RECAM

Carpet Recycling for Europe

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TITLE: SUSTAINABLE CLOSED LOOP SYSTEM FOR RECYCLING OF CARPET MATERIALS

PROJECT COORDINATOR: Martin Booij, DSM Fibre Intermediates

PARTNERS:	DSM	(contractor)
	GuT	(contractor)
	TFI	(contractor)
	EniChem	(contractor)
	Recotex	(associate contractor)
	TNO	(associate contractor)
	Laroche	(associate contractor)
	Durmont	(associate contractor)
	INCA	(associate contractor)

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Project funded by the European Community under the Industrial & Materials Technologies Programme (Brite Euram)

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Executive summary

Introduction

It is a bare fact that in Europe each year 1.6 million tons of carpet waste ends up in landfills (70%) or in municipal waste incinerators (MWI's). The combination of this fact with the growing legislative pressure in the European Community to move away from landfilling, and to stimulate the material, chemical, and thermal recycling of waste (in that order of priority), were the main reasons to start with the RECAM (*RE*cycling of *CA*rpet *M*aterials) project.

Looking to its overall composition, carpet waste contains a lot of valuable raw materials, such as polymers (PA-6, PA-6,6, PET, PP), natural fibres (wool), and inorganic fillers ($CaCO_3$ or chalk). The challenge was to develop a system that not only gives a technical possibility to reuse these materials (either as a material, a chemical feedstock, or as energy), but which also is better for the environment (lower emissions and less depletion of non-renewable natural resources), and economically acceptable. The latter means that the costs of the system may be higher than present day landfilling costs, but can be competitive on the longer term with the costs of MWI's.

The RECAM partners

A consortium consisting of the following partners carried out the RECAM project.

- The ***chemical companies DSM*** (project co-ordinator) and ***EniChem*** were present as raw material suppliers (PA-6, PA-6,6, PP) to the carpet industry. Both companies have a clear commitment to European chemical industry programs like Product Stewardship and Responsible Care. They have been active in other recycling programs (e.g. for the recycling of packaging waste) before.

- The ***European carpet industry*** in general was represented by ***GuT*** - Gemeinschaft umweltfreundlicher Teppichboden, and ***TFI*** - the German Institute for Carpet Research, whereas ***carpet manufacturer Durmont*** had a special interest in the production of environmentally friendly carpets.

- The ***German company Recotex*** (Recycling Concept Textil GmbH) was interested in expansion of its textile recycling business to the field of waste carpets.

- The ***French machine manufacturer Laroche*** had an interest to develop equipment for new growth markets, of which they considered carpet recycling to be one.

- The independent ***scientific institutes TNO*** (the Netherlands) and ***INCA*** (Italy) completed the consortium.

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Project objectives

At the start of the RECAM project in 1995, the following objectives were formulated:

1. Reduction of the carpet waste management costs with 30-50% (reference: landfill costs: 200-350 DM/ton; cost of MWI: 300-500 DM/ton at the start of RECAM).

2. Reduction of the use of non-renewable fossil fuels by alternative solid fuel supply to the process industry and SME's by energy recovery from non-mono and residual carpet material streams.

3. Recovery and reuse of high-quality raw materials like PA-6, PA-6,6, PP, and wool, from post-consumer carpet waste (PCCW) and post-industrial carpet waste (PICW).

4. A sustainable waste management system for PCCW and PICW, controlled and financially supported by the carpet industry, that has substantial environmental benefits compared to the existing landfill and MSW incineration routes, as evidenced by a comparative life cycle analysis (LCA) of both options.

5. A large environmental benefit of the complete RECAM system is to be expected when all the technical targets can be met.

Project results

In the course of the project, parts of the first blueprint of the system have been changed and the scheme has been simplified, because it appeared that a number of options had a low technical and/or economical feasibility. At the end of the project, the following results have been attained:

1. A reduction of the carpet waste management costs with 30% (reference: landfill costs: 200-350 DM/ton; cost of MWI: 300-500 DM/ton at the start of RECAM) is possible when the RECAM system is fully implemented. In a first stage (1-3 years), the carpet collection infrastructure will have to be built up and the greater part of the collected material will be processed to secondary fuels. In a second stage (3-6 years), more and more valuable mono-streams will be sorted out (first by manual sorting, later by automated sorting), building up the infrastructure for material (PA-6,6 and wool), chemical (PA-6 to caprolactam, PP to cracker feedstock), and advanced thermal recycling (secondary fuel from high calorific PP carpets).

2. Reduction of the use of non-renewable fossil fuels by alternative solid fuel supply to the process industry (mainly cement kilns and coal-fired power plants) by energy recovery from non-mono and residual carpet material streams is in principle possible. Today, the energy recovery from unsorted PCCW and PICW is taking place already on a 40-50 ktpa scale. When 1.0 millions tons of carpet waste would be recycled according to the RECAM system, annually the fossil fuel equivalent of 8 million GJ (the average energy consumption of 100.000 households) can be saved.

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3. Recovery and reuse of high-quality raw materials like caprolactam (for the production of PA-6), PA-6,6, cracker feedstock (for the production of PP), and wool from PCCW and PICW can be technically realized.

4. The organisation CRE (Carpet Recycling Europe) was founded and financially supported by the carpet industry to implement the RECAM results. This is a first step in the direction of the RECAM sustainable waste management system for PCCW and PICW. CRE will be at least active until the year 2000, and prolongation of this organisation is to be expected. CRE is presently working to realise a demonstration ID/sort centre (scale 10-25 ktpa).

5. The LCA study shows that there is a large environmental benefit when the complete RECAM system can be implemented. The environmental load of RECAM is for each of the investigated parameters in the LCA (abiotic depletion, green house potential, human toxicity, eco toxicity (aquatic), acidification, nutrification, photochemical oxidation, and land use) at least about 50% better than environmental load of the existing situation (70% landfill, 30% MWI's).

Key words

abiotic, acidification, aquatic, ashes, automatic, automotive, backing, back-to-feedstock, bulk bag, $CaCO_3$, calorific value, caprolactam, carpet, cement, centrifuge, chalk, chemical, closed-loop, collection, community, composition, container, co-product, cracker, cutting mill, depletion, depolymerisation, dust, economics, eco, emission, energy, engineering, environment, gate fee, granulator, greenhouse, grinder, fibres, filler, fine-grinding, fire retardancy, floor covering, fluid bed, hot-melt, human, hydrocyclone, incineration, identification, insulation, landfill, land use, LCA, legislation, life cycle analysis, logistics, market, mechanical, naphta, natural, near-infrared, nutrification, nylon-6, nylon-6,6, oxidation, pelletising, PA-6, PA-6,6, PE, PET, photochemical, plastics, polyamide-6, polyamide-6,6, polyester, polyethylene, polypropylene, portable, post-industrial, post-consumer, PP, producer, properties, pyrolysis, quality, recovery, recycling, resins, reuse, SBR, scale, shredding, sorting, storage, styrene-butadiene-rubber, textile, thermal, toxicity, transportation, underlay, waste, wool.

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PRESS RELEASE FINALISATION RECAM PROJECT (April 26, 1999)

If European legislation ends landfill options: Closed-loop recycling of more than 1 million tonnes of European carpet waste feasible

If in the coming years European legislation puts an end to landfill options for carpet waste, a European closed-loop system for the recycling of more than 1 million tonnes of carpet per year will become feasible. The implementation of such a system will be speeded up if the carpet industry introduces a waste disposal fee for newly sold carpets, similar to the recycling fee imposed by the car industry and the white goods sector in the Netherlands. The revenues created by this fee can be used to support the recycling of the less profitable carpet materials during the first years.

These are the main conclusions at the end of RECAM (REcycling of Carpet Materials), a three-year joint European project, aimed at developing an economically feasible, closed-loop system for recycling post-consumer and industrial carpet waste.

In Western Europe, every year 1.6 million tonnes of carpet waste, representing a total surface area of 900 million square metres (equivalent to 200,000 football fields) end up on landfills (70%) or in municipal waste incinerators (30%). However, discarded carpet should not be considered as waste, but rather as an 'ore' containing valuable raw materials such as nylon 6, nylon 6.6, polypropylene and wool. It has been shown that especially the 'back to feedstock' recycling of nylon 6 and the recycling of wool are economically viable, and in the long-term also the mechanical recycling of nylon 6.6.

Eventually it should be possible to collect more than half of all carpet waste in Western Europe in a closed-loop system. In such a system, the high-grade materials are chemically or mechanically recycled, while from the other materials 8 million Gigajoules of energy are recovered (the annual energy consumption of more than 100,000 households), thus saving significantly on the use of non-renewable fossil fuels.

RECAM project

The RECAM project, which was completed recently, studied the collection, identification, sorting and recovery of high-grade materials (chemical raw materials and polymers) and improved energy recovery from residual fractions (such as carpet backing). Meanwhile, the first steps have been taken towards commercialisation of the various parts of the closed-loop system. Closing the loop will require close co-operation horizontally (within the carpet industry) as well as vertically (throughout the value chain).

The RECAM project was carried out by a consortium made up of the chemical companies DSM (project coordinator) and Enichem, the European carpet industry (represented by GuT - Gemeinschaft umweltfreundlicher Teppichboden, and TFI - the German Institute for Carpet Research), Recotex, TNO, INCA, Laroche and Durmont. The research was financially supported with 10 million DM under the European Commission's BRITE-EURAM programmes (contract nr. BRPR-CT-95-0063).
PRESS RELEASE FINALISATION RECAM PROJECT (April 26, 1999)

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First steps to commercialisation

Successful collection and sorting pilot projects were co-ordinated by GuT in the Frankfurt region in Germany, using carpet identification equipment developed by DSM. DSM and Enichem developed chemical recycling processes that only require size reduction to recover caprolactam from nylon-6 carpets and cracker feedstock from polyolefinic (mainly polypropylene) and elastomeric carpet wastes respectively.

An identification and sorting centre will be established by CRE (Carpet Recycling Europe, a company set up by the GuT and the carpet industry). Andreas Bohnhoff, managing director of CRE*: 'Before the end of this year we will start-up the first commercial sorting centre in Germany developed by the Dutch industrial research institute TNO, and introduce sorted carpet streams for recycling on the market. DSM has already shown to be an interested potential customer'.*

At the end of this year, DSM will already start-up a commercial carpet recycling plant to process 100,000 tons of nylon-6 carpet into caprolactam in Augusta (GA, USA).

Enichem is similarly working on the conversion of polyolefinic and elastomeric carpet waste into a cracker feedstock for the production of olefins. A pilot plant that can handle both polyolefine/elastomer based packaging and carpet waste proved successful, and integrated treatment for both waste types is envisaged feasible.

Size reduction and pelletizing of waste carpet to produce fuels for e.g. cement kilns and power plants is commercially practised by Recotex already at a 20,000 ton scale in Veitshochheim (Germany).

Ed van Went, chairman of GuT, the organisation of the European carpet industry: '*The carpet industry wants to solve the carpet waste issue in an ecologically sensible and economically viable way. The RECAM project has created the required technological breakthrough. The carpet industry has founded CRE to bring the RECAM closed-loop into practice. During the first few years the costs can be covered by imposing a recycling fee on newly-sold carpet; long-term the RECAM system will be more cost-effective than municipal waste incineration, and the environmental score will be much better'.*

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1. Collection of carpet waste

The European carpet industry (via GuT, Gemeinschaft umweltfreundlicher Teppichboden) in cooperation with KABE (Konzentrierte Aktion Bodenbeläge Entsorgung) carried out a pilot project for the collection of carpet waste in the Frankfurt (FRG) region, which has a population of 1.6 million people. During this project, which lasted more than 12 months, more than 10,000 tonnes of carpet waste was collected.

Figure 1. KABE advertisement to gain attention for the carpet collection program.

Several different collection systems were tested, such as curbside collection (as a part of already existing door-to-door bulky refuse collection, figure 2a), bring-in systems (citizens bringing all kinds of reusable waste to recycling courts, figure 2b), container and big bag services (call-and-pick-up) for trade, etc.

Figure 2. a) Curbside collection of carpet waste b) Carpet container at recycling court

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The main critical factors with regard to collection were logistic flexibility, effective communication with local inhabitants and close contacts with local authorities.

Figure 4. Examples of brochures issued by K.A.B.E.

Recotex has focused on the collection of industrial carpet wastes, such as edge trim, cuttings (from automotive carpet), and off-spec material. With post-industrial wastes, being cost competitive with landfill or MWI alternatives is even more important than with post-consumer carpets. Also here, containers are most frequently used for shipping, and logistic flexibility (pick-and-haul, container change) is required. High local landfill costs appeared to be an essential stimulus for the recycling of carpet waste.

2. Identification and sorting of carpet waste

DSM Research has developed special equipment for sorting the collected carpet waste according to fibre type.

Firstly, there is the light-weight (< 3 kg) CarPID™ (*Car*pet *P*ortable *ID*entifyer, figure 5, next page), which can be used to determine the carpet face fibre type in an early stage of the collection process (presorting). The face fibre recognition is based on near-infrared spectroscopy. The unit works on rechargeable battery, and distinguishes PA-6, PA-6,6, PP, PET and wool carpets. Other fibre types (acrylics, cotton, etc. or fibre blends) are put in the category unknown. It takes less than two seconds (2 s) to determine the carpet face fiber type. The method is suited for all kinds of dyes and colours, and is not affected by dirt.

The portable near-infrared technology may find its way to other areas of plastic waste identification waste, beacause it can be made suitable for other polymer materials and surface types than present in carpet waste.

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Figure 5. Lab prototype (left) and commercial version (right) of the CarPID™.

Secondly, DSM has developed the more sophisticated CarRID™ ((*Car*pet *R*apid *ID*entifyer, figure 6), that can be used for the fast (< 100 ms) identification and sorting large amounts of carpet automatically. Being based on the same principle as the CarPID™, measurements are not affected by the colour of the carpet, the weaving pattern or dirt. The advantage of the CarRID™ is that the required identification time is so short, that carpets can be identfied while moving, which makes the automated identification & sorting much easier.

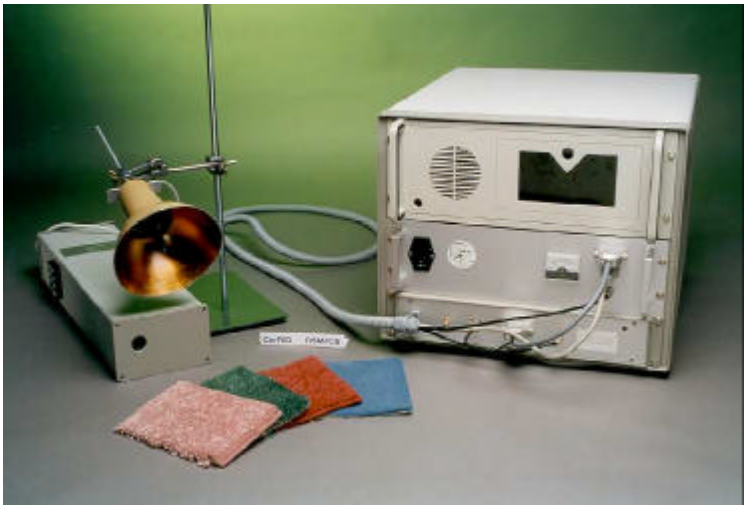

Figure 6. Left: Lab prototype of the CarRID™. Right: Lab prototype of the sorting clamp.

TNO integrated the CarRID equipment in an automated sorting line with special clamps, that carry the carpet along the CarRID, and next automatically put the carpet on the right pile of sorted carpets. This approach makes the sorting system insensitive for operator mistakes, and improves the labour conditions for the workers in this area, since the handling with large peices of carpet is greatly reduced. Automatic sorting is furthermore economically more attractive when large amounts of waste carpet have to

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be dealt with. This limits sorting costs to an acceptable level when carried out on large scale.
For the purpose of the RECAM research on carpet mono-streams, several sorting operations where carried out along the course of the project by K.A.B.E. in cooperation with DSM Research(figure 7).

Figure 7. Manual sorting of waste carpets (left) and sorted material in big bags (right).

3. Size reduction and separation of carpet mono-streams

Carpet waste streams sorted according to fibre type, the so-called carpet mono-streams, next can be further processed. The first step is always a cleaning (removal of non-carpet waste) and size reduction. Depending on the process for further work-up, this can be a single shredding process, or a more complex operation (grinding, sieving, windsifting, hydrocyclones, hydrocentrifuges). Recotex has been working in this area, and carried through a number of important equipment modifications to improve the on-stream time of the equipment.

4. Mechanical recycling of wool, PA-6, PA-6,6 and PP

With the equipment developed by Laroche, wool carpet waste can be recovered for use in so-called 'non-wovens'. The resulting mats (with a high or low density) can be used for insulating purposes and carpet underlays and have favourable market prospects because of their excellent flame-retardant properties.

Nylon 6, nylon 6.6 (by DSM) and polypropylene (by TNO) can be recycled mechanically to engineering plastics. Because of the different carpet colours involved, the recycled material can only be used in dark-coloured engineering plastic applications (such as under-the-bonnet car parts). For these applications, the shredding and grinding necessary in order to separate the fibres from the carpet backing is very expensive. In

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the case of polypropylene this is economically not very attractive, whereas for nylon 6 and nylon 6.6 further optimisation still is needed to improve the economics. The improvements need to be found in the pre-treatment (fine grinding, dry/wet separation of face yarn and backing).

5. Back-to-feedstock or chemical recycling of PA-6 and PP

An alternative for the mechanical recycling of nylon 6 that is economically more attractive is the so-called back-to-feedstock recycling (or depolymerisation) of nylon 6 carpet waste. A major advantage of this system is that the quality of the final product obtained (caprolactam, the raw material for nylon 6) is of the same quality as that of the original virgin material. DSM has developed a new process which, unlike existing depolymerization technology, does not have a phosphoric acid waste problem. Moreover, it also does not involve the costly step of fully separating the pile yarns from the carpet backing, which is the expensive part of the mechanical recycling.

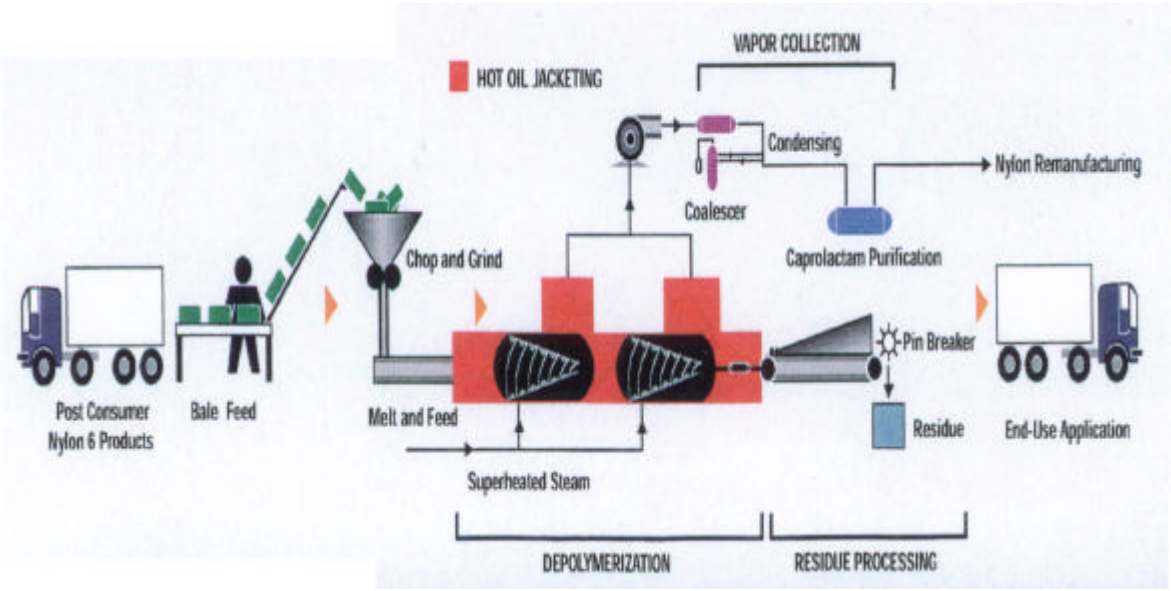

Figure 8. Simplified scheme of DSM's depolymerization process for PA-6 carpet waste.

At the end of this year (1999) DSM and AlliedSignal will jointly start up a commercial-scale plant based on this process in Augusta (Georgia, USA). This plant, built at a cost of NLG 160 million, will recover 45,000 tonnes of caprolactam from nylon carpet waste by depolymerizing nylon 6 into caprolactam. Thanks to this new facility, the total amount of carpet waste landfilled annually in the USA will be reduced by more than 100,000 tonnes. This is the first closed-loop recycling system for carpet waste in the world. The portable carpet identifier CarPID^{TM} is already used on large scale here.

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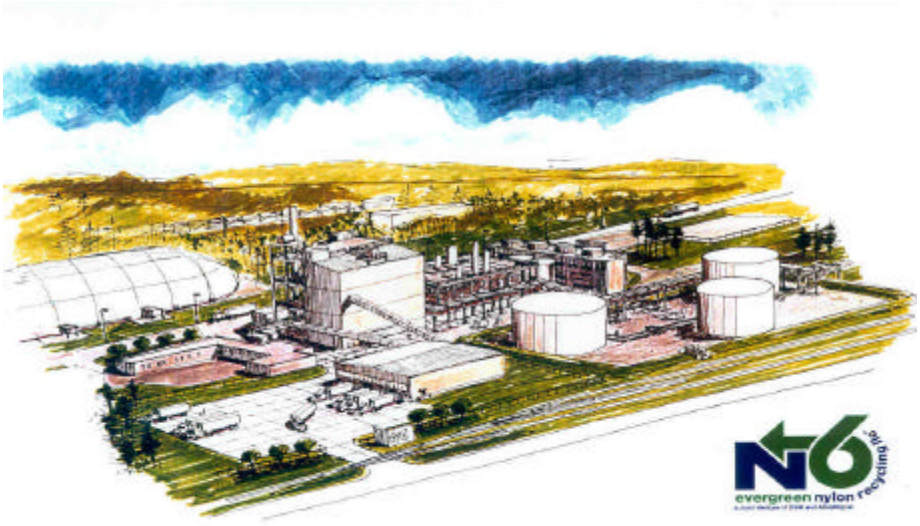

Figure 9. Artist impression of DSM's Evergreen plant in Augusta (GA, USA).

The other back-to-feedstock process was developed by EniChem and consists of the pyrolysis of PP carpets. In this process enriched PP streams originating from carpet waste, or even whole PP carpets can be pyrolyzed to a feedstock for a naphta cracker. Via this cracker, the raw materials for e.g. PP becomes available again.

Currently the consortium to which EniChem belongs is evaluating the feasibility of a demonstration pyrolysis unit together with BP Chemicals on a site in Grangemouth (Scotland).

6. Reuse

Durmont, a carpet manufacturer based in Austria, has demonstrated that the performance of nylon 6 carpet yarns based on caprolactam recovered from nylon 6 carpet waste by DSM is the same as that of virgin material.

Durmont has also developed technology to reuse its own production waste (edge trimmings, off-spec carpets) as filler in new carpet backing. In polyethylene hot-melt applications, a high level of substitution of virgin material was achieved without loss of properties.

7. Energy recovery and valorisation of the ashes

Certain kinds of carpet wastes are unsuitable for mechanical or chemical recycling. Face fibre materials other than PA-6, PA-6,6, PET, PP, and wool are not recognised by the RECAM identification tools. This is a choice that was made within RECAM. Sorting carpet waste into 6 differentiated piles (5 mono-streams and one 'unknown' pile) is already complicated (manual as well as automated sorting).

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Not only less-common face fibre types (e.g. cotton, acrylics) end up in the 'unknown' category. Also blends (wool/PP, PA-6/PA-6,6, etc. in various ratios) are found in the market. It is impracticable to develop recovery technology for these streams. The amounts available for each type are too small, and the effort to accomplish a separation into reusable (mono) materials is simply not worthwhile. A possible exception can be the wool/PP carpet blends. For the Laroche matting technology, PP is added to the recovered wool fibres. Maybe it may is feasible to accept these wool/PP blends, and route them to the wool stream.

Another material stream that is unsuitable for further chemical or mechanical recycling is the SBR/chalk fraction that comes from the process that separates face fibre and backing. This is necessary to obtain e.g. a pure PA-6,6 material for mechanical recycling purposes. Although in theory it could be reused as filler in carpet backing, this is technically and economically not feasible.

However, the TFI study showed that all these waste streams can in principle be used as secondary fuels (in addition to coal) in cement kilns and incinerators.

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