# REHAU AG + CO (& POLYSECURE GMBH)

A Circular Economy Business Model Case

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# Executive Summary


This report looks into the Circular Economy Business Model (CEBM) of Rehau AG's window solutions division. This is, within the Rehau group, the business unit which manufactures PVC profiles which are used, later by their customers, to frame window glass in domestic and commercial buildings.

The case-study has examined internal and external operations related to PVC profile production, usage and recycling; interviews with relevant managers took place.

Given sustainability and cost considerations surrounding PVC, Rehau practices a ***circular sourcing CEBM*** involving the whole value-chain in particular downstream actors such as customers and recyclers.

- PVC profiles are delivered to its customers, the window manufacturers, from whom it recovers the cuttings (the "post-industrial" waste / resource). This is financially incentivised and enables Rehau to melt, re-granulate and re-extrude, i.e. use as a *secondary raw material* in a *circular sourcing* process.
- Due to a long-standing landfill ban in Germany of PVC, the recovery and recycling of "post-consumer" waste, is a well-organised business, in which, take-back of end-of-life PVC window frames, is financially incentivised. The recycler shreds, melts and re-granulates this resource into a *PVC-recyclate*, i.e. a *secondary raw material*. Rehau, and other PVC extruders, are keen to purchase this recyclate since it is some 20% cheaper than virgin PVC. Apart from mild discolouring, properties of virgin PVC are practically maintained in the recyclate.
- Rehau has innovated by introducing glass-fibre to reinforce PVC and thereby dispense with steel content in window profiles. Such glass-fibre PVC (GF-PVC) window profiles present a number of advantages in terms of lightness, thermal insulation and cost of installation. To recover this new type of PVC, a specific tracing and sorting technology has been implemented in cooperation with a technology provider. Indeed, Polysecure GmbH's *tracer-based sorting* approach is an *enabling technology* which, thanks to a micrometric marker powder, is physically bonded to the raw material on a permanent basis, and enables identification and sorting at End-of-Life. Thus a *glass-fibre PVC recyclate* can be generated as a *new pure segregated secondary raw material fraction*.
- Since recyclers of PVC are providing raw material within the same value-chain, there is no loss of value; on the contrary, recyclate being some 20% cheaper than virgin PVC, there is in fact value retention, or even creation, some of which is passed on to end-of-life actors and PVC extruders such as Rehau. This balances out the cost of dedicated extrusion and tooling equipment, in which Rehau has to invest as well as quality assurance in dealing with recyclate.
- In terms of contextual factors, Rehau's CEBM is driven by growing demand for buildings in general and energy efficient ones in particular. Not only demographics and urbanisation play a role but increasing expectations and standards regarding a building's energy efficiency.
- A particular contextual impulse was generated by national regulation, namely the landfill ban of PVC in Germany as from 2005. Henceforth, end-of-life solutions had to be found, ensuring cooperation across the value-chain and among the trade associations of producers of PVC and major users (window manufacturers).
- Rehau has successfully implemented its **circular sourcing** CEBM, thereby




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    - Maintaining intensive links with its value-chain partners (customers, recyclers, technology providers)
    - Avoiding procuring over 10,000 to p.a. of virgin PVC through its substitution by PVC-recyclate and double that amount in 2017
    - Saving a six-figure Euro-Amount (according to our estimates) in raw material procurement in 2017
    - Processing through its Dekura recycling subsidiary around 55,000 to/a of old PVC and achieving 45,000 to/a output of PVC-recyclate for the extruder market
- SWOT for circularity
    - The salient strength of Rehau's CEBM is recovering resource and re-inputting it into the production process. Indeed whether through its recycler or its relationship with its customers, it is managing to source the greater portion of the PVC material needed for the inner window profile, on a circular basis.
    - Due to the cost advantage procured by recyclate, there is latent competition for this resource
- Going forward, a major sustainability consideration for Rehau and the construction industry in general, is the role of PVC. There is a trade-off between the properties of PVC, especially for window frames in terms of longevity, robustness and lightness versus the risks associated with improper disposal (incineration at certain temperatures causing formation of furanes and dioxins). When designing new products, a cradle-to-cradle, or at least closed-loop, approach, ought to be taken.
- Given on the one hand, the cost savings from recyclate and, on the other, environmental issues with PVC, Rehau's **closing the loop** thanks to both commercial and organisational procedures as well as Polysecure's Tracer-based Sorting, is a significant achievement. Whereas it is well implemented in Germany, due in part to regulation, its replication in *other* EU *countries* is to be strived for. Trade associations, value-chain dialogues and policy-making have a role to play in making this happen. Indeed, regarding the latter, bans on landfilling and probably on incineration, would promote material recycling ("*stoffliche Verwertung*"[1]). The combination of regulatory pressure and cost advantage of producing a secondary raw material could probably be replicated in *other sectors*: one of the prerequisites is to obtain a segregated waste fraction; this can be achieved by regulatory, behavioural or technological means, or combination thereof. Banning disposal via landfilling or incineration may also be seen as stimulating innovative solutions (and applying a CEBM pattern). Replication is further assisted by engaging a complete value-chain in the process.

[1] German notion for recuperation of *material* value



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# 1 Introduction

## 1.1 Background and context

R2π – Transition from Linear to Circular is a European Union Horizon 2020 project focused on enabling organisations and their value chains to transition towards a more viable, sustainable and competitive economic model in order to support the European Union's strategy on sustainability and competitiveness.

R2π examines the shift from the broad concept of a Circular Economy (CE) to one of Circular Economy Business Models (CEBM) by tackling market opportunities and failures (businesses, consumers) as well as policy opportunities and failures (assumptions, unintended consequences). Its innovation lies in having a strong business-model focus (including designing transition guidelines) as well as in the role of policy development (including designing policy packages).

The ultimate objective of the R2π project is to accelerate widespread implementation of a circular economy based on successful business models and effective policies:

to ensure sustained economic development,

to minimize environmental impact and

to maximize social welfare.

The mission of the project is therefore to identify and develop sustainable business models and guidelines that will facilitate the circular economy, and to propose policy packages that will support the implementation of these sustainable models.

A core part of this project is to work with organisations who are on the journey towards developing circular economy business models, as well as those who have the ambition to do so but have not yet begun. The project has conducted case studies of 18 selected organisations.

The 18 chosen cases covered all five priority areas highlighted in the EU Action Plan on the Circular Economy[2]: plastics, food waste, biomass/bio-based, important raw materials, and construction & demolition. Additionally, the cases were selected to ensure learning in each of the seven business model patterns defined by the R2Pi project: re-make, re-condition, circular sourcing, co-product recovery, access, performance and resource recovery, and these will be discussed in more detail in this report. To gather wide-ranging lessons from differing company sizes and maturities, the following were selected: 7 large corporations, 8 small, medium enterprises, 1 public entity, 1 entire value chain with both public and private organisations and 1 ongoing social project.

This report presents the case of the Rehau AG + Co. It was chosen due to its role in the construction sector as a large, global window profile supplier and due to its initiative to develop a circular take back model for glass fibre reinforced PVC.

It also presents its main technology supplier, Polysecure GmbH and its circularity-enabling tracer technology.

The next section provides a more detailed overview of the case organisation's business.

[2]https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=CELEX:52015DC0614



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## 1.2 Business overview

Rehau is an international leading specialist for polymer-based solutions for construction, automotive and industry.

*FIGURE 1 REHAU LOGO*

**Industry:** Polymer solutions for buildings, automotive and industry

**Founded:** 1948

**Area of operation:** More than 40 Production plants, more than 110 locations in Europe, North America, Asia and Australia. The headquarters are located in Muri in Switzerland.

**Products:** window systems, tubes, lay floorboards, surfaces for furniture, various parts for automotive

**Net sales:** 3,4 billion € in 2016 at group level

**No. of employees:** 20,000+ worldwide, 8,000+ in Germany.

**History**

The company was founded in 1948 in Rehau. The company replaced conventional materials with polymer. In 1958 the company extruded the first plastic window profile and in 2000 the company was the first producer of a window profile with a certification for a passive house.

The company initially established itself successfully in Germany and western Europe. Later it continued expanding in north America, Asia and Australia. Today, the company is in more than 50 countries actively present. [3]

The company is developer and producer of building components such as window systems, tubes, lay floorboards and surfaces for furniture. The company also develops and produces solutions for the automotive sector and the industry.

**High-level business model overview**

Rehau provides window manufacturers with PVC window profile systems. PVC windows consist of the glass panel, the window frame and mechanical parts. The window frame mainly consists of the PVC-profile, a steel reinforcement and seals.

The main materials glass, steel and PVC are recyclable materials. Thanks to their good recycling properties, the materials retain value on the recycling market. The German window profile manufacturers created a recycling initiative for window profiles called Rewindo[4]. Rewindo collects building materials containing PVC (window profiles, window shutters and doors) and reprocesses

[3] https://www.rehau.com/de-de/unternehmen/wir-ueber-uns/historie

[4] https://www.rewindo.de/



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these via shredding, grinding and extrusion) into recyclate. Such PVC recyclate can then be used in manufacturing window profiles and other new products.

Rehau developed a glass fibre-reinforced PVC ("Raufipro") for window profiles. This compound material has a higher stability than ordinary PVC, decreases heat loss and makes redundant the use of steel frame inside the profile. Since 2008, the company offers window framing systems containing the new material and has thus entered the PVC recycling stream.

*FIGURE 2 REHAU'S RAUFIPRO GF-PVC PROFILE*

So as to avoid mixing in the recycling stream, the compound material with the PVC mono-material, i.e. non glass-fibre reinforced, the company developed a *tracer based sorting* system together with Polysecure, a specialist for robust and multifunctional markers as from 2013. A fluorescent marker was added to the compound systematically as from 2015 which enables automatic identification by PVC recyclers. In 2016, Rehau entered the PVC recycling industry through acquiring a majority stake in a recycling company specialised in PVC recycling (Dekura) from Tönsmeier, a recycling expert (which maintains a minority share).



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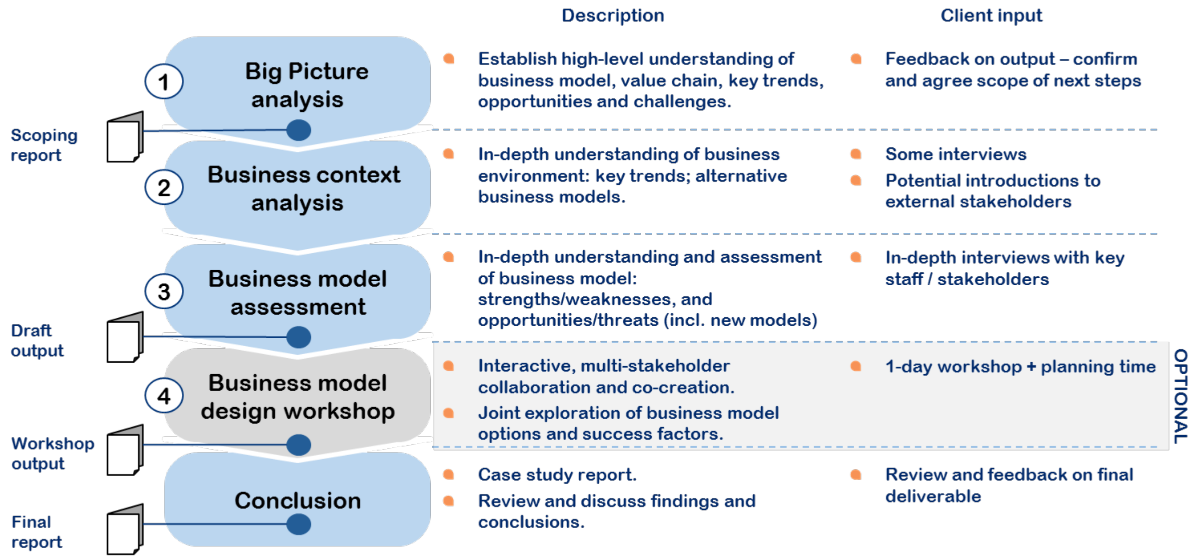
## 1.3 The case study analysis process

The case study process was structured in three main steps, plus an optional workshop, and concludes with this document as the final report (see diagram below). For this case study, meetings and interviews were held with managers from Rehau and Dekura, desktop research was conducted on both publicly available information and internal documents provided by the company. Specifically, a meeting was held at Rehau in Erlangen on 26.01.2018 with the Window Solutions Division, including procurement and recycling functions. A visit of Dekura's recycling plant was performed in March 2018. Moreover, a visit to Polyscure's facilities was carried out in November 2017. A discussion of the contextual analysis and CEBM took place with Rehau Window Solutions management on 28.05.2018. The optional business model design workshop has not yet been conducted and is planned for November 2018.

*FIGURE 3: CASE STUDY PROCESS*




## 1.4 Report outline

The first chapter introduction has provided a high level overview of the case and case study process. Chapter 2 presents the big picture surrounding the business, showing the context in which it operates and the key external factors. Chapter 3 is an analysis of the business at the building block level of the business model, including the circularity of the business, the financials and the strengths and weaknesses. Chapter 4 draws conclusions about the current state of the business and its future potential



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# 2 Rehau's business context analysis

## 2.1 Scope of the business context analysis

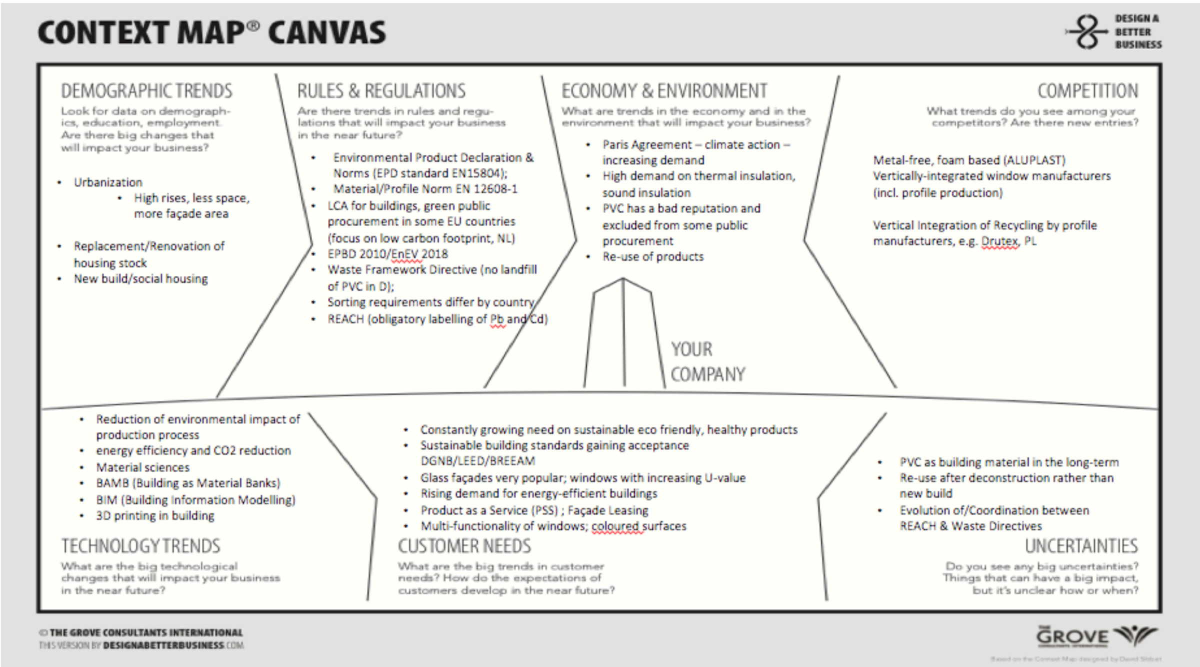
The objective of the context analysis is to identify the main external factors that are to be considered in order to explain the success (or failure) of Circular Economy Business Models (CEBM), as well as their potential role in accelerating the transition towards a Circular Economy.

The business context research was carried out in two stages. In the first stage, the case study team conducted desk research in order to identify the country and sector-specific factors that may potentially affect the business model. In the second stage, the team conducted interviews with relevant key stakeholders of the case organisation.

## 2.2 Contextual factor analysis

This section identifies the key trends and developments in the business context of building insulation materials in the construction sector and on the dynamics in the value chain of the production, recycling and disposal of mineral-based insulation material. The "Context Map Canvas" was used as a basis for discussion and categorisation of factors (see Figure below).

*FIGURE 4: CONTEXT MAP CANVAS*




### 2.2.1 Demographic trends

The increasing global population and ever higher concentrations of people living and working in cities is leading to a much higher demand for infrastructure and buildings, particularly in urban areas. Therefore, planning the supply to meet this growing demand for buildings as living and working places while especially taking into account aspects such as resource efficiency, comfort and



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affordable prices are becoming key factors in the development of infrastructure for citizens well being. This section explores key demographic factors of:

- Growing population and
- Urbanisation

that may impact the Rehau business model through rising demand for renovation, reconstruction and construction of buildings.

#### 2.2.1.1 Growing population

The worldwide growing population, currently numbering 7.6 billion, is estimated to grow to 9.8 billion people by 2050[5]. Additionally, global urbanisation is expected to grow approximately 1.84% per year between 2015 and 2020, 1.63% per year between 2020 and 2025[6]. These are key demographic factors that trigger the need to enlarge city infrastructure and buildings to deliver the necessary living and working space. Even in Europe, the total population of the EU-28 is projected to increase slightly from 505 million currently to 510 million by 2030, also with growing urbanisation[7].

*This can be seen as a positive factor for the future growth of Rehau and its overall sales, however, it presents significant challenges regarding ecological impact and social well-being. In order to grow sustainably, circular business models that reduce waste and reuse and recycle valuable resources will become more necessary. This represents an enabling opportunity for companies to gain competitive advantage through reducing resource costs and developing longer term relationships with customers, thereby meeting society's needs more efficiently.*

#### 2.2.1.2 Urbanisation

The world's population is moving inexorably towards the 10 billion mark. This growth will be happening primarily in our cities. The rural population has already stopped growing, but the world's population will add up to 1.5 billion people within the next 15 years[8]. The major move from the countryside into urban areas will evolve even more rapidly in Asia and Africa[9].

The EU-28 currently counts 72.5% of EU inhabitants as living in urban areas, and this is projected to rise to just over 80 % by 2050[10].

Along with the rising demand for buildings in cities, aspects such as the population concentration and the increase of noise pollution requires higher levels of building comfort and safety through sound insulation and fire resilience, as well as energy efficiency through thermal insulation.

Today, cities and urban areas are associated with approximately 70% of total global energy-related carbon dioxide emissions. Cities have a major responsibility in driving climate change mitigation. The awareness of cities on their impact is rising, and solutions and actions towards reduction of green

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[5] United Nations (2017, November 28). *World Population 2017*. Retrieved from https://esa.un.org/unpd/wpp/Publications/Files/WPP2017_Wallchart.pdf

[6] World Health Organization (2018). *Global Health Observatory (GHO) data - Urban population growth.* Retrieved from http://www.who.int/gho/urban_health/situation_trends/urban_population_growth_text/en/

[7] European Environment Agency (2016). *Population trends 1950 – 2100: globally and within Europe.* Retrieved from https://www.eea.europa.eu/data-and-maps/indicators/total-population-outlook-from-unstat-3/assessment-1

[8] United Nations (2018). *World Urbanization Prospects 2018.* Retrieved from https://esa.un.org/unpd/wup/

[9] United Nations Populations Fund (2018). *Urbanization.* Retrieved from https://www.unfpa.org/urbanization

[10] European Commission (2016). *Urban Europe — statistics on cities, towns and suburbs — patterns of urban and city developments.* Retrieved from http://ec.europa.eu/eurostat/statistics-explained/index.php/Urban_Europe_%E2%80%94_statistics_on_cities,_towns_and_suburbs_%E2%80%94_patterns_of_urban_and_city_developments



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house gas emissions within cities and urban areas are being developed through worldwide alliances[11].

Significant reductions in greenhouse gas (GHG) emissions are expected to be reached through the increase of building standards for new construction, retrofitting building envelopes, upgrading heating, ventilation, air conditioning and water-heating technology as well as implementing lighting, appliance, and automation improvements[12].

Urbanisation is as a key enabler for the demand for energy efficient building materials like window systems. Rehau achieves high-end heat insulation through its glass fibre-reinforced PVC profiles properties; indeed these make obsolete heat-conducting steel reinforcements inside the profile (and hence energy loss). In addition sound insulation is of such profiles is good and they entail low maintenance costs.

The recyclability of the PVC window frame material is an added benefit in the context of a resource-constrained future.

Additional opportunities may be offered by urbanisation in such areas as “urban mining” and “buildings as material banks”, which will be further discussed below.

## 2.2.2 Rules and regulations

Rehau as an international corporation with activities in more than 170 countries is involved in and affected by numerous international, European and national regulations. The company operates globally, owns physical assets and intellectual property in multiple jurisdictions and is involved in many different contracts on an international and national level.

The interest groups are active and involved in stakeholder conferences on various upcoming European and national legislation issues. In this report, the focus is mainly on:

- Regulations on climate and energy
- Waste framework Directive (in particular ban on PVC in landfills in Germany)
- REACH
- Environmental Product Declaration (EPD standard EN15804)
- Material/Profile Norm EN 12608-1 (display in appendix)
- EPBD 2010/EnEV 2018 (Energy efficiency of buildings)

that represent the key enablers and barriers of European and some national policies affecting Rehau’s business.

### 2.2.2.1 Regulations on climate and energy

The EU 2020 Climate & Energy Package results in binding legislation to set targets to be achieved by 2020. The three key targets are:

- reduction of green house gas emissions by 20% from 1990 levels,

[11] See https://www.c40.org/

[12] McKinsey Center for Business and Environment and C40 Cities (2017, November). *Focused acceleration: A strategic approach to climate action in cities to 2030.* Retrieved from https://www.mckinsey.com/business-functions/sustainability-and-resource-productivity/our-insights/a-strategic-approach-to-climate-action-in-cities-focused-acceleration



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- use of 20% renewable energy inside the EU
- and improvement of energy efficiency by 20%.

The measures for boosting energy efficiency are found in the Energy Efficiency Plan. It contains the Energy Efficiency Directive as a set of rules and obligations for meeting the 2020 targets and measures to make old and new buildings more energy efficient[13].

**Energy Efficiency Directive (2012/27/EU)**

The Directive (2012/27/EU) establishes a set of binding measures to help the EU reach its 20% energy efficiency target by 2020 along the whole energy value chain, from production to consumption. Specific measures and policies for member states include 1.5% energy savings per year in energy distribution, the empowerment of energy consumers to manage their consumption, energy audits, procurement of energy efficient buildings, products and services and renovation of 3% (by floor area) of publicly owned or occupied buildings each year. Countries can achieve the energy savings through their own means of favour, for example improving heating systems, installing energy efficient windows or insulating the building envelope. The countries report on their progress annually[14].

In November 2016, a new package of measures to facilitate the clean energy transition was presented. It includes a 30% energy efficiency target for 2030 and measures to update the Energy Efficiency Directive to insure the attainment of the new target.

**EU Energy Performance of Buildings Directive**

Besides the Energy Efficiency Directive, the Energy Performance of Buildings Directive is the main legislative instrument of the EU to improve energy performance of buildings. They intend to provide a stable environment for investment decisions taken on energy efficiency in buildings.

The current Energy Performance of Buildings Directive defines that all new buildings must be “nearly zero-energy buildings” from 2021 onwards, and for public buildings, this is required from 2019 onwards. The directive requires energy performance certificates for all buildings sold or rented. Each country must set their own minimum energy performance requirements for new buildings, major renovations and replacements of building elements such as roofs, walls and heating or cooling systems. This directive has been further revised to accelerate cost-effective building renovations to reach the goal of a decarbonised building stock by 2050 and to mobilise investments. [15]

Additionally, the EU Commission has published the EU Building Stock Observatory as a database to track the energy performance of buildings in European countries[16]. The Commission also created an initiative on smart finance for smart buildings to release public and private funds for energy efficiency and renewable energy in buildings[17].

*These directives can be seen as enablers for Rehau’s general business model and for raising the demand for their high-end insulating windows to increase energy efficiency and to enhance the energy performance of buildings. The requirement to renovate and improve efficiency of existing*

[13] European Commission (2018). *2020 climate & energy package.* Retrieved from https://ec.europa.eu/clima/policies/strategies/2020_en
[14] European Commission (2018). *Energy Efficiency Directive.* Retrieved from https://ec.europa.eu/energy/en/topics/energy-efficiency/energy-efficiency-directive
[15] European Commission (2018). *Buildings.* Retrieved from https://ec.europa.eu/energy/en/topics/energy-efficiency/buildings
[16] European Commission (2018). *EU Building Stock Observatory.* Retrieved from https://ec.europa.eu/energy/en/eubuildings
[17] European Commission (2018). *Smart finance for smart buildings: investing in energy efficiency in buildings.* Retrieved from https://ec.europa.eu/info/news/smart-finance-smart-buildings-investing-energy-efficiency-buildings-2018-feb-07_en



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*buildings is a potential enabler for the circular business model, offering additional opportunities to take back the discarded windows from renovated buildings.*

#### 2.2.2.2 Regulations on waste

Waste generation has, thus far, been an ever increasing by-product of economic wealth and growth. This critical link is to be decoupled through regulation on careful material management and conservation of resources. Modern technologies are often seen as enablers for new approaches on the efficient and effective use of materials.

**EU Waste Framework Directive 2008/98/EC**

The directive is a legal framework on treatment of wastes inside the EU. It strengthens proper waste management, recovery and recycling and reduces pressure on resources and their use. It is designed for protection of the environment and human health. The EU defined the minimum criteria on waste management and treatment for the EU-28 and has applied since December 2008[18]. Some member states have implemented advanced strategies.

Some key points of the directive are:

- Establishes waste hierarchy: first, prevention, then, re-use, recycling, recovery for other purposes such as energy and lastly, disposal
- Extended producer responsibility, which may include a constraint on manufactures to accept and dispose of products returned by users
- Special conditions apply to hazardous waste, waste oils and bio-waste
- Definition of end-of-waste criteria – expresses the conditions for waste materials to obtain the status of a product or a secondary raw material
- Recycling and recovery targets to be achieved by 2020 for household waste (50% by weight) and construction and demolition waste (70% by weight). [19]

**Hazardous wastes**

Wastes classified as hazardous require stricter control due to their greater risk for the environment and human health. These wastes are obliged to follow special handling, labelling, record keeping, monitoring and inspection obligations from waste production to final disposal. Mixing of hazardous wastes is banned. The classification into hazardous and non-hazardous waste is based on the system of classification laid down in the Directive's List of Wastes[20].

Even though old PVC profiles contain cadmium and lead, discarded PVC- profiles and new PVC profiles nonetheless contain organohalogens (Polyvinylchloride); these profiles are not considered as hazardous waste (cadmium has been banned in PVC since 2007).

Indeed heavy metals (Pb and Cd), formerly used as stabilisers for PVC, are *bonded* within the polymer, that is to say, they cannot propagate into the environment. There is some debate as to whether it is less hazardous to, in fact, recycle them and transform them into PVC recyclate for further use as window profiles or to dispose of them via incineration or landfill. REACH regulation

[18] EUR-Lex (2018). *EU waste management law.* Retrieved from https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=legissum:ev0010
[19] European Commission (2016, June 9). *Waste framework directive: Targets and reporting.* Retrieved from http://ec.europa.eu/environment/waste/framework/targets.htm
[20] European Commission (2016, June 9). *Waste: Hazardous waste.* Retrieved from http://ec.europa.eu/environment/waste/hazardous_index.htm



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foresees an upper limit of 2%of Pb and Cd in recyclate, presenting a challenge in detecting it. Rehau have to verify it with mass spectroscopy.

In the recycling process, old profiles are melted at temperatures around 200°C with no release of toxins, whereas incineration of PVC can release Furanes and Dioxins.

**Landfill ban**

A major driver for creating an End-of-Life solution for PVC in Germany (through collecting and recycling) has been the landfill ban. Indeed, this regulation was enacted in 2005 and alternative solutions therefore had to be found. Prior to the ban, xxx xxx tonnes of PVC were being landfilled annually.

**Sorting of wastes**

At the EU level, the sorting of PVC wastes differs country. Sorting is always driven by the national waste regulations and by economic logic (e.g. metals are always removed before demolition as they have a secondary resale value). Article 10 of the Waste Framework Directive defines, that "waste shall be collected separately if technically, environmentally and economically practicable and shall not be mixed with other waste or other material with different properties". However, these technical, environmental and economical practicability criteria differ by country, and this results in heterogeneous recycling practices - sometimes even within countries.

Rehau sees the diversity of regulations across Europe as barriers for their business as it means, different processes in different countries. The ban on landfilling of PVC in Germany may be seen, on the other hand, as a driver: indeed, recyclers pay up to €200/to for discarded PVC window profiles. In France, for example, where PVC may still be landfilled, recycling is however incentivised by a payment of €50 for every tonne which is not landfilled.

**Waste management in the Netherlands**

The Dutch, due to lack of physical space and continuously growing material consumption together with environmental deterioration of land, were forced to take stronger measures to reduce the landfilling of waste already in the 1980's [21]. The result is that the amount of waste sent to landfill decreased from 35% in 1985 to 2.3% in 2010[22].

The Netherlands have developed the 2050 Circular Economy Plan, a government-wide programme to move their economy to 100% circular by 2050. It aims at handling all materials more efficiently and moving away from the concept of waste towards all products and materials being considered valuable resources[23]. The Dutch approach is to avoid creating waste as much as possible, to recover usable and valuable materials and, as a last resort, to generate energy by incinerating residual waste.

Landfilling is only allowed for waste streams for which no recovery or incineration is possible. 79% of the Dutch waste is recycled, the remaining wastes are mainly used for energy production. The Dutch banned landfilling any waste streams (currently 35 waste streams) that are suitable for recovery or incineration. Well defined waste treatment standards, planning on a national level in cooperation

[21] Leonidas Milios, European Environment Agency and ETC/SCP (2013, February). *Municipal waste management in the Netherlands.* https://www.eea.europa.eu/publications/managing-municipal-solid-waste/netherlands-municipal-waste-management

[22] Rijkswaterstaat Environment (2018). *Elements of Dutch waste management.* Retrieved from https://rwsenvironment.eu/subjects/from-waste-resources/elements-dutch-waste/

[23] Government of the Netherlands (2018). *From a linear to a circular economy.* Retrieved from https://www.government.nl/topics/circular-economy/from-a-linear-to-a-circular-economy



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with local governments, extended producer responsibility (EPR) and intelligent stimulation on prevention and recycling were some of the elements that led the Netherlands towards such a low landfill and high recycling rate [24].

#### 2.2.2.3 Regulations on Products

Rehau's window solutions have to conform to European Environmental Product Declaration EN15804: this covers building materials and their environmental impact.

Material/Profile Norm EN 12608-1 covers window and door profiles made of unplasticised PVC; one of its important features is that recyclate may not be used on the outer (exposed) surface but only in the inner core. Where recyclate is used, there is the obligation of having a second extruder to distinguish virgin PVC from recyclate PVC.

### 2.2.3 Economy and environment

The business environment of global players is affected not only by socioeconomic factors like urbanisation, digitalisation and growing population but also by other worldwide economic and environmental trends. In this section, the following trends affecting the business are highlighted and discussed:

- Climate change discourse
- Energy efficiency in buildings
- Sustainable Development Goals
- Awareness of waste and recycling
- Circular economy
- Urban mining
- Commodity prices
- Conflicting perception of PVC in building materials

#### 2.2.3.1 Climate change discourse

**Kyoto Protocol**

The awareness of and concern for climate issues has grown steadily over the years. One of the key milestones was the Kyoto Protocol, an international treaty signed in 1997 in Kyoto, Japan. Participating states confirmed that global warming was occurring and that is was likely caused by human made CO2 emissions. The participating states agreed on reduction targets for green house gas emissions. The Protocol initiated political debates and global awareness on climate change and CO2 emissions. It helped increase demand a high energy efficiency as the fact that a high share of global energy is consumed through buildings came to light.

**Paris Climate Agreement**

The Conference of Parties (COP) takes place annually in order to discuss global climate efforts. In this regard, in 2015, the COP 21 in Paris is considered a landmark due to the so called Paris Agreement, involving more than 200 countries in the goal to keep global temperatures well below two degrees Celsius above pre-industrial times and to endeavour to limit them even more, to 1.5 degrees. Given

[24] Rijkswaterstaat Environment (2018). *Elements of Dutch waste management.* Retrieved from https://rwsenvironment.eu/subjects/from-waste-resources/elements-dutch-waste/



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this context, the EU has led significant efforts and actions in order to implement its target to reduce emissions by at least 40% by 2030[25].

Therefore, when discussing the reduction of emissions in the EU context, it is significant to consider that buildings are responsible for approximately 40% of energy consumption and 36% of CO2 emissions.[26] To tackle this issue, improving the energy efficiency of buildings and the renovation of existing buildings has the potential to lead to significant energy savings, reduction of CO2 and help achieve climate goals.

According to the UN Environment and International Energy Agency, the energy intensity per square meter of the global buildings sector needs to improve on average by 30% by 2030 (compared to 2015) to be on track to meet global climate ambitions set forth in the Paris Agreement.[27]

On this subject, the European Union set the target to increase Europe's energy efficiency by 20 % by 2020 by improving the energy efficiency of buildings and of a wide array of equipment and household appliances.[28]

*Climate and environmental awareness are seen as enablers not only for Rehau but any company pursuing more sustainable and circular business models.*

#### 2.2.3.2 Energy efficiency in buildings

Among the EU's buildings, 35% of them are older than 50 years and 75% of the building stock is energy inefficient. Depending on the country, 0.4 to 1.2% of the building stock is renovated each year. The EU estimates a high potential for reducing total energy consumption by 5-6% through renovation of existing building stock, resulting also in a 5% reduction in CO2 emissions in the EU[29].

Rockwool offers building insulation products worldwide, and the needs for building insulation depend on the climate. Houses have to align with the local climate conditions, and thus differ strongly by region. In warmer regions, houses serve more as a cold storage space during the summers, whereas in colder regions, the houses serve as a heat storage space during the winters. Traditionally, houses in colder regions have thick walls and are thermally insulated to keep them warm during the winter, whereas in warmer regions, they generally have little or no thermal insulation.  Today, the thermal insulation of houses and buildings in warmer regions plays a bigger role due air conditioning of buildings and the wish to avoid cooling losses.

*The awareness and the desire for greater energy efficiency in buildings is a clear enabler for high-end insulating windows and for circular activities.*

#### 2.2.3.3 Sustainable Development Goals

The Sustainable Development Goals (SDGs) are a range of 17 universal goals set by the agreement of 195 countries in 2015 through a United Nations process to provide guidelines and targets for an inclusive and sustainable agenda for future development.

[25] European Commission (2018). *Paris Agreement.* Retrieved from https://ec.europa.eu/clima/policies/international/negotiations/paris_en
[26] European Commission (2018). *Buildings.* https://ec.europa.eu/energy/en/topics/energy-efficiency/buildings
[27] UN Environment (2017). *Towards a zero-emission, efficient, and resilient buildings and construction sector - Global Status Report 2017.* Retrieved from http://www.worldgbc.org/sites/default/files/UNEP%20188_GABC_en%20%28web%29.pdf
[28] Eurostat (2017). *Greenhouse gas emission statistics.* Retrieved from http://ec.europa.eu/eurostat/statistics-explained/index.php/Greenhouse_gas_emission_statistics
[29] European Commission (2018). *Buildings.* Retrieved from https://ec.europa.eu/energy/en/topics/energy-efficiency/buildings



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The pillars of the SDGs are comprised of the 5Ps: people, planet, prosperity, partnership and peace. The pillars include areas such as climate change, economic inequality, innovation, sustainable consumption, peace and justice, among other priorities.

Considering the multi-scalar dimensions and the diversity of contexts of these goals, governments and companies are encouraged to strategically select key goals to be prioritized and embedded in their own agendas.

The following four key sustainable development goals can be considered relevant for Rehau and their building sector activities:

- SDG 9 – Build resilient infrastructure, promote inclusive and sustainable industrialization and foster innovation
- SDG 11 – Make cities and human settlements inclusive, safe, resilient and sustainable
- SDG 12 – Ensure sustainable consumption and production patterns
- SDG 13 – Take urgent action to combat climate change and its impacts.

Rehau do not mention these explicitly in their corporate documents.

#### 2.2.3.4 Awareness of waste and recycling

The issues of resource use, excess wastes and the need for recycling has caught the public attention in many ways at least since "The Limits of Growth" in 1972, the first publication of the Club of Rome[30]. Since then, waste management has advanced, mainly driven by regulation, and landfill bans and recycling goals have been pronounced and have continued to develop. The building sector is said to be one of the heaviest resource-consuming sectors, with construction and demolition waste equal to 25-30% of all EU waste generated. This consists of various products and materials, but where many of them could be recycled[31].

Today, overall awareness on the waste problem has reached the mainstream. Lately, the environmental impacts of plastic wastes regularly get broad attention from media and pubic.

The construction sector is, like most industries, still mainly driven by economic decisions though.

The European Thematic Strategy on Prevention and Recycling of Wastes describes key objectives to reduce the overall negative environmental impacts of resource use and insure a higher level of environmental protection through prevention of waste, promotion of re-use, recycling and recovery and establishment of the European recycling society, avoiding waste and using unavoidable waste as a resource whenever possible[32].

The EU Environment Action Programme sets objectives for waste policy in the EU[33]:

- to reduce the amount of waste generated
- to maximise recycling and re-use
- to limit incineration to non-recyclable materials
- to limit landfilling to non-recyclable and non-recoverable waste

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[30] The Club of Rome (2018). *The limits of growth.* Retrieved from https://www.clubofrome.org/report/the-limits-to-growth/

[31] European Commission (2018). *Construction and Demolition Waste (CDW).* Retrieved from http://ec.europa.eu/environment/waste/construction_demolition.htm

[32] European Commission (2018). *Review of the Thematic Strategy on the prevention and recycling of waste.* Retrieved from http://ec.europa.eu/environment/waste/strategy.htm

[33] European Union (2014). *General Union Environment Action Programme to 2020 - Living well, within the limits of our planet.* Retrieved from https://publications.europa.eu/en/publication-detail/-/publication/1d861dfb-ae0c-4638-83ab-69b234bde376



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- to ensure full implementation of the waste policy targets in all member states.

Today the EU-28 has large differences of awareness across value chains. Leading countries are Holland, France, BeNeLux, Germany and the United Kingdom. Eastern Europe and the Mediterranean area are moving more slowly. The trend towards circular products is still new and has not yet reached the mainstream.

#### 2.2.3.5 Circular economy

Although construction is one of the sectors that most cause the highest impacts on environment - taking into account the estimation that one-third of all global waste is produced in the building sector and most of this waste ends up in landfills[34] - circular and innovative business models in the construction sector have shown that it is feasible to combine the growing demand for materials and new buildings with sustainable value chains.

From the perspective of Rehau and other businesses that are stakeholders of this project, the circular economy concept has been considered a valuable tool embedding resource efficiency, long term perspectives and sustainable paths into the business agenda of the construction sector.

The Ellen MacArthur Foundation is promoting circularity of materials, and their studies state that the circular economy will cause growth of GDP[35]. "Reuse and high-quality recycling of building components and materials could reduce the need for new materials and decrease construction and demolition waste, if the split incentives created by a fragmented market are addressed. Sharing, multi-purposing and repurposing of buildings furthermore could reduce the demand for new buildings through better utilisation of existing floor space." The annual potential unlocked by 2035 for these opportunities are estimated to be between 400-600 million Euros in Denmark alone[36].

The German sustainable building council (DGNB) certifies buildings which demonstrate a commitment to sustainability objectives. The council has developed a rating system on the circularity of buildings following the principles of cradle-to-cradle. It is the first system that measures and evaluates circular economy in the building sector. The DGNB system is a market leader in Germany, and not only prestige objects like corporate head offices use such rating systems, but also other building owners make use of these circularity principles.

The concept of circular economy has gained substantial publicity and acceptance and has moved organisations and companies to set new standards, promote new practices and seek better solutions.

*Rehau has an explicit objective that 50% of its window profile production by 2020 ought to contain recyclate..*

#### 2.2.3.6 Urban mining

Over the centuries, a massive amount of materials in the built environment such as infrastructure and buildings have been accumulated around the world. These anthropologic material stocks have a high potential to be future sources of secondary materials as they reach their end-of-use status. Urban mining is an approach to recover stocks from existing buildings, make use of these materials

[34] European Commission (DG ENV) (2011, February). *Service contract on management of construction and demolition waste.* Retrieved from http://ec.europa.eu/environment/waste/pdf/2011_CDW_Report.pdf
[35] Ellen MacArthur Foundation (2015). *Growth within: A circular economy vision for a competitive Europe.* Retrieved from https://www.ellenmacarthurfoundation.org/assets/downloads/publications/EllenMacArthurFoundation_Growth-Within_July15.pdf
[36] Ellen MacArthur Foundation (2015, November). *Potential for Denmark as a circular economy – A case study from: Delivering the circular economy – A toolkit for policy makers.* Retrieved from https://www.ellenmacarthurfoundation.org/assets/downloads/20151113_DenmarkCaseStudy_FINALv02.pdf



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and long life products and to decrease the environmental impact of raw material mining and building material wastes. The “mined” materials can either be re-used in similar product applications or enter the secondary materials market to supply production. Landfill mining can be seen as a special discipline of urban mining.

In Austria for example, the BauKarussell is already practicing urban mining and is one of the first dismantling organisations focusing especially on re-use of high volumes of building materials. Re-useable components and materials are dismantled and offered to the building market, while recyclable materials are identified, manually separated and directed towards material recycling. The work is executed by social service providers, who educate workers and provide qualification opportunities to gain value for the job market. The project is publicly funded, but it demonstrates opportunities, through intelligent dismantling to reuse high volumes of building materials.

For example, insulation materials have been recovered in the dismantling of a Coca-Cola factory, and this recovered insulation was then re-used in the Biotope City Quartiers, a building constructed on the same site. The re-use potential in the construction sector in Austria is estimated to be up to 10% by mass, and similar approaches are happening in Switzerland, Belgium and the Netherlands[37].

*Urban mining is clearly not yet a trend, but it represents a new area of opportunity for innovative companies and those who understand the concepts of circular business models. It is not currently an enabler for Rehau or others in the sector but points to a massive potential of valuable products and material stocks in the built environment as well as offering ideas and examples of how to access that value.*

#### 2.2.3.7 Commodity prices

The report “Resource Revolution: Meeting the World’s Energy, Materials, Food, and Water Needs” by the McKinsey Global Institute explores the challenge of providing resources to a rapidly expanding world population.

The report depicts the price decline of key resources (energy, food, agricultural materials, metals) seen in the 20th century followed by a sharp increase since the year 2000. The volatility of resource prices was also increasing until 2010, when companies and governments began to realise the diminishing guarantee of cheap supply and energy and that new business models needed to be considered. From 2010, the volatility of the key resource prices seemed to decrease even as the general price level continued to increase.

[37] RepaNet (2018). BauKarussell – Beschäftigung & Kreislaufwirtschaft. Retrieved from http://www.repanet.at/baukarussell/#ErsteBauabwicklung



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*FIGURE 5 COMMODITY PRICES OF ENERGY, FOOD, AGRICULTURAL MATERIALS, METALS*


Two approaches to solving this resource challenge are proposed in the report:

- Expand the supply of resources available, or
- Use our current resources in a more effective and productive way.

The first approach is classified as not viable due to political and practical difficulties, "*supply chain bottlenecks*", missing infrastructure and further negative environmental impact. The report concluded that the resource productivity approach is more viable and could satisfy 30% of demand by 2030, while at the same time generating up to 25 million new jobs[38].

*The price volatility and general increase represent significant risks and barriers to traditional linear business models. Consequently, the proposed solution of resource efficiency and productivity are clear enablers for circular business models.*

### 2.2.3.8 Conflicting perception of PVC as a building material

Whereas even in some green building approaches PVC window frames are found to be efficient and durable, there remains among the general public perceived health hazards associated with PVC and organohalogens in general. Indeed many municipalities have decided to ban PVC from public procurement. This is the case for example of Munich in Germany, 60 cities in Spain and further municipalities across Europe.

[38] Ellen MacArthur Foundation (2018). *Case studies – Data-backed stories that drive change.* Retrieved from https://www.ellenmacarthurfoundation.org/case-studies/data-backed-stories-that-drive-change



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### 2.2.4 Competition

Whereas Rehau's GENEO product based on its glass-fibre reinforced profile is an innovation which dispenses with steel frames, there exist alternatives. Indeed, ALUPLAST, a company from Karlsruhe, Germany, uses "powerdur", a glass-fibre-reinforced PBT (Polybutylene terephtalate) lodged in its unplasticised PVC profiles. Aluplast claim to not only be able to recycle their profiles 100%, but also to separate the glass-fibre PBT and thereby reintegrate it into their production process.[39]

### 2.2.5 Technology trends

As overall requirements, energy efficiency, material productivity and other needs are identified, technology and digitalisation may create enabling tools for different ideas, practices and concepts. These can lead to more detailed planning, modelling, three dimensional (3D) design and new ways of data interaction. This section describes some technology trends in the construction sector:

- Building information modelling
- Building as material banks
- 3D printing
- Communication opportunities through digitalisation

#### 2.2.5.1 Building Information Modelling (BIM)

Building Information Modelling (BIM) is an approach to design the whole building in a 3D-model, where all elements of the different planners (architecture, static, technical installation, furniture, et al) are joined together within the model. The model shows spatial collisions between the elements in the building before it is constructed. BIM delivers visual support and data for decision making processes during the planning of a building. It is mainly a tool interesting for planners and architects leading towards more detailed planning, which can result in fewer mistakes during the construction phase and higher material efficiency.

*It is currently not clear what the impact of this may be on Rehau or other circular business models, however, it may offer opportunities for creating and testing more circular designs. Mainly architects currently seem interested in circularity, much more than other customer groups, and thus, new methods of design may bring new possibilities for circular construction.*

#### 2.2.5.2 Building as Material Banks (BAMB)

In the Project BAMB – Buildings as Material Banks, 15 partners from 7 European countries are working on circular solutions for the building sector. BAMB is looking for ways to increase the value of building materials resulting in less waste at the end-of-use phase. The idea is to give buildings the function as depositories of valuable materials, which will be maintained and reused in later stages rather than being treated as waste and discarded. Key tools for enabling BAMB are Materials Passports and Reversible Building Design to ensure the contents of the material bank are both known and able to be recovered later.

*BAMB seems to be of increasing in importance for the future. Combined with urban mining above, in the future, building materials may be far easier to track, dismantle, recover and re-use than they are today.*

[39] https://www.aluplast.net/eng-int/mehrwerte/technologien/



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#### 2.2.5.3 3D Printing

According to industry experts, it is likely that 3D printing of building components will be technically and economically feasible in the near future. Labour savings, material savings and positive environmental impact are predicted when managed properly[40].

*The approach is still at an early stage, and the impact of the technology on building insulation can not be foreseen at this stage. However, innovative companies will certainly be developing new products and testing new materials, and one can imagine some parts of windows being 3D printed in the future at the construction site. As it is 3D printers use an extrusion process, which is, in fact, the main manufacturing step executed by Rehau. Would a printer of 3D building components be able to recuperate at end-of-life? This seems unlikely; at best, there may be a fee to an EPR scheme, which, based on the payment, organises appropriate end-of-life valorisation.*

#### 2.2.5.4 Communication opportunities through digitalisation

Digitalisation is already leading to new communication platforms where, e.g., best practices are shared and new ideas gain wide outreach. The new possibilities in data tracking and communication enable the connection of specific needs with offers and can, for example, utilise matchmaking portals to facilitate previously difficult or expensive transactions.

*This trend of digital communication and data exchange has already revolutionised multiple industries but has not yet affected building materials. The near future may see new opportunities emerge such as platforms to find and trade used building materials or to separately collect dismantled materials for recycling. Such opportunities will be seized by companies who are motivated enough to recognise new models and flexible enough to implement them. Rehau uses digitalisation to communicate with its sales channels.*

### 2.2.6 Customer needs

- Constantly growing need on eco friendly, hazard-free products.
    - The challenge for here is balancing the energy-efficiency and longevity properties of glass-fibre reinforced PVC window profiles with the latent hazard of disposal through incineration or landfilling

Sustainable building standards gaining acceptance: a series of green building standards are not only being implemented but their observation is progressively becoming a factor in public and commercial construction orders. Some high-profile standards include LEED (Leadership in Energy and Environmental Design), BREEAM (Building Research Establishment Environmental Assessment Method) and DGNB (Deutsche Gesellschaft für Nachhaltiges Bauen).

- A report studying life cycle assessment by USGBC (U.S. Green Building Council)41, concluded that "aluminium window frames, with or without thermal breaks, are consistently the worst material relative to environmental impact when compared to the vinyl and wood alternatives reviewed". Furthermore, for a humid environment

[40] https://www.ellenmacarthurfoundation.org/assets/downloads/20151113_DenmarkCaseStudy_FINALv02.pdf

[41] Assessment of the Technical Basis for a PVC-Related Materials Credit for LEED," (LEED Technical and Scientific Advisory Committee PVC Task Group, February 2007)



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such as bathrooms, PVC or fibreglass frames are to be preferred since wood is liable to rot, according to GreenBuiliding.com[42].

  - DGNB has among its membership, the AGPU (Arbeitskreis PVC und Umwelt), which promotes the use of PVC as a reliable and established material in construction

- With particular regard to windows, these are expected
  - to provide ever better thermal insulation (increasing U-value)
  - to allow visible light transmission
  - to minimise air leakage
  - to maximise resistance to condensation
  - to become generally multi-functional (factors above) and decorative, allowing for coloured surfaces (outdoor and indoor)

- Glass façades are becoming ever more popular (mainly for commercial buildings); moreover the business model of façades is evolving, with examples of
  - Product as a Service (PSS) in the form of *Façade Leasing*

### 2.2.7 Uncertainties

In addition to general uncertainty over the future of EU policy and circular economy strategy, various factors have been identified as currently unclear but with a potential impact on the future success of circular business models and these are described below.

- PVC as building material in the *long-term*: whereas PVC in window frames is a tried and tested material with favourable properties in construction, it is nonetheless an organohalogen whose production is energy intensive and whose disposal either in landfill or via incineration is environmentally harmful. It is suspected of being cancerogenic and therefore maximum concentration levels in the workplace have been established.
- Re-use after dismantling rather than new build: as Circular Economy gains momentum, resources become constrained and governments seek to act as in the case of the Netherlands, one wonders if in the *medium-term*, there may not be an obligation to re-use upon dismantling of old-buildings, insofar as non-standardisation of window size allows.

#### 2.2.7.1 Environmental Product Declaration

The Environmental Product Declaration (EPD) declares the environmental performance of the whole life cycle of products and provides data for building design and assessments. EPD started in 1991 and is still an ongoing process with current amendments intended to better align with the European Product Environmental Footprint policy. EPDs deliver important product data for consumers which

[42] http://www.greenbuilding.com/green-bathroom-remodel-windows/



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could influence the market and become enablers for more sustainable products with lower environmental impact.

#### 2.2.7.2 Life Cycle Assessment (LCA)

LCA has become mandatory in some European countries before a building can be designed and built. Assessing the entire life cycle environmental impacts is important in long-term decision making. The leading countries are the Netherlands, Denmark, Belgium, France, Finland, Germany. Eastern and Southern Europe currently show less interest in this area. Since LCAs are very time intensive, it highly depends on policies and regulations whether LCA will gain further importance in Europe.

#### 2.2.7.3 Sustainable procurement (public and private)

Public and private procurement plays an important role in the construction sector. Green public procurement would focus the demand for more sustainable products and force building material producers into a more sustainable behaviour. The Netherlands, Germany and Finland are seen as front runners in sustainable public procurement for the construction sector. The Netherlands applies green public procurement criteria for buildings and infrastructure. Germany requires the application of the BNB system (Bewertungssystem für Nachhaltiges Bauen) for rating the sustainability of public buildings. Also the demand for DGNB certified buildings is increasing in the German private sector. Finland has started an ambitious circular economy programme in November 2017 which set special requirements for sustainable procurement[43].

#### 2.2.7.4 Private building rating systems

The inclusion of private rating and certification systems in designing, planning and construction of buildings, such as LEED, BREEAM, DGNB, support the demand for sustainable and eco-friendly products. Corporations are often pleased to announce that they are the occupant or the builder of a green building as part of a CSR strategy.

#### 2.2.7.5 Future of employment in the construction sector

In Germany for example, public tender processes (with exceptions) require the lowest price offer to be awarded the contract, and this leads to a high focus on cost reductions in the labour-intensive sector. The demand for inexpensive labour work pushes construction companies often towards subcontracting firms from counties with lower wages, which leads towards lower quality in the product (building). Also, little awareness of sustainability or waste reduction is cultivated among these less educated workers.

Furthermore, digitalisation and high tech products are finding their way into the construction sector. Some examples are exoskeletons for construction workers, which could make the sector more attractive for physically weaker people[44], or 3D-printing of buildings, where robots execute the physical processes of building and reduce the need for human labour. Such technologies are still in testing, but may be influencing the work environment of the construction sector in the near future.

On the other hand, urban mining may become more important in coming years and could require an increase in the amount of human labour and expertise in specialised areas. In Austria the BauKarussell is developing as the first dismantling company focusing especially on the re-use of existing materials[45].

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[43] https://www.sitra.fi/en/projects/leading-the-cycle-finnish-road-map-to-a-circular-economy-2016-2025/

[44] https://www.wired.com/2015/04/try-new-exoskeleton-construction-workers/

[45] http://www.repanet.at/baukarussell/



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*Predictions in a certain direction on all of the topics in this section cannot be made at this time and therefore represent both risks and opportunities for those seeking to invest in circular solutions.*



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# 3 Business model assessment

The business model assessment has been conducted through a combination of publicly available information, interviews with employees and stakeholders of the case organisation and documents provided by the organisation.

The objectives are to gain a deeper understanding of the circular business model and to map out the value chain and interactions in more detail in order to enable an analysis of the strengths and weaknesses as well as to consider the replicability and transferability of such a model to other entities and sectors.

In this chapter, Rehau's business model and its value chain are described. Thereafter, the circularity is assessed with its financial and nonfinancial outcomes along with the strengths, weaknesses, opportunities and threats associated with the circular business model. Lastly, final assessments and considerations for the company are discussed.

## 3.1 The Rehau business model

### 3.1.1 Business model overview

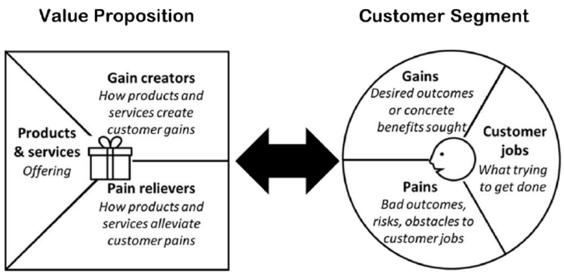
To review the Business Model we have examined the value proposition and the key elements of the model according to the Business Model Canvas approach, performed a circularity assessment and finally drawn up a SWOT table.

#### 3.1.1.1 Value proposition and customer needs assessment

Rehau's glass-fibre reinforced PVC window profile 'RAUFIPRO', is designed for window manufacturers. Its value-enhancing features are

- an innovative building product (glass-fibre PVC core) enabling the window manufacturer to sell windows ("Geneo")
- Less steel and therefore lighter
- better thermal insulation properties
- large surface (2x2m) and yet transportable by single worker (lower installation cost)
- while retaining durability properties of PVC windows

*FIGURE 6: CONTEXT MAP CANVAS*




- Rehau's value proposition for its main customer segment (window manufacturers) is generating following
  - **Gain creators** for its customers
    - innovative product component



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        - Better end-product properties (thermal insulation, weight)
        - Incentive for recuperating cuttings
    - **Pain relievers**
        - Installation weight and cost (lowered due to lightness, i.e. less manpower)
- Customer segment
        - **Who?**
            - Window manufacturers
        - **Jobs-to-be-done**
            - Manufacturing a high-performing, durable, product which can be easily installed and dismantled by their downstream customers (window installers)
        - **Pains/Gains**
            - Product to be positioned with USP
            - Controlling sourcing cost of major component (via recyclate)

- The role of technology is a major one, since the Tracer technology supplied by Polysecure is an integral part of recuperating and sorting post-industrial and post-consumer PVC glass-fibre waste (see Section 3.2.1.4).
- By recuperating the PVC profile cuttings of the window manufacturers, Rehau is able to melt, granulate and re-extrude these for new profiles.
    - Thus Rehau is able to lower its raw material cost (recycled PVC is up to 20% cheaper than virgin PVC)
    - To achieve this it requires the cooperation of its clients, i.e. that they sort their production waste (PVC vs. GF-PVC); it incentivises them financially to do so.

#### 3.1.1.2 Depicting the Business Model Canvas

In order to gather knowledge and understanding on Rehau's business, the business model canvas framework is applied, which structures the business model into 9 different elements. Each of these have been discussed with Rehau and are described below.



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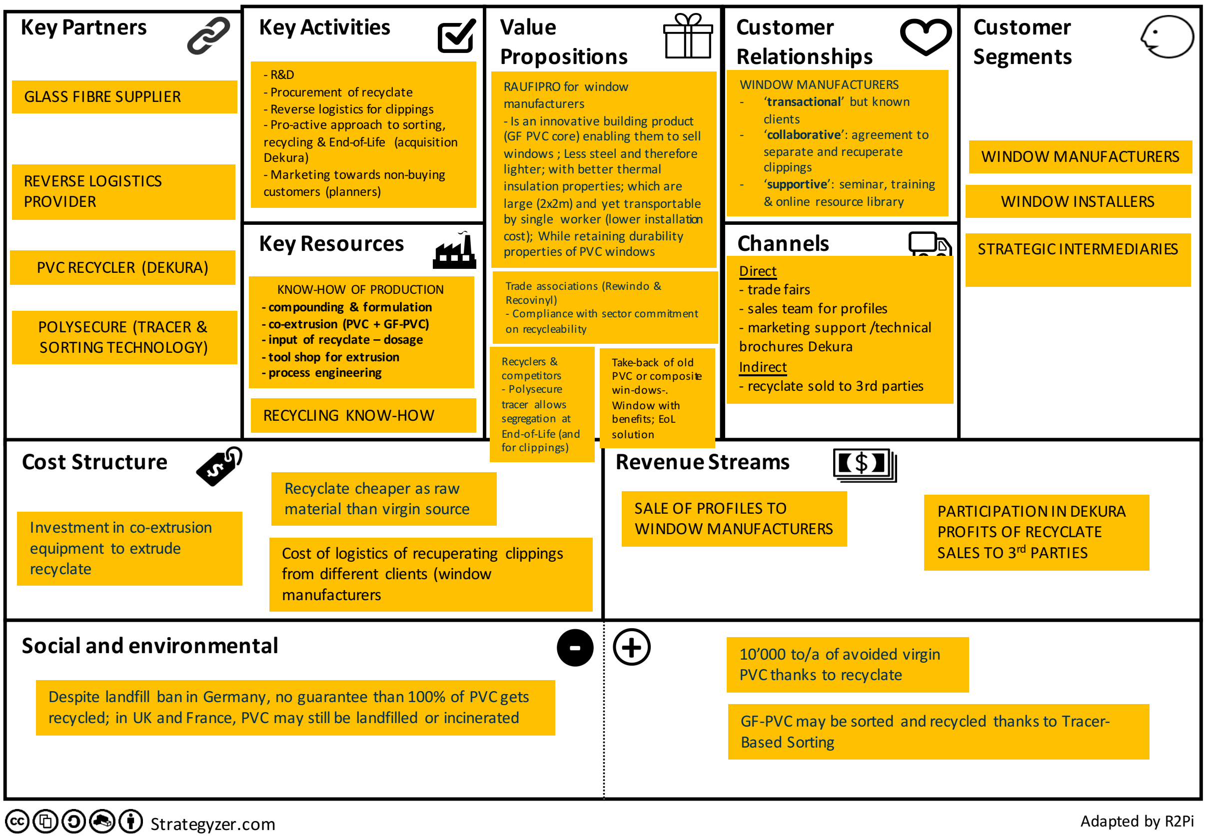
*FIGURE 7: BUSINESS MODEL CANVAS*




## Customer segments

Rehau has as its major customer, **window manufacturers**. These incorporate Rehau glass-fibre PVC frames into the overall end-product, i.e. a ready-to-be installed window. The end-product will include the glass, double- and triple-glazed, a handle and a system of hinges to allow opening/closing of the window as well as the typical feature of German windows “kippen”, i.e. a stabilised vertical leaning position.

In some cases, for large sites or customers, Rehau may engage in direct negotiation or with strategic intermediaries, if the specification corresponds to their type of product.

Indirectly, Rehau sells to window installers, demonstrating the advantages of their products and providing technical advice on installation.

## Value proposition

Whereas we have described how Rehau delivers value to its main customer segment, the window manufacturers (see 3.1.1.1), its value proposition goes beyond them to a range of other actors:

a) for trade associations

(i) of the window manufacturers, *Rewindo*, it allows them through the tracer technology to recuperate and sort at end-of-life covering both kinds of PVC (with and without GF) and thereby comply with their recycleability objectives (sector commitment that windows be recycleable and recycled)

(ii) of the use of PVC, *Vinylplus* and its recycling initiative, *Recovinyl*, enables them to demonstrate the recycleability of PVC and fulfil recycleability targets



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b) for Recycling businesses and competitors: Rehau's innovation, RAUFIPRO, the glass-fibre reinforced PVC profile, causes the waste stream consisting of old-PVC window frames, to have a new undesired element; indeed, competitors of Rehau, who are clients of the recycling plants to purchase PVC-recyclate, wish to obtain pure PVC-recyclate without glass-fibre content. Hence for both Recycling businesses and competitors, Polysecure's Tracer Based Sorting technology used by Rehau for its RAUFIPRO product, enables recyclers to identify and separate any GF-PVC coming into its waste stream. The separation occurs if the recycler has installed Polysecure's sorting machine. Currently the Dekura recycling plant has such a machine and performs sorting on Rehau's customers post-industrial waste, to obtain a pure GF-PVC reyclate.

c) for window installers: the value consists in the ease of installation due to weight and composite material, and in the fact that Dekura offers a take-back programme (with a financial incentive)

d) for B2C and B2B end-customers and their procurement guidelines: a high-performing window with a range of benefits, and a sustainability dimension with the end-of-life solution

**Customer relationships**

For window manufacturers, customer relationships can be viewed as 'transactional' but take place with known clients; they may also be considered as 'collaborative' through the agreement to separate and recuperate clippings.

Seminar, training and support on proper planning, installation and use of product are offered to direct and indirect customers, e.g. window installers. An online service is also offered.

**Channels**

Rehau's sales channels are direct with a sales team and engaging in usual marketing activites such as trade fairs and technical brochures

There also exists an indirect channel insofar as Dekura sells PVC-recyclate to 3rd parties.

**Revenue streams**

Revenues are generated through the sale of profiles to window manufacturers.

Through the majority holding in Dekura and its recycling business, Rehau participates in the revenues/profits generated by Dekura.

**Key activities**

As a major corporation Rehau has intense R&D activity; the RAUFIPRO/GENEO innovation is the result of such activity.
Being able to procure recyclate from recycler is important inasmuch as it lowers the material cost. Reverse logistics to recuperate the post-industrial clippings is provides the supply for recycling.
As a company, Rehau has had a pro-active approach to sorting, recycling & End-of-Life, embarking on the technology implementation with Polysecure and executing the majortiy acquisition of Dekura.
Lastly, it is important for Rehau to market its producst towards non-buying customers (e.g. planners).

**Key resources**

Rehau's know-how in production is a key resource since it covers (i) compounding and formulation (ii) co-extrusion, that is to say the simultaneous extrusion of PVC and GF-PVC (iii) inputting recyclate and dosage of GF (iv) a tool-shop for extrusion (v) process engineering.



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Co-extrusion requires an investment with dedicated machinery and tools. Additional quality checks are required especially when dealing with recyclate. The amortisation of these costs is to be balanced out against the cost advantage of using recyclate.

Moreover, the company has valuable know-how on recycling and the corresponding logistics including container-systems.

**Key partners**

Most of the key partners are deal with supplying raw materials, technology and services: (i) glass fibre supplier (and the particular surface properties of the product) (ii) PVC recyclers to provide recyclate and hence lower cost of material (Dekura and others) (iii) External reverse logistics providers (typically to recuperate post-industrial cuttings) (iv) Polysecure which has been instrumental in integrating its tracers into the PVC granulate compound combined with the designing and installation of the sorting machine to identify the GF-PVC once recuperated from the customers.

**Cost structure**

The recuperation of recyclate allows Rehau a reduction of up to 20% raw material cost per tonne, for the inner core component of the window profile. This is required to compensate the investment and cost of dedicated co-extrusion machinery and tooling as well as quality control; indeed, due to the variation in the composition of recyclate batches, some homogenisation may need to take place at Rehau. In total, about 15% of the tonnage required for the inner core consists of recyclate. In 2017, the company used 25,000 to of recyclate. Virgin PVC costs around €1000/to; recyclate about €800/to.

### 3.1.2 The Value Network

In order to fully understand the business model, it is important to appreciate how value (both financial and non-financial) is exchanged between the different stakeholders across the value chain.

In the case of Rehau, the material flow and value flow follow largely the same paths and are thus depicted on the flow map below along with the key partners and other actors across the value network.

#### 3.1.2.1 Material Flow

Rehau manufactures a physical product, the PVC window profile (or 'window frame') which is, in turn, a component of a complete window. The Schema depicts flows among the value-chain actors. The flows beyond the window manufacturer thus represent complete windows, with the distinction below.

- The black arrows represent linear flows of material and value (typically the whole window beyond the stage of the manufacturer), while the blue ones represent circular flows (enabling recovery of material and/or value) and here designate the PVC profiles.



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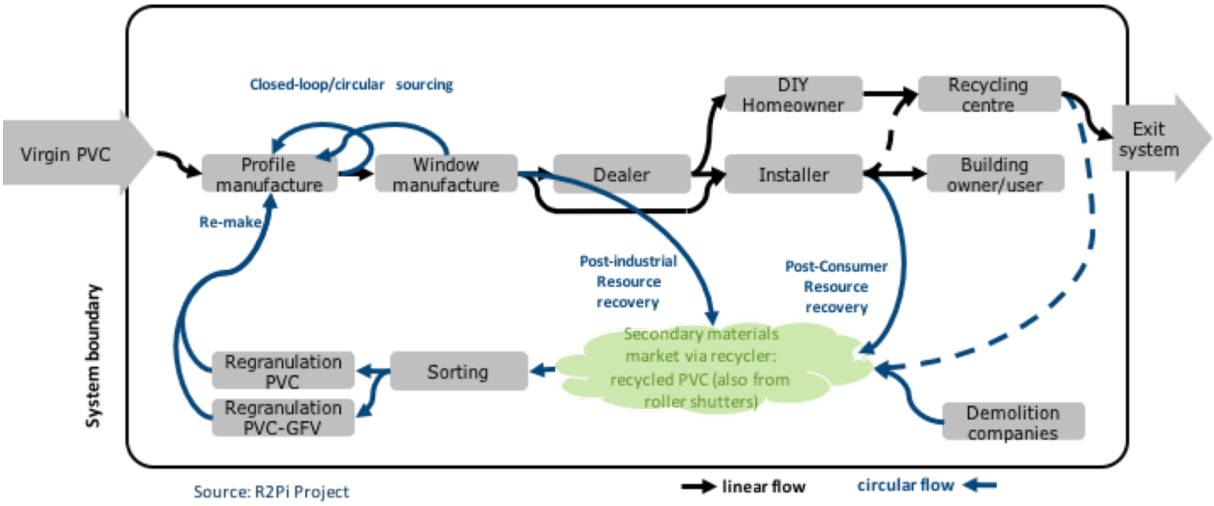
*FIGURE 8: MATERIAL AND VALUE FLOW MAP*




This mapping shows supplies of PVC flowing into the manufacturing process to deliver the PVC profiles: the clients of these are window manufacturers, who sell to dealers who, in turn, sell them to professional installers. The installer installs the window in the building; occasionally he is by-passed by DIY owners who install themselves. In the case of renovation or demolition, obsolete materials are dismantled by installers or demolition companies, who are legally required to properly dispose of the materials. The blue arrows indicate the recovery of PVC profiles or parts thereof. Sorting and re-granulation are performed by recycling plants, specialised in PVC re-processing. At present, only the Dekura plant in Germany is able to sort PVC versus GF-PVC on a flake basis since it has installed the Polysecure sorting machine. It must be said that GF-PVC is at present nearly exclusively within Rehau's controlled environment, namely its factory and its customers. Given a minimum 20 year lifespan of PVC windows, the GF-PVC profiles may emanate from the replacement and demoition market not before 2035.

The circular (value) flows are discussed in the next section.

#### 3.1.2.2 Value Flow

Since PVC recyclate is cheaper than virgin PVC, users of PVC are motivated to obtain recycled PVC. A whole value-chain is established in this respect, in particular in Germany.

Referring to the Value flow map (figure 3.4), linear value transfer is indicated by the black arrows, and occurs as a normal commercial transaction (*payment for goods*). Circular economy flows (blue arrows) usually lead to *mutual value* and often result in a payment for resource recovery. Thus the window manufacturer by not disposing of his cuttings but rather separating them and forwarding to a recycler, e.g. Dekura, receives an incentive payment (€200-400 /to). Likewise the installer, who replaces a PVC window frame, or a demolition enterprise, who dismantles a whole building's windows, may receive a payment from the recycling plant; Dekura currently pays €0-200 per tonne of disposed PVC window. After shredding and re-granulating, a recycler such as Dekura can expect to sell PVC recyclate for €700-1000/to, depending on the grade.



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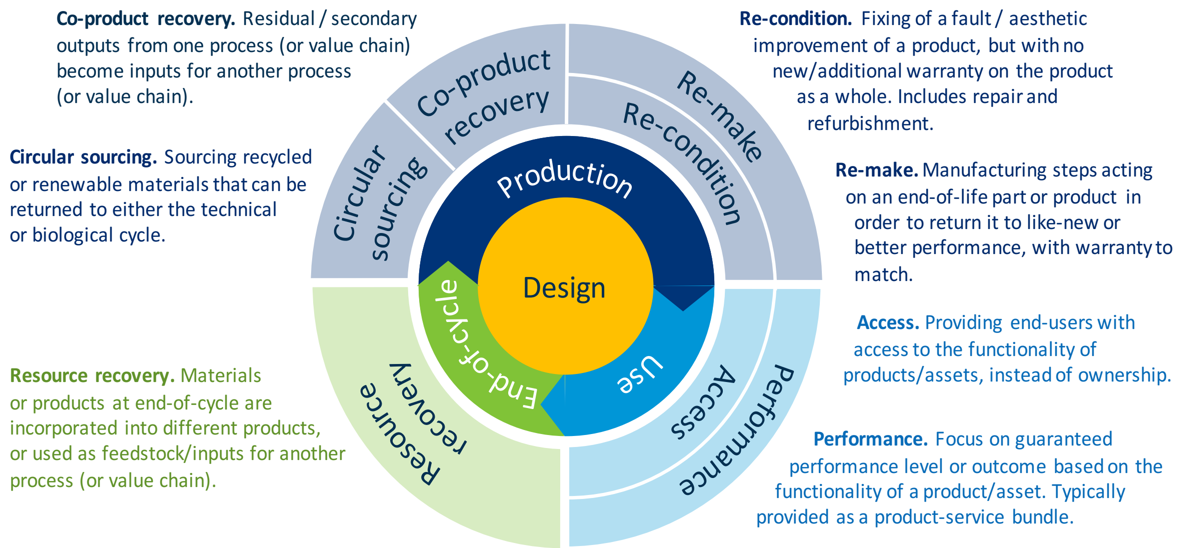
## 3.2 Business model circularity assessment

This section provides an assessment of the case organisation's circular business model. It begins with a depiction of the 7 Circular Economy Business Model Patterns identified by the R2Pi project, and describes which of these patterns are utilised by the case organisation. This is followed by the financial and non-financial outcomes of the business model as well as a discussion of its strengths, weaknesses, opportunities and threats, before final assessments are made to close the chapter.

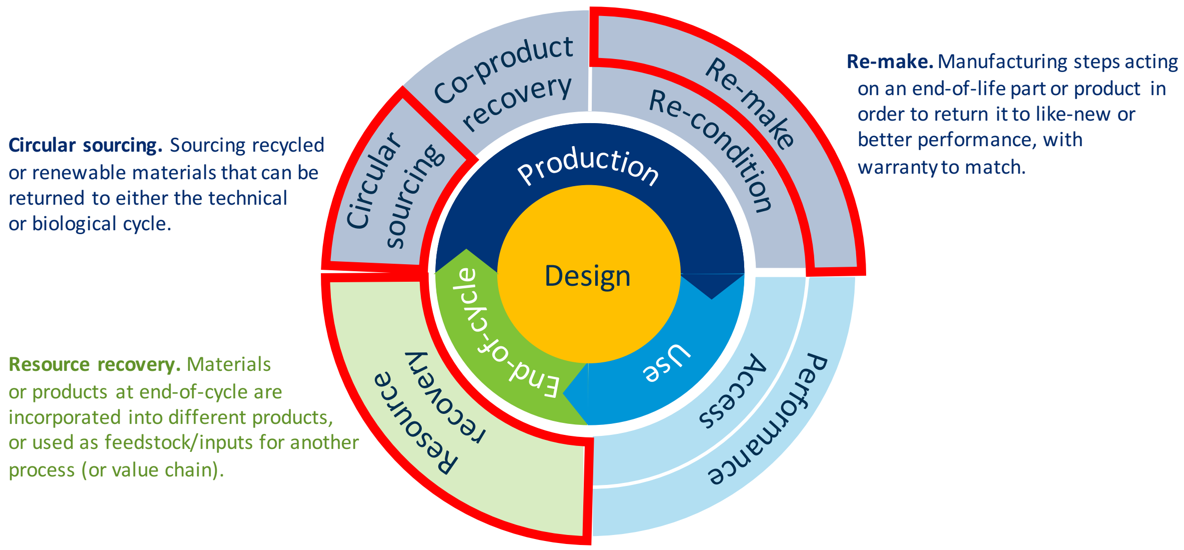
*FIGURE 9: CIRCULAR ECONOMY BUSINESS MODEL PATTERNS*




Source: R2Pi

Rehau utilises primarily the patterns of circular sourcing, re-make and to a lesser extent resource recovery, and these will be discussed in more detail in the following section.

*FIGURE 10: REHAU'S CIRCULAR ECONOMY BUSINESS MODEL PATTERN*



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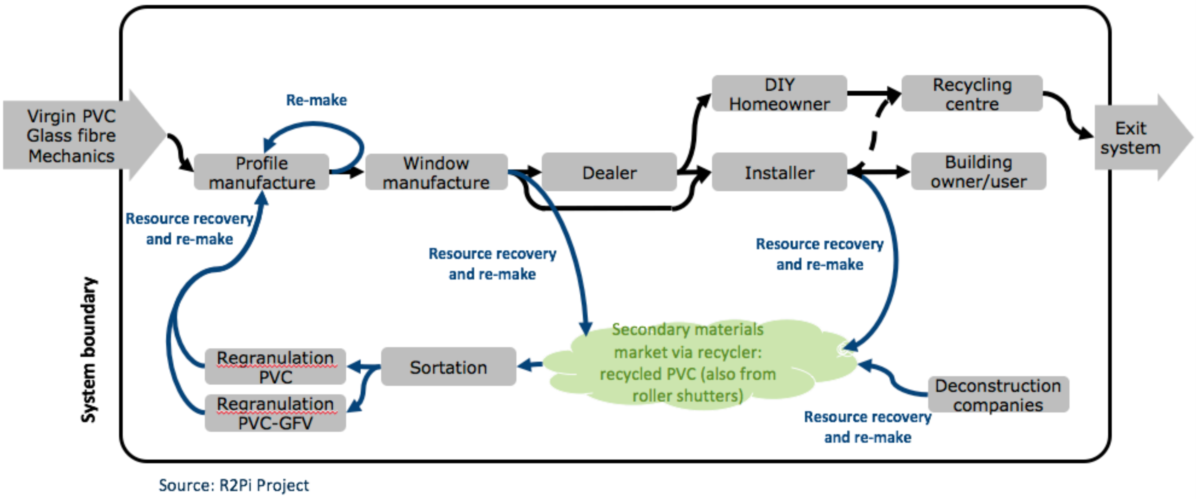
### 3.2.1 Circularity assessment

Achieving Rehau's CEBM, foremostly *circular sourcing* and *remake* is the result of several paths.

Circular Sourcing is the result of (i) resource recovery in different parts of the value chain and (ii) obtaining a secondary raw material (PVC recyclate).

Re-making involves introducing the recyclate into the manufacturing processing and extruding it into a new PVC profile.

*FIGURE 11: FLOWS AND CIRCULAR BUSINESS MODEL PATTERNS*




#### 3.2.1.1 Re-make: Internal production excess material

Rehau recovers excess material from internal production and re-granulates it for later extrusion.

#### 3.2.1.2 Resource recovery and re-make from window manufacturer

Rehau insists that their customers segregate their cuttings into PVC and GF-PVC so that clean waste fractions may be recovered. These cuttings are sent to Dekura for accurate sorting and re-granulation on a service basis. Ownership of the GF-PVC stays with Rehau and Dekura merely provides a re-granulation service. The re-granulated GF-PVC is sent to Rehau for re-make, i.e. integration into manufacturing process and extrusion. Should the amount of glass-fibre not be adequate, Rehau can re-balance the dosage by adding virgin glass-fibre.

#### 3.2.1.3 Resource recovery and re-make from installers and demolition companies

Recyclers and in particular Dekura are keen to obtain old PVC window frames as a source of secondary raw material. Currently they pay up to €200/to for the take-back at end-of-life. As usual the recycler then shreds and re-granulates the PVC, thus obtaining a secondary raw material. This is supplied to Rehau for normal integration in the manufacturing process, which systematically extrudes PVC recyclate for the inner core of the window frame. Recyclate is legally barred from being used in the outer shell of the frame (concern over heavy metals Pb and Cd and their potential diffusion into the atmosphere through erosion or abrasion even though they are bonded into the



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material). As mentioned in 3.1.2.1, currently, there is no GF-PVC emanating from installers or demolition since such profiles were only introduced to the market 5 years ago.

#### 3.2.1.4 Enabling Technology: Tracer-based sorting (Polysecure)

Closing the loop at End-of-Life of Rehau's GF-PVC is achieved through a significant *enabling technology*. Indeed, Tracer Based Sorting (TBS) as proposed by Polysecure, ensures tracer-marking of the GF-PVC at the outset. In fact, Polysecure provides Rehau with a unique tracer-marker powder, constituted of, among other things, rare earth elements; Rehau blends the powder with the PVC destined to be mixed with the glass fibre to create RAUFIPRO (GF-PVC). Through the blending a homogeneous marking takes place, so that even when shredded at End-of-Life, among an indiscriminate batch of old PVC, marked flakes can be identified ("traced") as GF-PVC: from the smallest flake will emanate a fluorescence when passing through Polysecure's sorting machine (the machine emits infra-red laser light which activates the fluorescence); those flakes which are fluorescent are separated from the others by compressed air valves. Hence, one obtains a sorted group of GF-PVC flakes, which can then be melted, polymerised and re-granulated into GF-PVC recyclate. (cf. **Appendix A** for details on Polysecure's technology)

Rehau has pro-actively implemented a solution today for an end-of-life of its RAUFIPRO product which is 25-30 years away at the earliest. It is very much an investment for the future (but necessitating a cash outlay of several million euros at present). It is a commitment to a future closed-loop with little pay-back in the short- or medium-term.

### 3.2.2 Financial and non-financial outcomes assessment

This section discusses various outcomes of Rehau's circularity activities.

#### 3.2.2.1 Reduction of virgin PVC usage

Bearing in mind that, as yet, there is little tracer-marked GF-PVC approaching end-of-life (since it was only introduced as from 2015 and the lifetime of a window is a minimum of 20 years), the main indicator is regarding pure unplasticised PVC used in manufacturing profiles. Indeed, by recuperating the clippings from its customers, Rehau managed to avoid the use of some 10,000 tonnes of virgin PVC in 2016. This was substituted by the recyclate composed of re-granulated PVC clippings. In 2017, the figure more than doubled to 25,500 to of avoided virgin PVC. Rehau also recuperates the GF-PVC clippings and lets them be shredded and re-granulated into GF-PVC recyclate.

#### 3.2.2.2 Cost savings

Through the substitution of recyclate for virgin PVC, Rehau achieves a substantial raw material cost saving on every tonne substituted. This corresponds to some €100-200/to. Yet this has to compensate the investment in the co-extrusion equipment and the additional quality control.

#### 3.2.2.3 Money train

By purchasing re-granulated PVC from recyclers and by collecting post-industrial waste, Rehau ensures that a maximum amount of money is kept within its own system. This is particularly true since its acquisition of Dekura, specialised in PVC recycling.

#### 3.2.2.4 Financial benefit for customers and recycling revenue

Direct customers receive payment for the take-back of post-industrial cuttings.



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Dekura, now a 75% subsidiary of Rehau, has a successful PVC recycling plant, treating some 55,000 tonnes of disposed PVC per annum and yielding some 45,000 to of secondary raw material (recyclate) for the market. At an average price of €750/to of recyclate, Dekura generates some €30 Million in revenues per year. The majority of its sales take place outside the Rehau group.

#### 3.2.2.5 Future reduction of virgin GF-PVC through secondary materials

Once the first tracer-marked GF-PVC window profiles get discarded in Germany, i.e. post-consumer waste (to be expected as from 2035), and if it can channelled to Dekura or to another recycler, who is able to sort GF-PVC from standard PVC, then Rehau will have a further source of GF-PVC alongside of its current recycling of post-industrial GF-PVC clippings. Thus it will be able to reduce its procurement of both virgin glass-fibre and virgin PVC.

#### 3.2.2.6 Issues regarding secondary materials

PVC reyclate is declared by legislation as “hazardous waste” due to its content of *historical* Pb and Cd. Although these were phased out in new material in 2007 at the latest, PVC window frames pre-dating 2007, will contain such heavy metals, due to their function as stabilisers. Whereas at present, windows are being recycled which are 30 to 50 years old, as time progresses however, the proportion of old-PVC profiles containing Pb and Cd will be diluted by those profiles manufactured since 2007 and reaching end-of-life (as from about 2037). And indeed the amount of Pb and Cd in the recyclate will be also diluted. As mentioned earlier, Pb and Cd bonded into the polymer may be the most appropriate way of keeping them out of contact with nature. Customers of Rehau, window manufacturers, are informed of this via a) the imprint on the profile “contains recycled material”, b) the delivery note indicates that it may contain Cadmium and lastly the recycling triangle with the number 3 is used to designate recycled PVC.

*FIGURE 12: SYMBOL FOR RECYCLED PVC*


### 3.2.3 SWOT analysis

This section contains an analysis of the Strengths, Weaknesses, Opportunities and Threats (SWOT) associated with the circular business model. It is important to note that this is primarily an assessment of the attributes of the business model itself and only secondarily of the specific attributes of the individual company. As is customary in SWOT analyses, the Strengths and Weaknesses are INTERNAL to the case organization’s business model. Whereas, the Opportunities and Threats are EXTERNAL to the case organization, coming from the context in which they operate.

The table below summarises the strengths and weaknesses that have been discussed in Chapter 3 and the opportunities and threats as discussed in Chapter 2.



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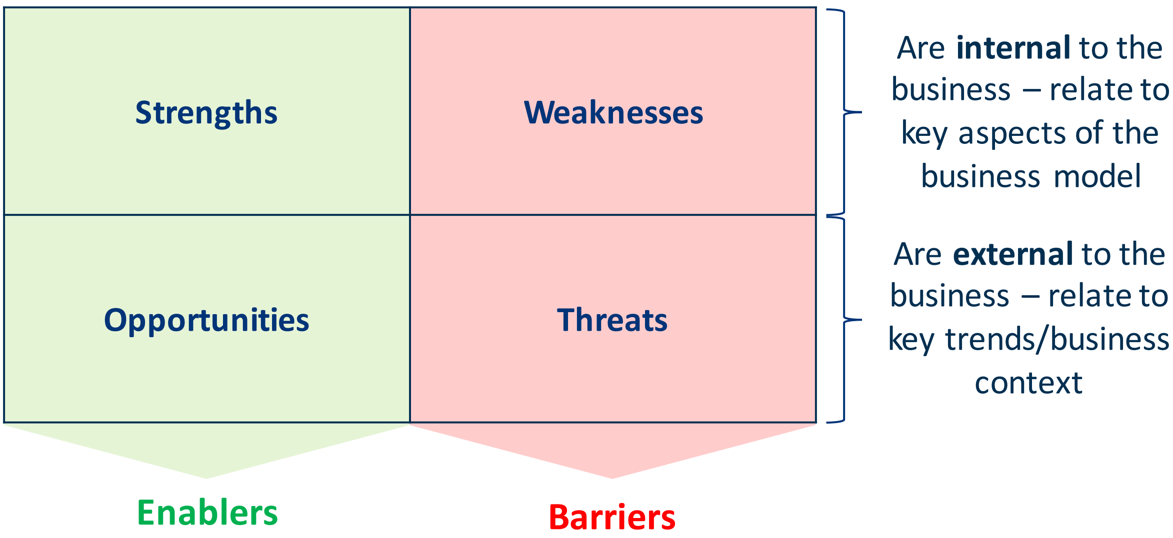
*FIGURE 13: SWOT TABLE*

| **Strengths** | **Weaknesses** |
|---|---|
| • Innovation in product design, organisational procedures (reverse logistics) and commercial relationships<br>• Longevity of PVC as building material in both virgin and recycled state<br>• High recycleability frequency of PVC (up to 21 times, massively prolonging longevity)<br>• Access to and use of recyclate to reduce costs<br>• Successful cooperation with Polysecure on tracer-based sorting technology<br>• Financial fire-power to enable vertical integration (acquisition of recycler)<br>• Quality of stakeholder relationships | • Organohalogen as main material (i.e. non biological) whose disposal can be hazardous and whose virgin production is energy intensive |
| **Opportunities** | **Threats** |
| • Increased customer demand for energy efficiency (including energy regulations)<br>• Medium-term ban on landfill in major markets (UK; F)<br>• Securing long-term supply through tracer-marking today of Raufipro (GF-PVC)<br>• Tracer-based sorting allows further product distinction (i.e. extendable to other product lines in the Corporation) | • Competition for recyclate<br>• USP of GF innovation challenged by competitors<br>• Future/alternative window technologies and/ or framing technologies<br>• Lack of harmonisation between waste directives and REACH |

*FIGURE 14: ENABLERS AND BARRIERS AS A FUNCTION OF SWOT*



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### 3.2.4 Final assessments

Rehau's CEBM is driven by a combination of costs, competition and environmental concerns. The combined *push* of sustainability intention and *pull* of recyclate pricing (below virgin PVC) has led Rehau to implement circular sourcing for a long period. More recently, with the introduction of its GF-PVC, the ensuing pressure of competitors to segregate it and the availability of the tracer-based sorting technology of Polysecure, Rehau has managed to *close the loop* on both its outputs for window profiles, namely PVC and GF-PVC.

These have also been achieved in the context of sectoral commitments of the plastics industry on recycling PVC ("Recovinyl") and of the window manufacturers, Rehau's downstream sector, on recovery of old windows and frames ("Rewindo").

By closing the loop, Rehau

- Secures recyclate supply
- Lowers its raw material cost
- Co-opts its value-chain (window manufacturers, installers, demolition enterprises and recyclers) into *retaining value* through non-disposal and into *contributing to sustainability*

Recyclers and customers by furnishing the secondary raw material to the original user (profile manufacturer), have become empowered; the recyclers of PVC are especially empowered since they produce a sought-after substitute to virgin PVC.

Where does Rehau go from here?

It is recommended that Rehau review CEBM potential for other product lines. In designing new products, a cradle-to-cradle approach is recommended, thereby avoiding hazardous materials; where this is technically not feasible and chemically-based polymers are still necessary, a closed-loop approach similar to that adopted for PVC and GF-PVC is essential. Having established a *visionary long-term commitment* of recuperating its GF-PVC in 25-years via Tracer-Based Sorting maintaining a closed-loop philosophy for future products ought to emulate that.

While Rehau has, historically, provided polymer solutions to the building industry, going forward, fossil-based polymers will decreasingly be accepted. Yet having acquired knowledge and serviced its target customers over many years, future innovations could be centred on the markets and services rather than the products: hence Rehau could investigate offering solutions for the building industry including windows but with alternatives to PVC …



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# 4 Discussion & Conclusions

This report has presented and assessed the Circular Economy business model of a leading window frame manufacturer, Rehau. It has combined circular sourcing, resource recovery and re-make activities into their CEBM. Although this is only one case study as an example of circular business model patterns, the lessons here may prove valuable to other businesses and sectors.

The intention of this chapter is to offer business leaders and policy makers considerations for further discussion and work on how to transition to more circular business models and policies.

The above implemented circular business model patterns seem replicable and transferable to other entities and other sectors and offer substantial potential for positive environmental and economic benefits. Companies and industries must, of course, reflect carefully on their specific context and product design when choosing which circular models to pursue.

## Considerations for business leaders

- Investigate the entire value chain for opportunities and efficiencies for total lifecycle value
- Collaborate across companies and even across industries to solve system-level issues
- Co-opt players of the value-chain to become actors of circularity
- Design for long life, durability, reparability, reusability and eco-design for lowest possible impact on human and ecological health
- Gain competitive advantage by being first or the best to provide circular models and close technical gaps for circularity by innovative technical solutions such as Tracer Based Sorting
- Seek highest level on hierarchy of value retention - first, prevent waste, then, re-use, recycle, recover for other purposes such as energy - avoid destruction of the value created and do not allow these investments to end in a landfill or incinerator
- Design with high value materials that are abundant, robust, reusable and recyclable; incorporate sortability into design
- Transition to renewable energy and means of production that reduce energy intensity in new, re-used and recycled products
- Develop circular models that provide extra value to customers, such as convenience, fulfilment of legal requirements, reduced cost over landfill
- Ensure that take-back logistics be sustainable both economically and ecologically - make efficient use of resources, e.g., take-back in combination with delivery rather than empty rides
- For replicating take-back on a global scale, design solutions to re-use locally and when not possible, to recycle locally
- Increase marketing of sustainability and circularity activities to increase awareness of and demand for circular products
- Engage employees in sustainability and circularity efforts and align target setting and performance evaluations with these activities.

## Considerations for policy makers

- Reduce taxes on labour to enable more labour-intensity for separation, recovery, handling, re-using and re-making to retain value of existing products and materials
- Increase taxes on virgin raw materials to incentivise recovery, repair, re-use, recycling and to ensure pricing reflects total costs of entire lifecycles



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- Strengthen eco-design standards and requirements across industries and continue to increase targets and standards for energy efficiency
- Continuously analyse whether there are new innovations like i.e. Tracer based Sorting which can close gaps in CEBMs and improve recycling rates and the efficiency of a CEBM.
- Require sustainability and circularity criteria in public procurement to create additional demand for circular products
- Provide tax incentives for re-use and recycling (e.g. zero or reduced VAT on these products)
- Ban landfilling or incineration of any materials that are feasibly reusable or recyclable and invest in new technology to ensure more materials become feasibly reusable or recyclable
- Where banning is not possible, reduce waste to landfill targets and increase taxes to landfill and incinerate
- Invest in secondary materials markets to enable recovery, re-sale and re-use of used materials
- Require additional separation of materials to enable more efficient take-back and recycling
- Ensure consistent resource ("waste") regulations across EU countries
- Invest in urban mining projects and infrastructure for this resource recovery
- Create clear and consistent long-term goals on circular economy to enable and boost further investments in circular infrastructure and business models.

As part of the continuing work of the R2π project, this report will be combined with the 17 other case studies, synthesised to gain cross-case lessons and discussed with other business and policy experts in the European Union, to then finalise and deliver Policy Packages and Business Guidelines. These are intended to enable organisations and their value chains to transition towards more viable, sustainable and competitive economic models that will ensure sustained economic development, minimize environmental impact and maximize social welfare.



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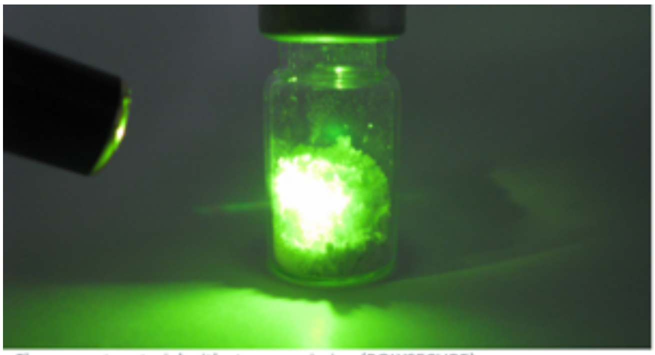
# Appendix A: Features of Polysecure's Tracer-based Sorting



Fluorescent material with strong emission (POLYSECURE)


Fluorescent tracer in packaging material (POLYSECURE)

### Tracer Based Sorting (TBS) –> how does it work?

- Add a fluorescent marker ("tracer") to a material. Identify the tracer and thus the marked material in a high throughput sorting process by the fluorescence of the tracer. Sort out the marked material from non or differently marked material by ultrafast pneumatic valves.
- Fundament of TBS is thus a sufficient number of tracers which can be excited to reliable signals and well distinguished in milliseconds from other tracers, from the fluorescence of the host materials and independent from pigments, additives and dirt in and on the host material.
- Furthermore, the tracers need to be temperature stable and chemically inert to survive the processing and to remain stable within the marked material throughout the use life.
- There are two principal ways to integrate the tracers for example into plastic packaging:
  - Via compounding / masterbatching -> robust, long term "doping" of the bulk polymer
  - Via the label, shrink sleeve or printed on -> "temporary intelligent flag"

POLYSECURE

3


Colored (opaque) shrink sleeve) Polymer label on plastic bottle White PET bottle with polymer label Partially transparent shrink sleeve

### Tracer Based Sorting (TBS) –> how does it work (for plastics)?

- After use and within waste sorting, marked materials are sorted according to the definition of the tracer: by compound, by application, by brand or – probably the most efficient – by recycling path.
- Sorted fractions can be further cleaned. Thermoplastic materials can be extruded to standardized granulates and re-used according to their specifications.
- In case the material is homogeneously marked (as in the PVC reference application), robust tracers may remain in the host material, serve as sorting marker multiple times and thus improve economic efficiency greatly.
- Important: TBS requires harmonization and then standardization! Then TBS can be a very efficient sorting technology, especially for plastics which otherwise have similar properties and are thus difficult to separate.

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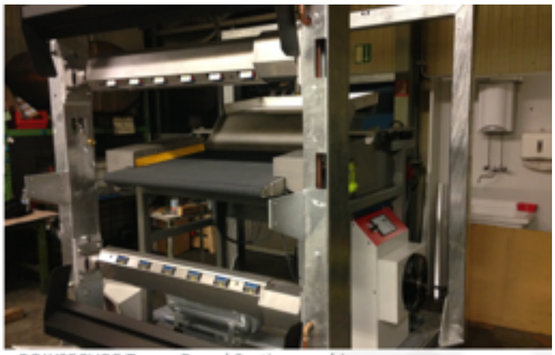
Fluorescent tracer in PVC flakes for sorting (POLYSECURE)

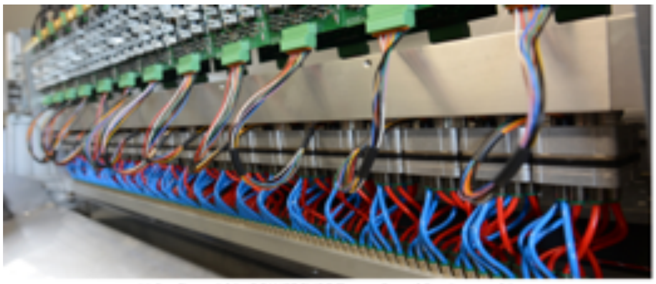


POLYSECURE Tracer Based Sorting machine

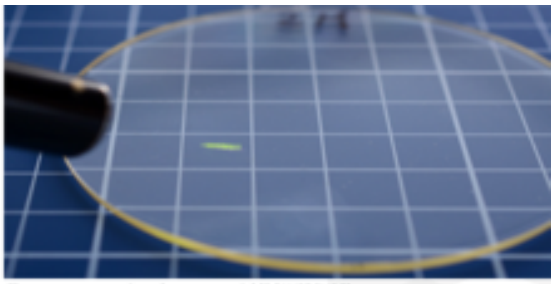
### Reference application: Sorting of glass fibre containing PVC flakes

- Solution to a sorting challenge in the PVC window industry: separation of PVC flakes with and without glass fibers to enable high quality extrusion and re-use of both streams
- Thousands of tons of PVC have been marked successfully with an efficient marker from POLYSECURE on a fully industrial basis -> unique positive experience with marker dispersion, stability, reliability, inertness and low marker concentration -> 10 ppm are realistic in light-colored plastics
- Successful development of the first sorting machine optimized to detect one specific marker and likewise separate marked from non marked PVC flakes
- Performance of the sorting machine and sorting concept: flake velocities: 3m/sec, throughput: ~2to/hour @ 1m width, flake sizes: 2-8mm; >98% pure accept stream

5 POLYSECURE



Valve line within POLYSECURE Tracer Based Sorting machine



Fluorescent tracer in polymer material (POLYSECURE)

### Reference application: Sorting of glass fiber containing PVC flakes

- Results on sorting quality show that identification within the sorting process is close to 100%, even at high velocities of the flakes -> separation by air-jets is the same for all sorting technologies, thus high identification rate is key to gain performance improvements
- TBS sorting machine is integrated within a new Rehau production site for 24 hours production.
- Sorting concept is tuned to handle differently colored plastic compounds:
  - darker colors require somewhat higher marker concentration
  - All other process parameters remain the same

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# Appendix B: Rehau Circularity Assessment

**Circular economy status and objectives**

S = Status today
O = Objective within 3 yrs

| | # | Tending towards LINEAR model | N/A | 1 | 2 | 3 | 4 | 5 | Tending towards CIRCULAR model |
|---|---|---|---|---|---|---|---|---|---|
| PRODUCT | 1 | We have not characterised the identity of our products in terms of generic materials (e.g., aluminum, polyethylene, steel etc.) | | | | | | S | The product is 100% characterized by its generic materials (e.g., aluminum, polyethylene, steel etc.) and/or product categories and names (e.g., coatings, paints, detergents, seating furniture). |
| | 2 | We have not assessed the chemical composition of materials (recycled materials included) used within our product. | | | | | | s | We have fully assessed the chemical composition of all materials (recycled materials included) used within our product. |
| | 3 | We do not seek to use recycled materials in our product | | | | | | S | We maximise the use of recycled materials from pre- or post consumer waste in our product and source these from outside of the manufacturer's |
| | 4 | We do not seek to use third party co-product or waste streams as an input to our own production | | | | | S | | We maximise the use of third party co-product or waste streams as an input to our own production |
| | 5 | We do not seek to use remanufactured, refurbished, or repaired parts and components within our products | S | | | | | | We maximise the use of remanufactured, refurbished, or repaired parts and components within our products |
| | 6 | We do not not seek to use rapidly renewable materials in our product | | S | | | | | We maximise use of rapidly renewable* materials in our product |
| | 7 | We do not not seek to use compostable/biodegradable materials in our product | S | | | | | | We maximise use of materials in our product that are commonly known to biodegrade or are able to undergo biological decomposition |
| | 8 | We do not consider the 'recyclability' of materials used in our products | | | | | S | | We only use materials in our products that are proven to be technically and economically recyclable (e.g. non-toxic, separatable into material |
| | 9 | Planned obsolescence is built into product design | | | | | | S | Product is designed for durability |
| | 10 | Product technical lifetime is below industry average | | | | | S | | Product technical lifetime is above industry average |
| | 11 | Product functional lifetime is below industry average | | | | | | S | Product functional lifetime is above industry average |
| | 12 | Product warranty period is below industry average | | | | S | | | Product warranty period is above industry average |
| | 13 | Product is not designed for disassembly to enable component/material recovery or reuse; nor is it biodegradable | | | | | S | | Product is designed to be economically disassembled enabling component/material recovery or reuse; OR is biodegradable with no |
| | 14 | Product is not designed with the intention to return to a 'technical' or 'biological' cycle, nor is there a defined plan for product recovery and | | | | | S | | Product designed to return to a 'technical' or 'biological' cycle, and a plan for product recovery and reutilization is defined. |
| | 15 | Product is not designed to be repairable | | | | S | | | Product designed to be economically repairable (by user or third party) |
| | 16 | Product not designed to be upgradable | | S | | | | | Product designed to be upgradeable, adapting to changing customer needs (e.g. by being modular, via software upgrades, etc.) |
| | 17 | Re-manufacturing is not taken into account in product design | | | | | S | | Product is designed to be economically re-manufactured |
| BUSINESS MODEL | 18 | Revenue driven mainly by asset sale | | S | | | | | Revenue driven mainly by monetising usage and/or performance of asset |
| | 19 | Value exchange mainly focused on driving a product sale transaction (e.g. competitive price) | | S | | | | | Value exchange focuses on customer lifetime benefit (including reducing/controlling cost of ownership; asset performance) |
| | 20 | Value proposition focuses on the product | | S | | | | | Value proposition is positioned as a service (including product/service |
| | 21 | Value proposition does not include maintenance or other value-added | | | S | | | | Value proposition includes bundled maintenance or other value-added |
| | 22 | We do not seek to reuse and put back into our production the co-products or waste streams from our operations. | | | | | | S | We maximise the reuse of co-products or waste streams from our operations, putting them back into our production. |
| SYSTEM | 23 | Repair services and availability of spare parts are not actively established | | S | | | | | Repair service network and spare parts are actively established in the |
| | 24 | Re-manufacturing services not actively established in market | | | | | S | | Re-manufacturing services actively established in market (own, or third |
| | 25 | We do not seek to reuse co-products or waste streams from our operations as an input to third party production (e.g. through direct or indirect supply relationships) | | | | | | S | We maximise the reuse of co-products or waste streams from our operations by supplying them to third parties as an input into their production (e.g. through direct or indirect supply relationships) |
| | 26 | We do not have in place a take-back or recovery scheme for our products at end-of-life (own or via a third party) | | | | | | S | We have in place a take-back or recovery scheme that fully covers all our products at end-of-life (own or via a third party, e.g. EPR arrangement) |
| | 27 | We do not have in place a take-back or recovery scheme for components our products at end-of-life (own or via a third party) | | | | | | S | We have in place a take-back or recovery scheme that fully covers all components from our products at end-of-life (own or via a third party) |
| | 28 | We do not have in place a recycling arrangement for materials within our products at end-of-life (own or via a third party) | | | | | S | | A recycling infrastructure is widely available for this type of product, and the material is already commonly recycled in practice with no special |
| | 29 | We do not provide incentives to return our product at end-of-life | | | | S | | | We provides incentives to return our product at end-of-life (e.g. deposit, |
| | 30 | We have no visibility on the actual effectiveness of our product take-back | | | | | S | | We have full visibility on the actual effectiveness of our product take-back |
| | 31 | We have no visibility on the destination of our products taken back at end- | | | | S | | | We have full visibility on the destination of our products taken back at end- |
| | 32 | We have no visibility on the actual effectiveness of material recycling from our products recovered at end-of-life | | | | | S | | We have full visibility on the actual effectiveness of material recycling from our products recovered at end-of-life |
| | 33 | We have no visibility on the destination of materials recycled from our | | | | | | S | We have full visibility on the destination of materials recycled from our |



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# Appendix C: Rehau Business Model Strengths/Weaknesses Assessment

**Business model diagnostic**

| | | Weaknesses | N/A | 1 | 2 | 3 | 4 | 5 | Strengths |
|---|---|---|---|---|---|---|---|---|---|
| **Value Proposition** | | | | | | | | | |
| | 1 | Our value proposition leaves significant customer segments' needs unmet | | | | | S | | Our value proposition fulfils all significant needs of target customer |
| | 2 | Customer satisfaction is low | | | | | S | | Customer satisfaction is high |
| | 3 | Our value proposition has no network effects | | | | | S | | Our value proposition has strong network effects |
| | 4 | Our charging and pricing models don't meet customer needs and | | | | S | | | Our charging and pricing models effectively meet customer needs and |
| | 5 | *We do not capture 'sustainability value' created for customers* | | | | | | S | *We fully capture 'sustainability value' created for customers* |
| **Cost/Revenue** | | | | | | | | | |
| Margins | 6 | Our margins are low compared with competitors | | | | S | | | Our margins are high compared with competitors |
| Revenues | 7 | Our revenues are unpredictable | | | | S | | | Our revenues are predictable |
| | 8 | Each sale requires additional effort | | | | | S | | Each sale generates follow-on recurring revenue / repeat purchases |
| | 9 | We earn no revenue before incurring costs of goods/services sold | | S | | | | | We earn revenue before incurring costs of goods/services sold |
| Costs | 10 | Our costs are unpredictable | | | | | S | | Our costs are predictable |
| | 11 | Our product cost structure is substantially higher than that of competitors | | | | | S | | Our product cost structure is substantially lower than that of competitors |
| | 12 | Our service cost structure is substantially higher than that of competitors | | | | S | | | Our service cost structure is substantially lower than that of competitors |
| | 13 | Our cost structuе has low economies of scale | | | | | S | | Our cost structure has high economies of scale |
| | 14 | Our cost structure is asset-heavy and costs are mainly fixed | | S | | | | | Our cost structure is asset light and costs are mainly variable |
| | 15 | Our cost to serve customers is misaligned with customer segments | | | | S | | | Our cost to serve customers is aligned with customer segments |
| **Operating Model** | | | | | | | | | |
| Key Activities | 16 | Our key activities can be easily copied by competitors | | | | | | S | Our key activities are hard to copy by competitors |
| | 17 | Our key activities need significant investment in order to scale with growth | | | S | | | | Our key activities easily scale with growth without needing significant |
| | 18 | Our key activities do not fulfil the core competencies we need | | | | | S | | Our key activities match the core competencies we need |
| | 19 | *Our key activities poorly support circular economy within our business* | | | | | | S | *Our key activities fully support circular economy within our business* |
| Key Resources | 20 | Our key resources do not meet the needs of our business model | | | | | S | | Our key resources fully support the needs of our business model |
| | 21 | *Our key resources poorly support circular economy in our business model* | | | | | S | | *Our key resources fully support circular economy in our business model* |
| | 22 | Our key resources can be easily built or acquired by competitors | | | | | S | | Our key resources are very hard to build or acquire by competitors |
| Key Partners | 23 | Key partners do not provide us with competitive advantage | | S | | | | | Key partners provide us with exclusive competitive advantage |
| | 24 | *Key partners poorly support circular economy within our business model* | | | | | S | | *Key partners enable circular economy within our business model* |
| | 25 | Key partners do not contribute any value to us for free | | S | | | | | Key partners contribute value to us for free |
| | 26 | Customers do not contribute any value to us | | S | | | | | Customers contribute value to us (for free) |
| **Customer Interface** | | | | | | | | | |
| Customer Segments | 27 | We do not understand the full potential value that could be created for | | | | | S | | We understand the full potential value that could be created for customers |
| | 28 | Customer loyalty is low | | | | | S | | Customer loyalty is high |
| | 29 | Customer churn is high (customer retention is low) | | | | | S | | Customer churn is low (customer retention is high) |
| | 30 | New customer acquisition rate is low | | | | S | | | New customer acquisition rate is high |
| | 31 | Our market share is shrinking | | | | | S | | Our market share is growing |
| Customer Channels | 32 | Our customer channels do not effectively communicate our value | | | | S | | | Our customer channels effectively communicate our value proposition |
| | 33 | Our customer channels do not effectively deliver our value proposition | | | | | S | | Our customer channels effectively deliver our value proposition |
| | 34 | Our customer channels are misaligned to target customer segments | | | | | S | | Our customer channels are well aligned to target customer segments |
| | 35 | Our customer channels do not effectively reach target customer segments | | | | | S | | Our customer channels effectively reach target customer segments |
| Customer Relationships | 36 | Our customer relationships are weak | | | | | S | | Our customer relationships are strong |
| | 37 | Our customer relationship model(s) are misaligned with customer | | | | | S | | Our customer relationship model(s) are aligned with customer |
| | 38 | Our customer relationship model(s) are misaligned with our value | | | | S | | | Our customer relationship model(s) enhance our value proposition |
| | 39 | Our customers can switch to a competitor at any time | | | | | S | | Our customers are locked into long-term relationships |



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# Appendix D: ICT and Technology as Enablers of CE Business Models Q&A regarding Rehau

1. Is the value proposition based on a particular technology (product/process)? Identify and describe it. On product side: RAUFIPRO, glass-fibre reinforced PVC window profile to increase tensile strength. On Recycling side: Polysecure tracer technology enables marking of virgin RAUFIPRO so that it on recuperation of post-industrial cuttings, GF-PVC may be identified, sorted from plain PVC. Same at end-of-life.
2. How does technology contribute to the value proposition (product/process) (is it the core of the value proposition, a key resource, a key activity, supports CEBM implementation – marketing channel, reverse logistics, etc.)? Technology is essential to the product and to the implementation of CEBM; it is a key resource, and is supplied by a key partner
3. Is technology (product/process) an essential element in the implementation of the business model (if this technology did not exist, could the model be implemented)? The circular sourcing of RAUFIPRO could not be implemented without the tracer technology
4. Is the current state of development of the technology (product/process) an obstacle to make progress on (fully implement) the CEBM? NO
5. Does the company carry out R&D / eco-design activities (of new products, processes) (internally / externally) to further develop its CEBM? YES
6. Does the company co-operate on any of its circular innovation activities with other companies or organisations? [**Innovation co-operation is active participation with other enterprises or organisations on innovation activities. Both partners do not need to commercially benefit. Exclude pure contracting out of work with no active co-operation**]. YES; 3 years of intense collaboration with Polysecure took place with many iterations of testing, in particular of the sorting machine.

   6.1. If yes, please indicate the type of innovation co-operation partner by location

| Type of co-operation partner | **[Your country]** | **Other Europe** | **United States** | **China or India** | **All other countries** |
|---|---|---|---|---|---|
| **A**. Other enterprises within the enterprise group | ☐ | ☐ | ☐ | ☐ | ☐ |
| **B**. Suppliers of equipment, materials, components, or software | X | ☐ | ☐ | ☐ | ☐ |
| **C**. Clients or customers from the private sector | ☐ | ☐ | ☐ | ☐ | ☐ |
| **D.** Clients or customers from the public sector | ☐ | ☐ | ☐ | ☐ | ☐ |
| **E**. Competitors or other enterprises in the same sector | ☐ | ☐ | ☐ | ☐ | ☐ |
| **F**. Consultants or commercial labs | ☐ | ☐ | ☐ | ☐ | ☐ |
| **G**. Universities or other higher education institutes | ☐ | ☐ | ☐ | ☐ | ☐ |



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| | | | | | |
|---|---|---|---|---|---|
| **H**. Government, public or private research institutes | ☐ | ☐ | ☐ | ☐ | ☐ |

6.2. Please, specify whether the co-operation partner has specific knowledge and skills in Circular Economy (e.g., does it offer CE specialized consultant services, such as Cradle to Cradle; does it have technology or sector specific knowledge, such as an eco-design company; does it have acknowledged expertise in a technology or sector specific research field, such as the Copernicus Institute of Sustainable Development)? No

7. To what extent is the CEBM supported by a network of **local / regional** actors (knowledge institutes; educational organizations; industry; market actors; government bodies and supportive organizations? Please, provide a description. Iniative by trade association of customer segment, *Rewindo* and of PVC users, *Recovinyl*.



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