WP T2 INNOVATION ON TEXTILE WASTE MANAGEMENT–

ACTIVITY A.T2.

Deliverable - Guideline

Additional ENTeR pilot - Textile waste coming from medical devices concerning COVID-19 emergency

Version 1

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CONTENT

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ENTeR – Expert Network on Textile Recycling

ENTeR works in five central European countries that are involved in the textile business, to promote innovative solutions for waste management that will result in a circular economy approach to making textiles.

The project will help to accelerate collaboration among the involved textile territories, promoting a joint offer of innovative services by the main local research centres and business associations ("virtual centre"), involving also public stakeholders in defining a strategic agenda and related action plan, in order to link and drive the circular economy consideration and strategic actions.

The approach of the proposal and the cooperation between the partners are oriented to the management and optimization of waste, in a Life Cycle Design (or Ecodesign) perspective.

1. Introduction

The dramatic increase in the use of disposable textile medical devices (such as medical masks, surgical gowns, surgical drapes, gloves, etc.) related to the COVID-19 emergency is leading to an increase in waste. Usually, this waste comes from medical structures (hospitals, clinics, surgeries, etc.) and follows specific procedures (according to national and international regulations) for their disposal after use, packaging, transport, storage, destruction and/or sanitation. The COVID-19 emergency is changing waste streams, due to the wide use of protective medical devices (in particular medical masks) by citizens, with waste being generated outside the usual health facilities and not following the usual disposal procedure but collected with municipal waste.

1.1. ENTeR and pilot case

According to the ENTeR project, the main objective is to reduce the amount of waste for destruction to prevent the depletion of non-renewable resources in the textile industry, with the aim of reducing the effects of the COVID-19 emergency. This additional pilot case aims to define a potential new way of managing medical waste to favour their recycling and/or reuse. This objective will be achieved through specific macro-activities focused on studying the nature of medical textile waste (in terms of base material, chemicals and biological contamination), to define the current procedures for medical textile waste management, to study the removal of chemicals and biological decontamination necessary for recycling/reuse of materials, to evaluate the economic and environmental benefits of recycling/reuse and to create guidelines and best practices for a new and more sustainable waste management for municipalities, regions and other competent authorities.

1.2. Pilot case objectivies

Reduce waste for destruction and provide guidance to competent authorities on how to manage the collection of textile waste.

2. Guidelines for the treatment of medical waste

2.1. Current procedures for medical textile waste management

Health care waste must be managed in a way that reduces the hazard, encourages reuse, recycling, recovery and optimises collection, transport, and disposal.

Textile medical waste is divided, according to specific legislation, into medical waste treated as municipal waste and hazardous medical waste with infectious risks. The first is subject to the legal regime and management methods of municipal waste. The second is instead waste coming from infectious isolation environments where there is a risk of airborne biological transmission, as well as from environments where patients remain in infectious isolation with diseases caused by group 4 biological agents. The management of the latter is regulated by law and may involve a preliminary sterilisation procedure to decrease the microbial load, followed by incineration.

In the pandemic situation caused by COVID-19 there has been an increase in disposable medical personal protective equipment and consequently an increase in medical waste not only from hospitals and clinics but also from the population with mass use to prevent the spread of the virus. There has therefore been an increase in medical waste, which in the case of use by the population is thrown together with municipal waste, making it potentially dangerous. In the pandemic situation, all textile protective equipment used in healthcare facilities is managed as infectious risk waste and therefore follows the management, storage and disposal regulations for this type of waste.

The continuation of the pandemic did not lead to a change in legislation in the medical sector, but the institutions had to deal with the problem of an increase, especially of masks, in the municipal waste coming from urban contexts, such as businesses and homes. To overcome this, each country has established rules for the management of such waste by its citizens, following the guidelines of the World Health Organisation and taking inspiration from the management of infectious waste in the medical sector. Although with some small differences, the various geographical areas of Europe have decided to manage masks from the population as undifferentiated waste or dry waste. This category of waste does not have a recycling or reuse destination, which is why its production percentage is clearly decreasing in Europe. Undifferentiated waste is managed by landfill or incineration, which in the fight against the spread of the virus may be a solution to be adopted in a short time, but with the continuation of the situation it becomes environmentally unsustainable leading to the destruction of recoverable material and continuous use of resources.

2.2. Materials and chemicals for medical textiles

The masks commonly used for the protection of the respiratory tract both in the medical field and in other sectors (surgical masks and respirators) are produced through the layering of non-woven fabrics, with different weights and different characteristics. In fact, even the simplest surgical mask is made up of at least 3 layers of non-woven fabric, of which the intermediate layer is different since it is the filtering element that must simultaneously have the capacity to pass air and block suspensions present in the air. The filtering capacity depends on this intermediate layer but also on the number of layers in the entire mask. The non-woven fabric used for the layers is produced using mainly two different technologies, spunbond and meltblow, which extrude the polymer using different techniques. The filter layer is obtained through the meltblow process and in the simplest surgical mask this layer is located between two spunbond layers. In respirators, the filter layer is made of an electret (or polarised) meltblow non-woven fabric to improve the filtering capacity. The most used material to produce these layers is propylene; in addition, polyester and hydrophobic cotton are used to a lesser extent. The layers are then bonded together through thermal or ultrasonic welding processes.

In addition to the layers, there is a metal nosepiece inside a mask to mould the mask to the shape of the wearer's nose. In addition, the masks have laces, which in surgical masks can be of two types, 2 elastic or 4 laces, while in respiratory masks they are 2 elastic.

Some of these devices have a water-repellent finishing layer on the outside to prevent water drops passing through it and improve protection. This finishing is usually fluorocarbon-based, as it allows the application of a water-repellent layer with simultaneous low surface tension. Hydrocarbon (waxes) or silicone-based finishing are also used.

2.3. Chemicals removal and sanitation

The major issue in the reuse/recycling of masks used for virus protection is their safe handling by operators of waste management and recycling facilities. Legislation concerning waste from the healthcare sector provides for the possibility of sanitising these materials before disposal. The particularity of the regulated process is the need to make the waste unrecognisable by shredding it into small parts without previous separation of the materials to be sanitised. This leads to the production of a mixed final material which may contain glass, plastic, paper etc.

Since the start of the pandemic, various technologies have been investigated with the aim of sanitising the masks in order to be able to reuse them, while at the same time guaranteeing the required filtering characteristics. These studies have led to the use of various types of sanitisation, with some cases where it is possible to reuse the masks several times, before they lose their filtering capacity or degrade irreversibly. These technologies are divided between using physical or chemical processes, through the use of hydrogen peroxide, humidity and UV radiation. The solutions devised using various methods and technologies all have a high removal rate of the virus with viral inactivity values above log 5, i.e. a removal rate of over 99.999% within a few minutes of processing.

The presence of possible finishing on the surface of the mask can lead to problems in processing the devices and obtaining a recycled product with a content of impurities and potentially harmful substances. The removal of surface materials such as finishing, and coating is something that many projects are working on. A solution to this issue can be provided by the REACT project of which Centrocot is the leader. In this project, the study of methods to remove finishing applied to acrylic fibre can be appropriately used to remove finishing on masks, as the chemistry of the compounds is similar. In addition, the multi-step process of acid/base treatment and UV irradiation has unfavourable conditions for the virus and can therefore act as a simultaneous sanitisation process.

3. Guidelines for the reuse of medical waste

3.1. Environmental evaluation

The LCA study focused on the comparison between the state-of-art (i.e. incineration/landfill) and a recycling action specific for the fabric, and different options were taken into account with the goal of initially screening them and spotting possible issues or criticalities.

When considering the overall outcome, results are quite variable.

As a general consideration, it is worthy to highlight that the greatest contribution to the overall impact of the masks come from the production and the finishing process (i.e. about 80% in the baseline 1-a). The second in particular covers a significant fraction of the impact (about 50% in the baseline 1-a) due to the chemicals used in the process. This could be read as a reason to boost the recycling of the material, in order to avoid at least the production of new virgin polypropylene.

Looking at the EoL scenario, the possible considerations are the following.

Starting from the baseline, the incineration scenario shows potential improvement in waste management environmental impact: by incinerating the whole amount of medical masks, the energy recovery (and the avoided generation of electricity) decrease the impact scores of about 5%. This result is not very significant because the baseline representing the current MSW treatment already takes into account a high fraction of incineration (i.e. 60%).

Coming to the recycling options, the mechanical recycling is potentially the best scenario from the environmental performance point of view. When compared to the other recycling scenario is it clear that the amount and the type of chemicals hypothetically used to treat the fabric before the mechanical step have an additional impact. This significantly affects the overall performance of the recycling and increases the score for several indicators by an average 15% compared to the only mechanical treatment.

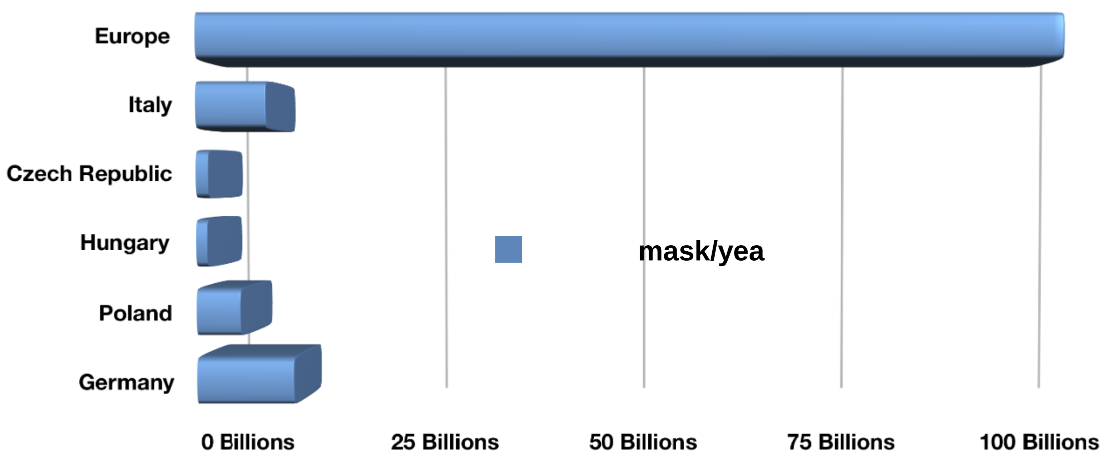
As a conclusion, it is possible to say that on a theoretical basis, the mechanical recycling could be a feasible option, both from the practical and the environmental point of view. Nevertheless, some further aspects should be considered:

- The recycling rate assumed in the study (i.e. 100%) could be not realistic. A lower rate sounds more reasonable, ideally 40-60%.
- The mechanical recycling process assumed in the study (i.e. the PET process) could be not fully representative for the polypropylene material used for the medical masks. Primary data should be collected to increase the overall robustness.
- No destination is considered in the present study for the recycled polypropylene. One or more options related to the possible use of the recycled material should be accounted, especially because recycled PP is usually mixed with virgin PP at up to substantial fractions to produce new products. However, given its inherent flexibility, PP can be recycled back into many different products, including:
    - Clothing fibres.
    - Industrial fibres.
    - Food containers/bins/gardening items.
    - Dishware.
    - Speed humps.

3.2. Economic evaluation

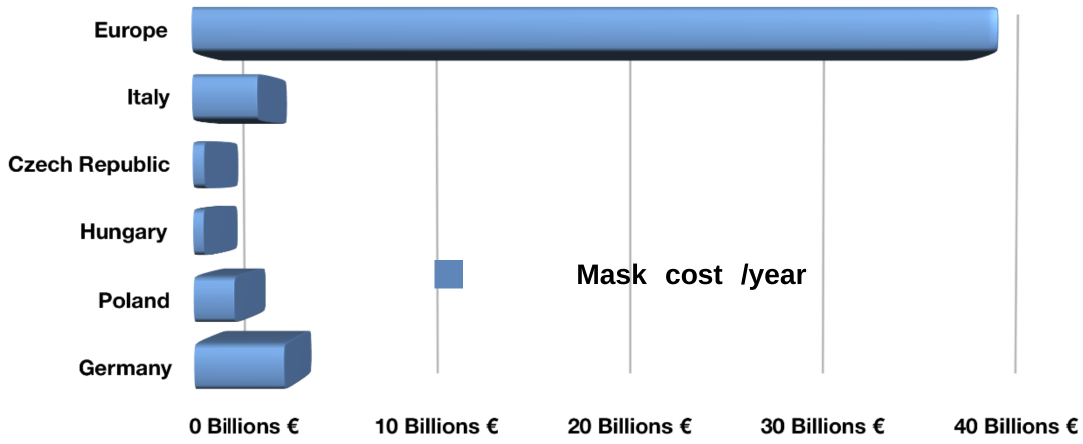
The economic scenario to produce waste mask evaluates the related costs of collection, logistic, sanitation/chemical removal and recycle of medical textile. This one provides a comparative study between current and proposed waste management practices such as waste recovery. The comparative study was carried out to verify if there are significant economic benefits. The economic value of mask for day is calculated by data from article on Asian mask consumption and actual habitant numbers for Europe and local investigated countries. European market which is around 100 billion masks per year.

	Asia	Europe	Italy	Czech Republic	Hungary	Poland	Germany
mask/day	2.228.170.832	358.938.828	29.021.676	5.140.311	4.636.968	18.166.373	40.216.292
habitants	4.612.337.109	747.789.224	60.461.826	10.708.981	9.660.351	37.846.611	83.783.942
Mask Coefficient use for habitants	0,48						
Mask/year (Billions)		96,91	7,84	1,39	1,25	4,9	10,86



If selling price of one mask is around 0,5 € and that typical first revenue margin is 30%, it is possible to calculate a global cost of raw material, production, transport, logistics and distribution of around 0,38 €. With this value, an estimation of global cost for mask use during pandemic in Europe and local countries is done, with a final cost just under 40 billion a year.

	Europe	Italy	Czech Republic	Hungary	Poland	Germany
Mask cost/year (Billions €)	36,83	2,98	0,53	0,48	1,86	4,13



If we adopt the pre-COVID situation, in the Economic scenario for the masks incineration, we note a sum of costs without advantages for Europe and local Countries. Indeed, all production phases are in China and out from Europe. In Europe remains only distribution and waste collection. This means that we have only cost, without revenues. Instead, due to COVID situation, Europe needs to shift as many steps as possible of industrial chain to avoid lack in mask procurement, creating revenues in Europe that can equalize cost to manage waste incineration. Instead, recycling waste bring a secondary raw material production and new process, that in according to Circular Economy principles and Industrial Symbiosis is a virtuous cycle that avoid waste increase in landfill creating new secondary raw material to produce new goods in Europe. According to this scenario, waste recycle of mask can generate an internal market with very high values and advantages to avoid both social and economic cost and, especially, to avoid supply lack. COVID-19 situation can create conditions for a strong effort to apply these concepts to real large cases with double advantages: independence of industrial production line by external factors and valorisation of production in an internal market without full external import of goods. If, as supposed in analysis, we succeed in this, an internal market of around 22 Billion € is foreseen avoiding market from other countries.

4. Conclusions - Guidelines

The study carried out to recycle the face masks used to spread the virus has revealed an economic opportunity for Europe. At present, the primary products to produce the masks and the technologies to make the non-woven material are located outside the European Community, with a majority in Asia. A market that currently costs Europe just under EUR 40 billion. Moreover, the destruction of end-of-life materials by thermal destruction increases costs without an economic benefit for Europe. The pandemic situation has led to a shortage of masks, which has consequently accentuated the need to move the industrial production chain as far as possible in order to balance incineration costs. The introduction of mask recycling processes has an economic impact on costs related to production and end-of-life management, as waste production is avoided and new secondary raw material is created, which can be used to produce new masks or other materials. Creating, as mentioned above, a European internal market of around €22 billion by stimulating the application of a mask recovery and mechanical recycling process.

The current waste collection management regarding protection against the SARS-CoV-2 virus has been implemented according to the recommendations issued by the WHO, which indicate that protection material such as masks and gloves as well as handkerchiefs should be handled as potentially infected, even when used by healthy people. This implies that citizens should handle the waste as unsorted. The regulations implemented by the various European states require that such materials be placed in bags that are properly sealed with ties or adhesive tape to avoid crushing the contents. The bags containing the material must then be placed in the unsorted waste bag. Finally, this material is managed through incineration in waste management plants. This management could be implemented with improvements to recycle the material, combining the WHO recommendations with the current system of infectious healthcare waste management.

A starting point is the use of specific collection bags distributed by the authorities made of polypropylene (the most used material for the manufacture of masks) in which citizens can throw the masks. The use of bags made of monomaterial chemically identical to the masks could also improve the recycling process. Indeed, once the bags arrive at the recycling plant, the PP bag can be prevented from being opened, thus avoiding potential virus leakage and hazards for the plant operators.

Another problem that needs to be solved during the management of these materials is the introduction of these specific bags for the collection of masks within a collection of material that is not recycled; this involves additional management steps, where the bags containing the masks should be separated from the rest of the residue. To overcome this problem, using a management system like infectious healthcare waste could be a solution. In the health care sector, these materials must be placed in special containers with a specific colour so that they can be easily identified. At municipal level, a collection system like that for batteries and oil could be reintroduced, with specific self-closing containers for the collection of bags containing masks, so that waste collection companies could collect these materials separately and take them to the specific waste management plants.

Some European regions have established a synergistic system of collaboration between the health system of registration and control of positive cases and municipal waste management companies. This collaboration has led to door-to-door waste collection in homes where positive persons are known to be present and are therefore in a quarantine situation. The national/local control centre transmits the personal data of the quarantined persons to the collection company, which is thus facilitated in the task of recovering the waste. The implementation of a similar system focused on masks would allow an improvement on the management and collection of the material, facilitating the recycling of the masks and would be an important building block for the circularity of the PP that is abundantly used in this situation.

A factor to be considered during the handling phase is the protection of the personnel collecting the waste. In this regard, studies carried out on SARS-CoV-2 have shown that the persistence of the virus changes depending on the material and obviously on the conditions. Considering the persistence of the virus on plastic surfaces (such as PP), the detection time was 3-4 days under laboratory conditions. A study focusing on surgical masks showed that the virus can persist for up to 7 days (approximately 0.1% of the inoculum) on the outer side of the mask under laboratory conditions. However, under conditions outside the laboratory, studies have shown that there are virus particles on the plastic surfaces 72 hours after application, but that their TCID50 value has clearly decreased. Considering that the half-life of the virus on plastic surfaces is 6.8 hours, the risks to the sampling operators are reduced with daily waste recovery, and the risk is further reduced by implementing normal mask procedures.

The recovered material could be sanitised to further reduce the infectious potential, and the sanitisation treatments that can be implemented are diverse and range from the use of chemical compounds to physical processes. Sanitisation at the regulatory level concerning infectious healthcare waste management practices is an optional practice, which allows the product to be sent to waste-to-energy processes. The major issue is the need to make the material unidentifiable. This system shreds and dries the waste without prior separation. There are various devices and technologies on the market for the decontamination and treatment of medical waste. Using these technologies, it is possible to treat various types of medical waste including used PPE (face masks, gloves, disposable coats and clothing in general, nappies, bandages, blood bags, test tubes and many others). As one of the examples we can mention the devices produced by the company Siemens: their CONVERTER device is a single-chamber shredder of medical waste. It can be used to treat waste according to codes. The waste is shredded into small, unidentifiable particles. The shredder and the blades are constantly rotating, and their mechanical energy causes a rise in temperature at which the moisture contained in the waste evaporates. In the case of treating municipal waste with no hazardous properties, the process ends after reaching a temperature of 100 °C; in the case of treating hazardous waste, the process continues until the temperature reaches 151 °C. The resulting shredded particles are then cooled and removed to storage. The final waste product resembles normal hoover dust; it is completely sterile, dry, odourless and contains no sharp components. The original volume of waste is reduced by up to 70% and the weight by almost a third. By using similar equipment to treat the masks alone, it is possible to obtain a sanitised material consisting mainly of PP from which only the metal contamination of the nose pads needs to be removed, which is a common separation practice in the recycling of plastic materials. Another effective sanitisation system can be the exposure of the masks to UV-C radiation by passing the masks through a conveyor roller under these lamps.

The LCA data have shown that the least impactful sanitisation method is physical sanitisation, avoiding the use of chemical compounds, so sanitisation by means of the Siemens CONVERTER would be economically and environmentally advantageous, bringing benefits in establishing circularity processes. Considering the sanitisation of the material by means of the CONVERTER, it would be possible to sanitise the material by just producing PP chips through granulation in extrusion. In fact, the operating conditions of PP extrusion are 200-250°C, far higher than the temperatures reached by the CONVERTER. The implementation of such a procedure would further reduce costs, as a process step would be skipped, and would also bring environmental improvements.

5. Best practices

Since the start of the pandemic, many efforts have been made to limit the problem of increasing waste, both in terms of reusing masks after sanitisation, recycling systems for end-of-life material and the design of new masks to counteract single-use or improve end-of-life possibilities.

The possibility of reusing the mask would influence the production of waste as it would allow a material designed to be a single-use device to extend its life. From this point of view, Nebraska Medicine in Omaha has introduced a process of sanitising the masks used by healthcare workers to extend the use of the device and reduce the amount of waste generated by the facility. The process of sanitising the masks is carried out by irradiating the surface with UV radiation at a higher energy than that required to inactivate the virus, guaranteeing a wide margin of decontamination of the surface. The masks are fixed on cables in a room with two UV radiation towers on either side, the walls of the room are covered with a material reflecting the UV radiation, and the room is equipped with an exposure dose meter so that the treatment is stopped with a start/shutdown outside the room. In addition, Nebraska Medicine has established guidelines for the management of this system, indeed, the health operators mark on the outside of the mask their name and the date of first use, at the end of the turn the operators deliver the mask inside a special brown paper bag labelled with the name, once the masks have been decontaminated, they are returned to the operator inside a white paper bag labelled with a new brown paper bag, and a mark with an indelible marker is added to the masks to keep track of the number of times they have been sanitised.

An extension of the life of masks was introduced during the general lockdown, the lack of supply of common surgical masks or respirators led companies to innovate with the introduction of community masks, which are neither medical nor PPE products and are intended to protect those around the user, so they must always be accompanied by preventive measures such as social distancing. These masks can be made from a variety of woven or knitted fabrics. This results in variability in filtration and breathability, with variations in filtration ranging from 0.7% to 60%. These masks have also been designed with a special pocket for inserting an interchangeable high-performance filter element, to have a fixed support with the possibility of washing it and a high protection efficiency. In order to improve the protective capacity of the community masks, the fabric used for their manufacture is finished with a layer of antibacterial material so that they become an effective device for protecting the user.

An interesting initiative in the mask recycling system has been carried out in France by Plaxtil. This French company, active in recycling and circularity in the textile sector, has implemented in July 2020 a system for the management, recovery, sanitisation, and recycling of the masks used by the population in the town of Châtellerault. Plaxtil has created a complete supply and recycling system for masks starting from the basics of material recovery at the end of their life. Through the collaboration of voluntary shopkeepers and SMEs, 50 collection centres have been installed throughout the town consisting of cardboard containers where used masks can be stored. The masks are then collected from the containers by operators of the AUDACIE social cooperative, which 'quarantines' the masks for four days before sending them to Plaxtil. The metal part of the masks is removed, and they are then shredded and disinfected using a UV irradiation process. This double sanitisation process ensures the safety of the operators, and then the masks are recovered through extrusion and moulding processes to produce plastic materials such as the components of the protective face shields used by the operators. This project demonstrated the possibility of recovering and recycling the masks on a citywide basis, leading the company to contact the authorities to set up a nationwide mask recovery process.

Other initiatives to facilitate the end-of-life of this material have been taken by modifying the way the masks are produced, i.e. no more PP masks but masks made according to eco-design criteria that see the end-of-life of the mask through biodegradation and compostability processes. An example is the mask made entirely of hemp, which is therefore compostable, with filtration efficiencies equal to those of FFP2 respirators. This mask has a hemp fibre structure without the aid of glues, and on the inside, there is a PLA film (which is also compostable) to increase filtering capacity. Another example of compostability is that developed in the Philippines, where they have started to produce protective masks from abaca fibres. In Canada, however, they have developed a compostable mask made from wood fibres. The AirX face mask created from coffee boasts a vegan, biodegradable, and antimicrobial design: it has received AATCC 100 certification, which means it meets the textile industry standard for antimicrobial fabric performance in the US. The mask itself is made from coffee yarn and is used with a biodegradable air filter insert made from silver and coffee nanotechnology that should be replaced approximately every 30 days.

Some research and ideas have led to the development of masks with a production concept that differs from the classic production of fabric or non-woven fabric. One example is the use of additive manufacturing processes. In fact, 3D printed masks have been developed with an appropriate compartment in which to insert the filtering element that gives the mask its breathability and filtration characteristics. The filtering element is incorporated into the mask and is a modular system produced from a polymer with copper nanoparticles, embedded in 3 layers of non-woven PP fabric, all interchangeable.

An alternative way researched is to use materials produced by bacteria to make the mask, the mask is created from a sample of common bacteria cultivated through the addition of products such as tea and sugar, this cultivation process takes a few weeks and the material created is translucent.

Finally, there are emerging technologies that incorporate mask sanitisation systems internal to the material structure, two examples are the mask with a carbon fibre layer and the mask with a UV sterilisation system. In the first case, the mask was created with a layer of homogeneous carbon fibre inside the layers of non-woven fabric. This layer of carbon fibre is used to heat the mask with a low current (2 amps), like a smartphone charger, destroying the viruses accumulated on the mask and making it reusable. In the second case, the mask is equipped with a double filtration system, a preliminary filter similar to the N95 filter, blocks 95% of particles up to 0.3 microns, microorganisms smaller than this size enter in a helix-shaped filter where there are UV-C lights that destroy 99.9% of the microorganisms with a final filtration efficiency of 99.99%, the process also works during exhalation, guaranteeing a purification of the air both at the inlet and outlet, breaking down genetic materials in milliseconds.