** in the BUDDIE-PACK project. Throughout the document, the selected manufacturing methods, the characteristics of the materials used, and the results obtained in prototype production are explored in depth, providing a solid foundation for future industrial implementations and scaling. In the analysis of manufacturing processes, the document provides a **detailed description of the techniques employed for producing the various types of packaging.** These include injection moulding, primarily used for manufacturing rigid packaging such as food trays and refillable bottles; blow extrusion, used for producing bottles and other containers with complex shapes; flat sheet extrusion, which serves as the basis for thermoforming processes; and thermoforming itself, which enables the creation of semi-rigid packaging adapted to different applications such as catering trays and meat packaging. Each of these technologies is carefully adapted to meet the specific functional and aesthetic requirements of the use cases, while optimising process efficiency and minimising waste generation.

The **analysis of tooling and materials constitutes another essential component of the document.** This section details the characteristics and specifications of the moulds used in the manufacturing processes, including both steel and aluminium moulds. Surface modifications applied to these moulds are also addressed, aiming to enhance key properties such as scratch resistance, ease of cleaning, and the aesthetic appearance of the packaging. Furthermore, a comprehensive analysis of the selected materials is presented, including recycled plastics and bioplastics, highlighting their advantages in terms of sustainability and compatibility with the requirements of reusable packaging.

**The core of the deliverable is the detailed description of the production of reusable packaging**, encompassing the manufacturing and justification of prototypes for each of the use cases defined in the project. These include rigid take-away food trays, rigid refill bottles for personal care products and bulk goods, semi-rigid catering trays for ready meals, semi-rigid skin packs for meat, and recyclable flexible Bag-in-Box® solutions for household care products. For each case, the manufacturing process, the materials used, and the results obtained are documented, with a special focus on the functional and sustainable characteristics of the prototypes. As mentioned in D3.1, Uzaje Use Case's packaging, the semi-rigid delicatessen packaging for supermarket counters, will be provided by an external packaging manufacturer. Therefore, its prototyping and production will not be described in this deliverable.

In terms of expected results, this deliverable aims to provide a **clear and detailed framework for producing reusable packaging** that meets the established criteria for sustainability and functionality. Key outcomes include validating the selected manufacturing processes, developing functional prototypes, and documenting replicable methodologies that can be applied in future developments within the sector. Additionally, the deliverable represents a **fundamental component of the BUDDIE-PACK project**, bridging the research and selection of materials with the practical implementation and validation of solutions in real-world environments.

**The next steps include scaling the validated processes to a pilot level**, implementing the prototypes in real-world usage scenarios, and collecting data on their performance. These efforts will allow further optimisation of materials and processes, ensuring that the reusable packaging developed meets the highest standards of sustainability and functionality. Through this deliverable and its comprehensive approach, BUDDIE-PACK not only addresses current challenges in the packaging sector but also lays the groundwork for a more sustainable future in resource use.

# 2. State of the art

## 2.1. Manufacturing processes

### 2.1.1. Injection Moulding



Injection moulding is one of the most versatile and important manufacturing processes capable of mass-producing complicated plastic parts with excellent dimensional tolerance. The process consists in injecting heated molten polymer into the mould cavity under high pressure and then cooling it to make it solidify into a moulded component [1].

#### Stages of the process

The injection moulding process consist of 6 discrete steps [2]:

1) **Clamping:** The first step of the injection moulding process is clamping. Injection moulds are typically made in two, clamshell-style pieces. In the clamping phase, the two metal plates of the mould are pushed up against each other in a machine press.
2) **Injection:** When the two plates of the mould are clamped together, injection can begin. The plastic, which is typically in the form of granules or pellets, is first melted down into a complete liquid. Then, that liquid is injected into the mould.
3) **Dwelling:** In the dwelling phase, the melted plastic fills the entirety of the mould. Pressure is applied directly to the mould to ensure the liquid fills every cavity and the product comes out identical to the mould.
4) **Cooling:** The cooling stage is the most straightforward; the mould should be left alone so that the hot plastic inside can cool and solidify into a usable product that can be safely removed from the mould.
5) **Mould Opening:** Once the part has cooled, a clamping motor will slowly open the two parts of the mould to make for a safe and simple removal of the final product.
6) **Ejection:** With the mould open, an ejector bar will slowly push the solidified product out of the open mould cavity. The operator should then use cutters to eliminate any waste material and perfect the final product for customer use. Waste material can often be recycled and reinjected for the next part, decreasing the material costs. Figure **2.1** shows the injection moulding process sum-up into four steps.

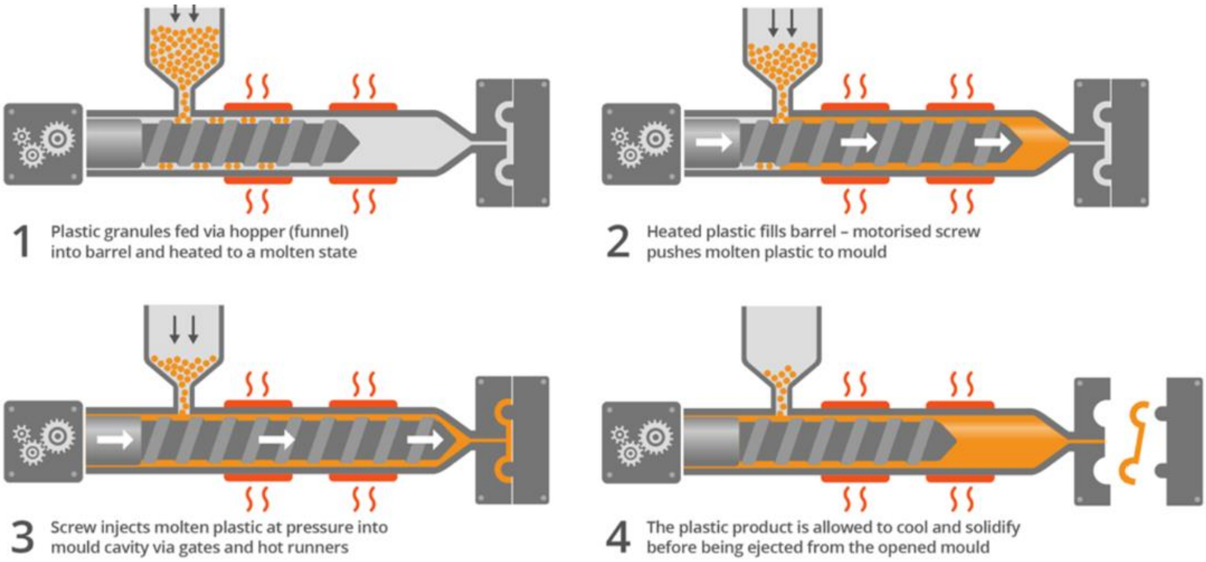



***Figure 2.1.*** *Injection moulding process [3].*

## Equipment

An injection moulding machine is equipped with a clamping unit, injection unit, the mould, the ejector system, the hydraulic system, the control system and the ancillary equipment [1]. Figure 2.2 shows some of the most important components of an injection moulding machine.

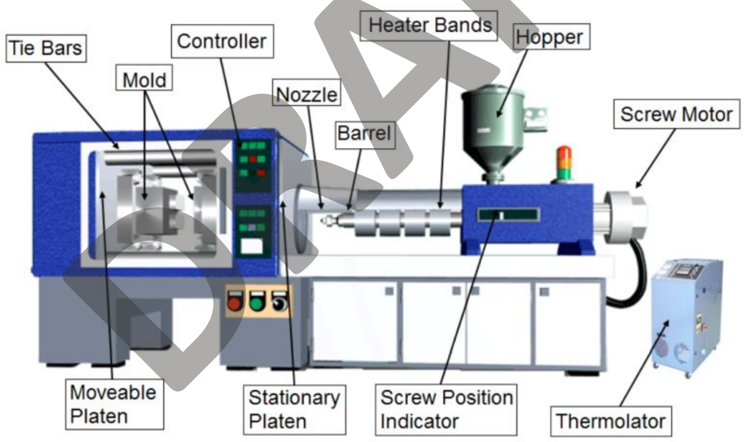



***Figure 2.2.*** *Injection moulding machine [4].*

## Advantages and Limitations

Plastic injection moulding advantages centre around great precision and high repeatability, combined with speed, a low cost per part and a huge choice of available plastics. Disadvantages include a higher initial cost and lead time compared to some other processes.

### Advantages

- **Precision:** Plastic injection moulding is perfect for producing very intricate parts. Compared to other techniques, moulding allows to incorporate more features at very small tolerances.
- **High repeatability:** Once the mould tool is made, identical products can be made. The number of uses, thus durability of the tool depends on the tool material choice.

- **Low cost per part:** Whilst there is an initial high investment for the plastic injection moulding tool, after that the cost per part is very low. Other plastic processing techniques may require multiple operations, like polishing, whilst injection moulding can do it all at once.
- **Fast:** Cycle times can be as low as 10 seconds
- **Material choice:** Large availability of materials for injection moulding
- **Special Surface Finishes, Engraving & Printing:** In addition to the large range of colours available, the injection moulding tool can be made with a special finish which will show at the final part.
- **Little plastic waste:** Part repeatability is very high for injection moulding. Even the sprues and runners are usually grind and the material reused.

**Limitations**

- **Initial lead time:** From product conception to final part can take months of design, testing and tool manufacturing.
- **High cost of investment:** Moulds are generally expensive, it drastically depends on the country of manufacturing
- **Careful design needed:** Plastic mouldings need very careful design to avoid tooling issues like undercuts (which will send up tooling cost significantly), locked-in features and not enough draft
- **Unflexibility:** Once the mould is manufactured, it makes a couple with the chosen material. It cannot be interchangeable with other materials due to shrinkage considerations.

### 2.1.2. Extrusion blow moulding

Extrusion blow moulding is a widely used process in the production of hollow plastic components such as containers (bottles and drums), toys, and automotive parts (Figure 2.3). This method enables the efficient and cost-effective manufacturing of complex shapes, establishing itself as one of the key techniques in the plastics industry. The process involves forming a hollow tube of molten plastic material, referred to as a "parison." This tube is captured by a mould once it reaches the desired dimensions. Subsequently, a needle is inserted to inject pressurised air, expanding the material until it conforms to the shape of the mould walls.



***Figure 2.3.*** *Extrusion blow moulding example.*

## Stages of the process

The extrusion blow moulding process is carried out in several fundamental stages. These are depicted in Figure 2.4:

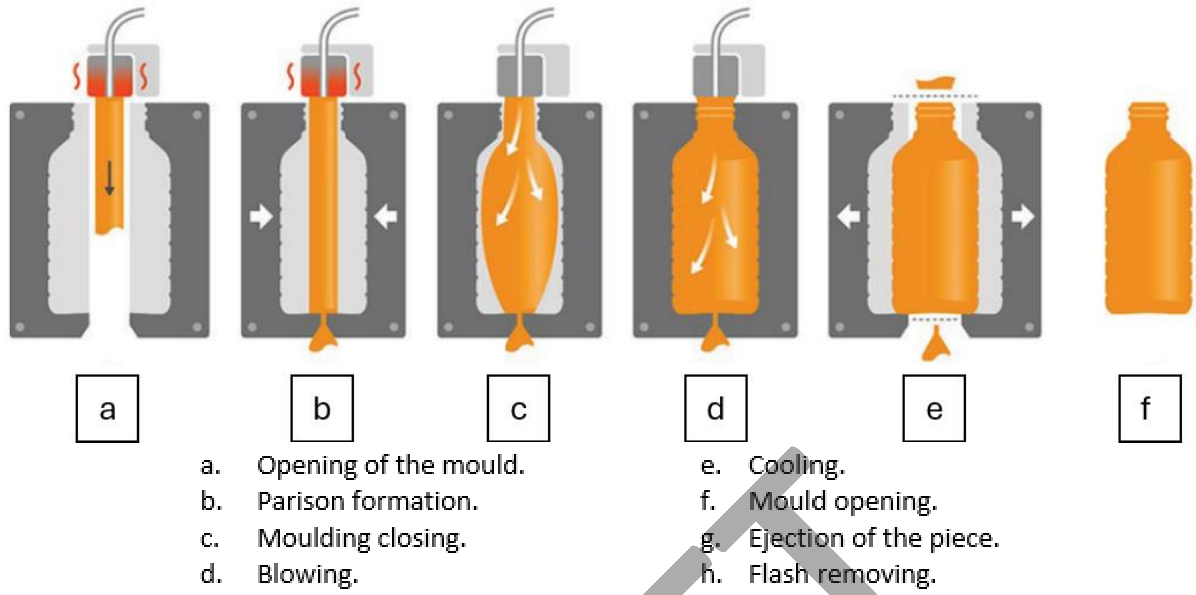
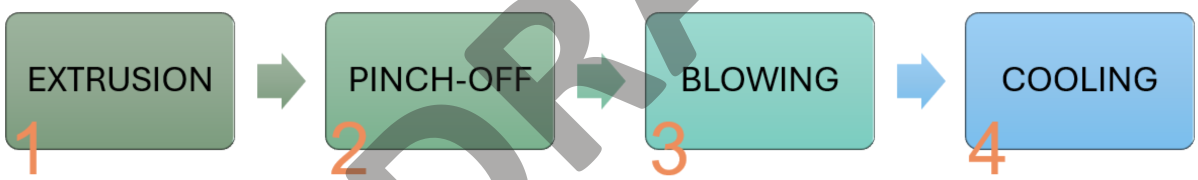



*Figure 2.4. Extrusion Blow moulding process stages.*

In a more simplified way, considering the entire transformation process, it could be summarised into four main stages:






## Equipment

The extrusion blow moulding process requires a series of specialised pieces of equipment that ensure the precise and efficient formation of hollow parts. Below are the main components and their features:

- **Head:** The main function of the head is to form the tube or parison from the molten plastic.
- **Nozzle:** Nozzles are crucial for adjusting the diameter of the parison and ensuring uniform inflation.
- **Head tools:** Nozzle centring screws: These allow for adjusting the wall thickness of the parison to ensure uniformity and quality in the final product, as shown in an example.
- **Cutting systems:** The primary function of cutting systems is to separate the parison from the extruded material flow.
- **Blowing elements:**
  - **Blowing head**: The mould traps the parison by closing and sealing it around the blow tube, which injects air to shape the product.
  - **External or needle blower**: This system inserts a needle into the parison once the mould is closed, allowing to produce multiple vertical pieces. The design is versatile and allows for different air entry positions.
- **Mould:** The mould is an essential component in the extrusion blow moulding process, as it defines the final shape of the product and ensures a high-quality surface finish. Its key features include surfaces

adapted to the material's needs, such as rough finishes for polyethylene (PE) or polished finishes for transparent materials like PET, PP, or PVC. Additionally, moulds can incorporate specific details such as logos, stripes, ribs, or inserts that enhance the design of the final product.

- In the BUDDIE-PACK project, an aluminium mould will be used for one of the case studies, as shown in the last section of this deliverable.
- **Mould cooling system:** It uses closed circuits with cooling fluids to efficiently dissipate heat. This system ensures rapid and uniform cooling, minimising variations in the material's crystallinity.

### Control Parameters

In the extrusion blow moulding process, the diameter and thickness of the parison are key parameters for ensuring product quality. The diameter, determined by the die, must avoid being too small to prevent rupture during blowing, or too large to minimise material waste from flash. Similarly, although a uniform thickness in the parison is desirable, areas with larger surface dimensions tend to result in thinner walls, which can affect the uniformity of the final product.

Programmed extrusion allows for dynamic adjustments to the die by varying the "gap" during the extrusion process, creating sections that are thicker or thinner depending on the specific requirements of the part. This ensures uniform wall thicknesses, enhances product quality, and reduces material consumption, optimising the process efficiently and sustainably.

### Use of Polyethylene in Extrusion Blow Moulding

The type of polymer used has a significant impact on the quality of the parison and the adaptability of the process. The most used polymer is polyethylene (PE). PE is the preferred material due to its high viscosity and melt strength. It is ideal for manufacturing-coloured bottles and jars for detergents, cleaning products, and personal hygiene items. This is exemplified in one of the case studies within the project. Additionally, PE is used for packaging milk, sauces, and dairy products due to its ability to withstand sterilisation and pasteurisation processes. It also exhibits high stress-cracking resistance when in contact with chemical products.

### Advantages and Limitations

The extrusion blow moulding process offers several advantages, making it the most widely used method for manufacturing hollow parts such as bottles and large containers. However, it also has inherent limitations that must be considered when selecting this technique for specific applications.

#### Advantages

- **Application versatility:** This is the most common blow moulding process, used to produce containers with capacities ranging from 125 ml to 5,000 litres.
- **Continuous production:** Enables a higher number of cycles per unit of time, enhancing production efficiency.
- **Compatibility with multiple materials:** Can be used with a wide variety of thermoplastics, increasing its adaptability to different products and industries.
- **Cost-effective moulds:** Moulds are less expensive compared to other processes, such as injection moulding.
- **Large dimensions without accumulated stress:** The resulting products can be large and are free from residual stresses.
- **Flexibility in structural design:** While dimensional accuracy is not exceptional, it allows for designs with extreme dimensional ratios, such as long and narrow or short and wide parts.

#### Limitations

- **Low dimensional accuracy:** Compared to processes like injection moulding, the precision of dimensions is lower, which may limit its use in high-demand applications.

- **Difficulty in thickness control:** Regulating the wall thickness of the product can be challenging, especially in parts with complex geometries.
- **Stiffness issues:** Rounded parts away from the centre of the piece may have low stiffness, requiring a significant increase in total thickness.
- **Warping in flat parts:** Flat pieces tend to warp; to prevent this, it is necessary to add necking or reliefs.
- **Material waste:** The generation of flash and trim represents an economic and environmental challenge, as it involves additional handling of leftover material.

The extrusion blow moulding process stands out as a versatile and widely used technique in the plastics industry, especially for the manufacturing of hollow products such as bottles, drums, and automotive parts. Its ability to adapt to different materials and geometries, combined with its production efficiency and competitive costs, makes it a key solution for various applications. However, it requires precise control of parameters and appropriate equipment design to overcome limitations such as difficulty in regulating thicknesses and flash generation. Overall, this process represents an efficient balance between technological innovation and industrial practicality.

### 2.1.3. Sheet extrusion

Sheet extrusion is a manufacturing process used to create thin, flat sheets of plastic suitable for a wide range of applications, including thermoforming of large and small items for the construction, automotive and packaging sectors. The process begins with feeding raw plastic material, typically in the form of pellets or granules, into an extruder. These materials are melted by the combination of heat and mechanical shear within the extruder's rotating screw. The molten plastic is then forced through a flat die, which shapes it into a continuous sheet. The sheet is rapidly cooled and solidified using a system of rollers, which also ensures precise thickness and surface finish. In packaging applications, such as thermoformed trays, the properties of the extruded plastic sheet, such as strength, flexibility, and barrier performance, are critical. These properties are influenced by factors such as the resin type, additives (e.g., for UV resistance, coefficient of friction, nucleating agents, antimicrobial agents), and the extrusion process settings.

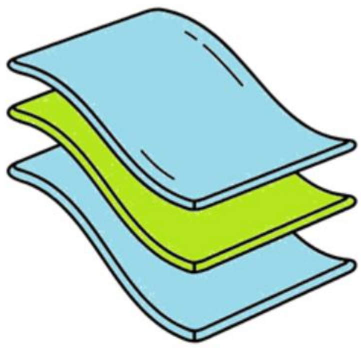



***Figure 2.5.*** *Coextruded multilayer sheet construction.*



#### Coextrusion and Number of Layers in Plastic Sheet Manufacturing

Coextrusion is an advanced extrusion process that enables the production of multi-layered plastic sheets, combining different polymers, grades, blends or systems in distinct layers (Figure 2.5). This technique allows manufacturers to tailor the performance characteristics of the final product by integrating the unique properties of each layer. The number of layers can vary depending on the complexity of the application; however, the most common set-up is three layers, allowing for a configuration with a thicker middle layer and thinner skin layers to target a specific functionality. For instance, a multi-layer structure might include a middle layer with recycled content for sustainability, and skin layers with specific features to enhance sealability, food contact safety or surface tension.

Modern coextrusion technology ensures precise control over layer thicknesses and uniform distribution, enabling the optimisation of material use while maintaining or enhancing product functionality. Sustainability concerns have driven a shift toward monolayer structures in packaging, as they simplify recycling processes by eliminating the need to separate different materials. This is critical for successful recycling practices, avoiding contamination of waste streams and minimising the challenges associated at the waste sorting point. Complex multilayer packaging structures, where separation by material is not possible, such as in the case of coextrusion and laminations, fain to fit in a circular economy, ending up in landfills or incineration. Coextrusion's unique flexibility in material combinations, multilayer design, dimension control and customisation, make this technique essential for balancing sustainability, performance, and cost-effectiveness in reusable packaging solutions.

#### Plastic Material Requirements for Sheet Extrusion

The selection of plastic materials and their grades is crucial for sheet extrusion as their properties directly influence the processability, performance, and end-use of the product. On the processability side, the material must exhibit appropriate melt flow characteristics to ensure consistent feeding, melting, and sheet formation. Thermal stability is essential to prevent degradation during the high-temperature extrusion process, while mechanical properties like strength and impact resistance determine the sheet's suitability for applications. Additionally, specific functional requirements must be addressed: food-grade compliance for safe contact with food products, barrier properties to protect against moisture and oxygen, chemical stability and resistance to repeated washing cycles in the case of reuse.

#### Sheet Thickness: Single-Use vs. Reusable Packaging

The sheet thickness for single-use packaging (SUP) is typically designed to minimise material use while maintaining sufficient functionality. While the range of SUP thickness depends on the material and the application, it often ranges between 200 to 600 microns. In contrast, reusable packaging requires significantly thicker sheets, often between 800 microns to 1.5 mm, to provide the durability, impact resistance, and structural integrity needed to withstand multiple use cycles, including washing, handling, and transportation.

### 2.1.4. Thermoforming



Thermoforming is a manufacturing process used to shape plastic sheets into specific forms by heating the sheet until it becomes flexible and then moulding it over a defined surface. The process begins with clamping the plastic sheet and applying heat. Once softened, the sheet is stretched over a mould, and vacuum is applied to ensure conformity to the mould's surface. After cooling, the formed part is trimmed to remove excess material, creating the final product. Thermoforming is highly versatile, allowing for intricate designs and varying thicknesses, making it widely used for producing packaging items like trays, lids, and containers. Thermoforming is a cornerstone technology in the packaging sector, enabling the production of lightweight, cost-effective, and highly customisable solutions for a wide range of industries. It is extensively used to create packaging products such as food and medical device trays, clamshells, blister packs, pods and lids, providing protection, convenience, and enhanced shelf appeal. The process is particularly valued for its flexibility, allowing manufacturers to produce packaging in various shapes and sizes while accommodating complex designs like compartments or embossed branding and information.

The most suitable polymers for thermoforming are **PETG, PP, CPET, HDPE, and Tritan™**, thanks to their combination of mechanical strength, thermal resistance, and ease of processing. **PETG** stands out for its high thermal resistance and flexibility, making it ideal for reusable applications. **PP** is lightweight, chemically resistant, and suitable for microwave-safe packaging. **CPET** withstands high temperatures without deformation, making it perfect for ovenable trays. **HDPE** offers durability and moisture resistance, though it is opaque. **Tritan™**, with excellent thermal and impact resistance, is ideal for reusable and medical packaging. The assessment of these polymers was conducted as part of **Deliverable 3.1: Report on New Functional Materials for Reusable Packaging**.

## 2.2. Tooling

There are several factors to consider when choosing between aluminum and steel moulds for injection and extrusion blow moulding. Both materials offer distinct advantages and disadvantages depending on the specific needs of the project, including production volume, part complexity, cost, and material properties [6].

In general, steel moulds are used for medium to large production (10 000 to 100 000 parts), when engineering materials are required. Aluminium moulds are mostly used for small series (5 000 to 10 000) or prototyping when standard plastics are required [7]. The mould durability depends on the injected material, type and nature of fillers and complexity of the injected parts.

### 2.2.1. Injection moulds

#### Steel

**Advantages [6], [9]**

- **Higher durability and longevity:** Steel moulds are much harder and more wear-resistant than aluminum moulds. This makes them ideal for high-volume, mass production runs with minimal maintenance.
- **Better for complex and intricate designs:** Steel moulds can withstand the stresses and complexities of intricate part designs, including thin walls, small features, and high precision.
- **Heat resistance:** Steel moulds handle high temperatures better than aluminum moulds, making them more suitable for materials that require high processing temperatures, such as certain engineering plastics.
- **Better dimensional stability:** Steel provides more dimensional stability over the long term, ensuring consistent part quality in high-production runs.
- **Rectification:** Steel is harder and more durable compared to aluminum. This makes it less prone to deformation during the rectification process, which is beneficial when precise flatness and a fine surface finish are needed. Moreover, magnetic properties of steel present advantages over aluminium to hold steel work pieces securely in place.
- **Standardized availability:** Steel presents a larger availability on shapes and presentations in the market. Plaques can be found under standardized thickness, already rectified, with holes for columns, drilling and tapping, reducing machining cost. In general, frames are in steel and can be found in the market as semi-finished products.
- **Flexibility:** Steel is suitable for the vast majority of materials, as well as designs with detailed precision and complexity, providing manufacturers with greater flexibility when designing and using injection moulded parts [8].

**Disadvantages [5], [6], [7], [8]**

- **Higher Initial Cost:** Steel moulds are more expensive to manufacture due to the cost of material (per kg) and the additional machining time required, making them less suitable for low-volume runs (<1000 parts) or prototyping of simple parts with standard plastics.
- **Slower lead times:** The machining of steel moulds is more time-consuming than aluminum, which results in longer lead times for production setup. However, when considering rectification of plane surfaces, steel is much easier to rectify compared to aluminium.
- **Thermal regulation:** Steel has lower thermal conductivity compared to aluminium, which can result in slower cooling times. This can make steel moulds less efficient than aluminum for shorter runs.
- **Heavier weight:** Steel moulds are heavier, which can be more challenging to handle and can also put more strain on machinery.

#### Aluminium

Aluminium moulds have established themselves as an efficient, versatile and economical alternative to traditional steel moulds in the manufacture of plastic components. Their wide application in injection processes is due to a set of properties that balance critical factors such as cost, production speed and quality in the manufacture of plastic parts. Aluminium is a structural material widely used for mould manufacturing due to its physical, mechanical and economic characteristics, which make it a strategic solution in a variety of industrial processes. Below are the main properties that make aluminium a key option for moulds:

- **High thermal conductivity:** Aluminium has an excellent ability to dissipate heat, allowing for rapid and uniform thermal distribution throughout the injection process. This characteristic is key to optimize production cycles, as heat is efficiently transferred to the plastic parts being formed. Rapid heat dissipation allows for faster cycle times, which increases production line productivity and reduces common defects such as sagging, shrinkage or variations in plastic solidification.

- **Low weight:** Compared to other traditional materials such as steel, aluminium is significantly lighter. This attribute facilitates the transport, installation, and handling of moulds during production processes. The lower weight also contributes to a faster response in injection systems, as the heating and cooling time is shorter. This provides a competitive advantage in the speed and flexibility of plastic part manufacturing.
- **Corrosion resistance:** Although aluminium's resistance to oxidation is lower than that of steel, this material has an excellent ability to resist the formation of corrosion under normal conditions. This makes it a viable solution for applications in humid environments or for products that may be in contact with chemical agents, if specific treatments or advanced alloys are used to improve its behaviour in these situations.
- **Low initial cost:** The initial investment for the creation of aluminium moulds is considerably lower compared to steel moulds. This characteristic makes aluminium a strategic option for small production runs, prototypes, and environments where investment in infrastructure is limited. The lower investment cost also allows companies to test new product designs with a lower capital investment and greater flexibility to adjust their production processes.

Furthermore, advances in aluminium alloys, such as the use of aluminium-silicon alloys, have significantly increased their durability, extending their use beyond prototyping applications to higher-demand production series.

***Figure 2.6.*** *Aseví use case´s aluminium mould.*

## Advantages of Aluminium Moulds in the Production of Plastic Components.

Aluminium moulds offer several specific advantages in the production of plastic parts.

- **Reduced cycle time:** Thanks to their high thermal conductivity, aluminium moulds allow for faster heating and cooling than other materials, thus reducing the manufacturing cycle time. This translates into greater efficiency and productivity on the production line.
- **Lower initial investment costs:** The production of aluminium moulds is more affordable than steel moulds, which is a strategic advantage for companies seeking agility in their production lines with lower financial risks.
- **Easy maintenance and adaptation:** The design and adjustment of aluminium moulds are simpler compared to steel. This makes maintenance, repair and modification easier, reducing production downtime.

- **Suitable for low-volume production and rapid prototyping:** Aluminium moulds are ideal for small-scale production batches due to their low costs and rapid manufacturing capacity.
- **Fewer defects in production:** Thanks to rapid heat dissipation, aluminium moulds allow for greater uniformity in the cooling process, which reduces defects such as shrinkage marks, burns, or depressions in the final piece.

### Comparison

The selection between aluminium and steel moulds for reusable packaging manufacturing depends on the specific requirements of each production process. Both materials offer distinct advantages and disadvantages, making them more suitable for different scenarios in terms of cost, production speed, durability, and ease of modification.

Aluminium moulds are generally characterised by a lower initial cost and higher thermal conductivity, allowing for faster heat dissipation and reduced cycle times. This makes them particularly advantageous for rapid production, prototyping, and low-to-medium volume series. Additionally, their lighter weight facilitates handling and modifications, which can streamline adjustments and reduce downtime. However, aluminium moulds have limitations in terms of mechanical resistance and durability, making them less suitable for intensive production processes that require high wear resistance or operation under high temperatures.

Steel moulds, on the other hand, provide greater mechanical strength and wear resistance, ensuring a longer lifespan even in demanding production environments. This makes them the preferred choice for large-scale manufacturing, where durability and long-term performance are key. However, their higher initial cost and lower thermal conductivity result in longer cycle times, and their greater weight can make handling and modifications more complex and time-consuming.

***Table 2.1.*** *Advantages and disadvantages of aluminium mould [9].*

| Parameter | Advantages | Disadvantages |
|---|---|---|
| **Initial cost** | Lower initial investment, suitable for prototyping and small batches. | Higher initial cost, but more cost-effective in the long term due to durability. |
| **Thermal conductivity** | High, allowing rapid heat dissipation and shorter cycle times. | Lower, leading to longer cooling times. |
| **Cycle time** | Faster due to better heat transfer. | More stable for high-volume production, but longer cooling times. |
| **Ease of modification** | Quicker and more cost-effective to adjust or modify. | More mechanically resistant, but modifications are more complex and costly. |
| **Weight** | Lighter, making handling and transport easier. | Heavier, but offers greater stability and structural strength. |
| **Corrosion resistance** | Good oxidation resistance, though lower in demanding environments. | Superior in extreme conditions but requires maintenance to prevent oxidation. |

The choice between aluminium moulds and steel moulds will directly depend on each company's priorities in terms of costs, production speed, production volume and expected durability. Aluminium moulds are a more cost-efficient option, especially for rapid production, prototyping and low-volume series, thanks to their lower initial cost, faster cycle speed and ease of modification. On the other hand, steel moulds are ideal for large production runs and applications requiring a high level of durability and long-term strength. Each material has its advantages and disadvantages, and its selection should be based on the analysis of the specific requirements of each project.

### 2.2.2. Blow moulds

Extrusion blow moulds are critical components in the manufacturing of hollow plastic parts, and their design and material selection are key to achieving the desired product quality and efficiency. These moulds need to meet several important requirements, including good thermal conductivity for efficient cooling, durability to withstand the demands of production cycles, and cost-effectiveness to ensure competitive manufacturing. Additionally, they should allow for easy modification in case of design changes or adjustments.

The materials used for manufacturing extrusion blow moulds must balance these factors. Common materials include aluminium, steel, and copper-beryllium alloys. Aluminium is often chosen for its excellent thermal conductivity, allowing for faster cooling and shorter cycle times. It is also lightweight and relatively easy to manufacture, which makes it a cost-effective option for small to medium production runs. However, aluminium moulds generally have lower durability compared to steel, limiting their use in high-demand applications. Steel moulds, while offering greater strength and longer lifespan, tend to have lower thermal conductivity, which can result in longer cycle times. Copper-beryllium alloy moulds offer the best thermal conductivity but come at a higher cost and can be more challenging to work with.

In extrusion blow moulding, the cooling capacity is generally lower than that of injection moulding, as the part is cooled primarily on the external surface, with limited cooling from the blow air. This requires a carefully designed cooling system within the mould to ensure efficient temperature control throughout the production cycle. The choice of material, therefore, must consider thermal properties, durability, and the specific needs of the manufacturing process.



## 2.3. Surface modification

Microbial contamination poses a significant challenge to preserving the safety of reusable packaging systems, especially in food processing and packaging environments, where maintaining hygienic conditions is paramount. The repeated use of plastic packaging, coupled with exposure to moisture, food residues, and inadequate cleaning practices, creates an ideal environment for microbial growth. This increases the risk of cross-contamination and can compromise product safety. A promising solution to address these concerns is the development of antimicrobial surfaces through surface topography modification. By engineering micro- and nanoscale features on the food-contact surface of the packaging, microbial adhesion, growth and colonisation can be effectively disrupted [10][11]. This approach draws inspiration from biological adaptions, such as the lotus leaf and sharkskin, which inhibit bacterial attachment and biofilm formation while exhibiting self-cleaning characteristics. Incorporating these surface textures can significantly enhance the hygiene and safety of reusable food packaging systems, reducing contamination risks and improving overall product safety.

The selection process for suitable surface textures began with a comprehensive review of recent literature on the development of superhydrophobic and antimicrobial surfaces. Micro- and nanoscale surface textures have been widely studied for their ability to inhibit bacterial adhesion, prevent biofilm formation, and achieve these effects through their physical architecture. Various textures were identified in the literature, including arrays of channels, ridges, grids, pillars, spikes, domes, and pores [13][14]. Based on fabrication feasibility and the potential for in-house production using additive manufacturing, three patterns were selected for further optimisation of wettability: a microchannel pattern, a grid pattern, and a bioinspired dome pattern modelled after the intrinsically hydrophobic properties of gecko skin [15]. These patterns are illustrated in Figure 2.7.

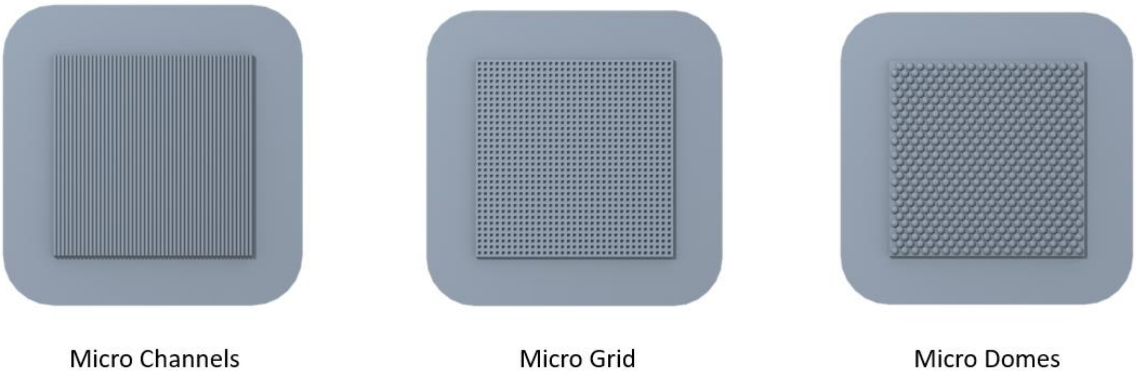



***Figure 2.7.*** *The micro- channel, grid and dome patterns selected for further optimisation of wettability.*

## Design of Experiments (DoE):

To optimise the hydrophobicity and oleophobicity of the selected patterns, a Design of Experiments (DoE) study was conducted using additively manufactured samples fabricated via stereolithography (SLA). In this study, the feature dimensions of each pattern were systematically varied to investigate their effects on water contact angle (WCA) and oil contact angle (OCA). The parameters and corresponding values used to vary the features of each pattern are summarised in Table 2.2.

***Table 2.2.*** *Parameter settings for the Design of Experiments (DoE) optimisation study.*

| | | | | |
|---|---|---|---|---|
| **Micro Channel Patterns** | | | | |
| **Parameter** | Settings | | | |
| **Wall Width (µm)** | 100 | 200 | 300 | 400 |
| **Wall Spacing** | Low (X 1 Wall Width) | Nom (X 2 Wall Width) | High (X 3 Wall Width) | |
| **Micro Grid Patterns** | | | | |
| **Parameter** | Settings | | | |
| **Wall Width (µm)** | 200 | 300 | 400 | 500 |
| **Wall Spacing** | Low (X 1 Wall Width) | Nom (X 2 Wall Width) | High (X 3 Wall Width) | |
| **Micro Dome Patterns** | | | | |
| **Parameter** | Settings | | | |
| **Dome Diameter (µm)** | 400 | 500 | 600 | 700 |
| **Pitch** | Low | Nom | High | |

| | | | |
|---|---|---|---|
| **Horizontal** | (X 1.25 Dome Diameter) | (X 1.5 Dome Diameter) | (X 1.75 Dome Diameter) |
| **Vertical** | (X 1.66 Dome Diameter) | (X 2 Dome Diameter) | (X 2.33 Dome Diameter) |

### Fabrication of Surface Pattern Samples:

Surface pattern samples were designed using Creo Parametric 10.0 (PTC Inc., Boston, MA, USA) and fabricated using a Form 3 SLA 3D printer (FormLabs Ltd., Somerville, MA, USA). The printer features a 250 mW laser with a spot size of 85 µm, operating at an optical wavelength of 405 nm. All samples were printed using Formlabs Grey V4 photopolymer resin at a layer height of 25 µm. After printing, the surface samples were post-cured in a Projet UV Finisher Box 300 (3D Systems Corp., Rock Hill, SC, USA) for 40 minutes, with rotation at the 20-minute mark to ensure uniform curing.

### Surface Wettability:

The wettability of the surface textures was evaluated by measuring the WCA and oil (OCA of samples. Measurements were conducted at room temperature using a First 10A FTA32 goniometer (First Ten Angstroms Inc., VA, USA) employing the sessile drop technique. Double-distilled water and virgin olive oil were used as probe liquids. Droplets of 8 – 10 µL were carefully dispensed onto the sample surfaces using a 3 mL syringe. For each treatment, five measurements were recorded to ensure accuracy and repeatability.

This report includes a summary of key results, omitting detailed datasets. The hydrophobicity and oleophobicity of the selected surface patterns were successfully optimised by fine-tuning the geometry of surface features. For micro channel patterns, the optimal configuration was identified as a wall width of 300 µm with “Nom” level spacing. This configuration resulted in a maximum increase in WCA and OCA of 49.5% and 108.9%, respectively, in the perpendicular direction. Conversely, reductions of 15.5% (WCA) and 13.5% (OCA) were observed in the parallel direction. For micro dome arrays, the pattern with a dome diameter of 600 µm and “High” level spacing exhibited the greatest hydrophobicity and oleophobicity. This configuration achieved increases of 17.0% in WCA and 28.1% in OCA. For microgrid patterns, the texture with a wall width of 300 µm and “Low” level spacing demonstrated the highest hydrophobicity and oleophobicity, with a 47.7% increase in WCA and a 109.2% increase in OCA.



The observed increases in WCA and OCA are attributed to liquid droplets existing predominantly in the Cassie-Baxter wetting state. In this state, the liquid droplet remains suspended on the surface features, trapping air beneath and reducing the contact area between the droplet and the surface, resulting in higher contact angles [16]. In contrast, patterns exhibiting no change or reductions in WCA and OCA are likely to induce a Wenzel wetting regime or a Cassie-Wenzel transition state. In these states, the liquid droplets penetrate the surface features, increasing the contact area between the droplet and the surface. This enhances the material's intrinsic wetting behaviour, resulting in lower contact angles. Figure 2.8 illustrates the droplets on the optimised surface patterns. “Pen” denotes the contact on microchannels in the perpendicular direction while “Par” denotes contact angle in the parallel direction.

The microgrid pattern with a 300 µm wall width and “Low” level spacing demonstrated the greatest increases in WCA and OCA. Consequently, this pattern was selected as the initial texture to be applied to the packaging surface to enhance hydrophobicity and oleophobicity. At this stage, manufactured surfaces are not expected to exhibit antimicrobial properties, as the feature dimensions significantly exceed the average size of bacteria (1 – 3 µm). However, the application of this pattern will serve as a preliminary evaluation of the feasibility of accurately and consistently fabricating microfeatures over large surface areas.

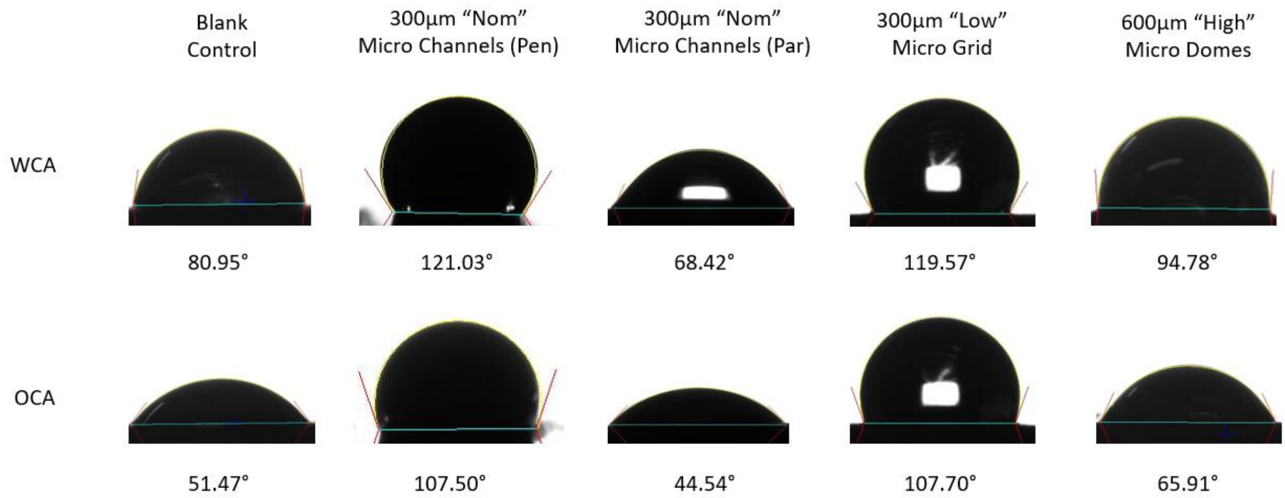



***Figure 2.8.*** *Images of the water contact angle and oil contact angle on the optimum surface patterns.*

### Injection Mould and Surface Topography Insert Design:

To fabricate the selected surface texture on the food contact surface of reusable packaging, an injection mould was designed and manufactured with an interchangeable insert. This design enables the application of various surface textures, which will be explored in future studies. Figure 2.9 illustrates the CAD model of the mould, highlighting the integration of an insert that allows for different surface topographies to be installed.



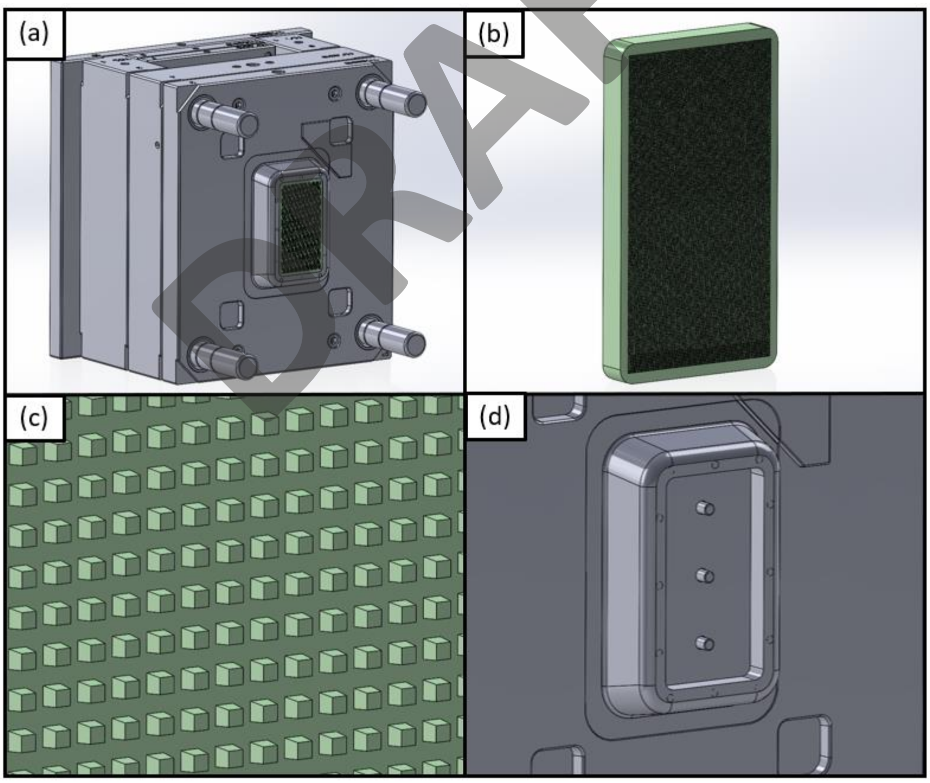



***Figure 2.9.*** *a) The moving half of the mould designed for producing a vacuum skin pack (VSP) tray.* ***b).*** *The interchangeable surface topography insert.* ***c)*** *Surface topography inserts, highlighting the negative side of the optimised micro grid pattern.* ***d)*** *The moving side of the mould with the interchangeable topography insert removed.*

# 3. Production of reusable packaging – By Use Cases

## 3.1. Vytal

**Rigid Take-Away Food Container**

### 3.1.1. Project requirements and specifications

The Vytal project sets out to create a rigid take-away food container that balances sustainability, functionality, and reusability. With an increasing demand for alternatives to single-use plastics in the foodservice industry, the project aims to design a durable packaging solution capable of withstanding industrial washing and repeated use. The container is intended to serve as a sustainable option in the food delivery sector, ensuring both long-term usability and environmental benefit.

To meet these goals, several key specifications were identified early in the project. The choice of material was a crucial decision, and **PBT Arnite T0622**, a thermoplastic engineering polymer, was selected for the combination of its thermomechanical properties, chemical, heat resistance, and dimensional stability, together with affordable price in the market and availability. These properties make it an ideal choice for the repeated thermal stresses and harsh washing conditions the container would face. Furthermore, the material's strength and durability ensure that the container can endure rigorous cycles without losing its form or functionality.

The container itself is designed with practicality and longevity in mind. It features a three-compartment bowl made from PBT, accompanied by a transparent flexible **PP lid (RF777MO)**. To ensure the product's strength and thermal resistance, specific wall thicknesses were chosen. The bowl has a thickness ranging from 1.5 mm to 2 mm, while the lid thickness is between 1.5 mm and 1.8 mm, optimizing both rigidity and durability. The design also incorporates features to facilitate stacking and nesting, addressing the logistical needs of the foodservice industry.

For the initial production phase, a batch of 2,500 units will be manufactured. This quantity was chosen to test and validate the container's suitability for its intended use, especially in industrial washing applications, which are crucial for ensuring the product's reusability. The moulds used for production were designed with durability in mind, and steel was selected as the material for the moulds due to its ability to withstand the high-volume cycles required for mass production. Steel moulds ensure that the production process can be repeated without compromising the quality or precision of the final parts.

Overall, the Vytal project's design and development focus on creating a high-performance, sustainable food container that meets the growing demand for eco-friendly alternatives in the foodservice industry. With careful material selection, precise design specifications, and durable tooling, the project is poised to offer a reusable packaging solution that will significantly reduce the reliance on single-use plastics (Figure 3.1).

***Figure 3.1**. Vytal three compartment developed under BUDDIE-PACK project. Initial design.*

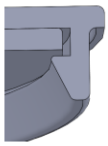
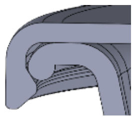
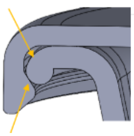
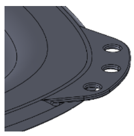
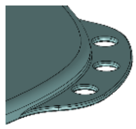
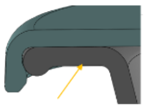
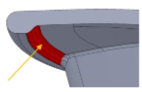
### 3.1.2. Tooling design and development process

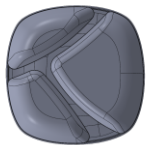
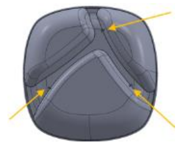
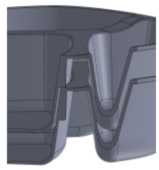
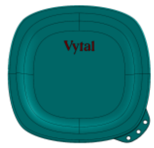
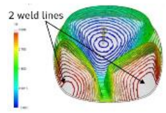
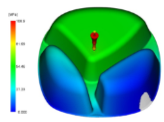
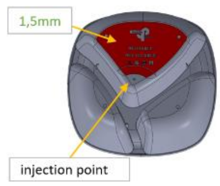
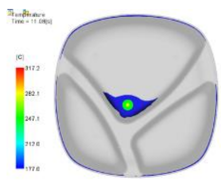
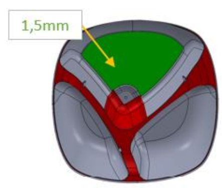
The tooling design and development process for the Vytal packaging was carefully crafted to ensure that the injection moulding process would yield high-quality, consistent parts capable of meeting the stringent demands of the project and beyond. This process was highly iterative, with continuous refinements made to address both material specifications and design optimisation needs.

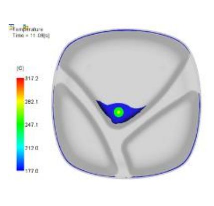
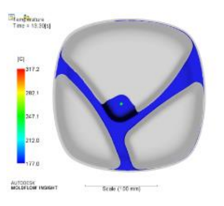
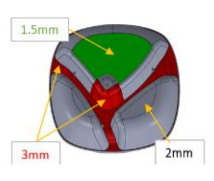
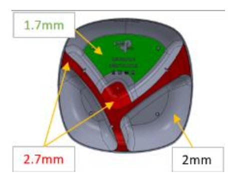
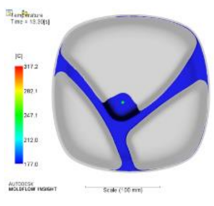
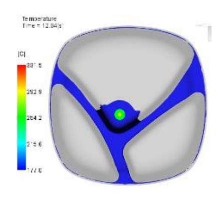
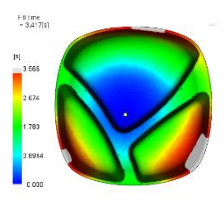
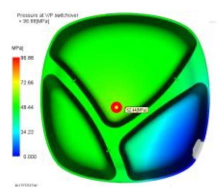
The journey began with the creation of the basic shape of the packaging, carefully considering its intended functionality: a new three compartments bowl. Factors such as the ability to withstand industrial washing, the need for efficient stacking, and ease of handling were fundamental to the design. Aesthetic considerations were also incorporated, ensuring that the packaging would meet the visual expectations for a market-ready product.

As the design progressed, a series of modifications were implemented to enhance the stability, functionality (sealing) and manufacturability of the part. Table 3.1 shows the overall process of passing from an initial design coming from ECHO partner to an injected functional part by using SolidWorks and Moldflow tools. At the end of this process, the design is ready to be shared with the mould maker for tooling manufacturing.

***Table 3.1**. Modifications in the production of Vytal packaging*

| Date | Modification | Description | View before | View after |
|---|---|---|---|---|
| M15 | Creation of a flat surface under the bowl | Modify design to increase bowl stabilty |  |  |
| | General thickness bowl 1,5 mm to 2 mm | Improving the filling of material in the mould | | |
| | General thickness lid 1,5 mm to 1,8 mm | Improving the filling of material in the mould | | |
| | Clipping design | Modification design of the clip for demoulding |  |  |
| M17 | Clipping design | Modification of radius |  |  |
| | | Reduction of clipping dimension | | |
| | Tab design | Modify tab positionning to determinate parting line of the mould |  |  |
| | Remove flat surface | Improving rigidity of clipping |  |  |
| | | No retaining zone on bowl for washing | | |
| | | Adding angle and radius in 3 retaining zones of water on bowl (between container) | |  |

| | | | | |
|---|---|---|---|---|
| | Bowl stacking | Adding 3 ribs for bowl stacking |  |  |
| | | Height stacking 23 mm | |  |
| M19 | Etchings | Adding etchings under and one side of the bowl |  |  |
| | Support feet | Adding 4 support feet higher than etchings under the bowl | | |
| | | Adding etchings on lid | |   |
| | Injection simulation (Moldflow): filling | The end of filling is not homogeneous in the 3 compartments | |   |
| | Injection simulation: switchover pressure | The switchover pressure at nozzle is about 1090 bar and 790 bar in the cavity | |  |
| M21 | Design on the back of the bowl | Reducing the thickness by 0,5 mm to slow the flow and obtain more balanced end of filling for the 3 compartments |  |   |
| | Injection simulation: part temperature evolution | The filling is not optimised. We cannot pack the peripheral cord | |  |
| | Design on the back of the bowl | Optimization of thickness after rheological simulation |  |   |

| | | | | |
|---|---|---|---|---|
| | Injection simulation: part temperature evolution | Change on thickness enables to correctly pack peripheral cord, avoiding deformation |  |  |
| M22 | Design on the back of the bowl | Second optimization of thickness after rheological simulation |  |  |
| | Injection simulation: part temperature evolution | The design is better to pack peripheral cord |  |  |
| | Injection simulation: filling | The end of filling is optimised in the 3 compartments | |  |
| | Injection simulation: switchover pressure | The switchover pressure at nozzle is about 830 bar and 530 bar in the cavity | |  |



One of the first key adjustments involved was maintaining consistent wall thickness as possible across of both the bowl and lid. The design of the bowl was adjusted in certain areas to improve material flow and achieve uniform thickness as possible as shown in Table 3.1. Rheological simulations provided valuable insights into how the material would behave under various conditions, guiding the design modifications necessary to optimise thickness and ensure structural integrity.

Regarding the packaging functionality, the design of the clips was the most critical aspect that needed to be addressed. The clips design is essential to prevent leakage. This step was critical to ensure that the lid clips would effectively release from the cavity without compromising deformation of the lid and the overall production cycle. These changes not only streamlined the demoulding process but also contributed to reducing cycle times, improving overall efficiency. Additionally, the design included the incorporation of ribs to facilitate better stacking of the bowls, contributing to storage efficiency. These ribs also enable a controlled air gap between the parts, promoting air circulation and preventing potential odors that might arise if the parts are stored under humid conditions.

Filling and packing process was studied by using Moldflow simulations to closely monitored how the material flowed into the mould, ensuring that it correctly fills all areas. This process is critical to avoid weld lines in functional zones. Any discrepancies in the material flow were addressed by adjusting both the design and process parameters under an iterative process. These adjustments ensure that the three-compartment bowl and lid was filled uniformly, preventing potential defects such as wrapping.

Additionally, both pressure and temperature were optimized during the injection process. The injection pressure and mould temperature were carefully monitored and fine-tuned to strike the right balance between high packing pressure, which helps to reduce voids, and lower temperatures to avoid excessive cycle times. These optimisations were essential in achieving a high-quality, consistent product while maintaining efficiency throughout the production process.

### 3.1.3.Tool manufacturing

Once the tooling design was finalised, the tool manufacturing phase began. For this project, steel tools were chosen as the optimal technology to meet the demand for high-quality parts in large volumes and to allow for potential use beyond the project. The tooling development was done in collaboration with a mould maker.

### 3.1.4.Tool validation and optimisation

The tuning process is an iterative process which consists of trials runs and adjustments. A series of test shots are conducted to produce initial samples. First, the injected parts are inspected and measured by metrology. Then, if there is any deviation between the part and the drawing, design is slightly modified. The latter conducts to the tool modification.

First trials enable us to validate simulated conditions and compare to injected moulded parts. We first validated filling of the part to check if the part was correctly balanced and the flow homogeneous. A comparison between Moldflow simulation and trials is shown Figure 3.2.

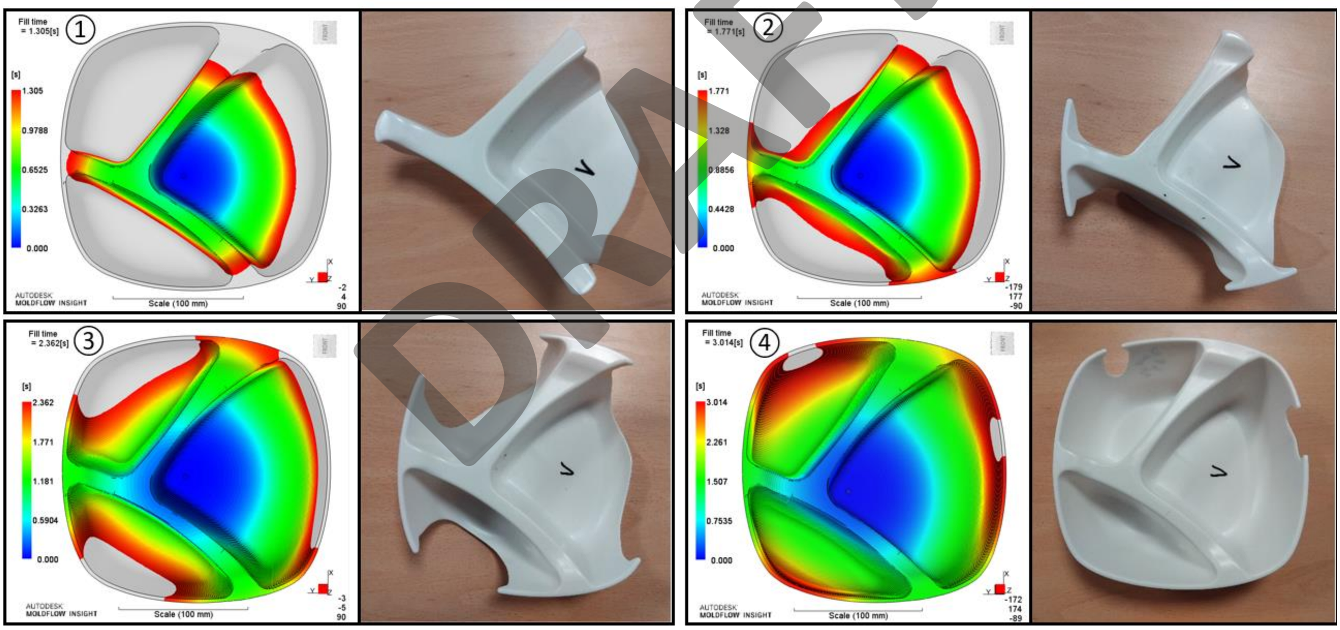



*Figure 3.2. Comparative between incomplete filling injected parts and simulation. Trails from 10/02/2025 at CADPRO with IPC team.*

Figure 3.2 shows a very good match between simulated flow given by Moldflow and the trials. It can be said that the trials validated simulation and thus, a high degree of confidence can be put on the overall model.

Injected moulded prototypes are shown in Figure 3.3, obtained under the tuning phase. First trials have shown parts with flatness deformations at the top edge of the bowl, as it can be observed in Figure 3.4. These deformations come from the geometry of the part (geometrical stresses), making the part unstable and hindering the lid's clipping. The compartments have indeed a tendency to come closer between them after the ejection.

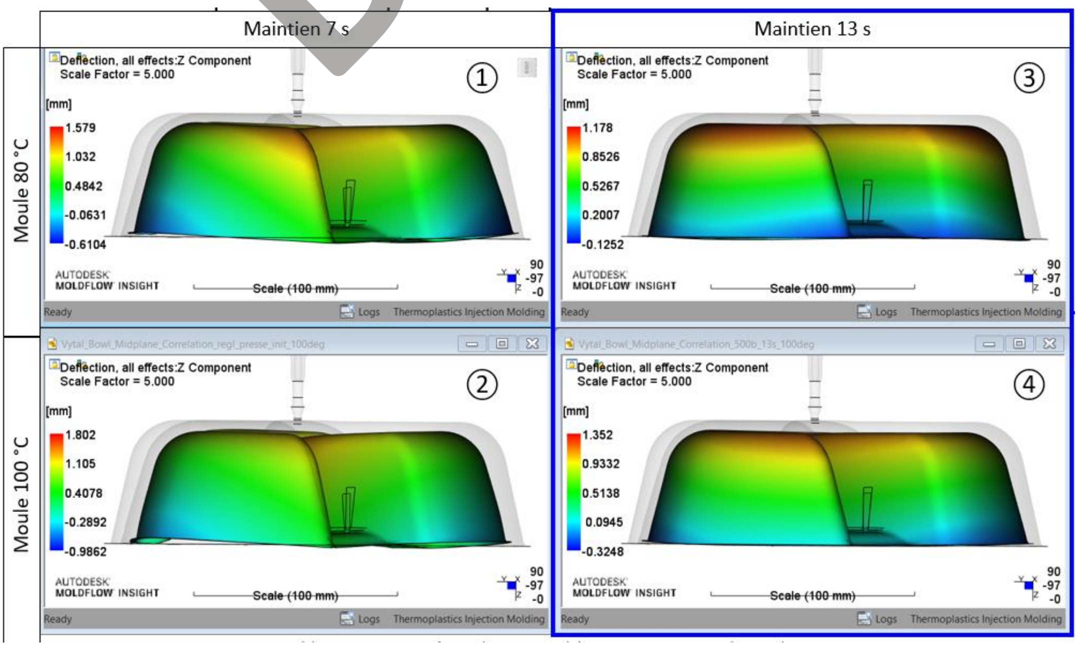
*Figure 3.3.* *Vytal three compartment developed under BUDDIE-PACK project. Injected part by CADPRO during tuning process (01/25).*

*Figure 3.4. Vytal prototypes under tuning process: flatness deformation given by geometrical stresses.*

Moldflow predicts such deformation and thanks to this tool, such phenomena can be minimized. Four calculations were run and are presented in Table 3.2. Table 3.2 presents the effect of holing time and mould temperature into the flatness deformation at the top edge of the bowl.

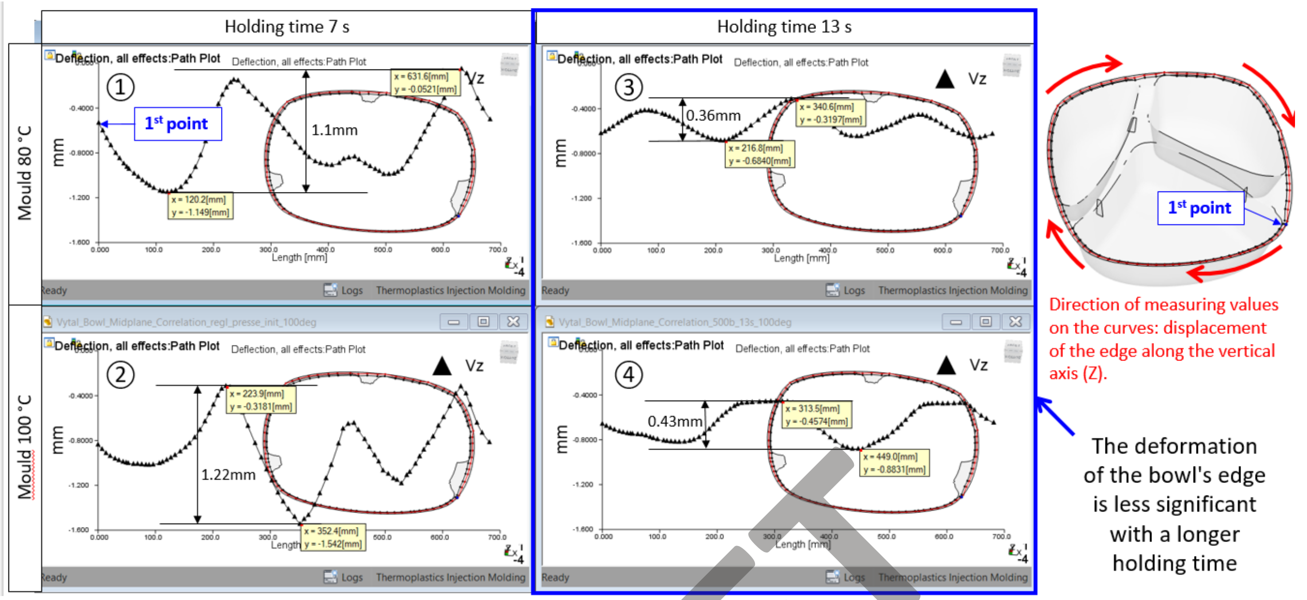
*Table 3.2. Moldflow calculations on flatness.*

| Calculations | Holding pressure | Holding time | Mould temperature | Flatness deformation |
|---|---|---|---|---|
| ① | 500b | 7s | 80°C | 0.84mm |
| ②* | 500b | 7s | 100°C | 0.75mm |
| ③ | 500b | 13s | 80°C | **0.12mm** |
| ④ | 500b | 13s | 100°C | **0.08mm** |



Bowl deformation is numerically amplified by 5 to increase readability

**Deformation at the top edge of the bowl**




**Corresponds to trials performed at CADPRO with IPC support on the 10/02/2025*



As it can be noticed in

Table 3.**2**, calculations 3 and 4, with 13 s of holding time, presented a lower flatness calculation. Temperature does not affect much the deformation. However, in theory, the higher the mould temperature, the better the dimensional stability. It can be expected that after first cycle of use (thermal, industrial washing), the packaging relaxes internal stresses produced under manufacturing. Preliminar industrial washing trials have been done at IPC. No significant deformation or wrapping was observed on Vytal bowl after repetitive washings. Thus, condition 3 and 4 will be used as a basis for next trials.

At this time, the information regarding the final trials is not available as they are scheduled to be conducted after the submission of this report.

### 3.1.5. Production implementation

Moldflow simulation enables us to define quite precisely process parameters to guarantee optimal material filling, steady state conditions and minimize deformations linked to internal or geometrical stresses.

Under BUDDIE-PACK project, 5000 parts (2500 lids and 2500 bowls) will be manufactured by using a 280T injection machine at Knauf industries.

### 3.1.6. Conclusions and lessons learned

The Vytal project has provided several valuable lessons in the development and manufacturing of sustainable, reusable food packaging solutions. Some key takeaways include:

- **Importance of simulation tools:** The use of design and simulation tools such as SolidWorks and Moldflow was critical in optimising the tooling and injection moulding process. Simulations helped identify potential issues early in the design phase, saving time and resources during the physical tooling process.

- **Material and process selection:** The choice of PBT and PP for the packaging material, combined with steel moulds for durability, proved to be well-suited to the project's needs. The careful selection of materials ensured that the final product would withstand the intended use and washing cycles.
- **Iterative design process:** The iterative design process allowed for continual refinement of the packaging's functionality and manufacturability. Regular modifications to the tooling, based on feedback and simulation results, ensured the final design was both efficient to manufacture and met all performance specifications.
- **Sustainability and scalability:** The Vytal project has demonstrated the feasibility of producing high-quality, sustainable packaging on a larger scale. The lessons learned can be applied to future projects aimed at reducing the environmental impact of packaging and promoting the use of reusable materials in various industries.

In conclusion, the Vytal project highlights the importance of careful planning, iterative design, and the use of advanced simulation tools in the development of sustainable packaging solutions. The insights gained from this project will be invaluable in guiding future efforts to create more environmentally friendly and cost-effective alternatives in the packaging industry.

## 3.2. Asevi

**Rigid Bottle for Laundry Detergent**

### 3.2.1. Project requirements and specifications

The BUDDIE-PACK project aims to develop sustainable and reusable packaging solutions that align with circular economy principles. Within this framework, the Asevi case study focused on designing and producing a reusable detergent bottle incorporating 50% recycled polyethylene (rPE). This initiative seeks to reduce environmental impact by integrating post-consumer recycled material while maintaining high-performance standards for packaging.

The development of this bottle (Figure 3.8) presented several challenges, including ensuring the structural integrity and durability of the material throughout multiple reuse cycles. Given the specific requirements of the detergent industry, the bottle had to meet strict technical and sustainability criteria, ensuring:

*Figure 3.5. Asevi's bottle production.*

- **Barrier properties** to protect the detergent from external factors and prevent degradation.
- **Strength and rigidity** to maintain the bottle's shape and withstand mechanical stress during transport and handling.
- **Stress-cracking resistance** to avoid material failure when exposed to chemical agents or prolonged use.
- **Aesthetic quality** and opacity to maintain brand identity, consumer appeal, and protection from light-sensitive formulations.

In addition to these functional requirements, the manufacturing process had to be efficient and seamlessly integrated into Asevi's existing production lines. The solution needed to be scalable, cost-effective, and compatible with industrial processes, ensuring that the packaging could be reused multiple times without compromising its mechanical properties, sealing performance, or overall appearance.

This case study explores the entire development process, from tooling design and material validation to manufacturing and final production implementation, demonstrating how sustainability and innovation can be successfully combined in industrial packaging solutions.

### 3.2.2. Tooling design and development process

The tooling design and development process was a crucial phase in ensuring the successful manufacturing of the reusable detergent bottle. The bottle's mould had to meet the technical requirements set in WP1 of the BUDDIE-PACK project while also allowing for efficient large-scale production with optimised material usage (Figure 3.9).

***Figure 3.6.*** *Asevi's bottle extrusión blow moulding mould.*

#### Bottle Mould Design

To achieve the desired structural and functional properties, an **aluminium mould** was specifically designed and manufactured. Aluminium was selected due to its excellent thermal conductivity, which facilitates precise temperature control during the blow moulding process, leading to improved cycle times and consistent part quality. The mould was engineered to produce bottles with:

- **An approximate weight of 100 grams**, ensuring the right balance between durability and material efficiency.
- **Homogeneous wall thickness**, optimising material distribution and mechanical performance.
- **High dimensional accuracy**, ensuring that each bottle meets strict tolerances for fit and functionality.

The mould design was optimised to support **the use of 50% recycled polyethylene (rPE)**, a material with different flow and shrinkage characteristics compared to virgin PE. To accommodate this, adjustments were made in the mould design, such as fine-tuning cooling channels and cavity geometry to minimise defects like warping or uneven thickness.

#### Cap Design and Development

In addition to the bottle, a **custom cap** (figure 3.10) was designed to ensure proper sealing and compatibility with the reusable bottle. The cap plays a vital role in maintaining the integrity of the detergent by preventing leaks, preserving chemical properties, and enabling multiple reuses without degradation.

- **Sealing Performance**: The cap was designed with a tight sealing mechanism to prevent detergent leakage during transport and use.
- **Material Selection**: The cap material was chosen to be chemically resistant and mechanically robust, ensuring long-term durability.
- **Injection Moulding Process**: Since injection moulding offers high precision and repeatability, the cap's manufacturing was subcontracted to specialised suppliers to guarantee consistent quality and dimensional accuracy.

By carefully designing the mould and cap to meet performance, sustainability, and production efficiency requirements, the tooling phase laid the foundation for a smooth transition into the manufacturing and validation stages.

***Figure 3.7.*** *Asevi's bottle injected custom cap.*

### 3.2.3. Manufacturing and fabrication

The chosen equipment is the blow extrusion machine from Asevi's facilities (Figure 3.11). The extrusion process will be carried out using the **Magic Machine model ME-L8-10/ND**, Registration 54-11 from 2011. This machine incorporates MAGIC ALL-ELECTRIC technology, which enables a 50% reduction in energy consumption compared to previous technologies. The mould has a clamping force of 18 tonnes, ensuring precise shaping and stability during the extrusion process. The extruder features a 90 mm diameter screw, providing a plasticizing capacity of **190 kg/h**. This allows for efficient and consistent material processing. A total of 18 temperature control zones are integrated between the extruder and the extrusion heads. These zones are equipped with resistors and thermocouples to maintain an exact temperature throughout the process. The selected materials are processed at a temperature of **185°C**, with a tolerance of ±2°C, ensuring optimal thermal stability. The approximate extrusion pressure is maintained at **220 bars**.

The test conducted with this machine demonstrated a cycle time of **17.1 seconds**. During this cycle, the bottle blowing phase lasted for **12 seconds**, followed by a 1-second discharge of the accumulated pressure within the bottle. This setup ensures high efficiency and precise control over the production process.

For the initial processability tests, virgin polyethylene **(ADVANCE EM-5333-AAH)** was used, allowing the establishment of the optimal process parameters. Once the tests were conducted, 50% rPE was incorporated, a material compatible with blow extrusion RECICLEX 50RX5503, which also offers advantages in terms of sustainability and recyclability.

Although the recycled PE grades available in the market have a higher cost than virgin PE, their reduced environmental impact and their ability to withstand multiple reuse cycles make them a viable option for detergent packaging.

***Figure 3.8**. Asevi's extruder Magic Machine model ME-L8-10/ND*

***Figure 3.9.** bottle weight control.*

### 3.2.4.Tool validation and optimization

During the validation phase, tests were conducted to analyse the processability of the material and ensure compliance with technical and sustainability requirements. Two testing sessions were carried out:

- **With virgin PE**, to optimise process parameters and validate the cap design.
- **With 50% rPE**, to evaluate the compatibility of the recycled material and its impact on production.

The first test was to produce bottles with virgin **PE (ADVANCE EM-5333-AAH).** This polyethylene has an excellent environment stress crack resistance and rigidity, high impact strength, moderate swell and high melt strength.

The weight of the resulting bottles was around 100 g (Figure 3.12), the thickness was homogeneous, and there was good material distribution. The mould performance was optimal. The results of the initial tests were excellent, allowing the validation of the initial design 3.2.

The results demonstrated that the material distribution was homogeneous, the bottle weight remained stable, and the mould operated optimally. The mechanical properties of rPE were validated, including tensile strength, flexural modulus, and impact resistance, ensuring its viability for use in reusable detergent bottles.

For the second test, 50% rPE was used **(RECICLEX 50RX5503),** with the aim of evaluating its behaviour in the process and its compatibility with the reuse system. The results were like those of the previous tests, and the prototypes met Asevi's aesthetic and functional requirements. The use of rPE ensures the recyclability of the packaging within the already established mechanical and chemical recycling routes for polyethylene, facilitating its integration into existing recycling streams.

### 3.2.5.Production implementation

With the validation of the process and materials, the reusable bottle containing **50% rPE** was successfully integrated into Asevi's production line. Unlike conventional single-use detergent bottles, this new packaging solution was specifically designed to withstand multiple reuse cycles, requiring enhanced mechanical performance and durability. To achieve this, the bottle features a **40% greater thickness** compared to standard PE bottles currently produced by Asevi, ensuring it can endure more than **10 usage cycles** without compromising its structural integrity or functionality.

The implementation of this prototype represents a significant step forward for both Asevi and the BUDDIE-PACK project. The successful adaptation of the production process to accommodate this more robust design highlights the feasibility of incorporating reusable packaging into existing manufacturing lines. Additionally, an important finding from the production phase was that no significant differences were observed in the processing behaviour between **virgin PE and rPE**. This demonstrates that the use of recycled material does not introduce complexities in manufacturing, reinforcing the potential for seamless integration of recycled content into industrial-scale production.

Even though rPE has a higher cost than virgin PE, its lower environmental impact and ability to withstand multiple reuse cycles make it a viable alternative that aligns with circular economy principles. This successful integration marks an important milestone in the BUDDIE-PACK project, proving that reusable packaging solutions with recycled content can be efficiently manufactured while maintaining high-performance standards. In image 3.10 we can see the only differences between the packaging made with virgin material and recycled material, which are visual differences.

***Figure 3.10.*** *Bottles manufactured for the BUDDIE-PACK project.
Left: virgin. Right: recycled.*

### 3.2.6. Conclusions and lessons learned

The Asevi case study within the BUDDIE-PACK project successfully demonstrated the feasibility of producing reusable detergent bottles using 50% recycled polyethylene (rPE) while maintaining high standards of functionality, durability, and aesthetics. This achievement reinforces the potential of integrating recycled materials into packaging solutions, contributing to the transition towards a more sustainable packaging industry. One of the key findings of this study was the effectiveness of **extrusion blow moulding technology** in producing high-quality reusable bottles while optimising the processing of recycled materials. The manufacturing process proved to be highly efficient, ensuring homogeneous material distribution and maintaining the structural integrity of the packaging. The tests conducted confirmed that incorporating **50% rPE** into the bottle production was feasible **without compromising mechanical performance or visual appeal**.

A critical factor in the success of this project was the thorough **in-factory validation of the manufacturing parameters**. The defined process conditions ensured that the bottles met the necessary technical requirements, including **barrier properties, strength, rigidity, stress-cracking resistance, and aesthetic quality**. The optimisation of the mould design played a fundamental role in ensuring material efficiency and product consistency, while the development of a **custom cap** guaranteed proper sealing and compatibility with the bottle. Another significant aspect of this case study was the **use of ALL-ELECTRIC technology** in the blow moulding machinery, which enabled a substantial reduction in energy consumption compared to traditional hydraulic systems. This technological advantage contributed to the overall efficiency and sustainability of the production process, aligning with the project's goal of reducing the environmental footprint of reusable packaging.

Despite the success achieved in this phase, the study also highlighted the **need for continuous assessment of the environmental impact and recyclability** of the packaging. Future project stages will focus on evaluating the long-term sustainability of the bottles, including their performance in multiple reuse cycles and their integration into existing recycling streams. In conclusion, the Asevi case study demonstrated that the **implementation of recycled materials in reusable packaging is a viable and effective strategy** for reducing environmental impact. The results obtained validate the potential of rPE-based packaging as a sustainable alternative for the detergent industry, setting a precedent for further advancements in circular economy initiatives within the packaging sector.

## 3.3. Smurfit Kappa

**Recyclable Flexible Bag-in-Box® for Personal Care Goods**

### 3.3.1. Project requirements and specifications

The objective of this project was to create a Bag-in-Box® (BiB) (figure 3.11) solution tailored for personal care products, focusing on the development of a sustainable, durable, and highly functional packaging system. A primary challenge was ensuring that the chosen packaging material could endure prolonged exposure to detergents without compromising its integrity. Additionally, the packaging had to maintain its strength during transportation, where it could be subjected to various impacts and vibrations that might threaten its structural integrity. The aim was to design a packaging solution that not only met the environmental goals of reducing waste and resource use but also stood up to the demands of industrial processes and handling.

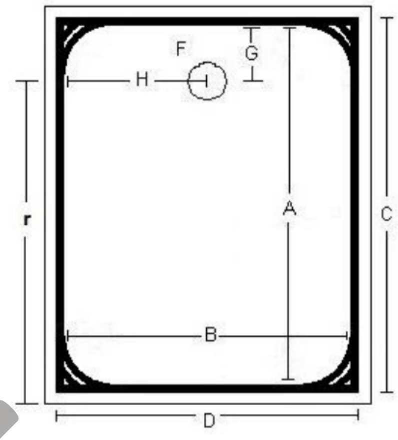

***Figure 3.11**. Bag-in-box design.*



### 3.3.2. Tooling design and development process

The design and development of the tooling were carefully tailored to meet the project's specific needs. The extrusion blow film process was chosen for its ability to create durable, flexible bags that could resist deformation under stress. The ability to control wall thickness during production was a critical factor, allowing for strong yet flexible packaging that could be stacked without compromising its integrity. Furthermore, reducing the number of joints or welds in the design improved the overall structural strength of the packaging, decreasing the risk of weak points that could lead to leaks or cracks.

*Table 3.3. Smurfit-Kappa (SK) packaging technical design*

| **Dimensions of SK packaging.** | | |
|---|---|---|
| A. INNER LENGTH | 500 mm |  |
| B. INNER WIDTH | 370 mm | |
| C. OUTSIDE LENGTH | 508 mm | |
| D. OUTSIDE WIIDTH | 378 mm | |
| E. WELD WIDTH | 4 mm | |
| G. DISTANCE GLAND CENTER-UPPER WELD | 378 mm | |
| H. DISTANCE GLAND CENTER-UPPER WELD | 4 mm | ***Figure 3.12.*** *Dimensions of SK packaging.* |

### 3.3.3. Manufacturing and fabrication

Extrusion blow film was selected to produce the BiB packaging due to its suitability for creating flexible yet strong bags. This process provides high resistance to impacts, drops, and external pressures, making it ideal for packaging personal care products. The production of the Bag-in-Box packaging involved the careful selection of PE materials, optimising the extrusion conditions to ensure the packaging met strength, durability, and sustainability requirements. The choice of LDPE over traditional HDPE reduced the amount of plastic required, contributing to lower emissions and waste during production. Additionally, the use of a corrugated cardboard box to house the plastic bag further enhanced the environmental benefits of the packaging solution.

***Figure 3.13.*** *Bag-in-box container outlet tap.*

***Figure 3.14.*** *Bag-in-Box manufactured for the BUDDIE-PACK project.*

### 3.3.4. Tool validation and optimization

To ensure that the packaging met the required performance standards, several validation and optimisation steps were carried out. The extrusion process was closely monitored, with testing conducted to assess the material's barrier properties, impact resistance, flexibility, and puncture resistance. The material used for testing consisted of LDPE and LLDPE, which was chosen for its suitability in the extrusion blow moulding process.

The tests showed that the material met the required standards for rigidity, puncture resistance, and recyclability, confirming that the packaging would perform effectively during transportation and handling. These results validated the choice of LDPE and the extrusion blow moulding process as the best options for this packaging solution.

### 3.3.5. Production implementation

Following successful tool validation, the production of the Bag-in-Box packaging was implemented using the validated design and materials. The prototypes produced in the initial testing phases demonstrated the desired properties, both functionally and aesthetically. The LDPE polymer provided the required flexibility and strength, ensuring that the packaging could withstand impacts, drops, and punctures during transport.

Additionally, the recyclability of the material contributed to the sustainability goals of the project. A cap or dispenser, produced through injection moulding, was incorporated into the design, further completing the packaging solution. The final prototypes were tested and found to meet the necessary sustainability, functionality, and quality criteria, paving the way for full-scale production.

### 3.3.6. Conclusions and lessons learned

The development of the Bag-in-Box packaging for personal care goods provided valuable insights into the design and manufacturing of sustainable packaging solutions. The project demonstrated the effectiveness of extrusion blow moulding in creating durable and recyclable packaging, with the ability to control wall thickness and reduce weak points in the design. The choice of LDPE as the material for the packaging proved to be a successful one, offering the necessary performance characteristics while supporting sustainability goals. Additionally, the iterative testing process allowed for continuous optimisation of the tooling and materials, ensuring that the final product met all required specifications.

The project also highlighted the importance of careful material selection and process optimisation in developing high-performance, sustainable packaging. The lessons learned from this project will inform future developments in the packaging industry, particularly in the creation of reusable and recyclable packaging solutions. Overall, the success of this project reinforces the potential of sustainable packaging options in reducing environmental impact while meeting the demands of the personal care industry.

## 3.4. Ausolan: Single portion tray

**Semi-Rigid Catering Trays for Schools and Nursing Homes**

### 3.4.1. Project requirements and specifications

The objective of this case study within the BUDDIE-PACK project is to develop reusable food packaging solutions tailored for Ausolan's food distribution system. A reusable single-portion tray was developed. This is intended for individual meals and special diets in a B2C model.

The main challenges of this development lie in ensuring durability and safety while maintaining compatibility with current food service operations. The trays must withstand repeated use, industrial washing cycles, and thermal variations (microwave application) without compromising mechanical integrity. Additionally, they need to be cost-effective for mass production and support Ausolan's transition towards more sustainable packaging solutions. To achieve these goals, the packaging must meet the following key requirements:

- **Material selection:** Engineering plastics such as PBT, offering heat, chemical resistance and mechanical strength.
- **Reusability:** Ability to withstand repeated heating cycles on microwave, use and washing cycles without degradation. The tray that is designed to be used as a serving dish, allowing people to eat directly from it.
- **Industrial compatibility:** Designed to integrate seamlessly into existing food handling and regeneration processes.

By addressing these requirements, the project aims to deliver a reliable, reusable alternative to single-use packaging, promoting sustainability and efficiency in the food service sector. **Figure 3.15** shows the initial design presented by ECHO.

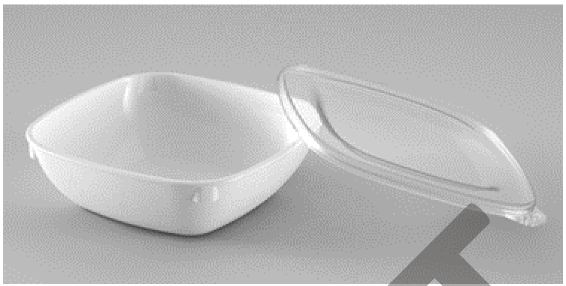


***Figure 3.15.*** *Initial designs presented by ECHO.*

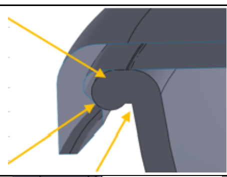
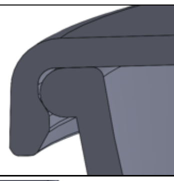
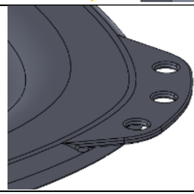
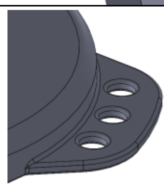


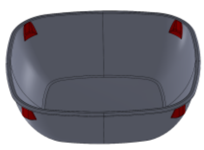
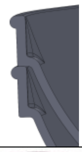
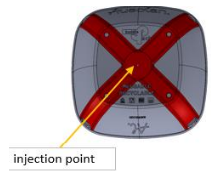
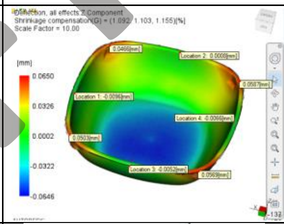
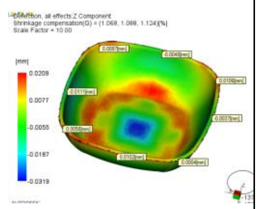
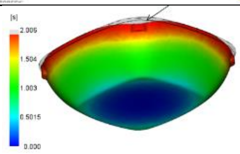
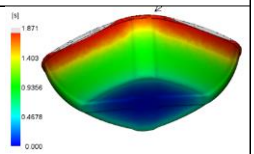
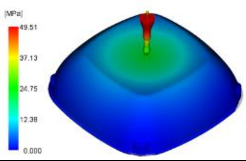
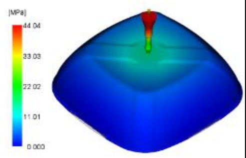
### 3.4.2. Tooling design and development process

The development of Ausolan's reusable packaging within the BUDDIE-PACK project is directly associated with Vytal project described in Section 3.1. As both use cases presents very similar requirements. This is the reason why the same material has been chosen.

**Table 3.3** shows the overall process of passing from an initial design coming from ECHO partner to an injected moulded functional part by using SolidWorks and Moldflow tools. At the end of this process, the design is ready to be shared with the mould maker for tooling manufacturing.

***Table 3.3*** *Modifications in the production of Ausolan single portion packaging.*

| Date | Modification | Description | View before | View after |
|---|---|---|---|---|
| M17 | General thickness bowl 1,5 mm to 2 mm | Improving the filling of material in the mould | | |
| | General thickness lid 1,5 mm to 1,8 mm | Improving the filling of material in the mould | | |
| | Clipping design | Modification of radius |  |  |
| | | Reduction of clipping dimension | | |
| | | No retaining zone on bowl for washing | | |
| | Tab design | Modify tab positionning to determinate parting line of the mould |  |  |

| | | | | |
|---|---|---|---|---|
| | Bowl stacking | Adding 4 ribs for bowl stacking | |  |
| | | Height stacking 12 mm | |  |
| M19 | Etchings | Adding etchings under and two sides of the bowl |  |   |
| | Support feet | Adding 4 support feet heigher than etchings under the bowl | | |
| M21 | Creation of preferential path on the back of the bowl | Increase 0.5 mm thickness into the bowl diagonal to accelerate the melt flow onto the 4 corners and obtain more homogeneous end of filling |  |   |
| | Injection simulation: deformation on Z axis (top edge of the bowl) | Less deformation on the top edge of the bowl with new preferential paths. |  |  |
| | Injection simulation: filling time | Better filling with preferential paths, reducing filling time |  |  |
| | Injection simulation: switchover pressure | Switchover pressure is reduced by using preferential paths |  |  |
| M22 | Preferential path geometrical optimization | Optimization of design after 3D printing prototypes |  |  |



### 3.4.3. Tool manufacturing

Once the tooling design was finalised, the tool manufacturing phase began. For this project, steel tools were selected as the ideal technology due to the project demand of quality parts in large volumes for the project and beyond. The tooling development was done in collaboration with MCDM mould maker.

## Mould requirements

- Bowl mould cavity and lid interchangeable in a same frame
- Injection by a 3 mm shut-off nozzle
- Ejection by stripper plate
- To be mounted on 150T injection moulding machine for testing and on 280T moulding machine for production.

**Bowl cavity:**

- PBT material
- Shinkage 2%
- Surface roughness smooth (polished 600)
- Mould temperature: 80-100°C, requires specific regulating nozzles (CBI 09)
- Laser etchings for markings

**Lid mould cavity:**

- PP material
- Shinkage 1.5%
- Surface roughness glass polished

## Mould description

The mould is composed of a frame and two cavities, one for the bowl and one for the lid. Each cavity consists on a moving half and fixed section. The following pictures describe the mould and some of the most important features. **Figure 3.18** and **Figure 3.19** show some pictures and sections views from the moving and the fixed part on the bowl version.

It is worthy to underline that, IPC designed and manufactured two parts of the mould by 3D metal laser fusion technology. The metal laser fusion allows to optimize thermal regulation. Conformal cooling technology enables to create a circuit of regulation as close as possible to the moulding zone, which is impossible to achieve with traditional machining. An upper core and a cool bridge were manufactured to this end and are shown in **Figure 3.20** and **Figure 3.21**. A complete view of the upper and lower core is shown in **Figure 3.22**.



***Figure 3.16.*** *Moving half bowl section.*

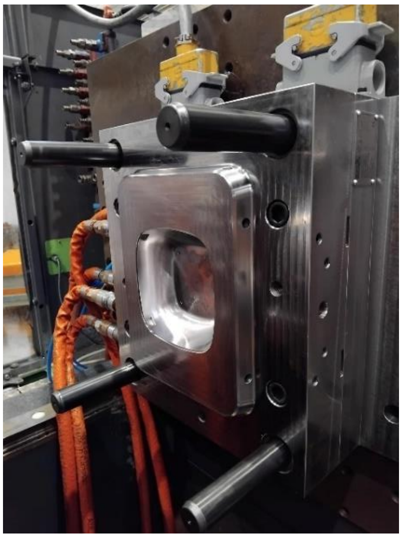


***Figure 3.17.*** *Fixed half bowl section.*

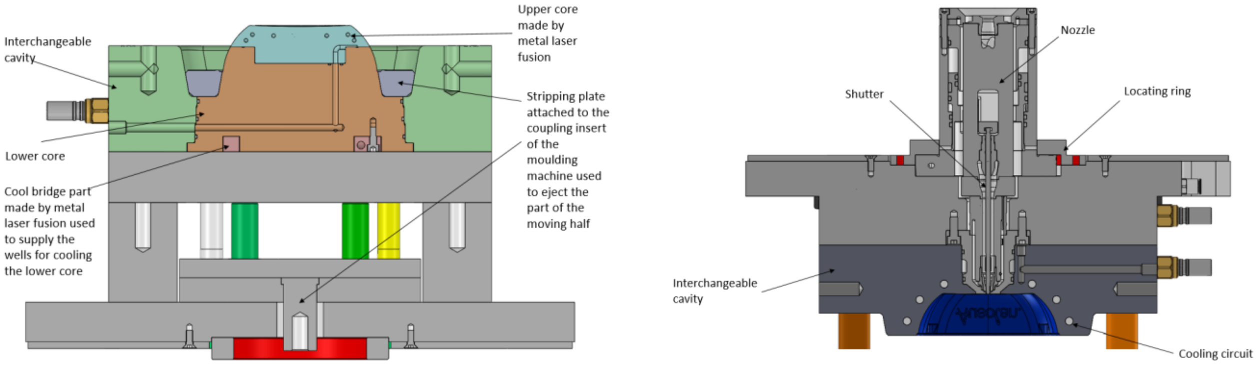



*Figure 3.18. Pictures and section views of the moulding machine. a) moving half, b) fixed half in bowl configuration*

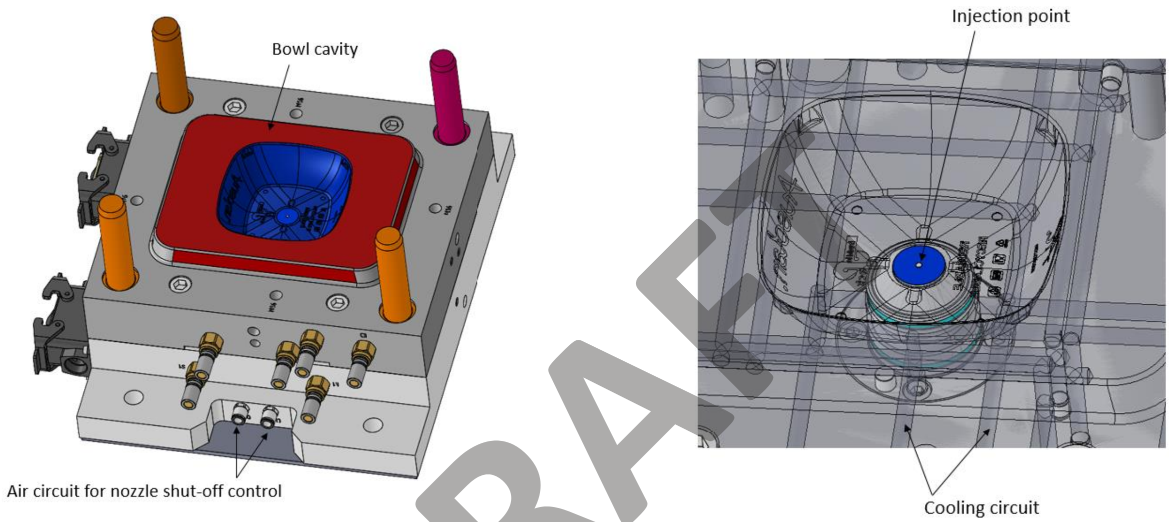



*Figure 3.19. Views and focus on the fixed half of the Bowl*

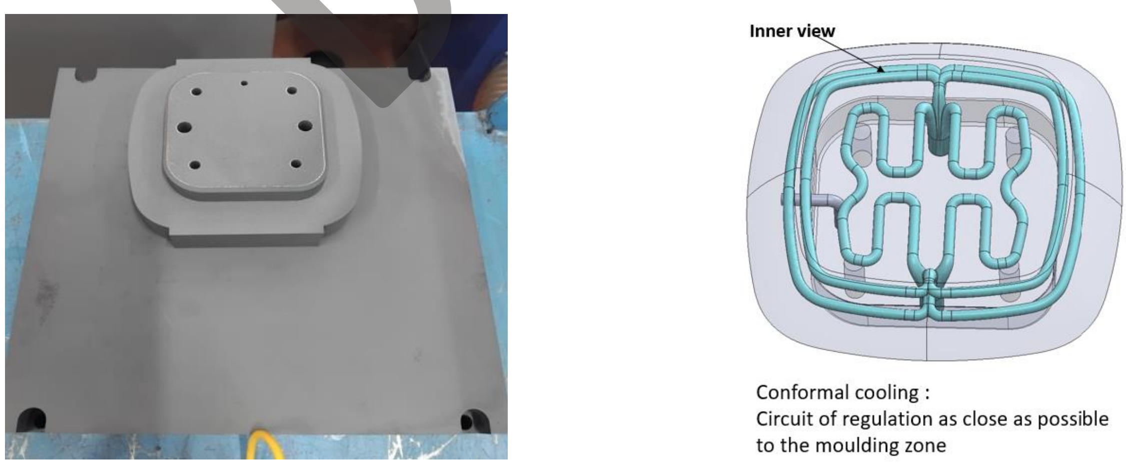



*Figure 3.20. Upper core part made by metal laser fusion*

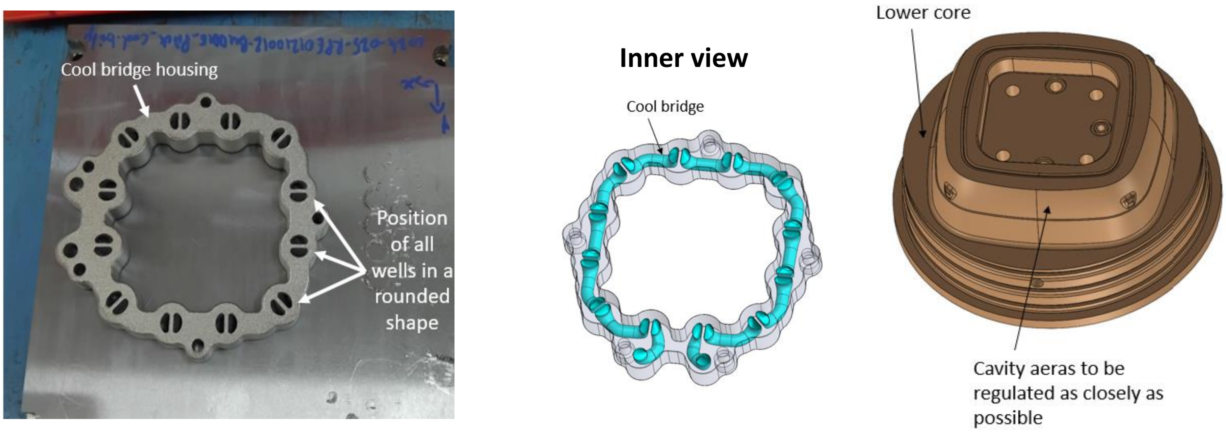



***Figure 3.21.*** *Cool bridge made by metal laser fusion*

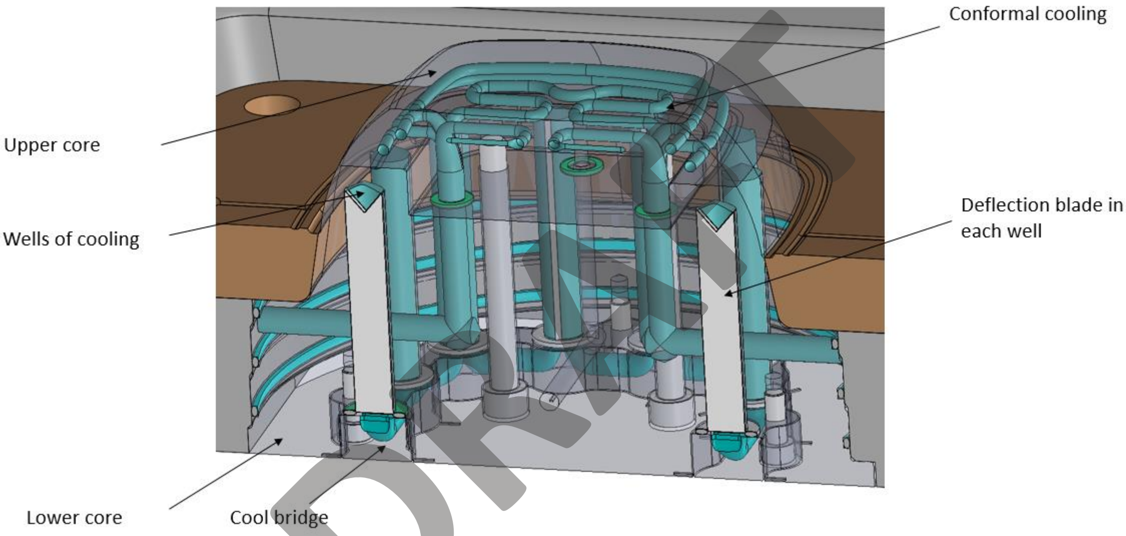


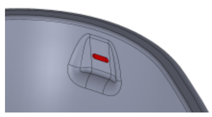


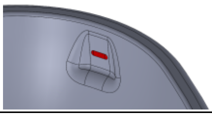
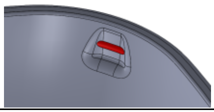

***Figure 3.22.*** *Thermal circuit view: upper and lower cores*

### 3.4.4. Tool validation and optimization

Three trials were performed to validate the Ausolan single portion bowl tool. **Table 3.4** shows modifications performed at the bowl tool after each trial. During the first, the bowl stayed on the fixed part of the mould instead of the moving part. For this reason, it has been chosen to add four holdbacks into each corner to force the bowl to stay at the correct part of the mould for ejection. The third trial enabled to completely avoid this issue.

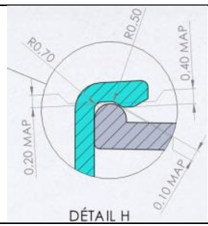
***Table 3.4.*** *Tool modifications for Ausolan single portion bowl.*

| Date | Modification | Description | View before | View after |
|---|---|---|---|---|
| M25 | Addition of 4 holdbacks inside of the bowl | Forces the part to remain on the moving part of the mould |  |  |
| | | Addition of a valve Meusburger E1673/8 | | |

| | | | | |
|---|---|---|---|---|
| M27 | Leakeage on the water circuit (mold maker issue, not design) | Valve modification | | |
| M28 | Enlargement of 4 holdbacks | Process optimization after second trial |  |  |

Two trials were necessary to validate the Ausolan single portion lid. **Table 3.5** shows the modification performed at the lid tool after the first trial. After first trial, a little burr is observed on the internal part of the lid. Regarding the design, a reduction of the draft angle and an increase in radii were performed to avoid such burr. Only one modification was required. PP has a relatively large process window to be injected. Thus, playing with the cooling time parameter, we will be able to adjust the sealing as desired.

***Table 3.5.*** *Tool modifications for Ausolan single portion lid.*

| Date | Modification | Description | Before | After |
|---|---|---|---|---|
| M28 | Draft angle | Reduction of the draft angle |  | Almost no visible burr |
| | Radius of curvature | Increase in radii R 0.5 and R0.7 to 1.2mm |  | |
| M30 | Any modification on design | Trials on different cooling times were performed and compared to Moldflow simulations to fix final process parameters | | |



In between trials, metrology tests were performed to validate the parts after each tool modification. Figure 3.23 shows the injected single portion tray and lid during the tuning phase. Moldflow enables us to find optimum process conditions to avoid, as much as, possible internal stresses. We have shown that the higher is the mold temperature, the most resistance is the bowl after washing cycles. The latter was well predicted by Moldflow.

It is also worthy to underline that final trials enable us to observe the effect of cooling time on the dimension of the part. For example, for lids, it was observed that the longer the cooling time, the larger the dimension of the lid.

***Figure 3.23**. Single portion tray injected prototype*

### 3.4.5.Production implementation

At this time, the information regarding the production is not available as it is scheduled to be conducted after the submission of this report.

Moldflow simulation enables us to define quite precisely process parameters to guarantee optimal material filling, steady state conditions and minimize deformations linked to internal or geometrical stresses.

**Table 3.6** shows the optimum process conditions for PBT bowl and lid given by Moldflow simulation and validated during the last trials.

Under BUDDIE-PACK project, 4000 parts (2000 lids and 2000 bowls) will be manufactured by using a 200t injection-moulding machine.

***Table 3.6.** Optimum process conditions for PBT Vytal bowl and PP (RG466MO) lid given by Moldflow.*

| Process parameters | PBT bowl | PP (RG4600MO) | Units |
|---|---|---|---|
| Mould temperature | 100 | 15 | °C |
| Nozzle temperature | 255 | 215 | °C |
| Injection time | 2.9 | 8 | s |
| Holding pressure | 300 | 400 | b |
| Holding time | 13 (constant profile) | 10 | s |
| Cooling time | 22 | 10 | s |



### 3.4.6.Conclusions and lessons learned

Ausolan single portion has been used as model for Vytal project. Clipping was designed the same and was first validated on single portion to be scaled to Vytal project. Both projects are similar, thus, conclusions and learned lessons have already been discussed in Section 3.1.

Therefore, it is worthy to underline some specificities of Ausolan 1 portion project.

- Preferential paths on the bottom of the bowl conduct to a better pack of the peripheral cord of the bowl, avoiding deformation.
- Conformal cooling has been develop and used to optimise thermal circuit of the bowl cavity with success.
- Ausolan single portion is not as structured as Vytal bowl. Ausolan single portion is just supported by a skin, while Vytal has 3 compartments that structures the part. Preliminar washing tests conducted at IPC showed more deformation on Ausolan 1 portion bowl compared to Vytal bowl.

- Increasing the mold temperature from 80°C to 100°C, showed a clear improvement in deformation after the first cycle of washing.
- For lids, it is important to note that the longer the cooling time, the larger the lid's dimensions become, resulting in a looser seal.

## 3.5. Ausolan : Multi-portions tray

Semi-Rigid Catering Trays for industrial kitchens

### 3.5.1. Project requirements and specifications

The objective of this case study within the BUDDIE-PACK project is to develop reusable food packaging solutions tailored for Ausolan's industrial kitchens. This development is intended to replace a current PP sealing single use tray for robust CPET tray with lid under a B2B approach.

The main challenges of this development lie in ensuring durability and safety while maintaining compatibility with current food service operations. The trays must withstand repeated use, thermal variations (oven application) and industrial washing cycles, without compromising mechanical integrity. Additionally, they need to be cost-effective for mass production and support Ausolan's transition towards more sustainable packaging solutions. To achieve these goals, the packaging must meet the following key requirements:

- **Material selection:** Engineering plastics such as CPET, offering heat, chemical resistance and high mechanical strength.
- **Reusability:** Ability to withstand repeated heating cycles on oven, use and washing cycles without degradation. The tray that is designed to be used in industrial kitchens to warm 8 portions of food.
- **Industrial compatibility:** Designed to integrate seamlessly into existing food handling and regeneration processes.

By addressing these requirements, the project aims to deliver a reliable, reusable alternative to single-use packaging, promoting sustainability and efficiency in the food service sector. **Figure 3.24** shows the initial design presented by ECHO.



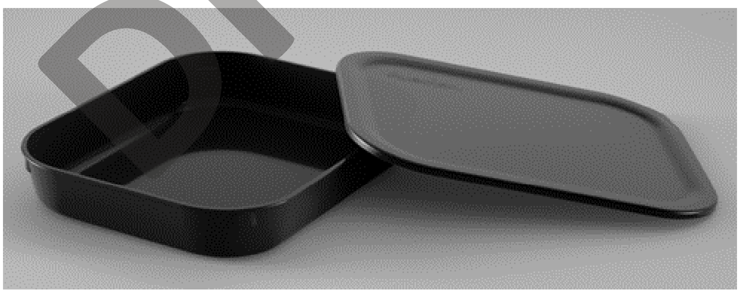


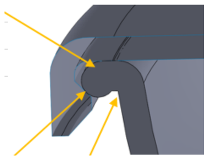
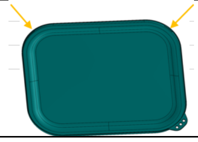
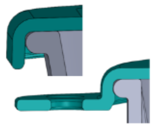
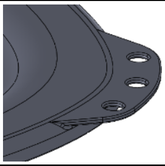
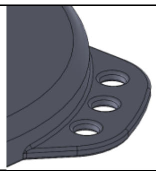
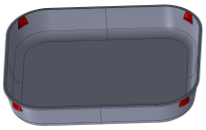
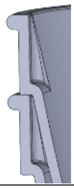
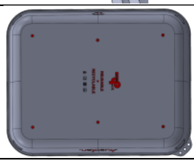
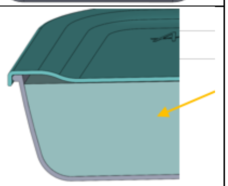
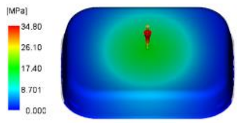
***Figure 3.24.*** *Initial designs presented by ECHO.*

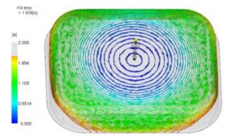
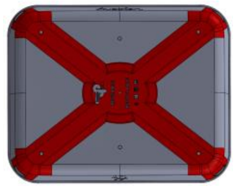
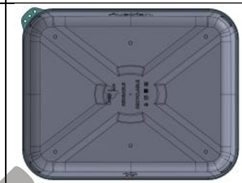
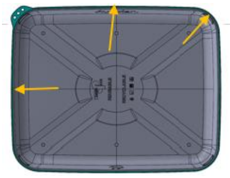
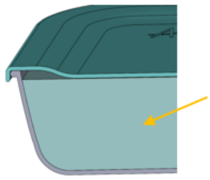
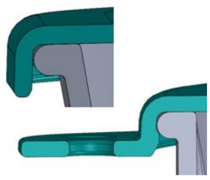
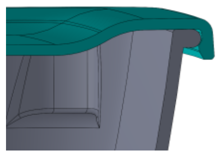
### 3.5.2. Tooling design and development process

Table 3.8 shows the overall process of passing from an initial design coming from ECHO partner through an injected functional part by using SolidWorks and Moldflow tools. At the end of this process, the design is ready to be shared with the mould maker for tooling manufacturing.

***Table 3.7.*** *Modifications in the production of Ausolan 8 portions packaging*

| Date | Modification | Description | View before | View after |
|---|---|---|---|---|
| M17 | General thickness bowl from 1.5 mm to 2 mm | Improving the filling of material in the mould | | |
| | General thickness lid from 1.5 mm to 1.8 mm | Improving the filling of material in the mould | | |

| | | | | |
|---|---|---|---|---|
| M18 | Clipping design | Modification of radius on bowl |  |  |
| | | No retaining zone on bowl for washing | | |
| | | 4 clipping on the lid corners<br>Reduction of clipping dimension | |  |
| | Tab design | Modify tab positionning to determinate parting line of the mould |  |  |
| | Bowl stacking | Adding 4 ribs for bowl stacking | |  |
| | | Height stacking 16 mm | |  |
| M19 | Etchings | Adding etchings under and two sides of the bowl | |  |
| | Support feet | Adding 4 support feet heigher than etchings under the bowl | | |
| | | Adding etchings on lid | |  |
| M21 | Volume inside of the bowl | Increase the volume to 2735 cm3<br>Increase length, width and decrease radius on corner | |  |
| | Injection simulation: switchover pressure | The switchover pressure at nozzle is about 350 bar and 250 bar in the cavity | |  |

| | | | | |
|---|---|---|---|---|
| | Injection simulation: filling | The end of filling has a delay on all 4 corners | |  |
| M22 | Design on the back of the bowl | Increase the thickness of 0.5 mm to accelerate the flow in the 4 angles and obtain more homogeneous end of filling and better packing the peripheral cordon |  |  |
| M28 | Rounded length and width design | Rounded shape to prevent deformation<br>Reduction of radius in corners to conserve volume |  |  |
| | Volume modification | Slight volume reduction of 2735 $cm^3$ to 2693 $cm^3$ | |  |
| | Clipping design | Peripheral clipping for sealing due to new specification |  |  |



### 3.5.3. Tool manufacturing

Once the tooling design was finalised, the tool manufacturing phase began. For this project, steel tools were selected as the ideal technology due to the project demand of quality parts in large volumes.

The first injection trials are scheduled for Week 10, after which the tuning process will take place throughout M31, M32. Full-scale packaging production at Knauf Industries is planned for M32 (April 2025).

## 3.6. Dawn Meats

**Semi-Rigid skin pack for meat distribution**

### 3.6.1. Project requirements and specifications

For this use case, the goal was to create reusable vacuum skin packaging (VSP) trays for the meat distribution industry. The primary focus was on selecting appropriate manufacturing processes and materials that could deliver functional trays with the necessary mechanical strength and durability for multiple use cycles. Sheet extrusion and thermoforming were identified as ideal processes for creating these trays, with PETG being the preferred material based on the material screening trial conducted during Task 3.1 of the project. The trays needed to withstand mechanical forces during packaging, as well as exposure to elevated temperatures during industrial cleaning. The solution aimed to ensure that the trays maintained their shape and integrity over repeated use cycles and remained compatible with vacuum sealing processes to extend the shelf-life of packaged meat products. Thermoforming was also chosen for its ability to incorporate design features, such as reinforcement ribs and nesting/stacking structures, which would enhance the trays' functionality and appeal to the market. Additionally, the seamless integration of PETG into existing VSP production lines was a key factor in the process selection, leveraging already established equipment and tooling.

### 3.6.2. Tooling design and development process

The selected manufacturing processes, sheet extrusion and thermoforming, were designed to create semi-rigid trays that could be reused in industrial environments. PETG, a versatile material, was chosen for its durability and resistance to deformation, which is essential for maintaining functionality over multiple use cycles. The trays were produced using a third-party packaging manufacturer, utilising the **Kiefel KMD 85 B thermoformer** (figure 3.28), which was already in use for single-use VSP trays at Dawn Meats. The key modification involved removing the spikes from the single-use tray design to improve the structural stability of the reusable trays. This change was essential to ensure the trays were easier to clean and more stable during use, while also eliminating potential issues related to microbial safety.


***Figure 3.25.*** *Dawn meats' thermoforming Kiefel KMD 85 B machine.*



### 3.6.3. Manufacturing and fabrication

The manufacturing of the reusable VSP trays was carried out using the **Kiefel KMD 85 B thermoforming machine**, a standard piece of equipment used for producing VSP trays. The PETG material was thermoformed into trays with a uniform thickness of 1.5 $mm^2$ and a final weight of 95 g. During the manufacturing process, care was taken to ensure that the trays' mechanical properties, such as tensile strength and impact resistance, were maintained post-thermoforming. This was verified through testing, which showed no deviation from the material's original technical specifications. Additionally, the trays underwent washing trials to assess their resistance to mechanical and physical wear after multiple cycles, ensuring that they could withstand industrial cleaning processes.

***Figure 3.26.*** *Dawn Meats' tray CAD design.*

*Figure 3.27. Dawn Meats' produced tray.*

As previously discussed, an important aspect of the Dawn Meats use case is thermosealing. The material selection of PETG was influenced by sealability with vacuum skin packaging lidding films. To ensure compatibility with current packaging lines in Dawn Meats, the tray needed to be compatible with currently used lidding films. The technical specifications of the final chosen lidding film are proprietary. The film itself is a multilayer construction that is recyclable, high barrier, and contains a polyethylene (PE) sealing layer compatible with the PETG.

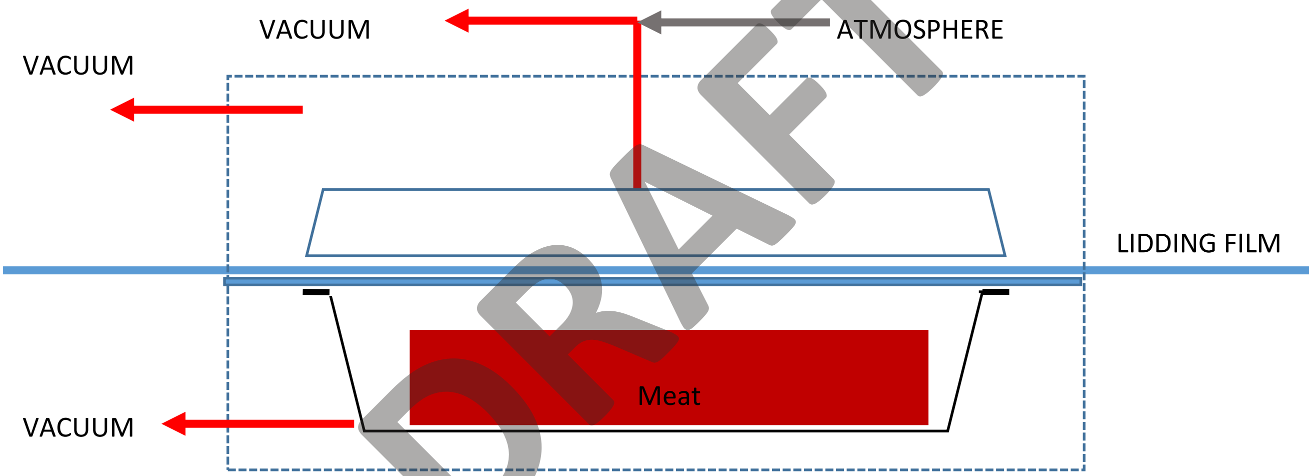



*Figure 3.28. Schematic of vacuum sealing process within sealing chamber.*

During the packaging process, the meat is placed in trays before the lidding film is applied. The lidding film is than heated before shrinking tightly around the meat and adhering to the tray when vacuum is drawn (Figure 3.28). The sealing machine used in the TUS resealability validation trials can be seen in Figure 3.29.


***Figure 3.29.*** *Left: Techpa TM50 Skin vacuum sealing machine. Right: internal machine bed for tray placement.*

### 3.6.4. Tool validation and optimization

The trays were subject to a series of tests to validate their functionality and performance. These included tensile and impact strength testing, as well as water vapour, $CO_2$, and $O_2$ permeability tests. The trays performed well in these tests, with no significant degradation of material properties observed after thermoforming. The trays were also tested for their wash resistance under various conditions, including temperatures up to 75°C, which revealed slight deformation after 15 cycles at the highest temperature. However, at lower washing temperatures (55°C and 65°C), the trays showed no deterioration. Furthermore, the trays' sealability and resealability were tested using a Techpa TM50 Skin sealing machine (Figure 3.29), demonstrating no loss of sealing performance after up to 15 cycles of sealing and washing.

### 3.6.5. Production implementation

The final trays were designed to be compatible with existing packaging lines at Dawn Meats. The selected lidding film, which features a multilayer construction, is recyclable and contains a polyethylene (PE) sealing layer that ensures compatibility with PETG. This film is critical for ensuring the proper vacuum seal and extending the shelf-life of the meat products. The use of these existing packaging materials and equipment should facilitate the easy integration of reusable trays into the production workflow, reducing the need for significant changes to Dawn Meats' packaging operations.



### 3.6.6. Conclusions and lessons learned

The development of reusable VSP trays for Dawn Meats highlights the feasibility and benefits of adopting sustainable packaging solutions in the meat industry. Through careful material selection, process design, and testing, the project has demonstrated that it is possible to create durable, reusable packaging that performs well in industrial settings. The use of PETG, combined with thermoforming and the optimisation of the tooling process, has led to the creation of trays that maintain their mechanical strength and functionality across multiple use cycles. This case study underscores the importance of selecting the right manufacturing processes and materials, as well as the value of integrating new solutions into existing production lines for seamless implementation. The lessons learned from this use case will inform future efforts in the development of reusable packaging solutions, contributing to the broader goal of reducing plastic waste and advancing sustainable packaging practices.

# 4. Conclusion

The **BUDDIE-PACK** project has made significant progress in the development of reusable and recyclable packaging, as reflected in the different case studies developed throughout the project. **Task 3.2**, which is part of **Work Package 3** of the BUDDIE-PACK project, is crucial for the manufacturing of reusable packaging prototypes. This deliverable not only justifies but also provides a detailed description of the work carried out in Task 3.2, focused on the creation of new reusable packaging, with a comprehensive approach that spans from market studies to environmental, economic, and sociological analyses, based on the first deliverables of the project (D1.1, D1.2 & D1.3). This deliverable marks a key point in the project, as it is in this phase that the necessary prototypes are developed to move forward to the next stages of the project, where large scale demonstrations will be conducted.

The case studies presented in this deliverable, corresponding to the companies *Asevi*, *Smurfit Kappa*, *Vytal*, *Ausolan*, and *Dawn Meats*, exemplify how different technologies and approaches are combined to meet the established sustainability and functionality objectives. Through the various manufacturing processes, optimisation of materials, and validation of barrier and resistance properties, progress is being made toward the creation of reusable packaging that is also efficient both in terms of cost and environmental impact. The tests carried out in each case, which include the optimisation of transformation parameters, validation of material properties, and evaluation of recyclability (reported in D3.3), ensure that the packaging meets the highest standards of quality, functionality, and sustainability.

This work demonstrated that it is possible to improve packaging sustainability through innovation in material and process design. Although challenges remain, the case studies presented show that the path towards a circular economy is a real possibility. Based on the results obtained, the BUDDIE-PACK project will move on to its pivotal next phase: the large-scale demonstrations of all the use cases, which should enable to test in real life the performance, sustainability and feasibility of reusable packaging and schemes.

Ultimately, BUDDIE-PACK should serve as a reference for future sustainable packaging initiatives, contributing to the global goal of reducing the environmental impact of plastics and promoting the transition to a more responsible and circular production model.

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