WP T2 – INNOVATION ON TEXTILE WASTE MANAGEMENT

ACTIVITY A.T2.3 PILOT CASES

D.T2.3.2 PILOT CASES

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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 is oriented to the management and optimization of waste, in a Life Cycle Design (or Ecodesign) perspective.

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1. Pilot case description – aim and scope

The Pilot case "Textile waste coming from medical devices concerning COVID-19 emergency"

The COVID-19 pandemic has revealed the urgent need for large number of disposable textile medical devices both for the healthcare workers (surgical gowns, medical masks, respirators, surgical drapes, gloves) as well as for the citizens (protective face masks). The dramatic increase in their use is leading to significant increase of waste production worldwide.

The additional pilot case of the ENTeR project "Textile waste coming from medical devices concerning COVID-19 emergency" aims to define a potential new way for medical textile waste management in order to favour their recycling and /or reuse. The aim is to study the medical textile waste materials (material, chemicals, biological contamination), to define current procedures for medical textile waste management, to study removal of chemicals and biological decontamination, to evaluate economic and environmental benefits of it´s reuse / recycling and to create guidelines and best practices for a new and more sustainable waste management

In Czech Republic, wearing of the face masks was mandatory from 19th March 2020 till end of June 2020 and is mandatory again after the summer break from 1st September 2020. As there was a lack of the the disposable face masks in Czech Republic at the beginning of the covid-19 pandemic situation, this product was not available on the market and the emergency supplies were restricted by the government to be supplied exclusivelly to the hospitals, doctors at ambulances and to other first response health services. To be compliant with the obligations according to the government action, the Czech citizens proactively started to sew the face masks from textile fabrics (100% cotton strongly preferred) at home.

Outside the ENTeR project, INOTEX in cooperation with external partners has developed the textile fabric with special treatment which is used for production of the textile face masks „FreshDye". These masks work on principle of the fotoactive dyestuff which after irradiation with common daylight generates the short-term reactive forms of oxygen; thanks to that, the mask is protected against the pollutants including aproved antibacterial effect. Thanks to that effect, it is not necessary to wash the masks at 100°C to decontaminate them; textile can be washed at 60°C. The approved durability of the photocatalytic dyeing at minimum 50 washing cycles prolongs the service life in comparsion to 100% cotton masks and significantly reduces amount of waste in comparison with disposable masks.

Within the pilot case, reduction of generated textile waste from disposable masks thanks to the „FreshDye" face masks will be evaluated.

2. Theoretical part

2.1. The respiratory PPEs related to the COVID-19

2.1.1. Respiratory protection masks

It is necessary to distinguish between the medical face masks and respirators.

A respiratory protection mask (respirator; synonyms: FFP masks, filtering face piece **(15)**) is a personal protective device used to protect the wearer from inhaling hazardous airbone particles (dust, infectious agents, gases, vapours). It covers at least the nose and mouth. Respiratory

protection masks must comply eith the European Personal Protective Equipment Regulation 2016/425/EU and the European standard *EN 149:2001+A1:2009 - Respiratory protective devices - Filtering half masks to ptotect against particles - Requirements, testing, marking*. They must wear the CE certification label.

Fig.1: Respiratory protection mask (respirator)

There are 3 types of respiratory protection masks: (13)

- FFP1 mask – the lowest level of performance; efficiency of at least 80% against airborne particles, the side leakage (around the face) must not exceed 22%. It is used when norovirus is present.
- FFP2 mask – average category of protective masks; efficiency of 94% solid and liquid irritant aerosols, the side leakage must not exceed 8%. It is used when TBC is present.
- FFP3 mask – high protection against solid and liquid toxic aerosols; minimum efficiency of 99%, the side leakage must not exceed 2 %. It is used when working with cytostatics.

In addition tot he penetration levels mentioned above, there are still othe requirements which must be met by masks of these three types.

2.1.2. Medical masks

The medical masks (synonyms: oronasal protection, surgical masks (15)) are the disposable face coverings used by infected persons, healthcare workers or public to ensure a barrier that reduce transfer of body fluids which may spread infection and protects other people around the wearer; they are not designed to protect the wearer against entry of infection. They are designed to fit loosely over the nose and mouth of the user. These masks are subject of approval and certification; they are not respirators and they undergo a different regulatory and certification process. (9)

The early reusable surgical masks were made of woven linen; their funciton was only to redirect the exhaled air away from the surgical wound. These cloth surgical masks were replaced in early 1960s with the synthetic materials (as described bellow in chypter 2.3.) that also provide bacterial filtration and improved filtration efficiency. (9)

Fig.2: Disposable medical mask

For the European market, the medical face masks are classified in type I or II; for the American one, in level 1, 2 or 3. (14)

In EU, the medical face masks must be compliant with the Medical Devices Directive and the European standard *EN 14683: Medical face masks - Requirements and test methods*. The masks must be certified with CE-mark.

The medical masks are subject to five tests described in EN 14683:

- Bacterial filtration efficiency (BFE)
- Breathability (delta P)
- Splash resistance (synthetic blood)
- Microbial cleanliness (Bioburden)
- Biocompatibility

The tests are performed on the masks as a finished product or on a samples cut from masks.

Based on the results from the tests mentioned above, the medical face masks are classified in two types (Type I and Type II) according to bacterial filtration efficiency; Type II is further divided according to wheather or not the mask is splash resistant (the "R" signifies splash resistance): (13, 18)

- Type I - designed to be worn by patients, not by medical staff
- Type II - to be worn by medical staff in those cases where there is no risk of splashes of body fluids
- Type IIR - designed to protect the nasal and mucous membranes against splashes of body fluids. Moisture impermeable.

Test	Type I (*)	Type II	Type IIR
Bacterial filtration efficiency (BFE), (%)	≥ 95	≥ 98	≥ 98
Differential pressure (Pa/cm^2)	< 40	< 40	< 60

Splash resistance pressure (kPa)	Not required	Not required	≥ 16,0
Microbial cleanliness (cfu/g)	≤ 30	≤ 30	≤ 30
(*) Type I medical face masks should only be used for patients and other persons to reduce risk of spread of infections particularly in epidemic or pandemic situations. Type I masks are not intended for use by healthcare professionals in an operation room or in other medical settings with similar requirements.			

Table 1: Performance requirements for medical face masks according to EN 14683:2019 (33)

The medical masks are considered medical devices of class I and the manufacturer has to run a risk analysis and additional testing if needed to respond to the European Medical Device Regulation 2017/745/EU. The manufacturer has to be registered as the medical devices´ manufacturer.

In the US, the medical masks are considered medical devices class 2. They are subject to tests according to US standard *ASTM F2100-11 Standard specification for performance of material used in medical face masks*. Several tests are not run on the final product, but on the different materials used in the final mask. According to the tests resultrsm the masks are classified in three levels.

The tests are the same tests as the ones described in European standard EN 14683, except that also the measurement of filtration efficiency regarding inert particles (latex) and fire tests are prescribed. The materials composing the mask are evaluated by five tests: (14)

- Bacterial filtration efficiency (BFE)
- Breathability (delta P)
- Splash resistance
- Particle filtration efficiency
- Fire test

2.1.3. Community masks

The community masks (synonyms: DIY masks, makeshift mouth-nose mask (15)) are only suitable for private use. These are not medical products not personal protective equipment. They are not suitable for use in healthcare or nursing, as occupational health and safety clothing or as other protective clothing to prevent from infection or other harmful substances.

They are aimed to be used only for a source control in community – to protect other people around the wearer from spreading the potential infection – and not for prevention. Their use should be always accompanied by prevention measures as by frequent hand hygiene and physical distancing.

The non-medical masks may be made from a variety of woven or knitted fabrics or non-woven textiles and various shapes. This huge combination of materials results in variable filtration and breathability.

Filtration efficiency depends on the tightness of the wave, fibre or thread diameter and, in case of non-woven materials, the manufacturing process (spunbond, meltblown, electrostatic charging). The

filtration of cloth fabrics masks has been shown to vary between 0,7% and 60%. The higher filtration efficiency means the more of barrier provided. (34)

The community masks should, however, meet the general requirements for textiles. They are intended to be repeatedly used and – thus – maintained and disinfected.They should be not harmful to health and should be provided with the maintenance symbols.

On a market, also the community masks with a "pocket" for insertion of a filter (e.g. from nanofiber non-woven textile) with declared high efficiency against airborne particles /infectious agens. In this case, the manufacturer of the filtering material should be able to provide the trustable documents (certificates, protocols) to declare it´s performances. The same should be also in case of textile materials declaring the antimicrobial or other performances. **(17)**

Breathability is the ability to breathe through the material of the mask. It is the difference in pressure across the mask; it is reported in millibars (mbar) or in Pascals (Pa) or, for an area of mask, in mbar/cm^2 or Pa/cm^2. Acceptable breathability of a medical mask should be bellow 49 Pa/cm^2; the acceptable pressure difference for a non-medical mask, over the whole mask, should be bellow 100 Pa. (1)

The filtration quality factor "Q" is a function of filtration efficiency and breathability. The higher values indicate the better overall efficiency. The recommended minimum Q factor is three (3). (34)

Fig.3: Community mask from textile (16)

There are not any special performances requirements regarding the community masks. However, the French Association for Standardisation (AFNOR Group) has developed a non-medical mask standard *FNOR SPEC S76-001 Barrier masks. Guide to minimum requirements, test methods, manufacture and use* which recommends minimum performance requirements (34):

- Filtration – minimum 70% solid particle filtration or droplet filtration
- Breathability – maximum pressure difference of 0,6 mbar/cm^2 or maximum inhalation resistance of 2,4 mbar and maximum exhalation resistance of 3 mbar

However, this document contains recommendations for design and use of the mass manufactured and homemade masks but does not allow conformity assessment. (32)

On the other hand, the Spanish Association for Standardisation (UNE) published the specifications for non-reusable and reusable hygienic masks: *Specification UNE 0064:2020. Non-reusable hygienic*

masks. Materials, design, manufacturing, marking and usage requirements and *Specification UNE 0065:2020. Reusable hygienic masks for adults and children. Materials, design, manufacturing, marking and use requirements.* These Specifications allow conformity assesment by laboratory based on technical specifications EN 14683:2019 + AC: 2019 or another equivalent. (32)

Test	Acceptance criteria for non-reusable hygienic masks	Acceptance criteria for reusable hygienic masks
Bacterial Filtration Efficiency (BFE), (%)	≥ 95	≥ 90
Differential pressure (Pa/cm^2)	< 60	< 60

Table 2: Acceptance criteria for hygienic masks
according to the Spanish Specifications UNE 0064:2020 and UNE 0065:2020 (32

Also in the USA, the US Association of American Textile Chemists and Colorists (AATCC) isdued on 1st June 2020 the first version of the draft *AATCC MXXX-2020 Guidance and Considerations for General Purpose, Textile Face Coverings: Adult*. (47)

The European Committee for Standardization (CEN) was asked by European Commission to make a European standard; based on that, the experts issued the document *CEN Workshop Agreement CWA 17553 Community face coverings - Guide to minimum requirements, methods of testing and use*. This document specifies the minimum requirements for reusable or disposable community face coverings intended for general public. (47, 48) It can be expected that later it will be followed by the European standard. This document defines the minimum requirements concerning the sizing, packaging, materials to be used, cleaning (the reusable masks should withstand the number of washing cycles as claimed by producer, at least 5 cleaning cycles, at minimum washing temperatue of 60°C), head hardness etc. It also defines two levels of community face masks according to their filtration efficiency to particles around 3 µm:

- Level 90% (filtration efficiency ≥ 90 %)
- Level 70% (filtration efficiency ≥ 70 %)

The defined breathing resistance and air permeability should be the following: (48)

- Differential pressure ≤ 70 Pa/cm^2, correlates to ~80 l/s/m^2 for a vacuum pressure of 100 Pa

or,

- Breathing resistance: - inhalation resistance of 2,4 mbar
  - exhalation resistance of 3 mbar

or,

- Air permeability ≥ 96 l/s/m^2 for a vacuum pressure of 100 Pa

2.2. The filtration mechanism of respiratory protective PPEs´

There are three mechanisms of removing particles from the airstream: inertial impaction, diffusion, and electrostatic attraction. Mechanisms for removing large particles are different than mechanisms for small particles.

For aerosol particles at the size of approx. 1 µm, the filtration effective mechanism is the inertial impaction. These particles have enough inertia and instead of flowing through the filter material, they deviate from the air streamlines, collide with the fibers and may stick to or be caught in them.

The effective filtration mechanism for for much smaller particles (0,1 µm and smaller) is the diffusion. The constant Brownian motion of oxygen / nitrogen molecules causes collisions between particles. Thanks to that, the small particles have increased chance to collide with the filter fiber and to remain there.

Another method of capturing both large and small particles is an electrostatic attraction. The electrically charged fibers or granules are embedded in the filter to attract oppositely charged particles and to remove them from the airstream.

The particles captured by the filter are held tightly to the fibers through van der Waals bonding and other forces. (9)

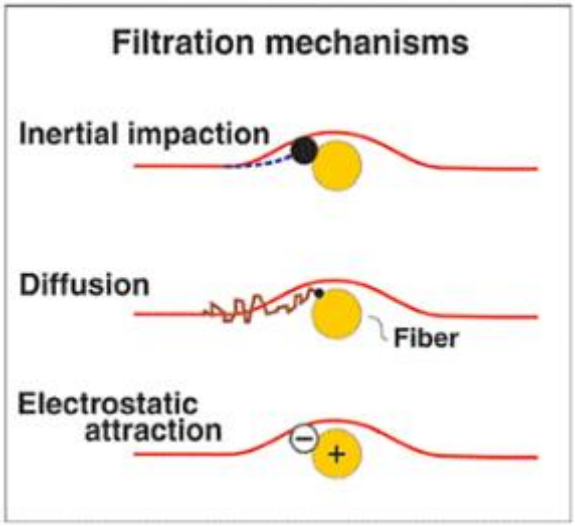

Fig.4: Filtration mechanism (9)

2.3. Materials used for the disposable medical masks

2.3.1. Materials used for disposable medical masks

The filtering materials of respirators and medical masks are typically nonwoven textiles – mostly the spunbonded polypropylene. Because polypropylene is inherently hydrophobic (water repelling), the polypropylene fiber surface needs to be modified to achieve hydrophilicity (water attracting) for filtration and trapping of aqueous particles. **(9)**

The materials which are typically used for manufacturing of disposable medical masks are a 20 g/m^2 polypropylene spunbond non-woven fabric and a 25 g/m^2 polypropylene meltblown non-woven sheet. The thickness of fibre is from < 1 to 10 µm. (35)

The common single-use medical masks are made from three or four layers of non-woven fabrics. The inner layer is a common non-woven fabric; it absorbs the moisture from the wearers´ breathe. The outer layer is made from the waterproof non-woven fabric used to isolate the liquid sprayed by the wearer. In the middle, there is a filter layer which has a barrier function against germs; this middle layer is made from the polypropylene meltblown non-woven fabric. The core material of medical masks is polypropylene meltblown non-woven fabric after electret treatment. (8) The thickness of a layer is 1 µm. (35)

The spunbond non-woven textiles are manufactured by direct spinning of polymeric granulates into endless fibers (filaments).The molted polymer is extruded through a spinneret and slightly cooled in the air. The spinneret can be rotated to deliver fibers in different arrangements. The filaments are subsequently deposited onto a conveyor belt in a random manner and bonded to form a flat continuous web; bonding is performed thermally by applying heated rolls (callendering), chemically (impregnation) or mechanically (needling). (20, 39, 40)

The meltblown non-woven textiles are made by extrusion of melted polymer through small nozzles surrounded by high speed blowing hot air; the gas blows the molten polymer onto a conveyor or take-up screen. The resulting microfibers are randomly deposited and form a fine fibrous, self-bonding web - non-woven textile. The benefits of this process are simplicity, high specific productiovity and solvent-free operation. (38, 39)

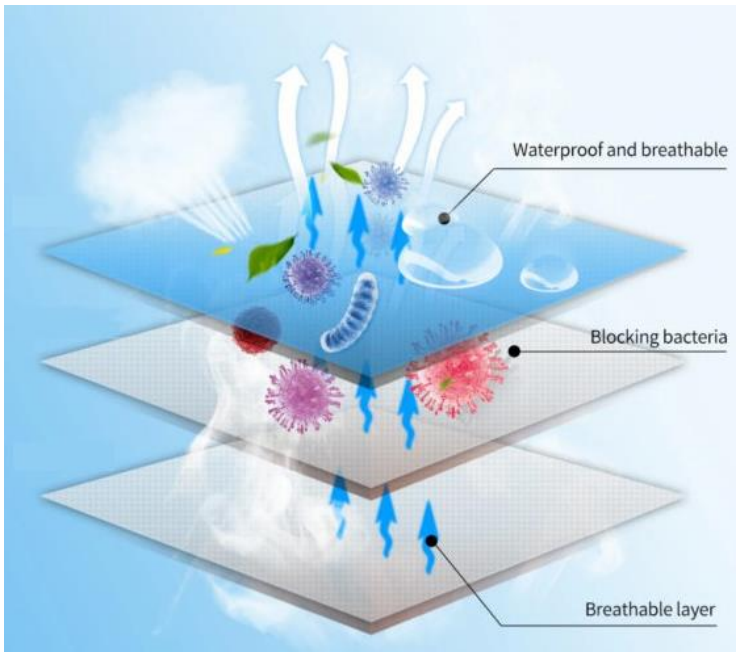

Fig. 5: Disposable 3 layer medical mask – functions of the layers (37)

2.3.2. Hazardous chemicals in materials used for disposable masks

According to the experts from NGO Health Care Without Harm (HCWH), many PPE, produced to be used during the COVID-19 pandemic, are likely to contain hazardous chemicals. The medical textiles used for production of

medical masks, may probably be treated with perfluoroalkyl substances (PFASs) to give them oil- and hydrophopbic properties. (36)

The perfluorinated substance widely used in textile industry for water- and oil resistant treatment of materials, was perfluorooctanoic acid (PFOA), along with its salts and PFOA-related compounds. Due to its persistent, bioaccumulative and reprotoxic properties, its production, placing on the market and use in EU was banned from 4th July 2020 by Annex XVII of Regulation 1907/2006/EU (REACH). In adition to this, from 4th July 2020 its´use has been also globally banned under the UN´s Stockholm Convention (implemented in EU by Regulation 2020/784/EU). The short-term exemptions were approved for several applications, including the three-year exemption on use of PFOA and its related compound in textiles for oil- and water- repellency for the protection of workers from dangerous liquids that comprose risks to their health and safety (till 4th July 2023); till 3th December 2020, there is also the exemption on its use for medical devices other than implantable which are under the scope of Regulation 2017/745/EU.

With respect to these exemptions, the medical masks produced during this COVID-19 pandemic in 2020 (before 4th July 2020) may be legally treated with C8-based perfluorocarbons and may contain PFOA, however it is criticized by NGOs.

Yuyun Ismawati from Indonesian NGO Nexus3 and her team carried out the home tests on widely used facemasks: they soaked the spunbond nonwoven facemasks in water to see how long it takes them to become wet, and they tried to burn them. It took 26 hours till the masks were getting wet indicating that a surfactant was applied to achieve water-repellency, and they didn´t burn completely which points that flame retardants were used. (36)

To replace the PFOA and othe C8-based perfluorinated substances in oil- and water resistant applications, the textile producers started to use the other short-chain PFAS like e.g. C6-based fluorocarbons. Though they are less bio-persistent than long-chain perfluorosubstances and their use is still legal, they are also under the pressure to be banned; some studies suggest they affect the same organs like the longer ones – the liver and the thyroid. (36)

2.4. Current waste management of the used disposable PPEs

In general, the single-use PPE and other medical devices shall be discarded in a way to avoid the risk of spreading infection. This hospital-grade waste is discarded according to the strict standard infection control precautions protocols. The most effective way how to dispose the infectious waste to prevent spreading of disease is incineration at high temperatures (more than 1000°C) at hazardous incineration plants. The waste decontaminated e.g. by microwave decontamination or autoclaving as well as the disposed face masks from public may be burned in municipal waste incineration plant. Landfilling of the healthcare waste is prohibited in Czech Republic.

The details on legal obligations concerning the waste management of used dispopsable PPEs in Czech Republic are described in Deliverable *D.T2.3.4. Pilot cases - feasibility study*.

2.5. Reuse of the medical face masks

During the early COVID-19 outbreak, all states in the world reported the problem of insufficient supplies of disposable medical masks and respirators. Their reuse through design modifications, cleaning and

decontamination was therefore discussed; it could not only to offer solution for lack of these devices on a market but also to decrease the amount of waste generated from it.

To compare use of the respiratory protective devices by healthcare workers and by public, the risk of exposure in general is likely to be significantly higher among the healthcare workers.

The key consideration of reuse of respiratory protection devices is their contamination by the wearer or by environment. Exposure to airborne substances can contaminate the external surface of medical masks as well as contamination of the filter material. The currently marketed disposable medical masks are made of materials that can degrade with commonly used standard means of disinfection (e.g. chemicals, heat or radiation). (12) As these disposable medical masks are not designed for reuse and also with respect to their potential contamination, their reuse (even by a single user) is discouraged. Without the manufacturing modifications, the current commonly used medical (surgical or procedure) masks cannot be effectively cleaned and therefore should be discarded after the use. (11)

Any method of medical masks decontamination must ensure removal of the viral contamination, be harmless to the user and not to damage integrity of the mask´s elements or the fit (e.g. tear or deform the filter, bend the nose clip, stetch the elastic bands). (12)

2.5.1. Challenges regarding the reusable face masks

The important parameter in case of the face masks whih should be intended for repeated use is the use of suitable materials. According to Wiener et al. (19), it is necessary to take into the account that the conditions of their common use (moisture, heat, lights intensity) are quite demanding, thus the materials intended to be used for manufacturing of such the masks must be tested regarding the lost of effictiveness, possible products of the material aging and of the hydro-, thermo-, photo- degradation not separately, but taking into account their combination. (19)

Currently, the face masks intended to be used repeatedly (including the simple and efficient sterilization) are made using the modern textile materials with special multifunctional characteristics. These multifunctional effects are achieved by treatment with new chemicals. With regard to this, there can be many new problems which may consequently cause that effect of use of these masks on the health of the users may be worse than infection caused by viruses. It is necessary to take into account that the total time of use of the face masks accompanied by release of the harmful particles may be extremely long; the total concentration of inhaled particles in human body may be over the accepted limits and therefore have a negative effect.

As Wiener et al. (19) points out, these new materials and plastics can contain many other auxiliary chemicals which may degrade and change during the lon-term use of textile product. It will be necessary to study their behaviour under the conditions of the atmosphere under the medical/respiratory mask (approx. 37°C, relatively moisture more than 90% and external effect of UV radiation and artificial light). The materials should be tested before the first use, during the use and at the end of their service life. Apart of the changes of materials integrity and of the mechanical capture of viruses, also the solid, liquid and gaseous particles released during the use and sterilization shall be studied. It will be necessary to study their presence in a human body and their possible long-term cumulation. (19)

For each protective device, also the appropriate matter of sterilization has to be defined. There are many various ones, but it is necessary to specify the conditions as e.g. intensity, time, concentration, wave length etc.; only the information about the washing temperature is not sufficient. The matters of the efficient sterilization have to be compliant with used materials especially taking into account occurrence of the harmfull products during potential material degradation. (19)

As a filtering layers of the masks are used the nano-fibre structures. To be able to capture the virus, the pores of this layer should be smaller than 50 nm which is a size of the virus. As the pore sizes in case of the standard nano-fiber layers is usually distributed from nano to micrometers, it can be achieved by folding the individual nano-fibre layers which need to be appropriately connected together. But these nanofiber layers are not resistant against the mechanical damage and their structure may be damaged (holes); therefore, their filtering efficiency would be significantly decreased or lost. In addition to that, after several abrasion cycles (abrasion among the individual layers of external mechanical action) can be released the fiber segments which may be also harmful. This can limit the reusability of these structures and shall be studied. (19)

Apart of that, there are also the more practical challenges in general. The quality and uniformity of the final product are amont the most important ones. With respect to that, traceability of the calue chain is crucial: to use the recycled material as a raw material to recycled fibers, it is necessary to know where the material comes from and which additives might be contained in the fibers. Other challenges occur when material or additive is changed (i.e. aiming to enhance product functionality, performace or cost); thanks to that, the incompatible materials may be obtained that cannot be reused or recycled with conventional recycling technologies. (22) Thus, this is a reason why companies using the recycled materials as a raw material prefer to recycle your own post-production waste or waste from partners with well defined waste production.

2.6. Recycling of the medical face masks

2.6.1. Main practical issues concerning collection and recycling of face masks

In general, there are several main practicals issues to be solved when intending recycling of used disposable masks:

- Logistic (safe separate collection and transport of used masks)

  In case of the masks which would be collected in health care facilities or industrial enterprises it seems to be easier to ensure the separate sollection because also some other types of waste are already collected separately there. Especially in health care facilities, the well organized system of separate collection of waste must on a high level of safety already exists.

  On the other hand, to organize the separate collection of used disposable face masks from public seems to be difficult. It is necessary to take into account that from safety reasons, the collected masks should be decontaminated before any recycling and therefore it would be necessary to separate them from other kinds of collected waste. With respect to that, it would hardly be economically sustainable to organise separate collection of used single-used masks from public in special collecting bins; to collect them together with any other kind of separately collected waste (e.g. together with plastics) would require the manual sorting which would put the workers ar the risk because of potential exposure to coronavirus.

- Decontamination of used masks

  There are available technologies for decontamination and processing of health care waste. Some examples are described in chapter 2.6.1.

- Separation of diferent materials and recycling
- Economical feasibility conditioned by sufficient quantity

2.6.2. Examples of technologies for decontamination and processing of health care waste

It seems that the decontamination technologies might be a good idea for decontamination and processing of used PPEs (including face masks) from health sector. (41)

There are various devices and technologies on a market for decontamination and processing of medical waste. Using these technologies, it is possible to process various types of medical waste including used PPEs (face masks, gloves, disposable gowns and clothes in general, diapers, bandages, blood bags, test tubes and many others).

As one of the examples we can mention the devices produced by company Siemens: their device CONVERTER is a single-chamber shredder of a medical waste. It can be used for processing of the waste under the codes Waste is there shredded into small, unidentifiable particles. The shredder and knives are constantly rotating and their mechanical energy causes an increase in temperature at which the moisture contained in the waste evaporates. In case of processing the municipal waste without hazardous properties, the process ends after reaching the temperature 100°C; in case of processing the hazardous waste, the process continues till the temperature reaches up to 151 °C. The resulting shredded particles are subsequently cooled and removed to storage. The final waste product looks like the ordinary vacuum cleaner dust; it is completely sterile, dry odourless and does not contain the sharp components. The original volume of the waste is reduced by up to 70% and weight by almost the third. The resulting product can be used as an alternative fuel with a calorific value of brown coal. (41, 42, 43)

From the regulatory point of view, in Czech Republic the legislative compliance of this process with the Act on Air Protection (201/2012 Coll.) would be necessary. The resulting product is a waste and can be classified in category *19 12 10* combustible waste (refuse derived fuel)* - waste usable as an alternative fuel. At first, the treated waste has to be "withdrawn" from hazardous waste category, issued by authorised person according to Decree No. 94/2016 Coll. on the evaluation of hazardous properties of waste. To become a fuel, the product would have to be tested and certified. Also there is an issue of released gasses and vapours from the device: when processing the hazardous (infectious waste), the potential presence of the infectious agens (the material is damp and dries out) can be expected. It is necessary to check how and where the technological flows from the devices are carried out and whether the removal of pathogens is 100% effective and cannot be re-cultivated. (41, 42)

Fig. 6: CONVERTER by company Siemens (41)

Another device for processing and decontamination of infectious waste is a device MEDIVAK MV6 intended for decontamination of the hazardous medical waste (especially used incontinence aids (diapers and disposable diaper panties) and pulp) and reduction of its volume (by up to 70%). In the device, the resulting decontaminated waste is sealed in special plastic bags. This treated waste is easy to handle, does not smell and the risk of infection is significantly reduced, according to producer of the device. As in case of CONVERTER, a treated waste shall be initially considered a "hazardous" waste and to classify it as "other", a "withdrawal" according to Decree No. 94/2016 Coll.would be needed. (41, 44, 45)

Fig. 7: MEDIVAK MV6 (45, 46)

2.6.3. Recycling of non-woven textiles

There are the commercial technologies for recycling of non-wovens available on a market. Many of the nonwovens producers are recycling edge trim material, rejected rolls or materials sent back from their customers. The material is reprocessed and reused as a raw material in production.

As an example, the **Starlinger** recycling technology using their "recoSTAR" line can be mentioned. The non-wovens scraps (either one type of plastic material or mixture of materials) can be processed and recycled into pellets; to separate the components of polymer mixtures (PES/PE, polymer/cellulose,...), special filtration is applied. In some cases, certain viscosities pose a challenge during pelletisation. (21) Starlinger offers two machines for the nonwovens recycling: "recoSTAR universal" line is a shredder/extruder combination mostly for recycling of polypropylene materials; and "recoSTAR dynamic" is a SMART feeder/extruder combination mostly for the recycling of polyester nonwovens. (22)

There is also the experience with recycling of absorbent hygiene products (AHPs). Bellow, several examples are mentioned.

The company **Knowaste** has been researching and developing technology for recycling 100% absorbent hygiene products (AHPs) since the mid-1990s. The Absorbent Hygiene Products include the disposable diapers, adult incontinence products (pads and pants) and feminine hygiene products. AHPs are made from combination of several materials: fibers to absorb moisture, super absorbent polymers to retain moisture and plastic membranes and tabs keeping the user dry and secure. Through the recycling process, the company converts the AHP waste into two valuable resources — fiber and plastics which can be then reused in various products. The patented process introduces also the advanced thermal treatment which sterilises the waste stream prior to separation. The waste is sent to an autoclave where it is shredded, separated and then sterilised using advanced thermal treatment technology and sorted to remove any contaminants**.** The resulting plastics are then granulated, pelletised and reprocessed offsite for reuse. The superabsorbent polymer is left in the fiber and deactivated, though the product should retain about 30% of its absorbent capacity. Fibres produced by the process are treated for use as a pet litter. The company cooperates with local, regional and national hygiene, healthcare or sanitary disposal companies and their customers. Thanks to the system of increased identification and soirce segregation, also the non-infection waste from the hospital sector can be recycled. The UK-based Knowaste was forced to close its 70,000 tonne-per-year recycling plant in Holland in 2007 after a new incinerator beat it on cost; also it was unable for Knowaste to find markets for the final product. (29) In 2011, Knowaste opened first AHPs treatment facility in UK (West Bromvich) and have planned to open another one in West London. Unfortunatelly, the Knowaste´s AHP recycling facility in West Bromwich was closed down in 2013; the planned new plant in West London was rejected because of the odour emissions issues and concerns with rgards to the impact on the nearby residentials and schools. (22, 23, 24, 25) In 2017, the company announced the plans to launch its recycling service in South Africa and to establish there a recycling plant. (27)

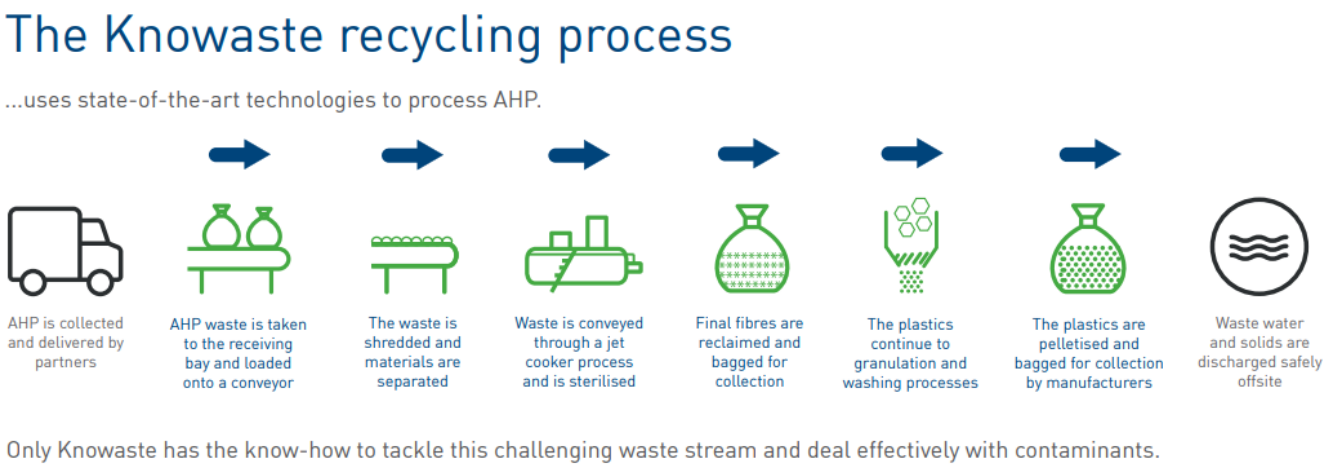

Fig. 8: Scheme of the Knowaste AHPs ´recycling process (24)

In 2019, Procter & Gamble opened a pilot plant for recycling of old nappies in Treviso, Italy. After going into full industrial scale with annual capacity of 10.000 tonnes, the second pilot facility in Amsterdam, Netherlands was launched; as a part of this project, the smart blue recycling bins are placed in souple of neighbourhoods. At present, the AHPs collected in Amsterdam are transported to the Italian facility in Treviso but it is planned to build a facility as well in the Netherlands. There are discussions about the facilities also in number of other countries. The nappies are processed by the patented process to reclaim plastics and fibers. The first step is washing out the contaminants and sterilisation, including the analysis to make sure that no contamination remains. Then the waste material is broken down into three categories of materials: cellulose, super absorbent polymers and mixed plastics. Each metric tonne of waste produces on average 150kg of cellulose, 75kg of plastic, and 75kg of super absorbent polymer. The plastics then may be used to make e.g. school desks, bottle caps or urban playgrounds, cellulose can be used for production of viscose fabrics or specialty paper and super-absorbent polymer can be used in gardening and flood barriers or as a litter. (28, 29, 30, 31)

Fig. 9: The blue recycling bin in Amsterdam (31)

The PHS Group company´s facility in UK uses a different process than Knowaste, converting AHP waste into refuse-derived fuel which can be burnt to produce energy. The process is named LifeCycle; it uses mechanical separation combined with chemical treatment. The wet products are shredded to break them down into components parts; after they are compressed to remove liquid. The waste is then chemically treated to keep it stable. (25, 27)

2.6.4. Studies and innovations on medical masks´reuse

Around the world, the experts are studying the possibilities of re-use or recycling of PPE. Bellow, we can mention several examples of the sustainable innovations or studies.

The Sterimelt technology, developer by the Thermal Compaction Group (TCG) from Wales, is able to process a wide range of uncontaminated polypropylene nonwoven disposable PPEs of any colour; the resulting polypropylene blocks can be than resold to the plastic industry to be recycled. In the UK, the number of hospitals have recently purchased their own Sterimelt recycling units to carry out the in-house recycling of their disposed PPEs. (4)

Fig. 10: The Sterimelt technology (4)

In Korea, the Korea Advanced Institute of Science and Technology (KAIST) research team has developed a nano-filter which can be used as part of the face masks. The common single-use face masks are made from three or four layers of non-woven textiles fixed together. Their inner layer is a common non-woven fabric, which is mainly used to absorb the moisture and moisture released by the wearer; the outer layer is a waterproof non-woven fabric, which is mainly used to isolate the liquid sprayed by the patient; the filter layer in the middle serves as a barrier against germs; for the middle layer, also the nano-fiber membrane may be used increasing the filtering efficiency thanks to its ability to filter very small particles. These common face masks are not reusable and shall be discarded after use; their filtering function is lost after washing or wetting by breath moisture during the long time wearing because their electrostatic function disappears when exposed to water. The face masks with the nano-filter developed by KAIST are reusable and can be hand washed more than 20 times; the inner filter can also be replaced. (5)

The researchers from TU Delft (Netherlands) in collaboration with Van Straten Medical B.V. developed a new way of sterilizing used respiratory masks and testing their quality. The researchers developed a specific protocol for transport and disinfection: the used masks are collected and tightly closed by institutions in a dedicated garbage bags and disinfected with alcohol in a container; containers are collected by a special transport. In a disinfection room, each mask is individually inspected and marked by staff in special protective clothing. Then, the masks are laminated in a bag a sterilised at 121 degrees for 15 minutes. Each mask can be recycled up to five times. The researchers have also tested the flow and filtering parameters of masks after the procedure; the results are promising. The repeated use of the masks can be an alternative for the shortage of mouth masks and increasing demand of hospitals and care institutions during the coronavirus crisis. (6)

In the US, the car manufacturer Ford is producing the reusable gowns made from air bags materials which can be washed up to 50 times. The University of Nebraska is testing decontamination of medical masks using the UV light, to prolong their life span and therefore, to reduce waste. (7)

3. Environmental characteristics and LCA

3.1. Disposal

During a pandemic the demand for disposing of waste PPE is increasing. According to World Health Organisation (WHO), in 2018 only 15% of hospital waste material around the world was considered dangerous (10% infectious and 5% hazardous because of its chemical or radioactive properties). (1) According to China´s National Development and Reform Commission, the Chinese manufacturers alone were producing 116m masks per day at the end of March. (36) During a pandemic, in all countries we can see an exponential growth in the infectious waste generated by hospitals or care homes; for example, the official data from Spain indicate the growth of the healthcare waste from the two worst-affected regions – Madrid and Catalonia – by 300 and 350%, respectively. (1)

COVID-19 emergency is changing the waste stream due to the large use of protective medical devices (in particular medical masks) by citizens with a waste that is generated outside the usual medical structures and that doesn't follow the usual disposal procedure but is collected with the urban waste.

According to the LCA study provided by *UCL Plastic Waste Innovation Hub* (52), if every one in UK would used one disposable mask each day for a year, it would generate 66.000 tonnes of plastic waste and 57.000 tonnes of plastic packagings. Use of reusable masks by general public (including washing them) significantly reduces plastic waste and the climate change impact comparing to use of single-use masks. Therefore, the single-use masks should be preserved for front-line healthcare workers. (49, 52)

3.2. Littering

Around the world, the high amount of single-use face masks or gloves is littering the streets, shopping carts, parking lots, sea, beaches or green parks, however it is not so often in Czech Republic (with respect to lower consumption by public because of the use of reusable textile masks). The discarded masks and plastic gloves used during the COVID-19 pandemic may threaten the wildlife. This causes the risks not only for human health, but also for environment.

Photo: Opération Mer Propre (Facebook)

The Polytechnica of Turin estimates for Italy a consumption of about 1 billion ($1x10^9$) of masks and half a billion ($0,5x10^9$) gloves per month in phase 2 of the COVID-19 lockdown, when production and social activities will be gradually resumed (49, 51). If only 1 percent of used masks would not be properly disposed of, 10 millions of them (about 40 000 kilogramms of plastic) will end up in the environment, according to the World Wide Fund for Nature (WWF). (2) The disposable gloves or surgical single-use face mask asks are made from the polymeric materials which are not biodegradable. The bright colours of latex gloves and masks can be mistaken as food by birds, turtles and other marine mammals and pose a mortal danger to them. (3)

3.3. Carbon footprint

According to the research made by *Ecochain* (50) comparing the CO2 footprint of the self-made cotton mask and of the single-use plastic mask (surgical grade N95 respirator), the carbon footprint of the cotton mask is 20% higher that in case of the disposable one. According to this study, the total footprint of one N95 face mask is about 50 g of CO_2-equivalent (for comparison, the footprint of one banana is around 80 grams); in case of the self-made cotton mask, it is 60 g CO_2-equivalent. The reason is a relatively high CO_2 footprint of the cotton fabric production cycle. (49, 50)

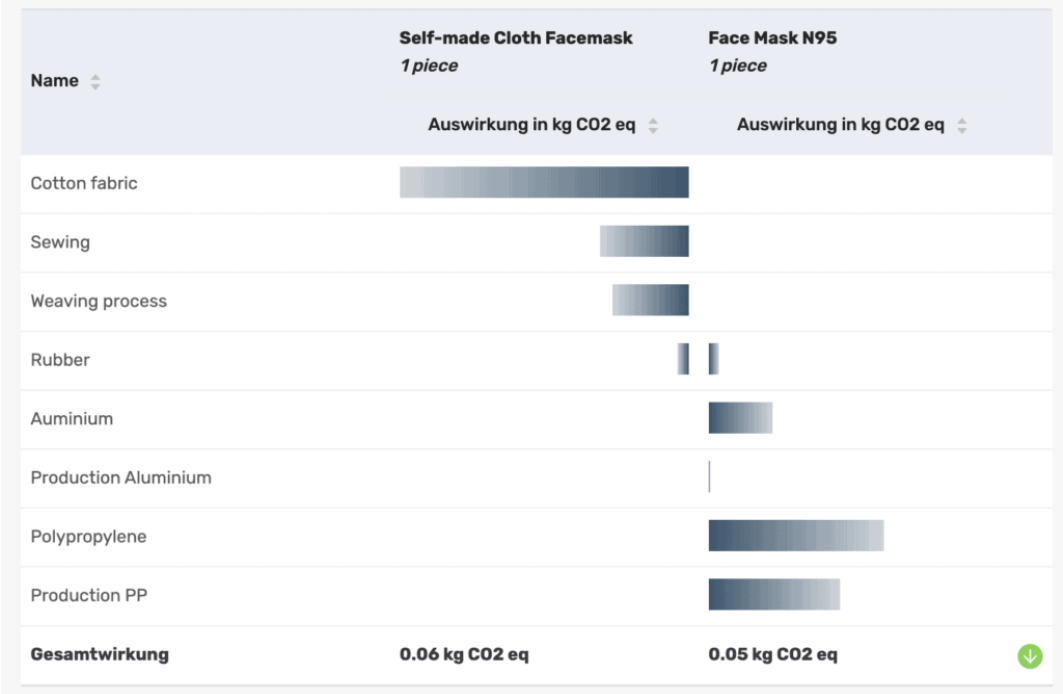

Fig. 11: Comparison of carbon footprints
of cotton self-made face mask and N95 face mask (50)

But the study has highlighted that this conclusion does not give a complete picture because these two masks are used in a different way. While the N95 mask is intended to be used only once, the cloth mask can be worn many times. So, this simple comparison as described above didn´t take into account the number of single-use masks that would be used during the similar period as the service life of a cotton mask. If they´ve compared the carbon footprints of these two types of masks after

30 days, the results very dramatically different in favour of the cotton masks. (Notice: washing the masks was not included). (49, 50)

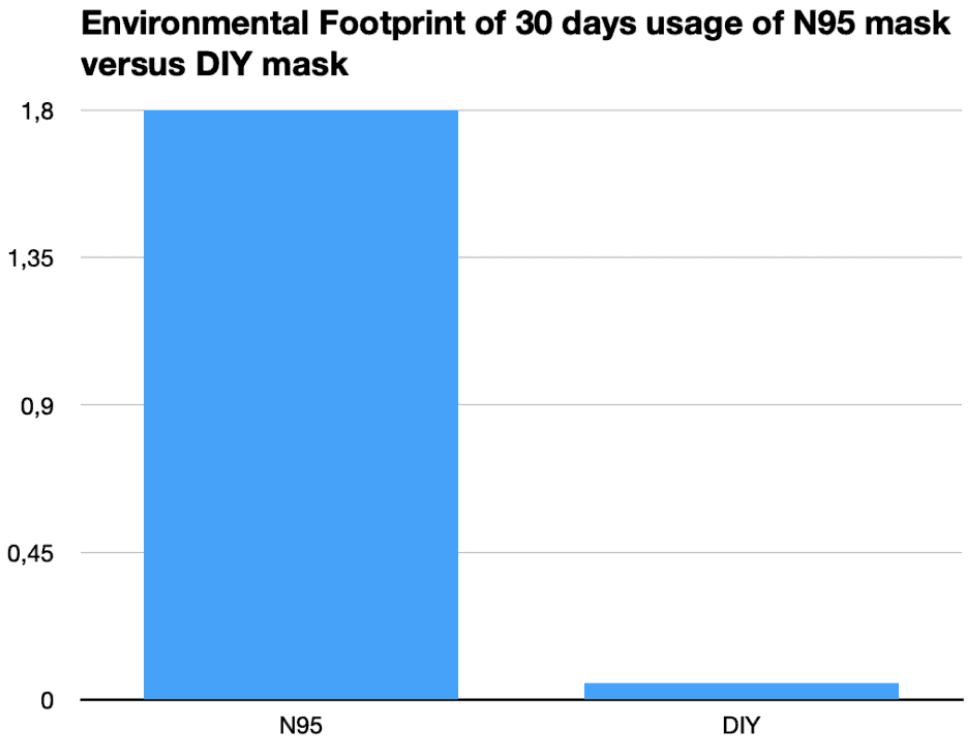

Fig. 12: Comparison of carbon footprints
of cotton self-made face mask and N95 face mask after 30 days (50)

And in addition, the reserachers used in their calculations the brand-new cotton fabric. But many people use the old fabrics, which reduces the footprint of the cloth face mask even further.

The study highlighted that although the carbon footprint of both types of a single mask is comparably low, the problem is the total amount of masks needed. As an example, in Germany the monthly consumption of FFP masks is about 17 million pieces. It correlates to 850 tons of CO_2 per month for N95 masks alone, preferably intended to be used by health professionals. According to the study, it is equivalent to 370.000 medium-sized beef steaks or driving 42.500.000 km with an 8l car. Germany claimed the need of 12 billion ($12x10^9$) masks if everyone would be supposed to wear a face mask in public; the carbon footprint would be around 720.000 tons of CO_2-equivalent. (50)

3.4. Environmental footprint

This situation is definitely a new challenge for the waste management. Replacing the single-use PPE with reusable (decontaminated between uses) or recyclable would reduce amount of waste.

Speaking about the respiratory protection for public, in Czech Republic we are obliged from 19th March 2020 to wear respiratory protection equipment (masks, respirators) in public places. Due to

the lack of the disposable products on a market, people in Czech Republic started to sew the face masks from textile fabrics. These textile masks can be washed and used repeatedly and, thus, the waste increase can be expected much lower than in other countries where the textile masks are not used so often. But – apart of that – amount of disposable face masks is also used by people in Czech Republic and is discarded as a municipal waste.

Photo: Claudio Schwarz on Unsplash

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