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**Post-Consumer Recycled (PCR) ETFE Foil: Recycling of the Chelsea and
Westminster Hospital ETFE Roof**

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SUMMARY

ETFE foils for architectural purposes have been used since 1982, starting with the Burger's Zoo project in Arnhem by Vector Foiltec GmbH (Maywald and Missfeld, 2018)¹. ETFE foils have proven longevity, as demonstrated by projects such as the Chelsea and Westminster Hospital roof project (UK), which was dismantled in 2023 after being in service for 33 years (Solanki et al., 2024)². Similarly, the Vodafone headquarters roof project (UK), which was dismantled in 2020 and recycled by Nowofol® Kunststoffprodukte GmbH & Co. KG, serves as an important study in the post-consumer recycling of ETFE foils. With growing demand and the necessity for building sustainably and using circular materials, ultralightweight building materials such as ETFE foils offer an optimal approach to covering larger spans while minimising the overall environmental footprint. ETFE, being a fluoropolymer, has many advantages, although its recycling after the end of its lifecycle needs to be assessed and promoted within the construction industry. The present manuscript closely follows the post-consumer recycling of ETFE foils to establish a detailed workflow, involving the dismantling process, transport to the recycler, cleaning, drying, transformation into pellets, and ultimately extrusion of the ETFE foil. This research study is part of a collaborative effort with Nowofol® Kunststoffprodukte GmbH & Co. KG and Fietz Polychromos® GmbH, which provided the necessary data to establish a realistic process flow for the post-consumer recycling of ETFE foils.

1 INTRODUCTION

The contemporary climate of the building construction industry, where only 40% of the construction waste is recycled/reused, moreover recycled construction material is mostly used

in second-grade construction (Severin & Michalíková, 2024)³. The building construction sector has been recognised as one of the eight sectors with the highest potential for circularity (European Commission, 2020)⁴.

The present research paper emphasises the recycling of ETFE foils. ETFE (ethylene-tetrafluoro-ethylene) is a transparent fluoropolymer, widely used in diverse applications due to its excellent material characteristics (Hu et al., 2017)⁵. The architectural application of ETFE foils was realised in 1982 by Vector Foiltec GmbH to cover the plant houses at Burgers' Zoo in Arnhem in the Netherlands. The ETFE foils in the project followed a three-layer pneumatically prestressed cushion system, that provided an insulated environment as well as an ample amount of daylight (LeCuyer, 2008)⁶. The ultralight nature (three-layer standard cushion system weighs about 1 kg/m²) of the material-system makes it appropriate for covering large span spaces such as atria, stadiums, and complexes (EPD-Vector Foiltec, 2021)⁷.

On 7th February 2023, ECHA (European Chemicals Agency) published a PFAS (Per- and polyfluoroalkyl substances) ban proposal, which also includes lightweight cladding solutions such as technical textiles and ETFE foils. As a recent update, on 24th June 2025, a draft background document was prepared by the Committee for Risk Assessment (RAC) and Committee for Socio-economic Analysis (SEAC) proposing a universal PFAS restriction proposal (European Chemicals Agency, 2025)⁸.

With the presented paper, the authors want to materialise a mandate on the recycling of ETFE foils and technical textiles, a move that can be supported unanimously by manufacturers and service provider companies as well as may help save the lightweight architecture industry, which is one of the most optimal solutions to reduce the overall environmental impact.

Life Cycle Assessment (LCA) is a widely accepted and frequently used holistic method to inspect the environmental impact of products, processes, and services (Dossche et al., 2017)⁹. Monticelli et al. (2009; 2016; 2017; 2023)^{10, 11, 12, 13} have assessed the environmental impact of ETFE foils and technical textiles using LCA methodology. Furthermore, the contemporary practices of end-of-life scenarios of ETFE foils had been assessed through market-available EPDs (Environmental Product Declarations) (Solanki et al., 2024)². Moving one step ahead, the present paper follows the recycling of the Chelsea and Westminster Hospital roof project (London, UK), which was built in 1990 by Vector Foiltec GmbH and was dismantled in 2023. The reclaimed ETFE foils were recycled and transformed into various formulations of PCR (post-consumer recycled) base ETFE foils with the collaboration of Nowofol® Kunststoffprodukte GmbH & Co. KG and Fietz Polychromos® GmbH. The entire recycling process (dismantling, cleaning, extrusion) has been described in the presented research.

Furthermore, the research will be continued towards modelling the Life Cycle Assessment of recycling ETFE foils as well as assessment through experimentation of comparative material characteristics analysis, the acoustic, thermal, optical, and mechanical properties between PCR-base ETFE foils as well as virgin ETFE foils to determine the efficiency of recycled ETFE foils.

2 RECYCLING OF ETFE FOILS

2.1 Background



Figure 1: ETFE roof of Chelsea and Westminster Hospital in London (UK) (source: Vector Foiltec GmbH)

The Chelsea and Westminster Hospital roof project was to cover the 4200 m² atria/internal streets of the hospital in London by Vector Foiltec GmbH in 1990; it was the first ETFE roof project in the UK, and the success of it materialised ETFE foil cushion roof installations on a range of urban buildings (LeCuyer, 2008)⁶. The project was refurbished in 2023, which resulted in a net total of 2444 kg of reclaimed foils (2235 kg of transparent foils and 209 kg of printed foils).



Figure 2: Visible damages on the reclaimed ETFE foils from the Chelsea and Westminster Hospital roof

Fig. (2) shows the reclaimed ETFE foil samples, which were out in the environment for ~33 years showing some damages related to bird foot marks as well as some wrinkles due to the removal process. The reclaimed ETFE foils were tested against the archive samples of the same batch by Uniaxial hysteresis tensile tests to assess the wind load behaviour and results showed the mechanical behaviour was comparable to the virgin ETFE foil (Solanki et al., 2024)¹⁴.

2.2 Process overview: Dismantling, Removal and Transport of reclaimed ETFE foils

The standard dismantling and removal of cushion process have been described as below (F. Scheidig, personal communication, September 2023):

- Technicians shall review all documentation related to the risk assessment, method statements, and other relevant safety procedures, and shall sign the necessary permits prior to commencing work.

- Before removing the cushion, the required exclusion zones shall be identified, established, and clearly marked to ensure site safety.
- The necessary tools and equipment shall then be transported to the roof area.
- Assigned safety personnel shall install appropriate rigging systems, using suitable anchor points, for the technicians to utilise safely.
- In the case of cushion replacement: The existing cushion shall be cleaned and deflated. The new cushion will be positioned on top of the old one to provide support. Each edge shall then be unhooked in sequence, allowing the old cushion to be removed and disposed of, while the new cushion is installed.
- In the case of complete system removal: Depending on site conditions, the cushions shall be deflated, cut from the perimeter, and removed or disposed of from site accordingly.
- Depending on site conditions, one of the following scenarios will apply:
Scenario 1: The reclaimed cushions are sorted and stored on site until sufficient quantities have been collected for transporting them to the recycling facility.
Scenario 2: The reclaimed cushions are rolled, packed, and transported to the production facility in Germany for sorting and R&D purposes, after which they are sent to the recycling facility.

An average calculated time based on multiple real life case scenarios to remove 1 m² of standard three-layer cushion would be ~10 min.

2.3 Process overview: Cleaning, melting and pelletisation of reclaimed ETFE foils

The 2235 kg of transparent reclaimed ETFE foil material from the Chelsea and Westminster hospital project was processed by Fietz Polychromos GmbH (Germany) to transform into material pallets that can be extruded into the ETFE foil.

The ETFE foil material first underwent basic quality control checks, consisting primarily of visual and manual inspections, to assess its condition and determine whether any contamination was present. This phase required minimal time and no mechanical input and was carried out by trained staff during standard shift hours. In most cases, no cleaning or segregation was necessary, as the scrap originated from production offcuts free from foreign materials. However, in this case, which involved post-consumer and heavily contaminated foils, the foils were manually cut into small pieces and cleaned using an industrial scale washing machine. Standard industrial cleaning agents were used during this step. The experimental cleaning process took approximately two weeks to process 2235 kg of ETFE foil material.

Following washing, the pieces were dried in a circulating air oven for approximately two hours at 80 °C. This step ensured the removal of residual moisture and prepared the material for further processing. The industrial grade circulating air ovens generally consumes 4-8 kWh of energy. Once dried, the ETFE pieces were agglomerated—a process necessary to ensure flowability for extrusion, as ETFE film pieces alone cannot be efficiently conveyed into processing equipment. Agglomeration was carried out by a third-party service provider using a process similar to milling, in which two heavy discs rotated against each other while the film shreds were blown between them. The heat and friction caused the material to partially melt and bind into short filaments, which were then ejected by centrifugal force. This pre-processing step ensured uniformity and consistency in feedstock quality for the subsequent melt extrusion phase.

The agglomerated material was then processed via melt extrusion. The extruder melted the ETFE and pushed it through a filtration unit with filter grades ranging between 55–155 μm , depending on the material's melt viscosity. Where viscosity was too low, the filtration step was omitted. The molten ETFE was extruded into multiple filaments, each approximately 3 mm thick, which were cooled and subsequently cut into granules using a pelletiser. The resulting granules typically measured $\sim 3 \times 2$ mm, making them suitable for downstream processing using standard plastic extrusion equipment. Fig. (3) illustrates the workflow which have been developed through a systematic questionnaire sent to Fietz Polychromos GmbH (A. Meuser, personal communication, January 2025).

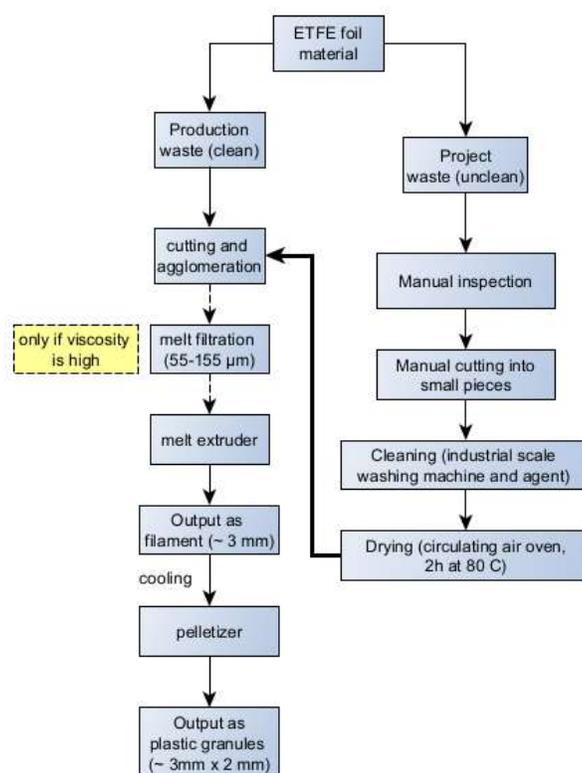


Figure 3: Recycling workflow of ETFE foils

2.4 Process overview: Extrusion of PCR base ETFE foils

After pelletisation, the ETFE granules were transported to Nowofol® Kunststoffprodukte GmbH & Co. KG, which extruded the PCR (post-consumer recycled) base ETFE foils of various formulations on a lab extruder, which can extrude the foils to a maximum width of approximately 380 mm.

The following experimental formulations at Nowofol® Kunststoffprodukte GmbH & Co. KG were realised:

- PCR: 100 %
- PCR / virgin: 50/50 %
- PCR / virgin: 25/75 %

- PCR / virgin: 10/90 %

2.4 Summarising data collection

Table (1) describes the data collected of critical activities starting from the dismantling phase to the regeneration phase. The data has been collected from the three major entities involved: Vector Foiltec GmbH, Nowofol® Kunststoffprodukte GmbH & Co. KG and Fietz Polychromos® GmbH.

Table 1: Data collection of activities for the LCA

Description of Activity	Unit	Value
Dismantling 4200 m ² of Chelsea and Westminster Hospital ETFE roof	manhours	700
Transporting the reclaimed ETFE foils to Vector Foiltec GmbH (Bremen) from London (UK)	tkm	2114
Sorting of reclaimed ETFE foils into Transparent and Printed category	manhours	40
Transporting the reclaimed ETFE foils to Fietz Polychromos from Vector Foiltec GmbH (Bremen)	tkm	752
Cleaning of reclaimed ETFE foils	manhours	80
Washing the reclaimed foil in industrial scale washing machine	kg	2235
Drying the foils in air circulating oven	kg	2235
Agglomeration process	kg	2235
Melt extrusion process	kg	2235
Pelletisation process	kg	2235
Transporting the reclaimed ETFE foils to Nowofol GmbH from Fietz Polychromos	tkm	1710
Melt extrusion and output as a foil	kg	2235

2.4 Future steps

The PCR-based ETFE foils shown in Fig. (4) present a unique opportunity to assess to what extent reclaimed foils can be utilised in building construction as well as the environmental impact of the entire recycling process mapped through Life cycle assessment.

The intention of the further research is to create a comparative analysis of material characteristics such as thermal, acoustic, optical, and mechanical properties between various formulations of PCR-based ETFE foils as well as the virgin ETFE foil, to assess the impact of the recycling process on material properties. Considering the enhanced performance of ETFE foils as a pneumatically prestressed solution (i.e., cushion), each type of PCR-based formulation will be welded into a 1 m² two-layer cushion that will be mounted on the aluminium extrusion (provided by VF Lightspan UG) and tested with an insulated single-chamber apparatus.



Figure 4: PCR base ETFE foils, extruded by Nowofol® Kunststoffprodukte GmbH & Co. KG

Simultaneously, the data collected from the various phases of recycling will be used to generate an accurate and realistic Life cycle assessment study of the ETFE foil recycling, which is largely missing in the literature, useful to optimise the recycling processes.

3 CONCLUSIONS

The research described through case of Chelsea and Westminster Hospital project, various phases of recycling ETFE foils for architectural purposes. The contemporary literature is lacking detailed data regarding Post consumer recycled ETFE foils. The described data here is the first step towards modelling a realistic and detailed Life cycle assessment study of recycling ETFE foils that have been exposed under environmental conditions, furthermore, establishing a comparative analysis of material properties between recycled ETFE foils and virgin ETFE foils to assess the overall behaviour. In lieu of proposed universal PFAS ban by ECHA, studies like this will provide a proof that projects built with ETFE foils in the future can be recycled safely as well as promote future research which will be in direction of utilising various types of recycled ETFE foils for architectural purposes.

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