Memorandum

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1 The concept of a circular life cycle for flexible PVC - summarising memorandum

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In view of increasing demands by authorities for alternatives to flexible PVC, the Danish PVC Information Council[1] wishes to highlight the particular properties of the material and the recycling possibilities. The PVC Information Council wishes to raise awareness of the potential for a circular life cycle in the case of the following product groups: floor coverings, roofing sheets, tarpaulins, advertising banners or cultural event streamers, floor protection equipment, bouncy castles, sports equipment and medical equipment.

Rambøll's analysis examined aspects including the market, the technical properties of the material and the current state of recycling technologies with reference to the above range of flexible PVC items, which are produced on a large scale. The aim is to point the way towards increased recycling of the aforementioned flexible PVC products.

This note summarises the investigation's three areas, which are separately reported on in the following Memorandums:

1) Market analysis for selected product groups
2) Historical additives in flexible PVC
3) Recycling technologies for flexible PVC

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2 Summary of conclusions of the analysis

This section is a compilation of conclusions and observations from the three Memorandums. Through the memorandums, Rambøll outlines the way in which a circular life cycle for flexible PVC could be realised, despite a number of challenges.

In general, the product categories were chosen based on their potential for generating waste and in relation to the volumes in the '2018 Mapping of PVC in

[1] The PVC Information Council represents the European PVC industry in Denmark: its members include several Danish companies. The Council serves as a knowledge centre for the many areas in which PVC is used. The PVC Information Council is part of the European PVC industry's VinylPlus® environmental programme, which has provided the funds for this report.

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Denmark' (Danish Environmental Protection Agency) as well as a preliminary assessment of comparable product characteristics.

2.1 A specific replacement for flexible PVC will not be easy

The analysis concentrated on the above-mentioned seven product groups, which are in widespread use and thus of significant value in the market. In itself, this shows that flexible PVC is a preferred material for these product groups, a fact which is underlined by most market stakeholders saying that it would be very difficult to produce similar goods without the use of flexible PVC.

The hallmarks of flexible PVC render it suitable in these particular products for a number of reasons including wear resistance, weather resistance, service life, safety and other very specific characteristics.

Flexible PVC has a long service life. In the context of the circular economy and optimal sustainability, were flexible PVC products to be made recyclable, trade users could achieve significant resource savings since flexible PVC production would have recourse to recyclate as an alternative to using virgin materials.

We might expect medical equipment with a short service life to yield relatively clean recyclable volumes and thereby to represent a significantly sustainable sector for flexible PVC.

2.2 Historical additives are challenging when it comes to reuse

The analysis could not determine specific details of the particular additives or the date on which they were phased out of Danish production and trade. Meanwhile, the PVC Information Council has stated that flexible PVC products manufactured or traded by Danish companies no longer contain problematic substances, based on current knowledge. The Danish Statutory Order on Lead in 2002 prohibited the use of heavy metals. Many years ago, Danish companies phased out the use of low-molecular-weight phthalates. A recently adopted EU prohibition ensures that these substances are not used in European production, nor can they reach consumers via imports from third countries. Yet one must be wary of possible illegal imports from China, which is the world's largest producer of PVC.

Despite the phasing out of these undesirable substances some years ago, there is still the possibility that they will appear in waste streams due to the long lifetime of PVC. An example is the vinyl floor in Bromma airport outside Stockholm, which was laid almost 70 years ago and is still in use today. At the time, knowledge of the substance's hazardous qualities was less developed than today; this means that when it is time to dispose of the flooring, the content of undesirable phthalates and heavy metals, as well as its very likely asbestos content, will be problematic. Technologies for removing undesirable substances from waste are under development. Hopefully, they will enable recycling of this older type of waste.

The entire exercise involving reuse of flexible PVC waste depends on the ability to separate 'pure' waste from old waste, which may contain undesirable substances. This report puts forward a labelling order as a possible solution to this challenge. Such an order would enable the waste processor to identify a waste fraction in flexible PVC as freely recyclable. To set recycling in motion, one can start with production and installation waste that is recyclable without complications. A Nordic order is already in place allowing installation waste to be collected and used as a raw material in new floors.

In order to promote sustainable additives in PVC products, VinylPlus[2] has instigated mapping of the 200 most-used additives, as part of the so-called Additive Sustainability Footprint (ASF) initiative. ASF is a tool companies can use to assess whether or not additives they wish to develop are sustainable. The ASF tool can be used retrospectively as well as for future developments. For example, ReVinylFloor has investigated which substances were historically used in vinyl floors in the period between 2000 and 2018; they also evaluated the sustainability of their new additives.

With regard to medical equipment, past use of additives is less relevant, in that the equipment is typically used within two years of its manufacture. In other words, the issue is not the same as for products that have a long service life. If the new EU regulation becomes synonymous with achieving 'pure' waste fractions within the next few years, medical equipment made of flexible PVC will qualify as a single-strand waste stream that is free from undesirable substances.

For a decade now, pilot projects have been in place around the world to collect and recycle PVC-based medical equipment. The PVC Information Council states that it has collaborated with the Danish Environmental Protection Agency, the Danish Technological Institute and Region Hovedstaden (the Capital Region of Denmark) in a project involving the collection of 2,000 PVC oxygen masks for recycling. The project showed that Denmark could collect and recycle medical equipment made of flexible PVC. There are moreover similar projects in Australia, the UK and most recently in Belgium. A possible Danish order on collection and recycling will therefore be able to draw on experience in sorting, contamination risks and the quality of reclaimed material in several countries.

2.3 Recycling technologies for flexible PVC exist

The following four categories of recycling technology were evaluated for their level of maturity for the market and appropriateness as a possible Danish model for processing flexible PVC waste:

1. Mechanical recycling
2. Solvent-based reclamation
3. Cleaning technologies
4. Chemical recycling

Reviewing the various technologies shows some mature, proven ***mechanical*** recycling technologies that can be deployed on flexible PVC within a broad range of product groups. Mechanical recycling in combination with mechanical shredding and subsequent sifting allows for flexible PVC fibres to be separated. The use of inorganic fillers in products such as flooring may pose a problem for mechanical recycling as it can be difficult to separate the fillers from flexible PVC.

A ***solvent-based reclamation*** may be used as a supplement to mechanical recycling. This option allows filtering of flexible PVC in its decomposed state. Here, the materials that are not dissolved by the solvent in question can be separated from the dissolved flexible PVC.

Cleaning technologies that can remove undesirable additives (including stabilisers which contain lead or cadmium and phthalates-based flexibility) are still in the development phase.

Where ***chemical recycling*** is concerned, the chlorine content of PVC is a general problem, since PVC emits chlorine when burned, and this forms hydrochloric acid. It does not look as if examples of commercial plant can be found for pyrolitic treatment or dehydrochlorination, where syngas or similar

[2] VinylPlus is the European PVC industry's environmental programme. It encompasses the entire value chain around solutions to several challenges in connection with PVC, including an increase in recycling, in sustainable additives and a lessening of impacts on our climate.

building blocks for the production of new plastics are produced. Gasification may supplement the more traditional recycling technologies in the future, but where possible, the use of traditional plastic-to-plastic recycling technologies will be preferable. The reason for this is that these technologies do not require investment in plant to the same extent as does gasification; also that the polymer structures in the recyclate are retained.

2.4 Sector-specific take-back systems demonstrate real potential and can be efficient

The analysis has shown that in certain sectors such as flooring, it has already been possible to take reabsorb parts of the product range with a view to using this is the production of new materials. This can apply to waste both within production itself and to trimmings left over from installation. Such situations permit complete certainty as to the nature and purity of the specific product for recycling.

In the case of products that have been used (floor coverings, roofing sheets, tarpaulins, advertising banners, etc.), soiling will have occurred; cleaning will be necessary before reuse or any preparatory recycling treatment.

If there is sector-specific organisation therefore with regard to the reabsorption of products in the distribution chain, knowledge of the product will be amassed so that efficient handling of waste can be assured.

'Open' delivery forms on the other hand risk flexible PVC from a variety of sources impeding traceability and increasing the risk of including undesirable additives in the mix. Whether PVC products can be included in the circular model depends on the strictness of quality parameters.

3 The path towards increased product circularity

Based on the assessment of issues, our starting point for a vision of increased circularity in flexible PVC products should focus on:

- trade consumption of PVC products including production and installation waste that can be certified as free from undesirable substances
- the sectors and products that can yield significant, uniform volumes
- medical equipment made from PVC as a specific area.

Since the product areas that are the subject of the present investigation are almost exclusively handled by the trade, flexible PVC waste arising in households has not been included in the investigation.

3.1 What do the conclusions reveal?

In a very general way, conclusions may be summarised in the below table. The term 'substitutability' relates to specific functional requirements as primary preconditions for the use of flexible PVC. Beside this, consideration is also given to long operating life and the opportunity for take-back and recycling. The data in the table also considers increased consumption and the accompanying waste from plastics other than flexible PVC, since these cannot be repeatedly reused or recycled in the same way:

	Floor coverings	Roofing sheets	Tarpaulins	Advertising banners and similar cultural event streamers	Flood protection equipment	Bouncy castles and sports equipment	Medical equipment
Volumes (possibility of large volumes)	YES	YES	YES	Perhaps	Perhaps	YES	YES
Service life (general)	Long	Long	Long	Short/ medium	Long	Long	Short
Substitutability	NO	NO	NO	Potential open	NO	NO	NO
Trade as primary user?	Trade	Trade	Mostly trade	Trade	Trade	Both domestic and	trade
Differentiated use depending on additives	YES	NO	NO	NO	YES	NO	YES

Table 1: Overview of findings in the summary

The table indicates that the product groups at the centre of the investigation are relevant to recycling. This is especially true since in the first instance, the study is limited to industries in the B2B production, distribution and consumer markets. We can be fairly certain that the necessary knowledge of individual products, their characteristics and processing needs can thereby be attained.

An approach could therefore be possible that establishes take-back schemes and/or leasing/rental models in these product areas via the distribution chain. All this should result in larger, more homogeneous waste fractions going to recycling. The leasing and rental models can ensure that new, 'pure' products are set apart from 'old' ones. This constitutes a strong argument in favour of recycling, with increased familiarity with the products and the specification of quality norms for flexible PVC. It will create ownership of the drive to recycle, whether or not the product manufacturer is large enough to execute their own recycling treatment or opts to acquire recycled flexible PVC as a raw material.

One of the questions that arises, however, is whether volumes from differing product groups should be kept separate depending on the additives that are brought into the recycling mix. This should become clear with more specific work on how take-back should be organised and details finalised. Similarly, the issue of responsibility of stakeholders and the tasks they must perform will be decisive in enabling the circular life cycle.

3.2 What approach can best ensure a circular life cycle for flexible PVC?

The main problem in establishing a circular system for flexible PVC is that there are at present no visual or technical means of differentiating between old and new PVC products and ensuring that undesirable additives are kept out of the life cycle. As previously explained, flexible PVC products currently produced or distributed by Danish companies do not contain problematic substances in the view of today's scientists. Such products can be freely used within a circular life cycle. The fact remains that PVC products have long lifetimes and for some years to come, waste containing undesirable substances from earlier items will arise. This is the fundamental challenge in recycling flexible PVC.

Based on the analyses and the fact that neither cleaning nor sorting technologies can provide total assurance, it seems best to focus on three priorities when creating the basis for flexible PVC circularity:

1. Labelling
Distributors and manufacturers of flexible PVC products should introduce a labelling system to allow easy identification in future of the flexible PVC products that can be freely recycled.

2. Selective dismantling
Today there is significant awareness of the types of materials used in construction. In future it will be very easy to identify substances in specific building products. Identification of waste will happen at the source. Currently a lot of work is going into establishing certification for materials to provide a dataset that reflects which parts of an object can form part of a circular economy.

3. The development of identification technologies
Requirements are in place today for the separate treatment of PVC waste with a view to its disposal. Special schemes will make future identification easier. All that remains will be to separate old waste from new. Here, the development of scanners to detect undesirable historic additives will be decisive. Such differentiation requires laboratory analysis, which at the moment is a very expensive. Hence, not all products can be recycled into new raw materials that meet current legislative requirements. There is therefore a need to develop new identification technologies which, in combination with mechanical recycling technologies, will be able to identify products and remove them from the recycling process.

4 System requirements for further work

In a circular system for flexible PVC, the collection of flexible PVC waste must exclude undesirable historic additives. This requires separate collection close to source to ensure a high degree of traceability. It must be decided by sector and by product what is the most appropriate way of obtaining the materials.

The collection function will have to be defined depending on the product area in question. Medical equipment will require dedicated collection equipment. In principle it should be possible to treat such waste in the same way as any other recyclable business waste, using approved carriers. Moreover medical equipment has a short service life, which also means that undesirable historic additives in waste will be phased out of the system relatively quickly, thanks to sector initiatives for legislation on phasing out and substitution. Similarly, the resulting recyclate will be better able to meet the content requirements of the PVC sector for product groups with short lifetimes.

Construction companies will to a large extent subject flooring and roofing sheets to thorough mapping and screening for problematic substances. In this way recyclable waste will either be extracted from the individual company’s waste sorting system or be processed by an approved sorting facility on the basis of previous mapping. In future, with increased or selective shredding and possible labelling, it will be far easier to separate waste with undesirable substances and recycling will therefore increase significantly.

Bouncy castles, tents, tarpaulins etc. will presumably need to be collected on order, or there will be an opportunity for trade users to deliver these items to a processor. Since these products are destined for recycling, collection will be straightforward.

There will be a need to clarify for raw material suppliers, product manufacturers and trade users what form a possible flexible PVC declaration will take, as well as applicable quality levels. This will ensure that trade users are well informed about the products they use so that they can contribute towards an increase in recycling. Such product declarations could also be incorporated in the discussion on how processing prices will be set for the treatment of both collected and delivered waste.

The basis of the system with respect to product and material flows will be linked to a series of main stakeholders and will take the following general form:

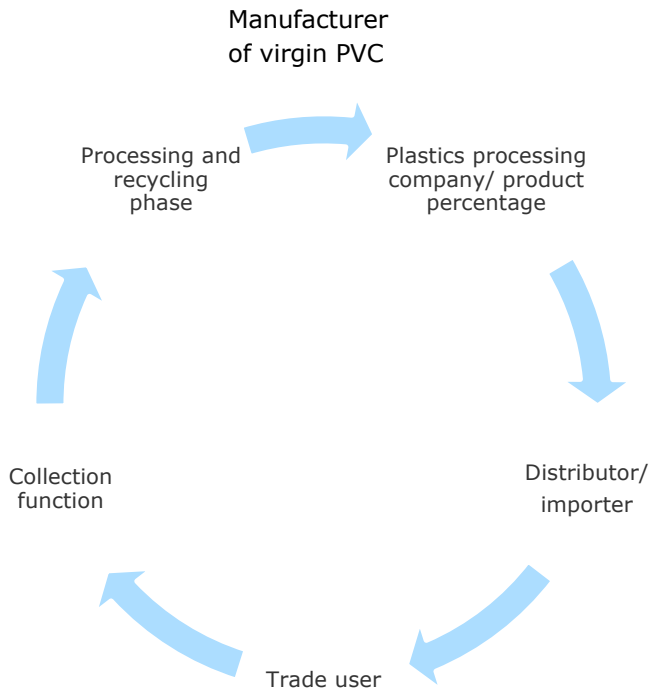

Figure 1: General model of material flows and stakeholders

The structure of any system must take account of these stakeholders. The following specific recommendation is for a structure that reflects the three priority areas, namely *labelling, selective shredding* and *identification technologies.*

4.1 Labelling

Labelling and product declarations for new products will be crucial with regard to the future collection of floor coverings, roofing sheets, advertising banners and cultural event streamers, tarpaulins, bouncy castles, sports equipment and climate management equipment. This will ensure transparency for as many products as possible within each category with respect to a basis for eliminating undesirable additives.

Each manufacturer will have to be responsible for labelling, as part of his or her participation in the new system. Each sector can agree specific labelling of the products; however there must be a scheme jointly signed by manufacturers and distributors whereby they undertake to accept responsibility for the purity of products that will be part of a take-back or recycling process. One form of leverage to encourage stakeholders to accept responsibility could be an exemption from duty on labelled products.

In this way two types of waste streams can be created:

- specifically labelled recyclable waste of which significant parts will come under take-back arrangements
- other waste that requires further identification before onward processing can take place.

In connection with labelling, further steps in the material flow must be organised to be able to manage labelling and subsequent take-back. Other sectors have established take-back schemes based on a price for volumes of waste fractions. An example of this applies for instance to the processing of hard PVC. Alternatively, distributors of certain products will have to assume responsibility for take-back, which however requires the involvement of several stakeholders and significant coordination and training.

4.2 Selective dismantling

Flexible PVC products are long-lasting; it will be some time before labelled construction materials appear at waste sites. Selective dismantling should help take-back of PVC construction waste for more detailed assessment of recyclability. Here, it is thought that specific certificates for materials will be key to the robustness of a system. But for some time to come it will be necessary to subject waste to checks within the processing, such that the system knows where undesirable substances cannot be absorbed into production and material flows.

4.3 Identification technologies

To close the loop with respect to flexible PVC material and product flows, the processing phase will be key to ensuring that both old and newer products can be managed, until the day on which labelled products are the norm. It will take some time and in the meanwhile, thorough checking of the material stream leading up to processing will be required.

It is important that the collection and processing phases do not admit old PVC waste – for example, flexible PVC waste from households that is delivered to recycling sites. As long as no simple identification technology is in place, collection and processing should be restricted to the product groups listed in this memorandum, whose manufacturers have subscribed to the scheme and the labelling of new products

The processing link should have recourse, and be obliged to undertake, checking of PVC materials with known mass-spectrometric detection technology. This is time-consuming and expensive and requires appropriate equipping of the system, with exemption from paying duty on products a possible part of the basis for sustainability. For the same reason, it is important that test methods be developed that will

be able to identify, as part of the ongoing process, which additives are contained in the PVC and can be separated so that undesirable substances are phased out of the system. At that point, the system will be able to open up to possible processing of all other types of flexible PVC waste.

4.4 The circular system model

In conclusion, we can present a system which is defined by, and organised according to, the three circles in the below diagram. Specific roles and responsibilities must be attached to the different links in the chain to ensure circularity A series of development ideas must also be considered with the ambition of creating a flexible PVC product system that is as comprehensive as possible.

The below model is not necessarily the final one, but can serve as a basis for future work in the sector. Finally, we present several specific ideas for the model.

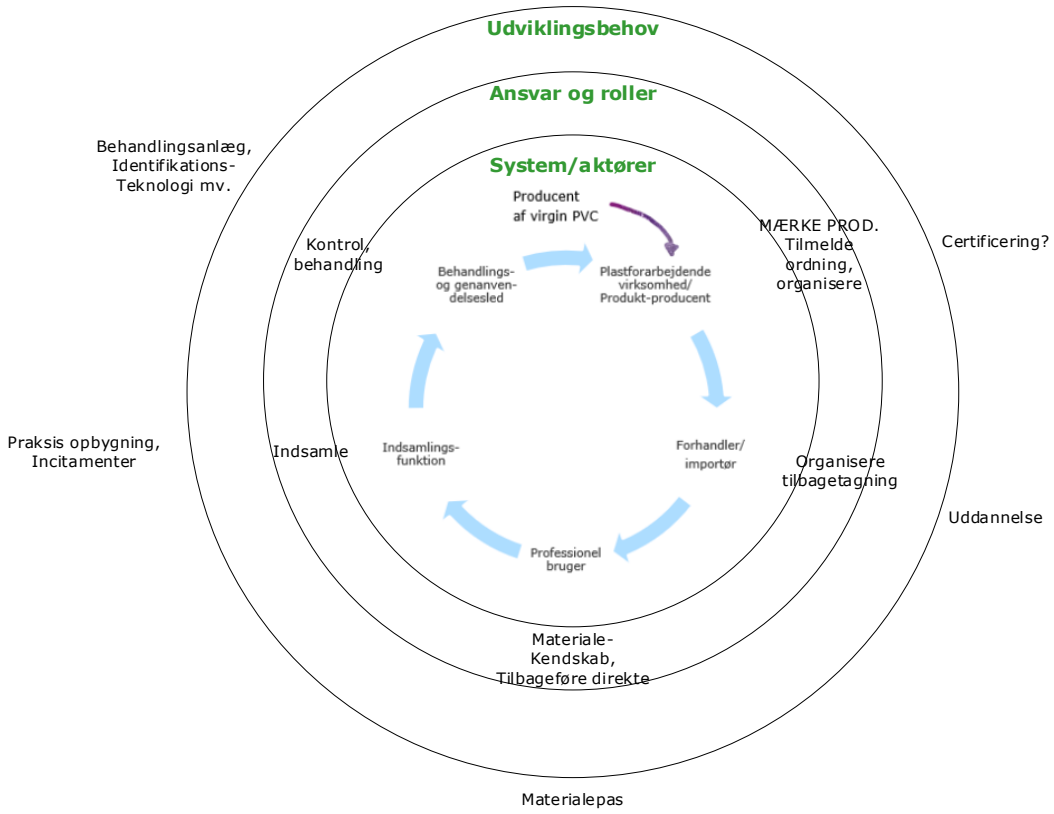

Figure 2: Model for a circular system for processing flexible PVC

4.5 Ideas to bear in mind when designing a flexible PVC circular model

The following list should be understood as ideas for discussion and further determination of a system best suited to the sector's and the respective stakeholders' shared reality.

The labelling of products and take-back

- A labelling system that guarantees products entering the market from a specific day are free from undesirable additives. This is a precondition for membership in a circular flexible PVC system, and for a company's exemption from duty
- A joint company can be set up, or distributors can establish private take-back orders for their own products that ensure that installation and production waste as well as end-of-life labelled

products are collected for recycling. In this way, traceability can be ensured and individual distributors can report on the efficacy of collection. Such systems can encompass both private consumers and industrial companies
- Distributors are responsible for ensuring that the volumes they collect and deliver to authorised recycling sites under the flexible PVC scheme meet the requirements for freedom from undesirable additives. The distributor can choose to have a waste company take on the practical aspects of the task.
- Industrial users (e.g. fitters of flooring and roofing sheets) who produce cuttings and waste will collect it and return it to the distributor when they have collected an appropriate volume. Since this waste will have been recently created it is expected that it will not contain undesirable historic additives and will comply with traceability requirements
- Manufacturers who have production waste can either recycle it into their own production or deliver it for recycling
- Trade users collect pre-consumer waste and return it to the distributor or a waste processor with whom they have an agreement
- Another advantage of private take-back orders will be in the form of logistics chains that enable leasing and recycling systems and thus facilitate the change to circular business models in the Danish PVC sector
- Private take-back orders and membership of the circular flexible PVC scheme will also create an incentive for the individual distributor and company to ensure that their products can be more widely recycled in a technically and economically efficient way. This might be through the individual company incorporating reuse in the product designs to a greater extent. The flexible PVC scheme will encompass the option of invoicing between members, where easily recyclable flexible PVC products will attract a higher price than those that are hard to recycle.
- There will be an overall requirement for recyclability of products and product groups registered under the circular order for flexible PVC
- Duty will be levied on products not registered under the order
- Possible other plasticisers or additives will be recorded in a database in connection with the order to ensure future awareness of additives and compliance with the order.

Collection of medical equipment

- Medical equipment will be directly collected by the health sector as a separate category of waste
- Medical waste made from flexible PVC will be billed in the same way as other flexible PVC waste with respect to recyclability

Processing and technology

- The processing element can be expected, based on existing mature processing technologies, to be mechanical regranulation of flexible PVC, with a central processing site in Denmark. We presume there will be additional technological associations for processing, depending on the main sources of the specific PVC streams. These may for example include cleaning and prior separation
- Recycling technologies based on known technologies
- High quality regranulate produced will be of interest to the PVC sector for use in their new products
- Unlabelled/undeclared waste must be identified, and the recycling facility must undertake ongoing random sampling of the waste they receive. Similarly, testing of final raw materials must be done to ensure that they meet the requirements of the PVC sector
- Income from products subject to duty that are not registered under the flexible PVC circularity order will help to finance the development of new technologies for recycling flexible PVC, including the development of detection technologies for scanning and identifying products with

undesirable historic additives, as well as other development to help increase the recycling of flexible PVC