

Strategy and Development of Recycling Technology for End-of-Life Vehicles(ELVs) in Germany

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Abstract

The quantity of passenger cars in industrial countries has been significantly increased in recent years. According to prognoses, this tendency is likely to continue in the forthcoming future. As a direct consequence, an increase of End-of-Life-Vehicles (ELV) will confront us with the problem of "ELV-Recycling". In order to cope with this situation, the European regulation for the treatment of End-of-Life-Vehicles (09/2000) has been transferred to national law in Germany (ELV-Regulation from 1 July 2002). The long term aim is to reduce residues from the ELV-treatment to less than 5 wt% from 30 wt% within the next 10 years (2015). For that reason, there is a need for innovative and more efficient recycling techniques tailored to future materials in automobiles. The design process at automotive industry is continuously changing due to the strong demand on optional equipment and new technical solutions for fuel saving. Light materials, such as aluminum and plastics, consequently become more important and cause a decrease of ferrous metals. Since plastic materials are often used as compounds, a separation into initial material types by means of mechanical recycling methods is not possible. For that reason, efficient recycling can only be realized by introducing recycling-friendly car designs. In the end an integrated approach of auto makers and recycling industry is of decisive significance for the fulfillment of future regulations.

Key words : End-Of-Life-Vehicles (ELV), ELV regulation, shredder light fractions (SLF), Automotive Shredder Residues (ASR), dismantling plants, material/raw material/energetic recycling

요 약

최근 들어 산업화된 국가에서 승용차의 대수는 비약적으로 증가하고 있으며 이러한 추세는 당분간 지속될 것으로 예상된다. 따라서 사용 후 폐기되는 자동차의 대수 또한 증가할 것이며 이를 재활용하는 문제가 심각히 제기되고 있다. 이러한 문제를 해결하기 위해 2000년 9월 유럽에서 제정된 폐기 자동차의 처리에 관한 규제 조항이 독일에서는 2002년 7월 1일부터 법률로서의 효력을 지니게 되었다. 이 법률 제정의 장기적 목표는 차후 10년 내에 폐자동차를 처리하는 과정에서 발생하는 잔류물을 현재의 30 Wt.%에서 5 Wt.% 미만으로 줄이는데 있다. 따라서 차후 자동차를 구성하는 재료들에 대한 좀더 혁신적이고도 효율적인 재활용 기술에 대한 개발 필요성이 대두되고 있다. 자동차 생산 산업에서 디자인 공정은 계속하여 변화되고 있는 바, 이는 자동차 운행 시 연료를 절감하기 위한 선택적 장치와 새로운 기술적인 해결책에 대한 요구가 강하게 제기되고 있기 때문이다. 따라서 자동차 제조에 사용되는 재료로서 알루미늄과 플라스틱 등과 같은 가벼운 재료들의 사용량은 증가하고 있으며 철과 같은 무거운 재료들은 그 사용량이 점차 감소하고 있다. 그런데 자동차 구성 재료들 가운데 플라스틱류는 흔히 합성된 상태로 사용되고 있으므로 이를 기계적 방법에 의해 각각의 구성 플라스틱 성분으로 분리하기는 불가능하다. 이러한 이유로 인해 폐자동차를 구성하는 물질들의 효율적 재활용을 위해서는 재활용하기에 용이한 상태로 자동차를 디자인하여 제조하는 것이 필요하다고 할 수 있다. 이와 함께 폐자동차 재활용율을 향상시키는데 관한 규제를 만족시키기 위해서는 자동차 생산업체와 재활용 산업체의 통합적 협동체제가 요구된다.

주제어 : 폐자동차, 재활용 법적 규제, 경량 소재 산물, 소재 잔류물, 해체 공장, 구성물질/재료/에너지 재활용

1. INTRODUCTION

Based on statistics of 2004, about 45 million. passenger

cars have been registered in Germany. 3.2 million. cars are defined as ELVs for which there is a big export market to eastern European and African countries. The export of ELVs amounted to nearly 50% so that finally 1.6 million vehicles are expected to be recycled in Germany. In the forthcoming future, the export portion will decrease due

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to new EU-regulations and saturation of demand in current import countries. As a consequence, ELVs in Germany are likely to increase.

ELVs still contain many valuable materials and harmful operating fluids. Therefore, an environmental-friendly treatment and a high recycling rate can be regarded as main objectives. As already mentioned, changing design concepts and material compositions in passenger cars are one of the major reasons for the growing complexity of recycling techniques, since compounds do not allow a complete separation of the material mix only by means of mechanical methods. These materials represent the biggest part of the Shredder-Light-Fractions (SLF) or Automotive Shredder Residues (ASR) coming from the shredding process.

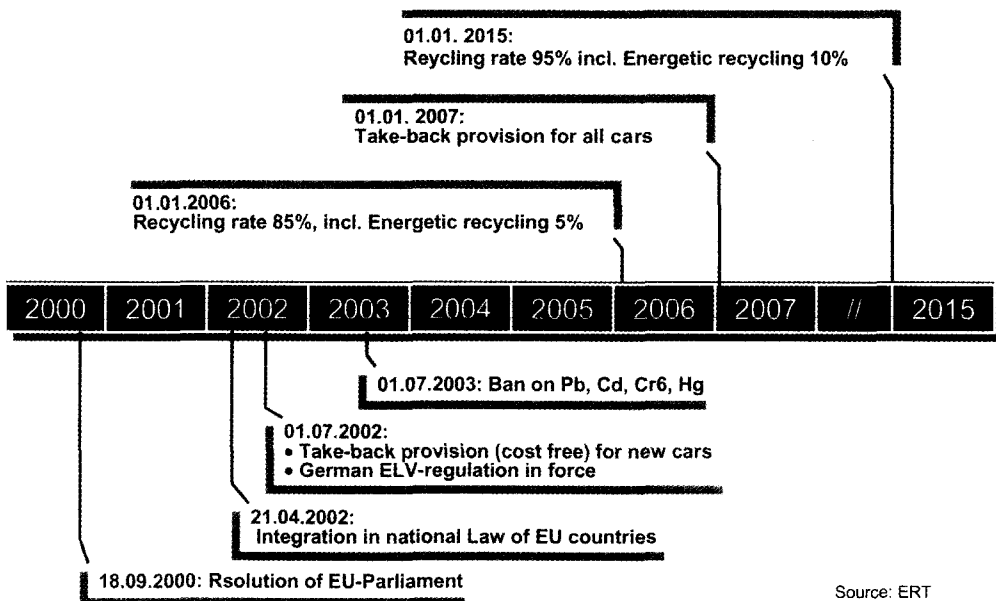
As a consequence, the focus of research activities particularly lies on innovative methods of separation techniques. Nevertheless, high-tech recycling is not a guarantee for efficient and also economic recycling in practice. For example, recycling-friendly car designs and material selection can significantly help to reduce later costs at the recycling stage. For that reason, solutions only become effective when recycling concept are commonly worked out by car manufacturers, recycling plant operators, R&D institutions and suppliers of technical equipment.

Based on the current ELV regulations in the EU and Germany, this paper deals with strategies of efficient ELV recycling. The strategies provide new concepts of dismantling, shredding and ASR pre-treatment plants. Finally, practical experiences made with plants for material, raw material and energetic recycling will be described in the study and in the summarized presentation at the symposium.

2. Legal Requirements

2.1. Development of ELV regulations in Germany and the EU

The European Parliament issued a regulation for the treatment of End-of-Life-Vehicles on 18 September 2000. One important aspect of this regulation refers to the return of vehicles to the recycling plant which should be free of charge for the last owner of the vehicle. Furthermore, the member states have been obliged to significantly reduce toxic substances in vehicles. More issues of the directive are concerned with the storage, treatment and recycling of End-of-Life-Vehicles. The objective of the EU regulation is mainly to protect the environment, but also to strengthen the domestic market. The most important



Source: ERT

Fig. 1. Development of ELV regulations in Germany and the EU.

issues of the ELV-directives are:

- 09/18/2000: Resolution of EU Parliament
- 04/21/2002: Integration into national law of EU countries
- 07/01/2002: Take-back provision for new cars (free of charge for cars produced later than 2002)
- 07/01/2003: Ban on Pb, Cd, Cr6, Hg etc.
- 01/01/2006: Recycling rate of 85% incl. 5% energetic recycling
- 01/01/2007: Take-back provision for all cars
- 01/01/2015: Recycling rate of 95% incl. 10% energetic recycling.

The listed dates are again illustrated in Fig. 1.

2.2. Recycling Rates based on the ELV Regulation

An area wide infrastructure has been already set up in Germany in order to realize a regulated and environmental-friendly recycling of about 1.6 million ELVs. The traders (car manufacturers, importers, recycling industry) consist of acceptance stations, dismantling and shredding companies. Up to now, the average recycling rate of an ELV is about 75 wt%. From 2006 onwards, 80 wt% have to be treated by material recycling or reutilized, and 5 wt% have to be processed by energetic or raw material recycling (i.e. recycling rate of 85 wt%).

(1) Recycling rate for dismantling plants

As additional requirement, operators of dismantling plants will be obliged to treat parts, materials and operating fluids by means of material recycling and should achieve a recycling rate of at least 10 wt% relative to the total sum of all yearly dismantled ELVs. All metal parts, such as rest car bodies, scrap, spare parts as well as fuel are not to be taken into the calculation. Old tires and batteries can be included in the calculation if they have been left at certified recycling plants. For example, examinations on the model Volkswagen Golf II have shown that weight of dismantled parts amounted to 94 kg. This value corresponds to a recycling rate of 10.6 % based on an average empty weight of 884 kg.

(2) Recycling rate for shredding plants

Operators of shredding plants have to fulfill yearly requirements for nonferrous parts of shredder residues:

- a) 1 January 2006: at least 5 wt% has to be reutilized based on the total of the vehicle weight.
- b) 1 January 2015: at least 5 wt% has to be supplied to material recycling and additionally 10 wt% has to be reutilized.

In 2006, 5 wt% can be treated by energetic recycling. This recycling rate will be limited to 10 wt% in 2015, so that 5 wt% will have to be processed by raw material or material recycling. The different legal requirements based on the ELV regulation are listed in Table.

Table 1. Recycling rates based on the ELV and distribution regulation according to recycling methods.

Recycling Criterion	Reutilization of spare parts (metals) + material recycling of FE & NF metals	01/01/2006	01/01/2015
Annual recycling rate	~ 70%:	85%	95%
Processes for recycling rate			
▶ at least reutilization & material recycling		80%	85%
▶ limited energetic recycling rate		5%	10%
Distribution regulation (+)			
	~ 70%:	85%	95%
▶ Dismantling process		70%	70%
▶ Shredding process		(+) 10%	(+) 10%
		(+) 5%	(+) 15%

2.3. Effects of the Regulations for ELVs and Waste Disposal on the Automotive Industry and Recycling Companies

Since the ELV regulation has come into effect, recycling industry has to face new challenges. New legal requirements and the resulting market development will cause higher competition within the branch. The regulation for waste disposal and operation of biological waste treatment plants (in German "AbfAbIV") is valid since 1 March 2001. The new regulation prohibits the deposit of untreated municipal and industrial waste from 1 June 2005 onwards [Kim, J. G., 2004 : Recycling Technology for the Treatment of ELVs. GRAMMAR 2004, International Symposium on Green Technology for Resources and Materials Recycling, KIRR & IWRRC, Nov. 2004, Seoul, Korea.]. For that reason, the deposit of shredder light fractions is not possible without any previous pretreatment. Based on the legal requirements, a substantial development and improvement of shredder technologies is needed. In recent years, some attempts have been made and are now pushed ahead by automotive industry, operators of dismantling and shredding plants as well as plastic industry. Principally, one of the main focus lies on economic efficiency and the fulfillment of legal requirements.

3. STRATEGIES AND CONCEPTS FOR RECYCLING

3.1. Principle Concepts for Improving Recycling Efficiency

With regard to the passenger car's life cycle, recycling activities can be started at different stages. The development of ecological and economical recycling concepts should begin at the early stage of vehicle design. Three basic strategies have to be applied to improve productivity and recycling efficiency:

1. Avoidance strategies, i.e. avoidance of unnecessary material and energy input
2. Reduction strategies, i.e. reduction of waste residues and environmental pollutants.
3. Recycling strategies, i.e. recycling-friendly ma-

terials, design and methods within the whole life cycle of the vehicle

3.2. Product-Process, Product and (Old) Material Recycling

In Fig. 2 three recycling stages are illustrated. After finishing the car body assembly, waste or valuable material normally arise at the workshop. "Product-Process recycling" is used when these materials are reused for the next production processes.

"Product Recycling" is another recycling stage and refers to the reutilization of parts after the dismantling of ELVs. The rest car bodies and parts from the dismantling station are delivered as scrap mix to the shredding plants where the treatment is called "Material Recycling". During the whole product life cycle the recyclability and dismantling efficiency as well as the energy and mass flow should be evaluated. As depicted in Fig. 2, a careful material selection is necessary before starting the product-process recycling. The criteria for material selection are reduction of type variety (i.e. primal material of components with similar functions) and the recycling compatibility of material types. Recyclables as secondary raw material as well as standardized processes should be preferred. Light weight structures are important to reduce fuel and emissions during operation. Uncomplicated maintenance and repair can help to protect the resources. Dismantable car parts and modules need to be designed by aiming at low dismantling times and non-destructive separation. Time for draining can be also reduced if there are optimized solutions for taking out operating materials.

As far as the shredding process is concerned, a higher separation rate is inevitable in order to make the treatment of problematic SLF more efficient. Especially the treatment of SLF is one of the primary problems today. More investments and technical innovations are needed to realize high quality treatment of SLF. However, the ban on certain heavy metals (e.g. Pb, Hg, Cd, Cr⁶⁺) will probably reduce the rate of pollutants and consequently benefits the development of environmental friendly recycling methods.

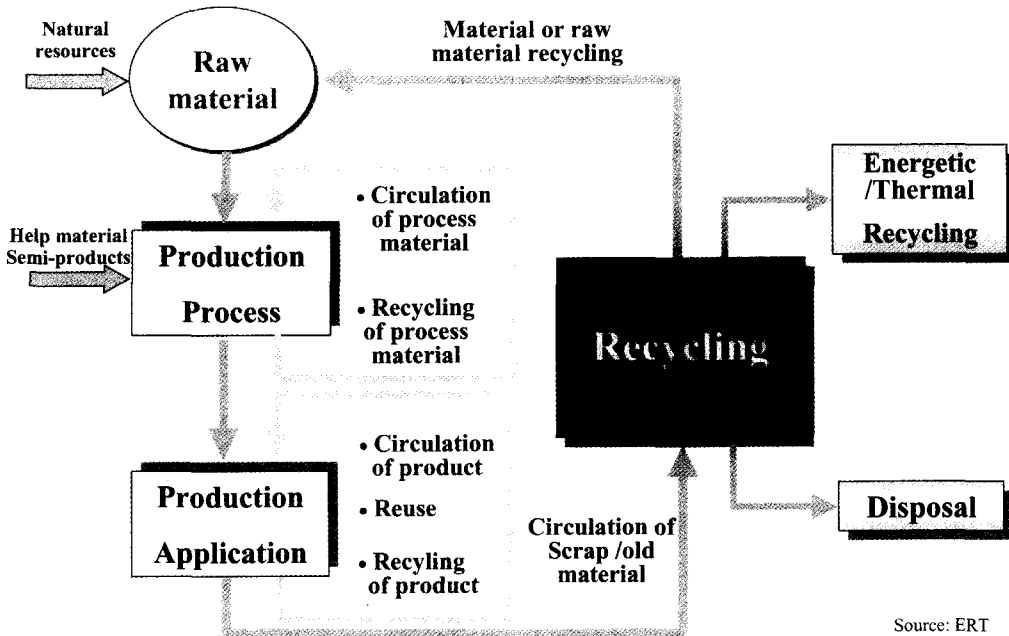


Fig. 2. Schematic of Process, Material, Product and Scrap Recycling [ERT].

3.3. Basic Principles of a Recycling-Friendly Design and Conception

The strategy for an early adaptation of the design process can be applied by following essential measures: Dismantling studies for each product should provide results concerning material composition and assignment of suitable recycling cycles. Then, components have to be structured and designed in a recycling friendly way. Concepts for easy dismantling as well as compatible material compositions are also important for cost effective recycling at a later stage. Before start of production, materials and harmful substances have to be indicated. The classical design process under consideration of recycling requirements is listed in following section:

1. Planning and conception phase (review of design task)
 - a. product analysis (dismantling study)
 - b. determination of cycles
 - c. consideration of environmental and ELV regulations
 - d. recycling-friendly component structures

2. Preparation and design
 - a. dismantable design of structures
 - b. recycling-friendly material selection and joining technologies
 - c. consideration of treatment methods
3. Start of Production (SOP)
 - a. indication of materials and harmful substances
 - b. preparation of dismantling manuals

3.4. Concepts for the Recycling of ELVs in Future

As already mentioned, the long term aim is to reduce waste residues of the ELV treatment from 30 wt% to less than 5 wt% within ten years or until 2015, respectively. In order to achieve this objective, dismantling as well as shredding technologies are to be improved simultaneously. A technical concept which has been worked out to meet the new requirements is described in Fig. 3. The process flow comprises the strategic treatment of shredder residues from the stages dismantling, shredding, ASR-pretreatment and finally recycling.

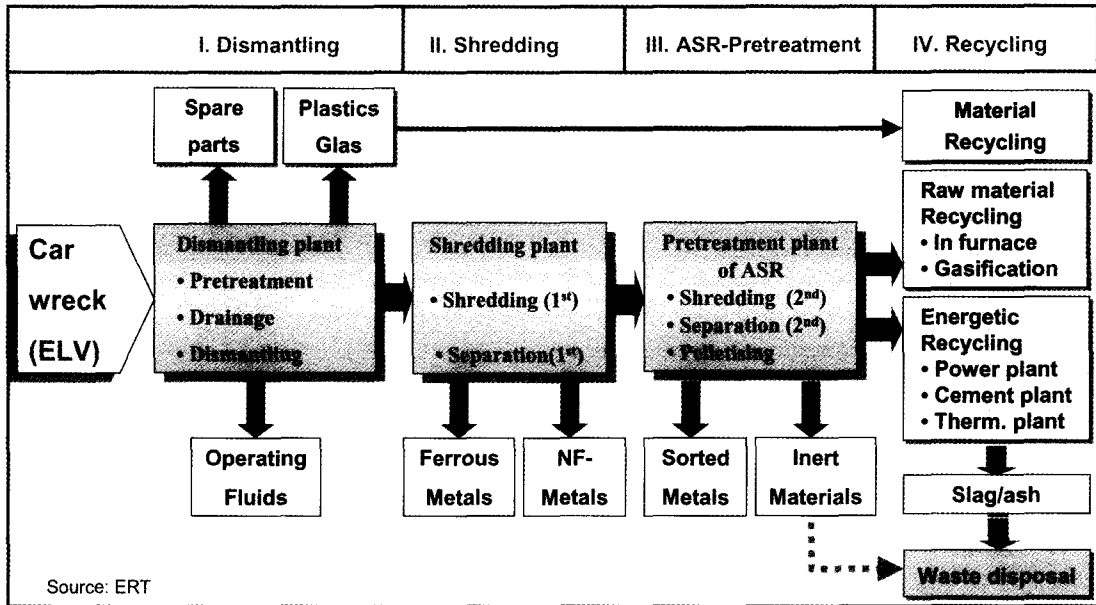


Fig. 3. Concept for the Recycling of ELVs in future [ERT].

4. DISMANTLING PLANTS

One important aim of the dismantling process is to gain spare parts which can be reused for other vehicles. Reutilization means that parts are used for the initially designed purpose. These parts belong to the “recycling cycle during utilization of product” since used products are directly introduced to a new service stage after being treated or even untreated. The dismantling process continues with spare parts which still contain unusable components. These materials can only be treated by material recycling (e.g. large plastic parts).

4.1. Requirements as to Dismantling Plants based on the ELV Regulation

The ELV regulation contains the safety precautions for dismantling plants concerning equipment and the operation itself.

4.1.1. Requirements as to the Technical Equipment

Reference size and area distribution for ELV treatment:

The structural area of the dismantling plant has to

meet the legal requirements in terms of water and ground protection. Therefore, fortified areas with precipitators for light liquids are to be installed. These areas should be implemented in particular for the acceptance area where ELVs with rests of operating fluids are stored. Furthermore, the areas of drainage, dismantling and storage of liquids are to be protected against ambient influences (e.g. by roofing). Special precautions have to be taken in order to avoid environmental pollution caused by mineral oils and acid liquids (e.g. special ground fortification). Only certified equipment should be used for the drainage of areas which are completely or partly influenced by weather influences (precipitators for light liquids, coalescence precipitators, e.g. according to the German Industry Standardization DIN 1999).

The requirements can be summed as follows:

- density of surfaces of plants, safe storage
- drainage
- removal of dangerous parts and materials, respectively
- dismantling and recycling of certain metal parts as well as large scaled plastic components and glass

The operating area has to be subdivided into following parts (indication required):

- acceptance area (acceptance and registration)
- entry storage for untreated ELVs
- operating parts for the pretreatment of ELVs (for drainage)
- storage for pretreated ELVs
 - dismantling
 - storage for usable car parts
 - storage for rigid waste to be recycled or deposited
 - storage for liquid waste to be recycled or deposited
 - storage for rest car bodies to be taken away
 - area for consolidation

4.1.2. Requirements concerning the Plant Operation

Pretreatment:

When car acceptance has been finished operators of dismantling plants directly have to

- disassemble batteries
- treat the liquid gas tank by following the guidelines of the manufacturer
- dismantle pyrotechnic parts by qualified personnel (dismantling of closed structures or disposing in assembled condition)

Following operating fluids and equipment have to be removed and gathered separately before any further treatment begins:

- fuel (including liquid gas for vehicle drive)
- coolants
- brake fluids
- screen cleaning fluids
- refrigerant agent from air conditioning (CFC)
- oil filter
- motor oil, gear oil, difference oil, hydraulic oil and antishock oil

Dismantling:

The operation plant should be able to realize a non-destructive dismantling of all car parts in terms of technical, organizational and personnel requirements. Furthermore, operators are obliged to remove the materials and parts listed below (regarded to be hazardous for the environment):

- latent heat-storage unit

- shock absorber
- components with asbestos
- components with mercury
- indicated parts and materials of the EU regulation which have been introduced later than July 2003.
- materials that do not belong to the vehicle

At dismantling plants following parts and materials have to be removed before surrendering the rest car body to the shredding plant:

- catalysts
- balancing load
- aluminum rims
- front, rear and side windows as well as glass roof
- tires
- large plastic parts, e.g. shock absorber, hub caps, radiator grill, if these materials cannot be separated for later material recycling
- metal parts with copper, aluminum and magnesium, if these materials cannot be separated either

Reutilization, recycling and disposal:

Parts and materials from ELVs should be primarily recycled or reutilized. Recycling and reutilization of operating fluids such as brake fluids, hydraulic fluids, coolants etc. is to be proofed in terms of technical and economical feasibility. Waste material for recycling and disposal should be stored separately in labeled containers. Before surrendering rest car bodies to shredding plants, 10 wt% of components, materials and operating fluids have to be reutilized or prepared for material recycling by 1 January 2006 the latest (average value per year referred to the total weight of empty vehicles).

Documentation:

Introduction of an operation journal about registration, draining, dismantling, reutilization etc.. Information on the treatment and storage of ELVs should be included as well.

4.2. Conception of a Model Plant for Dismantling

4.2.1. Methods of Dismantling

Dismantling plants consist of several structural

elements that might differ according to their arrangement but still have to follow structural limitations. The main stations of the dismantling plant are

- Drainage
- Dismantling
- Storage of valuable materials and residues
- Compression of car body
- Sale of usable car parts

This paper puts emphasis on the legal requirements that should be fulfilled to receive the operating license. Furthermore, the concept represents a guideline for an efficient disassembly method. The disassembly process can be supported by computer-aided guiding systems, e.g. a data base that manages car specific information and instructions for the workers. Hence, the worker is

always aware of the parts to be dismantled in the right order and with suitable tools. These computer aided systems are already in operation and subject of further development.

The dismantling principle based on the “island-type-system” enables a non destructive removal of spare parts and is highly flexible towards different working volumes for draining. It is quite common that the working volume strongly varies due to different filling amounts and conditions of the vehicles. Fig. 4 illustrates the process flow at an island-type dismantling plant.

4.2.2. Major Functions of Selected Components Acceptance area

Subsequent to the delivery, ELVs are to be stored next to the entry or directly transferred to the

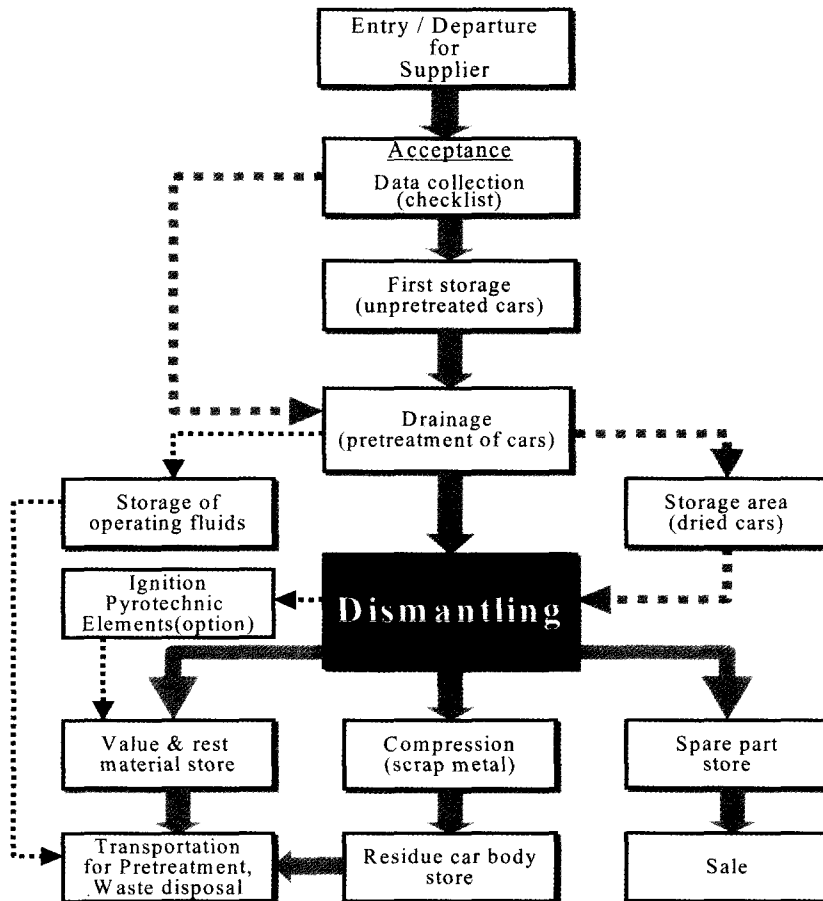


Fig. 4. Process steps at an island-type dismantling plant [ERT].

acceptance area (dependent on capacity). The acceptance area is needed for optical examination of the vehicles and the documentation of following parameters:

- Type
- Kilometric performance
- Cubic capacity
- Weight of empty car body
- Date of first registration
- Performance
- Vehicle identification number (VIN)

All tires should be disassembled if the ELV is drained at a subsequent step. More equipment is needed in the acceptance area, such as lifting platform, hardware for diagnosis of engine and gears, scale, tool shelves, connections for air compression and a PC for data input. Finally, an internal identification number should be assigned to the single vehicle so that all further process steps can be retrieved by the workers (storage, sales, drainage, dismantling).

Drainage:

It is recommended to roof the area, to protect it against explosions and to ventilate it by air. Furthermore, each draining point needs a resistant floor fortification (mineral oil, acids) and a precipitators for light liquids. A heating system is recommended in order to make use of a decreasing viscosity of liquids at higher temperatures. Thus, it might be easier to remove liquids from their storage even at winter times. The removal of batteries and tires enable a better accessibility, especially during drilling of the shock absorbers and the removal of their liquids. Operating liquids can be transferred to separate containers and then returned to the reprocessing cycle. Draining in an early stage is important to avoid a leakage and mixing of toxic substances. Furthermore, removed liquids cannot cause contaminations which might occur in subsequent process steps, e.g. during shredding. Thorough draining is therefore inevitable to prevent future damages. In general, materials that have to be drained and separated are: auto fuel, diesel fuel, motor oil, gear oil, filter oil, shock absorber oil, differential oil, power steering oil, coolants, brake fluids, windshield water.

Dismantling station:

Major aim of dismantling is to gather spare parts and to gain valuable materials. Potential spare parts are to be processed, documented and stored for sale. A non-destructive disassembly is quite important to sale dismantled components as spare parts. The most preferred spare parts are for example: axles, starter, hitch, drive shafts, exhaust, outside rear-view mirrors, illumination system, fuel pump, brake caliper, electronic parts, injection system, gears, catalyst, car body parts, cooler, generator, engines, gasifier, shock absorber, ignition distributor. The effectivity of spare part dismantling is influenced by demand and offer of the market, and consequently by revenues in relation to the dismantling effort.

Valuable materials are not regarded to be spare parts because they are sold due to their materials composition. This category comprises cables (copper), aluminum (rims, car body parts) and catalysts (platinum). Those parts that are neither spare parts nor valuable materials are called residues. In this case, plastic with impurities or compound glass belongs to this category. Normally, the dismantling operator claims a fee for residues from the operator of the recycling plant. Before dismantled car parts are delivered to compression, press all airbags and belt pretensioner have to be dismantled.

4.2.3. Design and Conception of a Dismantling Plant

The calculation of the plant size should be based on the yearly throughput in order to run to capacity and to operate economically. The maximum time needed for the treatment of a single vehicle is about 55 minutes. Therefore, the daily throughput is about 9 cars. Based on 220 labor days per year, the annual throughput amounts to 2000 cars. Thus, the respective single areas of components can be determined.

If less than 2000 vehicles are expected, an economic operation of the plant is not given. For that reason, and in order to run to capacity, the expected number of vehicles should be many times higher than the minimum value.

The respective amount of throughput of the smallest plant of 2000 cars per year is derived from the

following frame conditions:

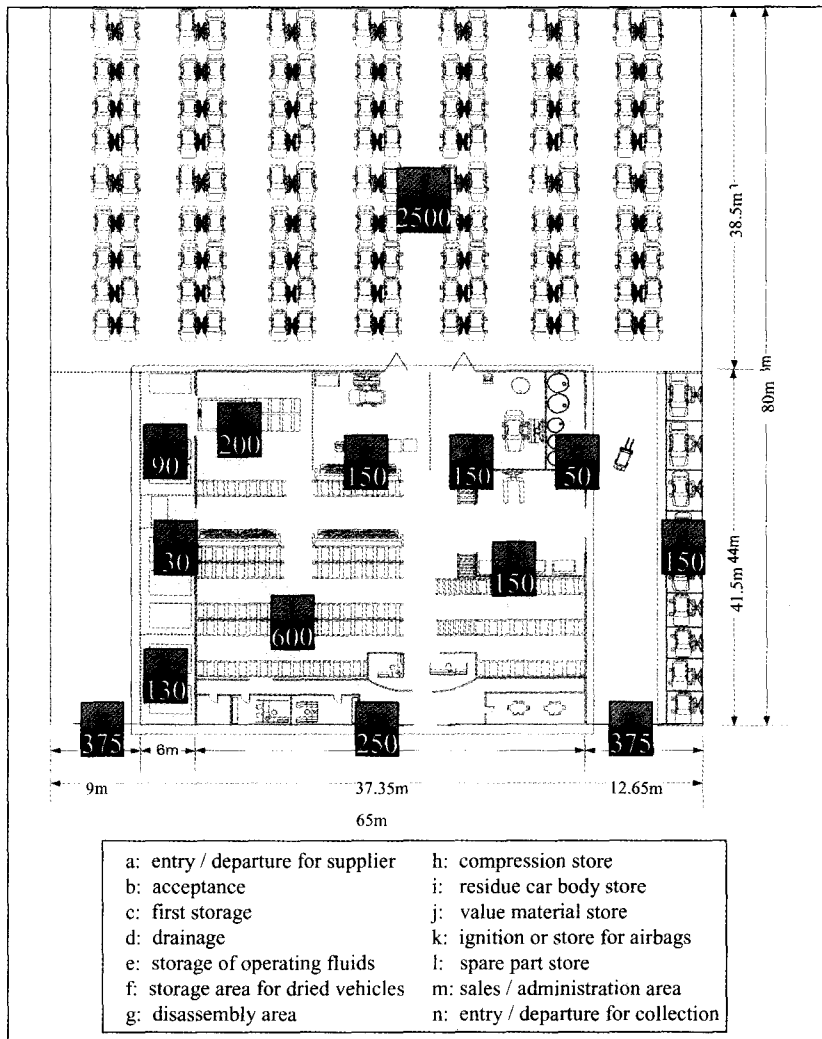
- Estimation basis: 55 minutes for maximum time expenditure per car that corresponds to 9 cars a day.
- 220 labor days per year
- There are 14 main components defined for 2000, 4000 cars etc. Thus, the total area of the plant is

$$A_{tot} = \sum_{i=1}^n A(i) \quad i = 1, 2, \dots, n, \quad n = 14$$

5200 m² of total area are needed for the throughput of 2000 vehicles and 9400 m² for the annual throughput of 4000 vehicles.

The following objectives are of importance for the set up of a model plant:

- compact design (optimal utilization of space)
- functionality, i.e. short ways to subsequent stations
- possibility of scaling up the model plant, e.g. for higher throughputs



[Source: ERT]

Numbers: areas in m²

Fig. 5. Schematic of a dismantling plant for an annual throughput of 2000 vehicles

Fig. 5 presents a model concept of a dismantling plant dimensioned for a throughput of 2000 vehicles. The single components as well as the different area sizes are listed in the same figure.

4.2.4. Investment Costs and Equipment for the Dismantling Model Plant

The total investment costs for the dismantling plant with a yearly throughput of 2000 cars might amount to about 2.5 million. to 3.0 million. US\$. The building costs comprise almost over 70% of the total costs whereas 28% refer to technical equipment of the model plant:

- 72% of total investment costs for e.g. building structure, sealing of floor and transport ways, ground work and domestic technique.
- 28% of total investment costs for transportation vehicles (fork-lift truck etc.), draining devices and plants, compressors and pipes, hydraulic lifts, devices for motor diagnosis, scrap press, shelf storage system, air conditioning suction device, tools, EDP etc.

The highest investment costs especially arise at ground works and house technology due to legal requirements of the government for the sake of environment protection.

5. SHREDDER PLANTS AND PRETREATMENT OF SLF

5.1. Requirements based on the ELV regulation

Operators of shredding companies have to be officially authorized to install and run their plants. The authorization is required to ensure environmental and employment protection as well as to fulfill the legal requirements of the "Federal ambient pollution control act". Furthermore, plant operators are only allowed to accept ELVs which have been treated in authorized dismantling stations.

According to the general requirements, operators of shredding plants have to keep operating journals containing detailed information on registration and processing data as well as on the disposition of materials.

5.2. A Concept of a Shredding System

Rest car bodies from dismantling plants are normally shredded together with other scrap material. The function of shredding plants is to cut and separate input material into the valuable fractions ferrous scrap and NF scrap mixes as well as NF residues which are also known as shredder residues. After classing, ferrous scrap can be used as substitute material for pig iron (cooling scrap) at iron and steel industry. Major aim of the scrap treatment is to gain homogeneous batches with defined qualities.

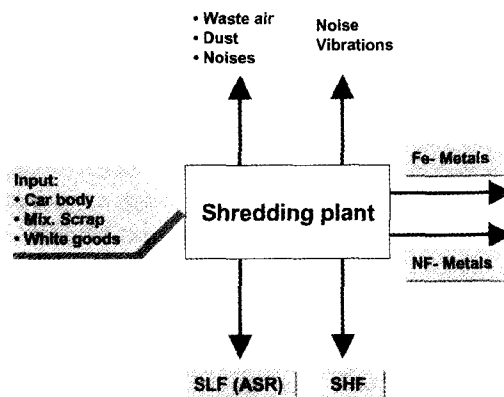


Fig. 6. Input and output material at a shredding plant.

Output streams such as FE- and NF-pscrap are profitably sold. Shredder light and heavy fractions should be transferred to mechanical pretreatment in order to separate more valuable material.

It is important to be aware of a new regulation prohibiting the disposal of untreated shredder residues by 1 June 2005. Furthermore, measures have to be taken for noise protection, suitable foundations and vibration dampers as well as dust exhausting equipment. With regard to exhaust air and dust, special requirements defined in the "Federal ambient pollution control act" are to be fulfilled.

5.2.1. Composition of the Shredder Input Material

The quantity of part fractions resulting from the shredding process is strongly dependent on the composition of the input material and the applied separation technique. The input material is subject to the current market situation and might vary signifi-

Table 2. Composition of shredder input material [FZK]

Shredder input material	[wt%]
Rest car bodies	27 – 34
Scrap mix	Up to 44
“White goods“	15 – 23
Other materials	Up to 16

cantly from the listed values in Table 2.

However, the material composition of new vehicles can be specified in detail (see Table 3).

Changes of the material composition influences the shredder input material with a time delay which is again dependent on the average service life of the vehicle. The decrease of metals for the sake of plastic materials makes it more difficult for the recycling industry to achieve the required recycling rate. A direct dependency between the material development in automotive industry and the composition of the shredder input material is not possible due to its changing combination. For economical reasons shredding plants in Germany do not treat ELVs

exclusively but have to add other scrap mixes to the input stream.

5.2.2. Composition of the Shredder Output Material

The composition of the part fractions in the output stream are roughly estimated due to the variations of the input material. Following band width represents a typical composition of the output material [Thome-K.], [Wallau 1], [FZK]:

- shredder scrap amounts to 69 wt% or 65 – 90 wt%, respectively
- the FE portion of the shredder scrap is about 95 – 98%
- FE metals from rest car bodies are added to shredder scrap and are more than 90 wt%
- The portion of SLF is about 6 – 25 wt% (increasing tendency)
- The portion of SHF is about 1 – 10 wt%

Nearly half of the heavy fraction consists of NF

Table 3. Material composition of new vehicles [Christen].

Main material groups	1990	1995	2000	2005
Steel and iron	68%	63%	60%	58%
Light metals	5,5%	7%	8%	10%
Plastic	10,5%	12%	14%	16%
Other (glass, rubber)	18%	18%	17%	16%

Table 4. Composition of the shredder output material [Kolbe/ERT].

Shredder scrap (70%)	SHF (7.5%)	SLF (22.5%)
Fe-Metals	NF-Metals (45%) with: ▶ Aluminum (41%) ▶ Zinc (29%) ▶ Copper (5%) ▶ Lead (2%) ▶ Other (23%) Residues (55%) Subdivided into: ▶ Polyvinyl chloride ▶ Rubber ▶ Glass ▶ Stones	Material mix with: ▶ Plastics (49%) ▶ Metals (14%) ▶ Glass, ceramics (12%) ▶ Wood, cellulose, Fibers (11%) ▶ Dust, Impurities (9%) ▶ Coatings, Sand (5%)

metals whereas the rest consists of plastic and other materials which are known as shredder residues (SR). In future, a disposal of these fractions will be prohibited so that suitable treatment technologies have to be established soon. Rest car bodies have a disproportionate influence on the quantity of shredder residues relative to the weight of the car bodies (25-28 wt%). Due to the increasing quantity of plastics as well as glass and light metals, one has to reckon higher amounts of shredder residues in varying combinations. Table 4 contains an overview of estimated values concerning the composition of shredder heavy fractions. As already mentioned, these values might vary according to the composition of the shredder input material.

In compliance with the new regulations heavy and light fractions are to be treated in further processing

steps. NF-metals and heavy fractions can be taken out by metal separators and then prepared for material recycling. Shredder light fractions and residues from shredder heavy fractions have to be treated in order to separate recyclable parts from the stream.

5.2.3. A Model Plant for an Efficient Shredding Process

Revenues from the sale of recycled metals are the main source of income whereas shredder residues have to be treated with costs. These treatment costs are strongly dependent on the quality of the shredder residues. For example, light fractions that have been already cut will cause lower costs due to their higher bulk density compared to coarse material. Another influence factor is given by the rest metal content in shredder residues. In order to estimate accruing costs

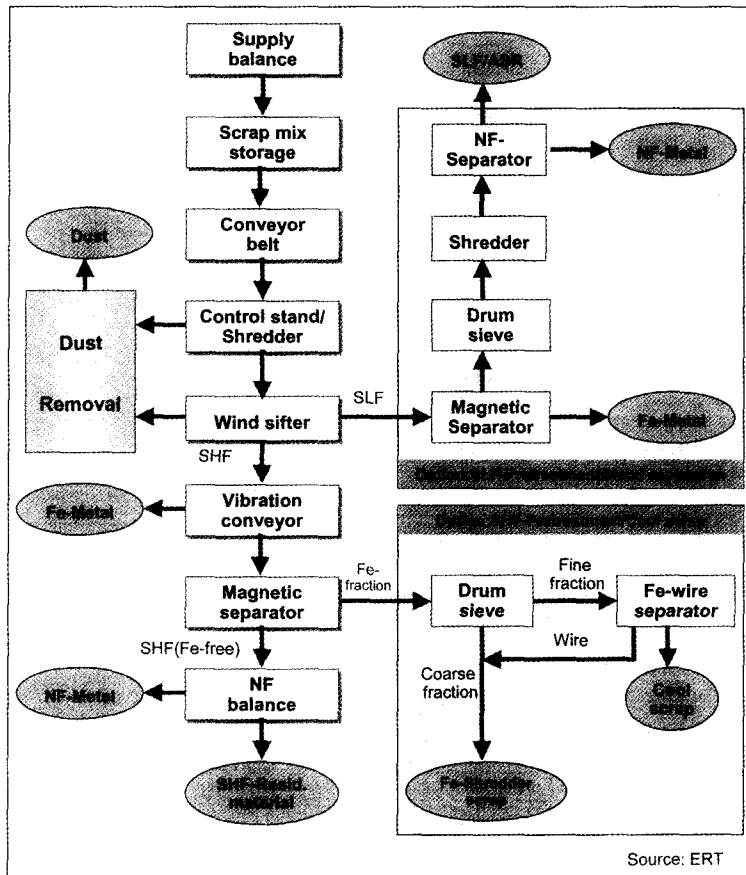


Fig. 7. Schematic structure of an efficient shredding plant [Kolbe].

for the plant operator, samples have to be taken from the material at regular intervals. The market value of the ingredients and their portions are the basis for price determination. So far, the preparation of NF shredder output material seems to be economically reasonable for most of the plant operators. Fig. 7 shows the schematic structure of a model plant for shredding. The electric station provides current to the main motor of the shredder and the conveyor belt. The velocity of the conveyor belt and the rotation speed of the shredder are regulated by the controller station. The de-dusting plant serves to exhaust dust from the shredder as well as from the air separator which separates heavy fractions from light fractions. A vibrating system separates rubber from the stream and enables a uniform distribution of the rest material. Magnetic separator, sieve drums, separator for NF-

metals and a sorting cabin are used for further separation of the shredder mix. The output material consists of shredded ferrous fractions, copper and FE materials, rubber, FE/NF metals, SLF inert fractions, mixed NF-metals as well as high calorific SLF. The pretreatment lines for light and FE-fractions are indicated as optional solutions in Fig. 7 and may be realized in different combinations. The example shows that due to these measures the plant operator achieves three more fractions that can be profitably brought to market. Furthermore, the recycling rate can be improved for the sake of the legal requirements in future.

5.3. Conception of a ASR Pretreatment Plant

The comminution aggregate represents another important technical component of the dry process

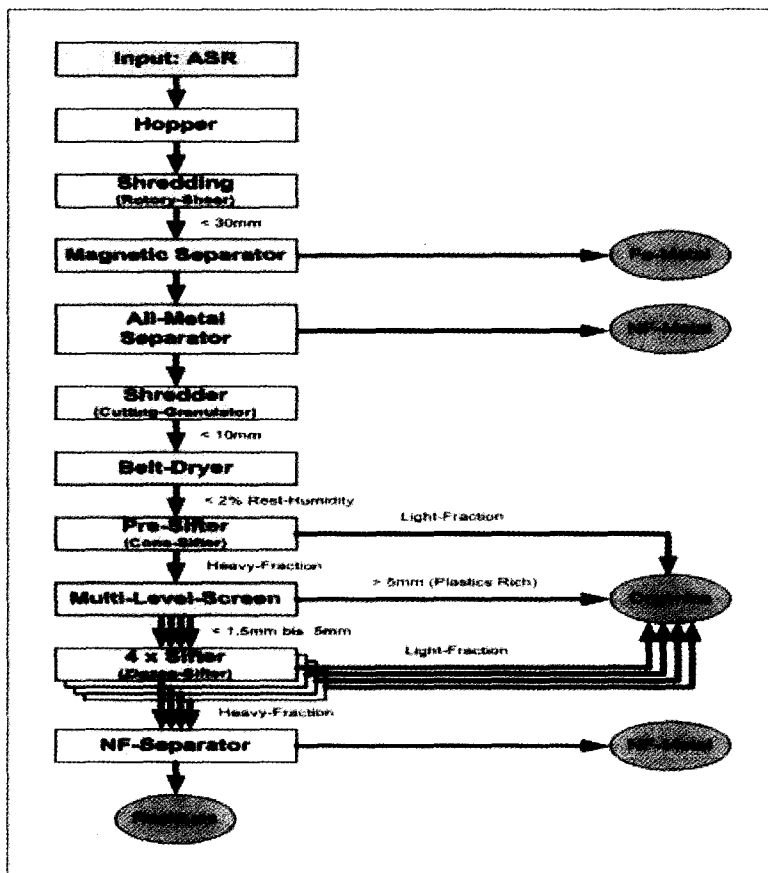


Fig. 8. Process scheme for the pretreatment of ASR [ERT].

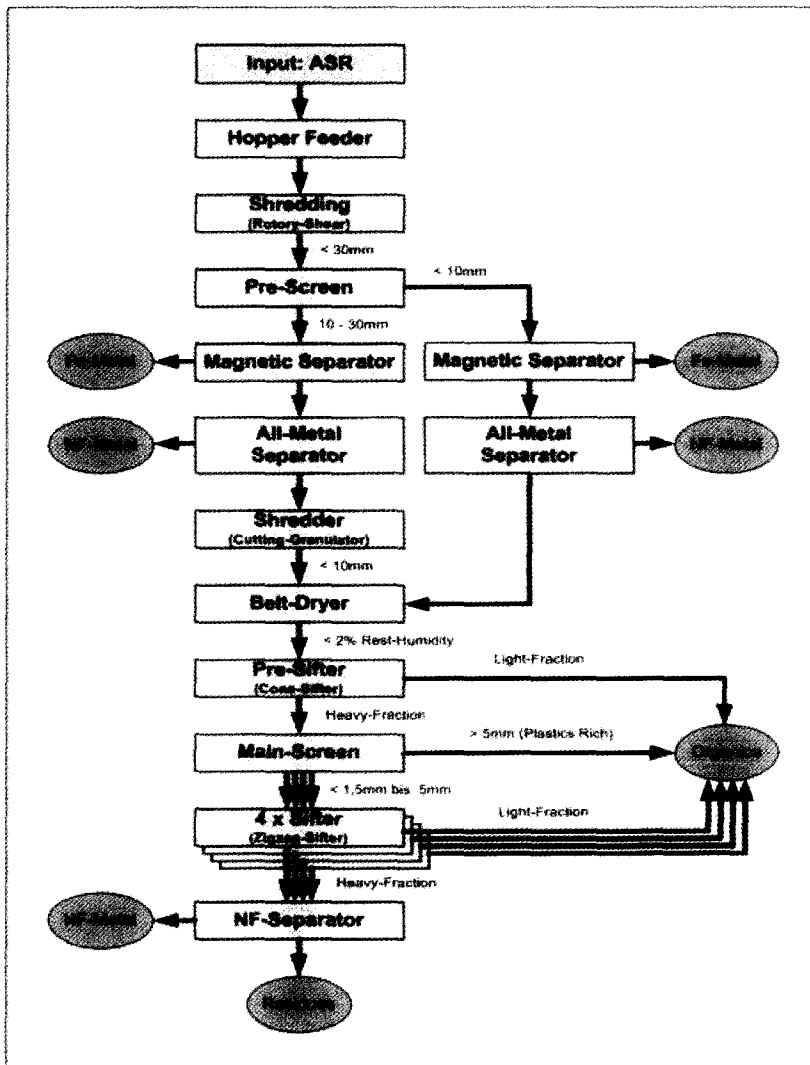
(cutting and rolling mill). The comminution of the shredder conglomerate significantly influences the efficiency of the described sorting techniques. Fig. 8 illustrates the process flow for the pretreatment of shredder light fractions.

The main process steps described above have to be arranged in a layout in order to set up the first alternative concept of the model plant. Furthermore, the quantity of applied components has a decisive influence on the process efficiency.

The pre-dried material comes out of the hopper and

is cut to pieces smaller than 30 mm. The subsequent stations are represented by the magnetic separator for ferrous and the all metal separator for the separation of nonferrous metals. The shredder finally cuts the material to particles of 10 mm size.

Now, the belt dryer dries the material (2% moisture content) with different heating modules of 100 kW power. Dependent on the required moisture content the amount and power output of the modules might vary. The cone sifter separates the dried material into light and heavy fractions (the light fractions are mostly



[Source: ERT]

Fig. 9. Process scheme for the pre-treatment of ASR.

organic fractions). In order to filter organic fractions from heavy fractions we need additional screens and sifters whose general functionality has been described in above section. In this case, a 4 step-multi level screen is used which firstly enables to separate coarse fractions of more than 5 mm size and secondly, provides homogeneous sizes for the Zig-Zag sifters. The multi screens are important for the Zig-Zag technology since the applied sifters always require homogeneous sizes.

The organic fractions of high calorific value are filtered out of the stream. The rest of the material is again treated in order to separate NF-metals from residues, such as minerals.

The second alternative concept is based on the first alternative and contains some modifications (Fig. 9). In order to minimize mechanical abrasion of the second shredder, a pre-screen can be arranged behind the first shredding process. The pre-screen enables a filtering of pieces between 10 and 30 mm as well as less than 10 mm. As in the first alternative, the magnetic and the all metal separator separate ferrous and NF-metals out of the pre-sorted material. In this case, two separators are to be implemented due to the already split material streams. All other subsequent processes are similar to the first alternative. All in all, an increase of investment costs is estimated to be about 30,000 to

50,000 Euro. On the other hand, there is a potential for cost saving concerning maintenance and spare parts.

6. MATERIAL, RAW MATERIAL AND ENERGETIC RECYCLING

Recycling is a collective term and stands for different ways of treatment methods. The main recycling techniques can be subdivided into:

- material recycling
- raw material recycling and
- energetic recycling

6.1. Material Recycling

Large plastic parts from dismantling plants can be treated by material recycling as long as they are not compounds. This cycle is called the “material recycling cycle” and can be described as the return of used products after being treated mechanically. Major aim is to achieve similar qualities of used products for a later reutilization. The recovery of metals from the shredding process is one example for this method. After air and magnetic separation as well as the swim-sinkprocess the metallic fraction’s purity grade is high

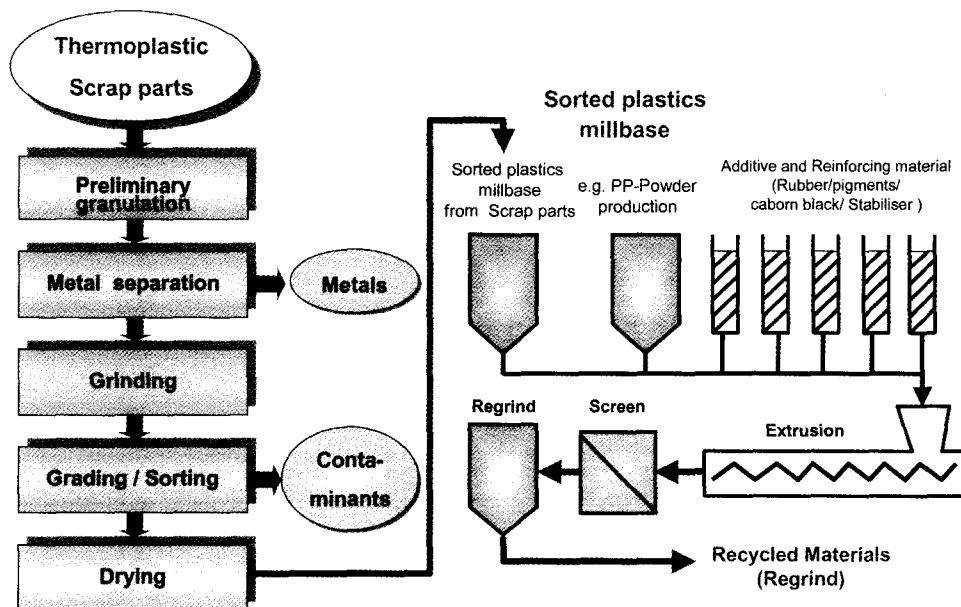


Fig. 10. Typical material recycling process for thermoset scrap from ELVs [ERT].

enough for reutilization.

During the pretreatment process the polymer structure should not be destroyed or changed. The recycled material can be added to the new material or even used as substitute material.

6.2. Raw Material and Energetic Recycling of ASR (SLF)

Major aim of raw material recycling is to gain products substituting materials from crude oil such as methanol. In this case, plastic fractions or shredder light fractions with high plastic content are treated by suitable conversion methods such as gasification, hydration or carbonization. In the end, the substitute material can be introduced to the crude oil cycle. Furthermore, raw material recycling is also used to produce reducing agents in blast furnaces.

Chemical recycling is regarded to be a part of raw material recycling since plastic structures are reduced to monomers, cleaned and then prepared for the production of new plastic products. This method is particularly interesting for complex materials and high impurities when mechanical treatment would not lead

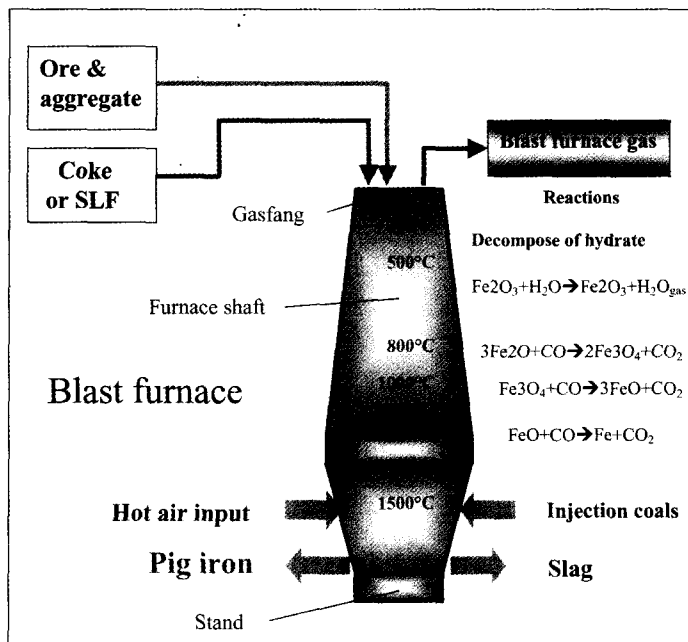
to successful results.

Shredder light fractions with their heterogeneous composition are not suitable for material recycling but have to be treated mechanically in order to gain high calorific materials. The recycling of shredder light fractions from ELVs at industrial plants must be in compliance with the national regulation for “recycling management and waste” (KrW-/AbfG). Provided that the economic and technical efficiency is given, a treatment of SLF is always preferred.

6.2.1. Recycling for the Blast Furnace Process

The blast furnace is a top loader kiln which continuously runs to melt iron ore and agglomerates (sinter and pellets) to liquid pig iron. For this purpose, coke is added as heat carrier and reducing agent. Reactions will take place at different temperatures and constitutions of gases in the furnace. The equations for reaction are summed up in Fig. 11.

The reaction gases are heated by the cowper to 1000-1350°C and transferred to the base frame through blow mouldings. Oxygen of the heated air reacts with carbon of the reducing agent (coke, coal, oil, SLF). CO₂ which arises at temperatures of 2500°C starts to



[ERT]

Fig. 11. Schematic construction and reaction process of blast furnace.

react with carbon to carbon monoxide (CO). CO is needed to reduce ore at different levels of oxidation.

Experiments of "EKO Stahl GmbH" in Eisenhüttenstadt and "Thyssen Stahl AG" have shown that raw material recycling can be realized by adding ASR (SLF) to the blast furnace process. Since the blast furnace is a closed system, all emissions are prevented from streaming outside. Due to the high temperatures of nearly 2300°C chemical links can be broken and a regeneration of dioxins and furans is avoided. In the past years, coke has been substituted by fuels with coke content such as coal dust, oil or natural gas. Therefore, high calorific, organic SLF can be used as substitute reducing agent in order to save the expenses for coke. In case of a low portion of disturbing materials (e.g. copper máx. 0.3 wt%) within SLF an injection ratio of 50 kg/t pig iron can be achieved. For this recycling method SLF has to fulfill following conditions:

- Used SLF should be injectable and conveyable.
- Carbon in SLF has to be transformed to an adequate degree, i.e. at least 70% has to be transformed to gas.
- Disturbances should be avoided during the input of pretreated SLF.
- The quality of produced pig iron is not to be decreased by substances, e.g. copper, chrome, nickel, molybdenum and arsenic. These substances have to be eliminated in the previous treatment of the SLF.

6.2.2. Recycling at Gasifiers

Gasification is another method for raw material recycling of treated SLF. Organic compounds are mostly transformed to CO, CO₂, H₂O and H₂ by partial oxidation. In various gasification processes the temperature is about 700 to 1500°C. The basic process scheme is shown in Fig. 12.

- I. The pretreated SLF is charged to a container for storing
- II. SLF is conveyed to a gasification reactor by means of an input system such as a lock hopper system, an input screw, pipelines
- III. Gasification media such as air, steam or oxygen

are added to the gasifier.

- IV. High temperatures of 700 to 1800°C and pressures of up to 30 bar arise in the gasification chamber. The gasification medium and carbon of the gasification material (SLF) react to raw gas and synthesis gas, respectively.
- V. A discharge system consisting of screw, lock hopper system and output container enables a conveying of slag out of the gasification reactor.

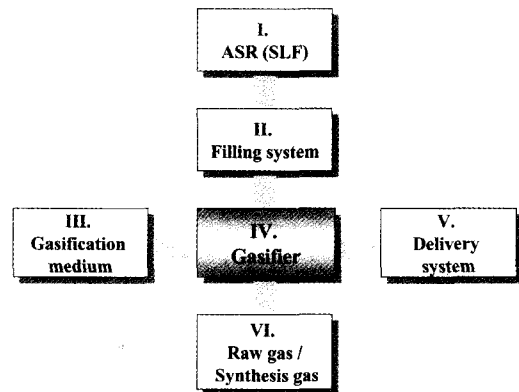


Fig. 12. Principal process of ASR gasification [ERT].

SVZ - Process:

The high technical efficiency of the recycling process has been already proven and therefore contributes to fulfill the future requirements of a modern recycling plant. The company "SVZ-Schwarze Pumpe GmbH" operates several plants in which solid, liquid and paste-like waste with hydrocarbon content can be recycled with coal addition (material and energetic recycling). The gasification of solid material is realized by six classical packed-bed reactors and one modern slag-bed reactor. Liquid material (e.g. tar and oil) can be treated by flue stream reactors.

Major objective of the waste gasification is the extraction of raw synthesis gas. The substances of the synthesis gas are carbon monoxide CO, carbon dioxide CO₂, hydrogen H₂ and methane CH₄. Raw gas can be used for the synthesis of diesel fuel or ammonia. A gasification of SLF material in bulk is not possible due to the quality standards of the gasification technology. For this reason, SLF is mixed with domestic waste and has to be transformed to pellets in advance. Hence, the pretreatment step enables a high throughput and a good

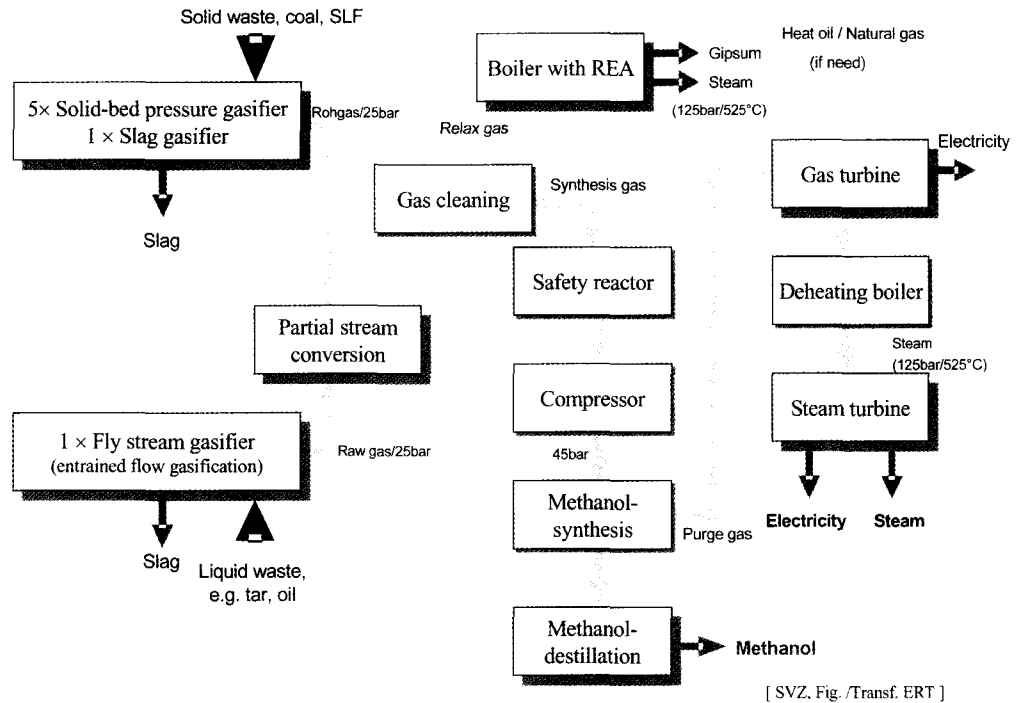


Fig. 13. Process scheme of the SVZ Schwarze Pumpe.

material stream. The whole pretreatment process consists of the technologies: crushing, classing, drying, separation of Fe-/NF-metals, inert substances and heavy fractions and finally pelletizing.

The high calorific fraction mainly consists of pellets and plastics (together 66.8%) as well as heavy materials which are not pelletized (6.7%). Plastics come from the recirculation of the separated iron-plastic mix.

Although the SLF's input quality varies, no significant changes of the pretreatment and pelletizing process are necessary. The throughput of the press is comparable to pelletized domestic waste (1.2 to 1.5 t/h) and fulfills the quality requirements of the gasification.

SLF pellets are mixed with other gasification substances (e.g. wood, old plastic, slag) together with coal. The mix rate is limited to maximum 30% and particularly depends on the ash content of the SLF. The features of the gasification process itself are as follows:

- pressure at 25 bar and in reduced atmosphere
- temperatures between 1300°C to 1800°C within the

reactor by adding steam and oxygen

- the throughput of packed-bed and flue stream gasifier is about 10-15 t/h and of slag bed gasifier 35 t/h

At present, an annual amount of 84,000 t SLF can be processed. Without the mass portion of the separated components (FE- and NF-metals, inert materials and ablated water) and the high calorific heavy metals, the SLF mass portion to be pelletized amounts to 66.8% or 56,000 t, respectively. Under consideration of a mixing ratio of 50% SLF and domestic waste the annual total capacity of the plant is about 112,000 t/a.

6.2.3. Energetic Recycling of ASR

Recycling of SLF in waste combustion plant at Würzburg:

The pretreated SLF is mixed to the conventional domestic waste and receives a thermal treatment during combustion. This special kind of co-combustion of SLF was tested at the waste combustion plant at

Würzburg, Germany in 1998. The total input of SLF was about 220 t SLF and corresponded to 24 and 31 wt%, respectively.

As already described in previous section, the domestic waste has a much lower calorific value than SLF. For this reason, the vessel has to be dimensioned under the SLF conditions in order to avoid an overload. The plant of Würzburg is equipped with two combustion lines that enable a throughput of 12.5 t/h with a calorific value of 8400 kJ/kg. The test phase has been accomplished without any disturbances of the normal plant operation. Moreover, the insertion of SLF did not influence the concentrations of heavy metals or dioxin and furan in the pure gas. As far as the recyclability of slag e.g. for road construction is concerned, the SLF content should not exceed 10 wt%.

Costs for a thermal treatment of SLF at the plant of Würzburg are between 100 and 120 €/t. Table 5 contains a specification of the ASR/SLF for the thermal treatment process.

Table 5. Contains a specification of the used ASR/SLF.

Components	Units
Calorific value	$\geq 11000 \text{ kJ/kg}$
Ash content	$\sim 55\%$
Metal portion (Fe & NF)	$\leq 4\%$
Metal alloying	$\sim 14\%$
Heavy metals	Equivalent to household waste
Halogen (Cl, Br)	$\sim 1\%$

7. SUMMARY AND CONCLUSION

The quantity of ELVs in Germany has significantly grown in the past, and this tendency is likely to continue due to the increase of registrations for new passenger cars. This development also means that recycling industry has to face new challenges concerning the treatment of existing shredder residues. Their quantity is also dependent on the material development for passenger cars. In compliance with the ELV regulation at least 10 wt% of ELV components and operating fluids have to be reutilized or recycled before transferring the rest car bodies to the shredding plants (01/01/2006). This average value

refers to the empty weights of all ELVs that have been accepted by the dismantling plant per year. Hence, the amount of car bodies for shredding plants is likely to be reduced. Nevertheless, the increasing use of plastic material at automobiles makes the recycling industry to strengthen its activities to fulfill the legal requirements of the ELV treatment.

As a first step, model plants have to be developed and established. Process flow and equipment must be adapted to the different recycling types (material, raw material and energetic recycling) which should have been assigned to the recyclable parts in advance.

A specific dismantling concept has been described in this paper. The model plant fulfills the current and future requirements and refers to a yearly throughput of 2000 ELVs. The size can be scaled up for throughputs of 4000 and 6000 vehicles per year as well.

The evaluated shredding concepts correspond to authorized systems in Germany that meet the requirements of the ELV regulation. In spite of the high separation quality at shredding plants, shredder light fractions still have to be treated additionally for later raw material and energetic recycling. The described SLF treatment concept is based on a detailed study of single components such as cutting devices, air separator, sifter etc..

Principally, pretreated SLF can be used in different recycling processes. However, profound research has shown that an efficient application is given with raw material recycling at blast furnaces, at the gasification plant "SVZ" and with energetic recycling at waste combustion plants.

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種 類	內 容
論 說	提案, 意見, 批判, 時評
展望, 解説	現況과 將來의 견해, 研究 技術의 綜合解説, Review
技 術 報 告	實際的인 試驗, 調査의 報告
技術, 行政情報	價値있는 技術, 行政情報를 간결히 解説하고, comment를 붙인다.
見 聞 記	國際會義의 報告, 國內外的 研究 幾關의 見學記 등
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談 話 室	會員相互의 情報交換, 會員 自由스러운 말, 隨霜 등
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