Action 2.1

Evaluation of the current status of the recycling / energy recovery of End-of-Life Tyres (ELTs) and End-of-Life Vehicles (ELVs) in order to achieve European targets

CENTRO RICERCHE FIAT

Project partners

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Upgrade ELV Management

The 2000/53 Directive, also called ELV Directive, deals with the end of life vehicles (ELVs) providing guidelines and fixing rules for a good ELV management in order to achieve the European targets of reuse/recycling and recycling/recovery. Even if the ELV directive has been implemented by each European Member, the ELV management is slightly different among several Countries. In the following, the latest upgrade of the Italian situation is shown, as well as a wider overview on Europe. Eventually, the most significant differences are highlighted comparing the European scenarios with the worldwide ones.

The ELV management in Italy

In Italy the ELV management is based on a strong collaborative system of all involved companies. Such a system is the result of a great work carried out since 2008 when Fiat Group Automobiles signed with the two Italian Ministries (Ministry of Economic Development and Ministry for the Environmental, Land and Sea) and with all the ELV chain associations (dealers, dismantlers, crushers, shredders and companies in charge of energy recovery). It was the first case in Europe of Agreement where all companies were represented and they worked together for the achievement of a common goal, that is the European targets. In the ELV chain (Figure 1) each role is defined and represented by associations:

- Carmakers and importers (ANFIA and UNRAE)
- Dealers (FEDERAUTO)
- Dismantlers (CAR, CAN, FISE UNIRE)
- Crushers (ASSOFERMET)
- Shredders (AIRA)
- Energy recovery (AIR)

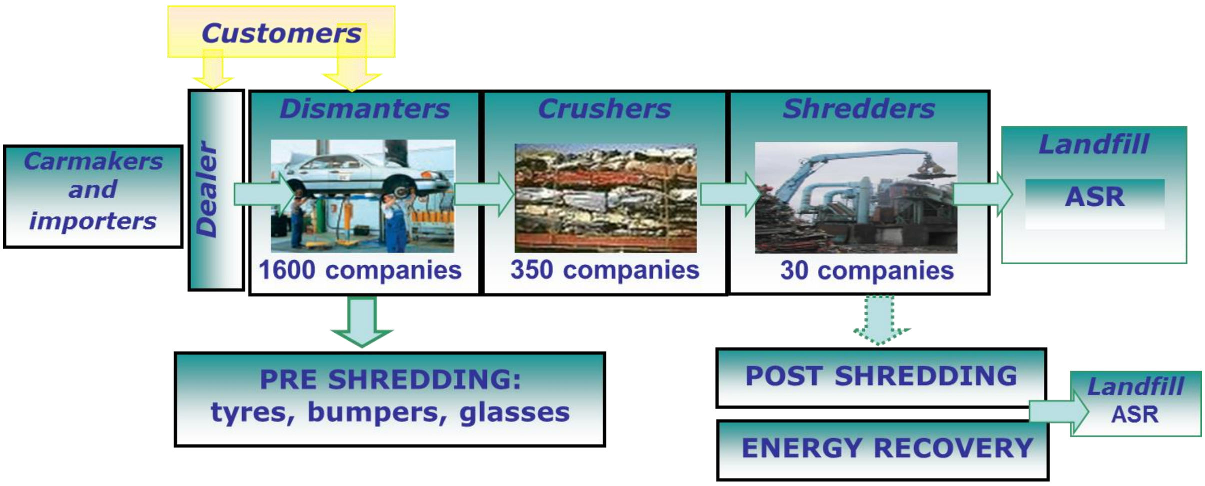


Figure 1 - The Italian ELV management chain

Thanks to hard work of the ELV chain, Italy has always been able to comply the requirement of the ELV Directive and mainly of the 2006 targets (reuse/recycling 80% by weight and reuse/recovery 85% by weight). In Figure 2 the quotas of the last three years are shown.

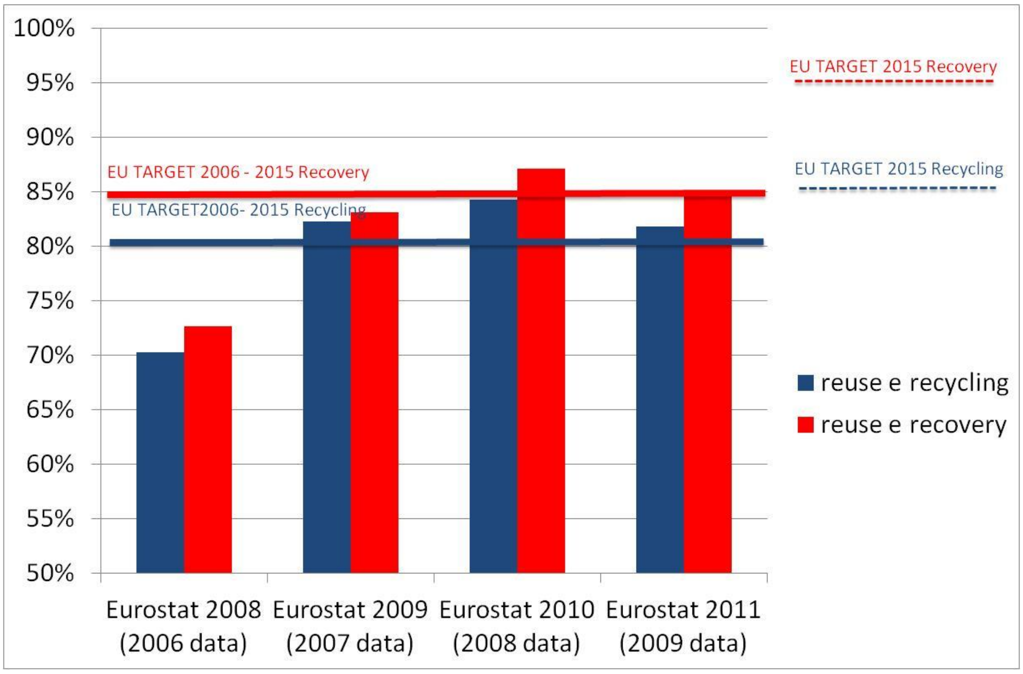


Figure 2 - Main results: targets for Italy

Today, a great effort of all companies involved in the ELV management is required, that is the achievement of the 2015 European targets (reuse/recycling 85% by weight and reuse/recovery 95% by weight). In order to fulfil this goal, an increase of post-shredding to separate material flows with an economic value (e.g. metals) and the development of solutions for the energy recovery are necessary. One of the main initiatives promoted by the Fiat Research Centre and three of the main Italian shredders is the TARGET FLUFF project, which has as goal the development of post-shredding plants and, if sustainability is ensured, as well for energy recovery. The first results are already available, but the work is still on going.

Several other projects and initiatives are currently under way and are focusing on finding out and steadying market demands of materials recycled from the end of life vehicles. The material flows, which are recycled from ELVs and have already economic and environmental sustainable applications or very high chances to find a market demand, are mainly polypropylene from bumpers, glass from windshields and rubber from tyres.

The ELV management in Europe

The ELV management in Europe follows guidelines of 2000/53 Directive, but shows also some differences in enforcing these law because of different European Countries scenarios. In order to verify the targets achievement, Europe chose to collect data supplied by Member States in a centralized system. Eurostat is the statistical office of the European Union and, on the basis of the Member Countries data transmission, provides information on the reuse, recycling and recovery quotas for each one. In Figure 3 and Figure 4 the last four years (from 2006 to 2009) trends respectively of reuse-recycling and reuse-recovery are shown. Comparing the results, effort of each Country in achieving the 2015 targets is clearly evident. Anyway, all Countries with certain exceptions are able to fulfil easily the 2006 targets, but only few of them achieve now the 2015 ones. The 2015 targets are much ambitious because they limit the landfill disposal at only 5% by weight so an improving of recycling and energy recovery is required to attain the goal.

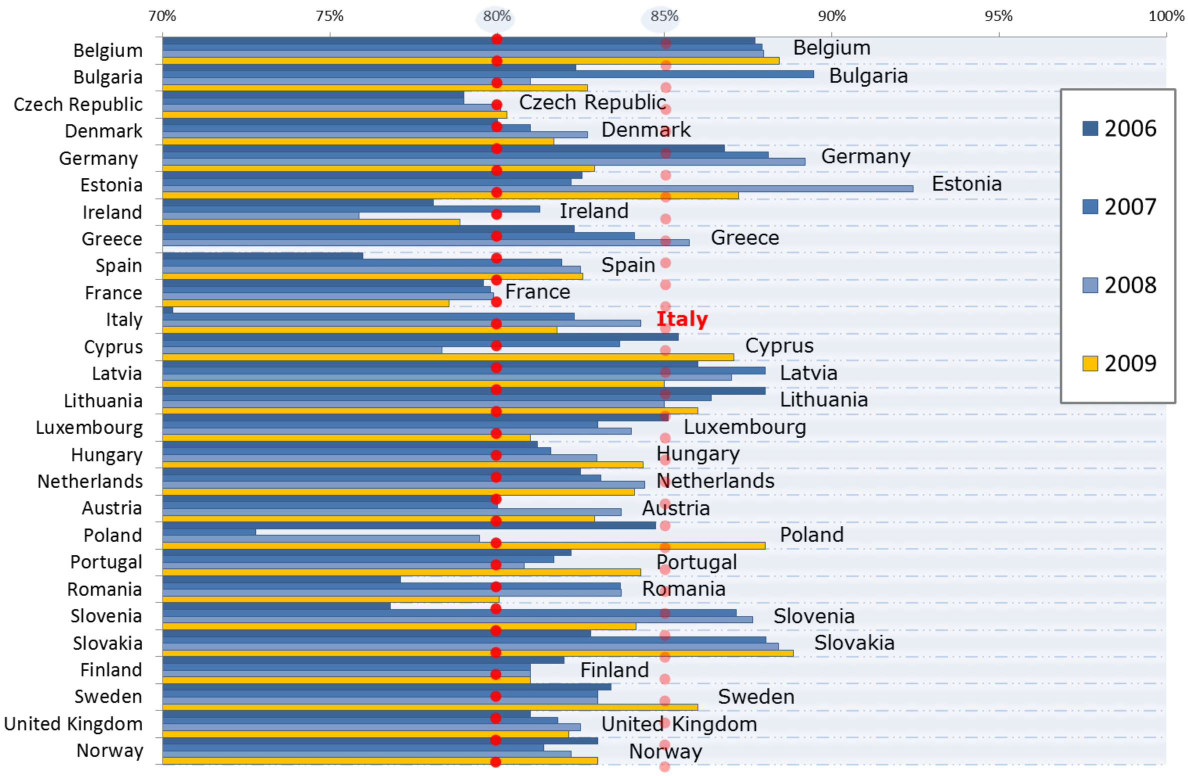


Figure 3 - EUROSTAT 2011: EU reuse an d recycling targets (by 2006 in red, by 2015 in transparent red)

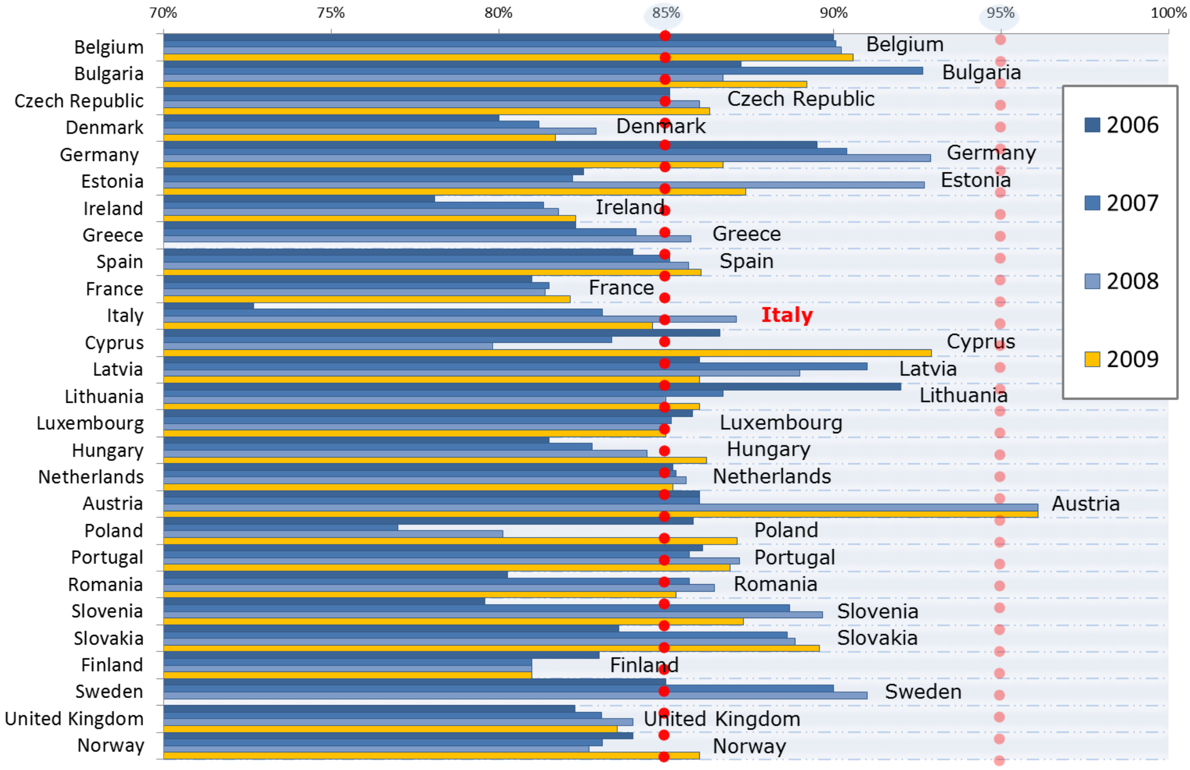


Figure 4 - EUROSTAT 2011: EU reuse and recovery targets (by 2006 in red, by 2015 in transparent red)

The ELV management in extra-European countries

The non-EU countries situation is even more different respect to the European one. As a matter of fact, there are cases where ELV management is not regulated, other cases where only a draft a law is available and also others where there is a regulation on the way of the European one, which is usually the most restrictive. Of course, such differences depend on lifestyle conditions, as well as on the cultural and environmental sensitivity of a Country. Anyway there are other reasons, even if less significant, which do not limit landfilling. That is, for example, the case of US since it has a low population density and so there are size for landfill disposal. In the last years even US is growing the environmental awareness and it is gathering information on how the ELV issues are managed in other Countries.

A large number of countries out of Europe introduced a law on ELV management similar to the European 2000/53, for instance Turkey, Serbia, Russia. Other Non-European countries (Brasil, China, South Korea...) are thinking at ELV Management laws.

Upgrade ELT Management

The End of Life Tyre (ELT) has the 160103 code in the European Waste Catalogue (EWC), but it must not be considered simply as waste because it is a valuable resource both in terms of material quality and energetic power. As a matter of fact it has already remarkable market demands as recycled material for several applications. In order not to waste such a resource, it is important to plan a good ELT management. In the following, an update of the ELT management is shown considering the Italian, European and worldwide scenarios.

The ELT management in Italy

In the past in Italy the ELT had to be dismantled and managed separately because it was considered an environmental hazardous waste. Nevertheless, in the last years, awareness of its potential has increased so a new ELT collection and management system has been planned. Besides, taking into account ELTs affect the target quotas of about 3% by weight and looking at the ELTs flow in detail, it is possible to understand why the recycling of this kind of material is so important. Every year, in Italy, a quantity of about 380.000 tons of tyres reach the end of their lives as a result of the tyres of vehicles on the road being replaced (Table 1).

PRODUCTION OF ELT	tons/year	ELT USE
Tyres removed because of replacement	365.000	
End-of-life tyres from vehicles to be demolished	61.000	
Total	**426.000**	
	of which	
	46.000	**retread or reused**
	380.000	**identified as ELTs**
	of which	
	100.000	subjected to recovery of material
	180.000	subjected to recovery of energy
	100.000	lost along illegal channels and on illegal landfill sites

Ref. Ecopneus rough estimates expressed in t/year (2010)

Table 1 - Quantities of ELTs recovered in Italy every year (based on 2010 data)

The decree n. 82 of April 11th 2011, according to the provisions of the article 228 of legislative decree no. 152/06 and subsequent modifications and supplements, has, as main goal, the ELT management in order to improve recovery, prevent waste and safeguard environment. The decree and the new ELT management system from the past are based and focused on the following points:

- According to the "producer responsibility" principle, the tyres producers and importers are responsible for the ELT management
- An environmental fee on the sale of every new tyres and every new vehicle is introduced and updated every year in order to permit the ELT waste management and recovery and ensure a strong management system and a traceability of the materials and waste flows

During 2011, ECOPNEUS collected and treated nearly 73 kt of ELTs, exceeding its annual ELT management obligations by 10%, in fact in 2011, for the first year, the Italian ELT Management Decree imposed a collection & recovery target of 25% of the quantity of tyres placed on the market by its members in 2010.

Regarding the ELT from ELV, the environmental fee is effective by 11 May 2012 and the tyre collection system is under construction.

The ELT management in Europe

Each European Member State has adopted an ELT management, which is the best, according to the political, economic reality of the country itself. ETRMA (European Tyre & Rubber Manufacturers' Association) published the 4th report on end of life tyres management [1] to show an overview on the ELT management scenarios.

In 2010, about 3.3 million tonnes of used tyres were managed in Europe and this represents 2% increase in arisings compared to 2009 (Figure 5).

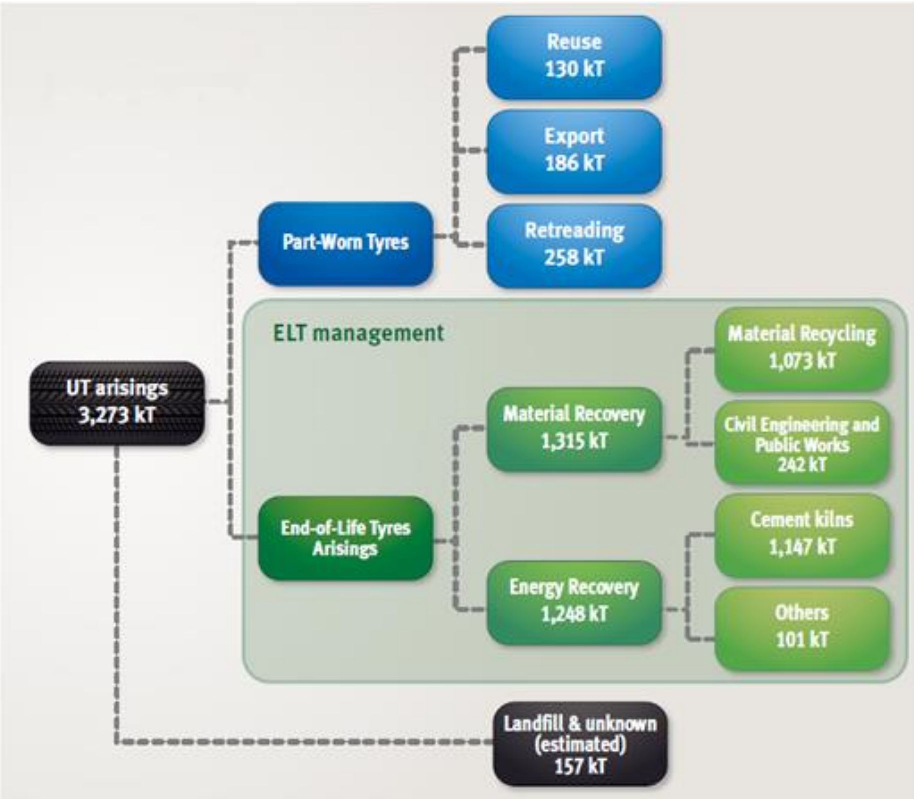


Figure 5 - ELT management in Europe in 2010 (Ref. ETRMA)

Today, within the EU, ELT managements are based on the following systems: producer responsibility, financing through a tax or free market system (Figure 6).

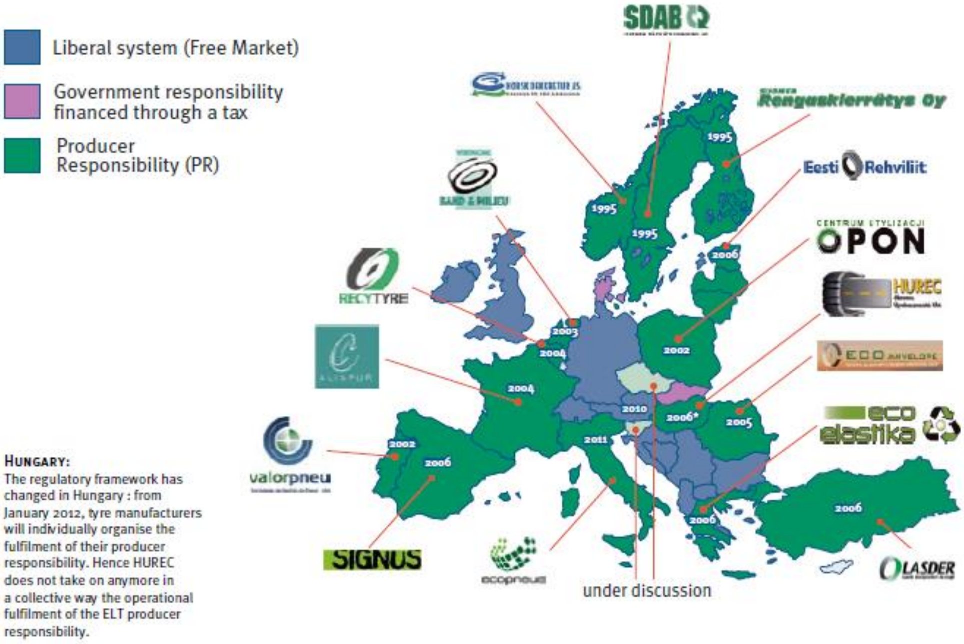


Figure 6 – Country specific implementation and ELT management companies (Ref. ETRMA)

The ELT management is improved continuously over the years and in 2010 only 4% of the used tyres arisings are tipped in landfills or have unknown recovery routes while recycling, recovery, reuse and retreading contribute to a substantial 96% of used tyres recovery (Figure 7).

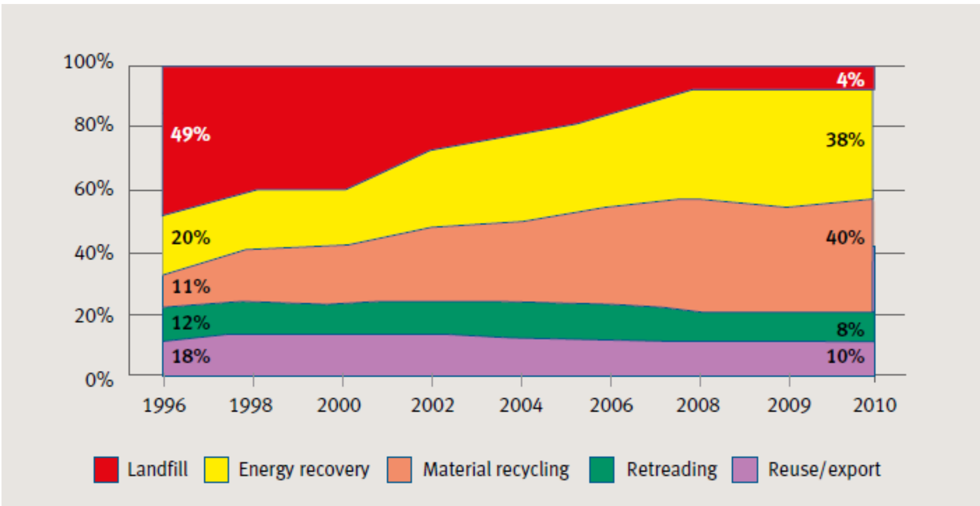


Figure 7 – Evolution of recovery routes since 1996 (Ref.: ETRMA)

In 2010 Europe managed about 3.3 million tonnes of used tyres (including tyres for retreading and reuse/export), the same quantity as in 2008 and up 2.2% compared to 2009.

The latest ETRMA statistics show that, in 2011, 95% of all used tyres were collected and treated in Europe, 2% more recycled despite a 3% increase in used tyres arisings. Table 2 shows the amounts of ELTs managed in 2011 per member of EC.

National figures (tonnes)	Used Tyres (UT) Arising	Reuse of Part-worn tyres			ELT Arising	ELT recovery				Landfill/ Unknown	Total UT recovery	UT
		Reuse	Export	Retrea-treateding		Material			Energy			
	(A)	(B)	(C)	(D)	(E)= A-(B+C+D)	Civil engineering[1] (F)	Recycling[2] (G)	Total [3] (H)=(F+G)	Energy recovery (I)	(J)	(K)= (B+C+D+ H+I)	(L)=K/A [4]
Austria (est.)	63.000	0	0	3.000	60.000	0	24.000	24.000	36.000	0	63.000	100%
Belgium	87.000	0	8.000	5.000	74.000	1.000	59.000	60.000	14.000	0	87.000	100%
Bulgaria (est.)	25.000	0	0	3.000	22.000	0	8.000	8.000	5.000	9.000	16.000	64%
Cyprus (est.)	4.000	0	0	0	4.000	0	0	0	0	4.000	0	0%
Czech Rep. (est.)	63.000	0	0	2.000	61.000	0	10.000	10.000	32.000	19.000	44.000	70%
Denmark	44.000	0	1.000	0	43.000	0	43.000	43.000	0	0	44.000	100%
Estonia (est.)	10.000	0	0	0	10.000	0	6.000	6.000	3.000	1.000	9.000	90%
Finland	53.000	0	0	1.000	52.000	46.000	4.000	50.000	2.000	0	53.000	100%
France	416.000	45.000	0	48.000	323.000	50.000	115.000	165.000	158.000	0	416.000	100%
Germany	670.000	10.000	92.000	85.000	483.000	0	220.000	220.000	263.000	0	670.000	100%
Greece	44.000	0	2.000	2.000	40.000	0	23.000	23.000	11.000	6.000	38.000	86%
Hungary	43.000	0	0	0	43.000	4.000	18.000	22.000	21.000	0	43.000	100%
Ireland	28.000	3.000	1.000	2.000	22.000	6.000	14.000	20.000	0	2.000	26.000	93%
Italy	433.000	27.000	21.000	34.000	351.000	0	70.000	70.000	180.000	100.000	332.000	77%
Latvia (est.)	10.000	0	0	0	10.000	0	5.000	5.000	4.000	1.000	9.000	90%
Lithuania (est.)	11.000	0	0	0	11.000	0	5.000	5.000	4.000	2.000	9.000	82%
Malta (est.)	1.000	0	1.000	0	0	0	0	0	0	0	1.000	100%
Netherlands (PC only)	65.000	0	16.000	2.000	47.000	0	37.000	37.000	10.000	0	65.000	100%
Poland	190.000	5.000	0	20.000	165.000	0	55.000	55.000	110.000	0	190.000	100%
Portugal	90.000	1.000	0	17.000	72.000	0	47.000	47.000	25.000	0	90.000	100%
Romania	57.000	0	0	0	57.000	0	14.000	14.000	43.000	0	57.000	100%
Slovak Rep. (est.)	25.000	0	0	1.000	24.000	0	23.000	23.000	1.000	0	25.000	100%
Slovenia (est.)	11.000	0	0	0	11.000	0	6.000	6.000	5.000	0	11.000	100%
Spain	283.000	10.000	24.000	35.000	214.000	14.000	92.000	106.000	108.000	0	283.000	100%
Sweden	73.000	0	1.000	0	72.000	13.000	16.000	29.000	43.000	0	73.000	100%
UK[4]	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A	N/A
Norway	45.000	0	2.000	0	43.000	16.000	19.000	35.000	8.000	0	45.000	100%
Switzerland	53.000	3.000	0	5.000	45.000	0	13.000	13.000	32.000	0	53.000	100%
EU26+NO+CH (2011)	2.897.000	104.000	169.000	265.000	2.359.000	150.000	946.000	1.096.000	1.118.000	144.000	2.752.000	95%
Turkey	246.000	N/A	N/A	N/A	246.000	0	49.000	49.000	43.000	103.000	92.000	75%5

Countries with Producer Responsibility regime in 2012: 16 countries
Number of ELT management companies set up by ETRMA tyre producers operating in Europe in 2012: 14

[1]Civil engineering, public works & backfilling
[2]Recycling: includes granulation, use of ELTs in steel mills and foundries as well as use as dock fenders, blasting mats, ...
[3]Material recovery

[4]UK official recovery figures are unavailable at the time of launching the press release. The EU 2011 UT arisings of about 2.9 million tonnes do not comprise UK data, estimated at 430 kt.

[5]In Turkey, the 2011 national UT arising is estimated at 246.000 t. The producer responsibility obligation for 2011 is limited to collecting and managing 50% of that tonnage. This obligation is set to progressively rise to 100% by 2014. In 2011, the national UT recovery rate of Turkey dropped since producers that are not members of LASDER only fulfilled 10% of their obligations whilst LASDER fulfilled 100% of its obligations.

Table 2 - Annual used tyres recovery of ELTs per member of EC in 2011 (Ref. ETRMA)

The ELT management in extra-European countries

According to the International Rubber Study Group (IRSG) report, the global tyre output is estimated at 1.5 billion units. Figure 8 shows the increase of ELT recovery rate from 1994 to 2010 taking into account three markets (USA, Europe and Japan).

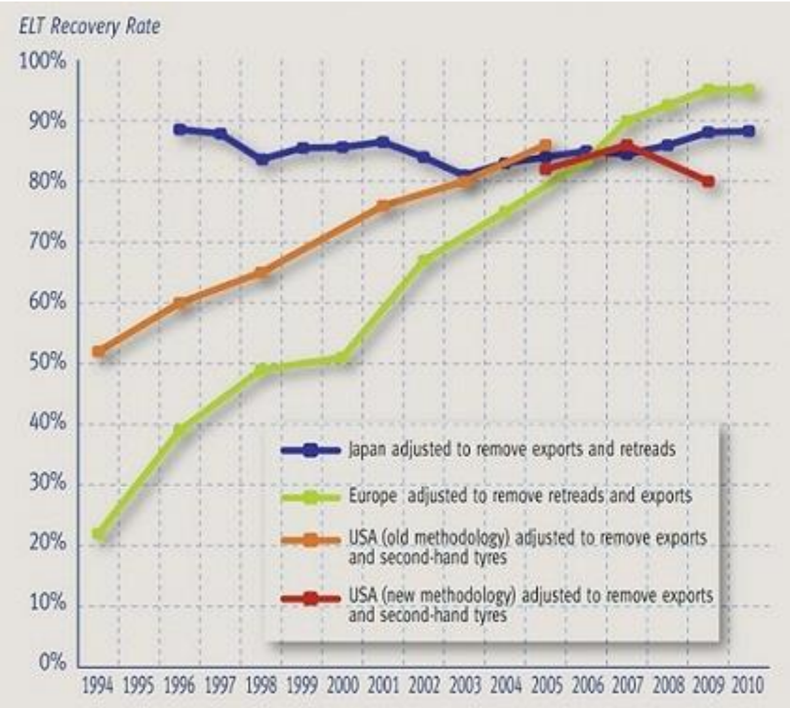


Figure 8 - Historical recovery rates estimates for ELTs (Ref. ETRMA, JATMA & RMA figures, adjusted to calculate harmonised ELT recovery rates)

An overview on the worldwide scenarios about the ELTs recovery (export, landfill, energy and material recovery) is provided by Ecopneus processing data from ETRMA, RMA, JATMA and CRIA (Figure 9**Errore. L'origine riferimento non è stata trovata.**) [2].

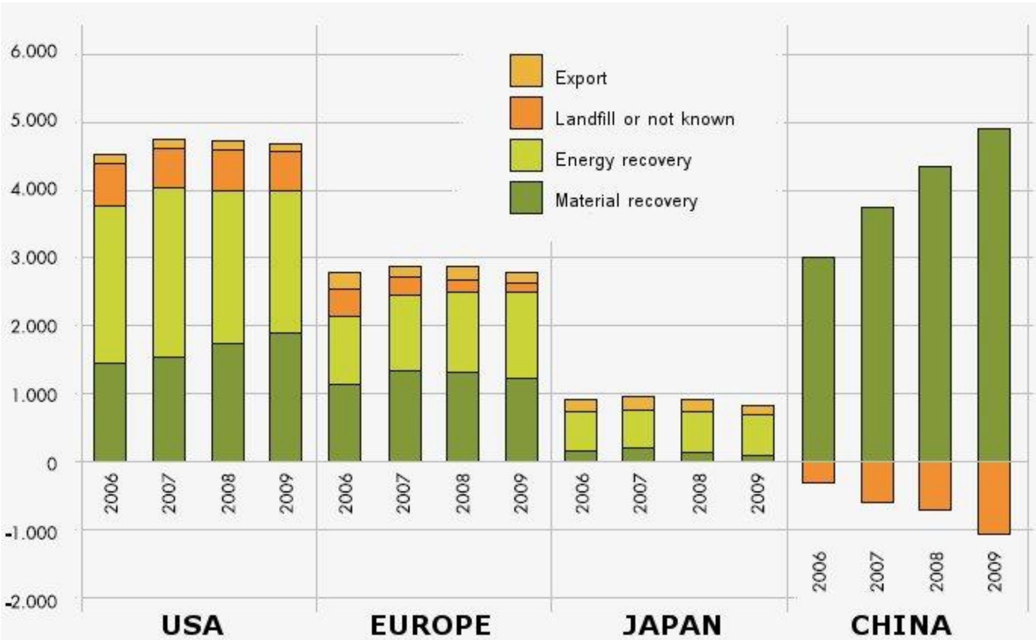
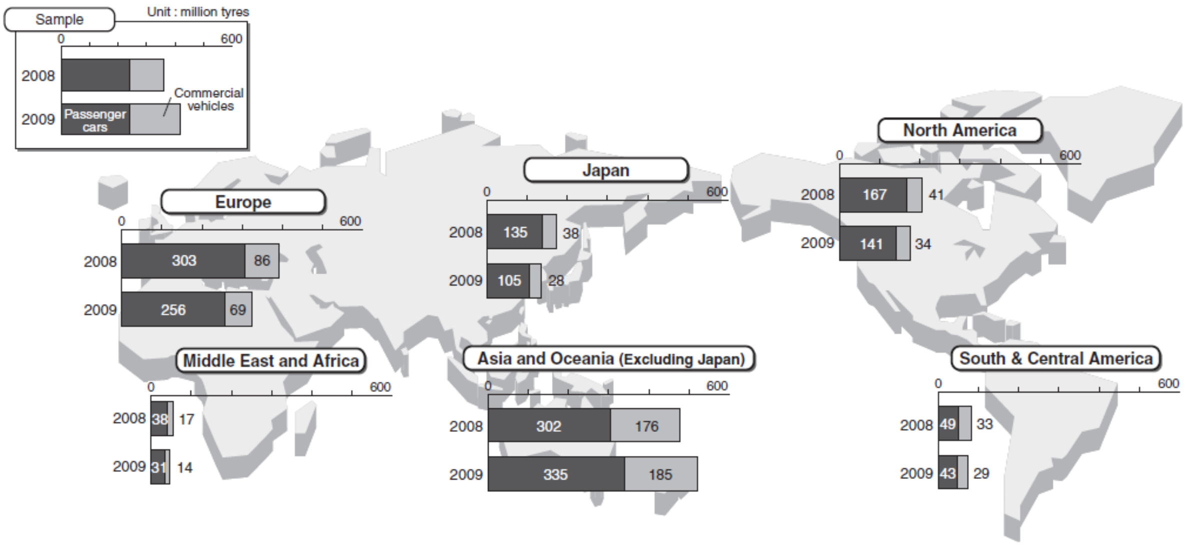


Figure 9 - ELTs recovery in the world (ktons/year) – 2006/2009 (reference: Ecopneus)

In order to see amounts of tyres managed by year in the world focusing on the kind of tyre (passenger cars or , an overview of tyres production, taking into account also extra-



EU markets, is shown in Figure 10.

Figure 10 – Tyre Production Worldwide (reference: JATMA)

Global Industry Analysts, Inc. (GIA), a reputed publisher of off-the-shelf market research, forecasts the global market for tyres in OEM and replacement markets is projected to reach 1.8 billion units in annual sales by 2017.

Materials	Passenger car	Truck
Rubber/Elastomers[a]	48%	45%

Recycling technologies of rubber from ELT

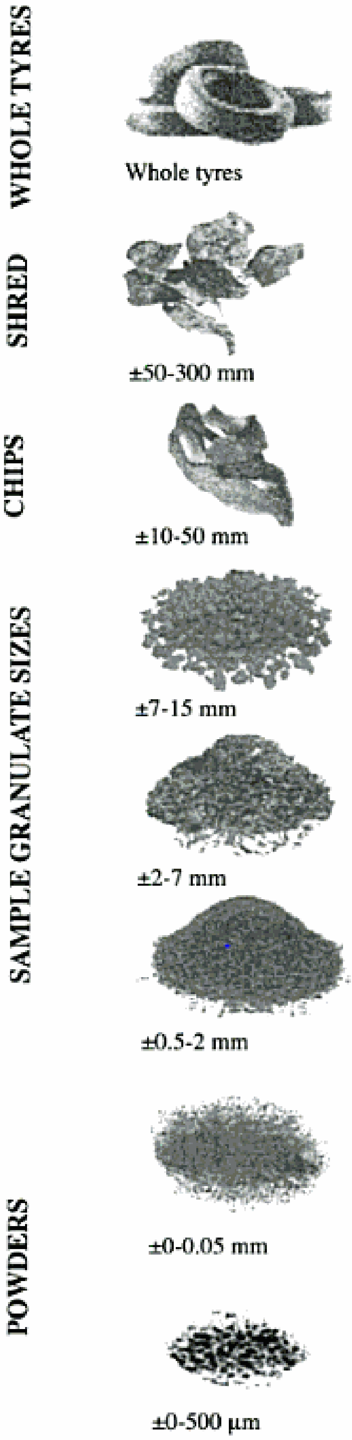
Tyres are complex products because they are made of high quality materials since they have to ensure specific performances, mainly from the safety point of view. Generally speaking, tyres are mixtures of synthetic and natural rubber, but, actually, they are made of different materials (Table 3). Such materials are all recyclable and, after their end of life, have already found several applications as recycled materials thanks to their high quality features.

Carbon black and silica[b]	22%	22%
Metal	15%	25%
Textile	5%	-
Zinc oxide	1%	2%
Sulphur	1%	1%
Additives	8%	-

[a] Truck tyres contain proportionately more natural rubber in comparison to synthetic rubber than do car tyres.
[b] Different varieties of carbon black are used for different purposes and may appear in other categories of material

Table 3 – Composition of car and truck tyres (Ref. Adapted from Hylands, Shulman 2003)

Of course, tyres are not all equals, for instance one of the most obvious difference is between tyres for passenger cars and for trucks. As a matter of fact, the truck tyres show a higher metal content and the use of natural rubber instead of synthetic rubber as used in the tyres for passenger cars. Metals should not have problems to be recycled, even if, indeed, their recycling depends on the technology used to separate metal from rubber. Besides also the rubber powder have to be treated with specific processes in order to be recycled and thus reused in other different productions.
Rubber, recycled from end of life tyres, can be distinguished, on the base of dimension, in different typologies of materials: whole tyres, shred, chips, granulate, powder and very fine powder.
Tyres recycling solutions depend also from dimensions of material and, as a general rule, smaller dimensions ensure higher recycling possibilities but at higher process cost.
A classification by size of the rubber recycled from tyres, including main uses of such a material, is shown in Figure 11 [3].



Whole tyres can be used untreated or treated with mechanical devices to make them more flexible or manageable.

Principal uses: artificial reefs, construction bales; embankments, sound barriers, stabilisation or as feedstock for further treatment.

Shred is the result of mechanical treatment to fragment, rip or tear the tyre into irregular pieces ±50-300 mm in any dimension.

Principal uses: lightweight fill, backfill, drainage, thermal insulation for roads or buildings, sound barriers, landfill engineering, or as feedstock.

Chips are produced as shred resulting in irregularly shaped pieces ±10-50 mm.

Principal uses: backfill, bridge abutments, lightweight fill for construction, drainage, landfill maintenance, road and sports foundations, soil treatments or as feedstock.

Granulate is the result of processing the material to reduce it in size to finely dispersed particles ±1-10 mm. There are two principal methods of size reduction in use today:

ambient size reduction: mechanical processes at or above ordinary room temperature that shear the rubber to reduce it to a desired size resulting in irregularly shaped recyclate.

cryogenic size reduction: liquid nitrogen or commercial refrigerants embrittle the rubber to reduce it to a desired size resulting in smooth regular surfaces.

Chemicals, microbes, microwaves, magnetic shock and high pressure water blasts have also been attempted.

Principal uses: artificial turf, automotive parts; crash and noise barriers; flooring, paving and roofing supplies; playground and sport surfaces; footwear; soil treatments, solid wheels; road furniture and traffic systems; rubberised asphalts; sports, carpet underlays; vibration mats or as feedstock for further treatment.

Powders are the result of processing rubber to achieve finely dispersed particles of <1 mm by ambient or cryogenic or special treatments, e.g., pyrolysis, reclaim, devulcanisation.

Principal uses: automotive parts; cable bedding compounds; fillers for tyres; footwear; porous bitumen binders; SAMs/SAMIs; sealants; sports equipment; surfacings or as feedstock for specialised treatments.

Very fine powders are the result of a range of specialised treatments that upgrade or contribute distinctive properties to the material.

Principal uses: automotive parts; carbon material; coatings and sealants; ingredients for tyres; partially devulcanised materials; pigments for inks, paints; thermoplastic elastomers.

Figure 11 – Categories of post-consumer tyre materials and their principal uses

One of the most important applications, already known since many years, but with very wide improvements also today, is the use of rubber from ELT in bituminous aggregates for pavements.

The asphalt rubber is widely used in several Countries since many years, mainly in U.S.A., which are the first to discover and exploit the advantages of such a material. Concerning the European situation, one of the most active Country is Spain, which recycled around 7000 tonnes of ELTs in 2010, while a bit lower, around 4500 tonnes, in 2011 because of the economic crisis. In Italy, the use of asphalt rubber is still in a testing phase which began 4 years ago also thanks to the help from Europe. As a matter of fact, in the last years, Europe has funded some projects with the aim of promoting the use of ELTs in rubberized asphalts. Some of the latest examples are:

- RoadTire [4], that is an EU-Life+ project carried out by Greece and Italy to promote the use of ELTs in road construction. The main outputs of the project were the development and construction of a pilot road to prototype and demonstrate innovative methodologies (wet and dry processes). The environmental issues were taken into account, using the Life Cycle Assessment (LCA) methodology to work out the environmental impacts due to use of rubber from ELT. In Italy, the ring road at Reggio Emilia was paved with rubberized asphalt.
- A feasibility study funded by EC by means of the Life+ initiative. In particular, the study involved the Province of Turin, the Politecnico university in Turin, Ecopneus as representative of tyres producers, Fiat Research Centre and some companies in charge of operations of recycling and using of asphalt rubber. An important output of such a project was the realization of the Borgaro-Venaria ring road, paving around 3,6 km with asphalt rubber (**Errore. L'origine riferimento non è stata trovata.Errore. L'origine riferimento non è stata trovata.**). TyRec4Life project is

the consequence of such a study and will keep on paving other roads with asphalt rubber.

Figure 12 - Inauguration of the Borgaro-Venaria ring road, made of asphalt rubber

- A project in Val Venosta, launched in 2011 by the Province of Bolzano, with the aim of paving a part of street (400 m) with asphalt modified with rubber recycled from ELTs in order to drop down the noise pollution. Testing showed a reduction of about 4 db with an improving of the tyre/asphalt grip coefficient. Moreover, also cost was cut by half respect to the traditional solution.

The use of rubber powder recycled from ELTs to the production of rubberized asphalts leads so many advantages, both in terms of safety and in terms of environmental, social and economic sustainability. One of such advantages, that is the noise reduction, has been explained by an Iterchimica's technical note [5], which is about the phono-absorbent features of rubber modified asphalts. Such a report shows some advice on choice of the best materials according with shape, size and distribution in the bituminous mixture. Besides, other technical data are provided to planning and engineering pavements in order to reduce noise taking into account the main causes (air pumping, aerodynamic flow, vibration, stick-slip and stick-snap).

Other experiences of use of ELT both in asphalts and in other similar applications was carried out.

ReRoad [6], project funded by the 7th Framework Programme, aims to develop knowledge and innovative technologies for enhanced end of life strategies for asphalt road infrastructures. The environmental impact of the ReRoad solution was investigated with the LCA tool.

RecTyre [7] is a project funded by the Executive Agency for Competitiveness and Innovation (2009-2011) with the aim of using of end of life tyres, as lightweight filler, for the construction of the embankment. Within the project, an LCA was carried out showing a minor environmental impact of the RecTyre embankment with respect to the use of used tyres as a fuel, for the production of cement clinker, in a cement kiln.

The state of the art on ELTs recycling and energy recovery is well-known since several time and, in literature, this issue is widely explained. An overview on the state of the art is provided by Ecopneus who summarized main applications of ELT-derived materials [8] and for energy recovery from ELTs [9]. Anyway, the big differences are not related to technologies, but mainly depend on the typology and quality of material both for recycling and for energy recovery. As a matter of fact, more innovative issues consist on finding the best setting on the material parameters (density, size, viscosity and many other characterization) on the basis of conditions where such materials are used for.

The state of the art on recycling technologies has been updated focusing the attention on the Italian situation also by means of visits to companies which work in ELT recycling.

Visits have involved the following companies:

- Rubber Affair [10], which manages a plant in Settimo Torinese being able to treat around 24000 tons/year of tires with production of around 15000 tons/year of rubber powder and granules besides the steel recovery and textile material from the carcasses. Main applications of rubber powder and granulates are phono-insulating panels and special floorings in sporting fields, gyms or sporting footsteps. The

residual products of the shredding, that is steel and fibre, are respectively sent to recovery and disposal.
- Maris [11] in Rosta, that is a town near Turin. Such company is expertise in analysis on tyres and on recycled materials from ELTs. Besides, it has a strong knowledge on the process for devulcazation of rubber and it is specialized in the manufacturing of co-rotating twin-screw extruders.
- Tritogom [12] is located in Cherasco, that is a town in the province of Cuneo. Within the "Impianti Aperti" initiative managed by Ecopneus, the plant has been showed and explained by Tritogom staff. Such a plant treats ELTs using exclusive dry grinding technology, capable of separating rubber from the canvas and from iron attached to the worn down tyres. The recycled rubber granulate has several dimensions (0-0,4; 0,5-0,8; 0,5-2,5 and 1,0-4,0 mm) and it is used as recycled material for many applications (in the rubber and building industry, flooring, sports grounds and asphalts).

The update was also done at Ecopneus [13] and Ecotyre [14], two of the first companies born to accomplish the required of the decree n. 82 of April 11th 2011. As a matter of fact they are in charge of the ELT collection on the national territory.

The visits were not only limited to recycling companies, but also to those involved in dismantling of ELVs and, as consequence, of ELTs. The attention was focused in particular on some of the main dismantlers and crushers in Italy:
- F.M. [15] is an important dismantler in Druento, that is a small town in province of Turin and Calò Roberto S.r.l., an important dismantler near Rome. Such visits was strategic in order to see the workaround the ELV and ELT management focusing on the depollution and the reuse and recycling operations, in particular the information are related to the volume of tyres from ELV, the equipment involved and the working time for the tyre dismantling and separation between rubber and wheels.
- The new EcoFirenze [16] dismantling plant, whose inauguration was in March 2011, is one of the best dismantling centres in Italy up to date in terms of technology level and quality management. The great success is due to joint venture of five of the most important dismantlers in Florence and it is a very good example also in order to achieve the European targets. Interesting result was the optimization of the dismantling operations that involve also the tyre dismantling.

The visits involved also some among the main Italian shredders:
- Ecofrantumi S.p.A. in Ferrara is a particular shredder in Italy because is the first example of shredder managed by dismantlers. Due to this fact all the tyre are sorted and treated together with a clear improvement of the economical sustainability.
- Centro Recupero e Servizi (CRS), company of the Derichbourg Group near Turin, manages a car shredding plant in Settimo Torinese and its business comes mainly from metal recycling. CRS manages also a landfill even if new solutions for ASR, in order to avoid or reduce sensibly the landfilling, are investigated as well.
- Feralpi S.p.A [17] is one of the most important steel suppliers for the Italian construction industry. The steelworks is located in Lonato del Garda in the province of Brescia. Feralpi manages a car shredding plant and, with Faeco S.p.A [18], company of Feralpi Group, also a landfill for special wastes coming from shredding plant and metal recyclers.

The last two companies are both involved in the TARGET FLUFF project and they are interested in the energy recovery of Automotive Shredder Residue (ASR), that is the solid residue that by now is

still disposed in landfill. With these companies CRF made investigation about different recycling and recovery options for tyres from technical, environment and economical point of view.
During meetings, it was possible to improve knowledge on the newest processes applied to the crush shredding and to the separation of those materials which can be recycled or recovered mainly thanks to their high calorific net value.

The State of the Art, mainly from the research point of view, was updated also attending to conferences, workshops and seminars concerning the environmental issues on the waste management.

Every year, the International Trade Fair of Material & Energy Recovery and Sustainable Development is held in Rimini. During the last event, one of the topic was concerning the recycling and energy recovery technologies of ELT. About the first issue, the results of two research projects were shown:

- TyGre ("High added value materials from waste tyre gasification residues") [19], a research project funded by the European Community's Seventh Framework Programme, is focused on the waste tyres recycling and promotes a thermal process mainly devoted to the production of ceramic materials. The goal of the project consists in redirecting the gasification process towards material recycling, and exploiting the high potential of the gasification solid by-products by coupling a second thermal process, dedicated to the carbothermal reduction synthesis of ceramics, to the preliminary waste tyres gasification.
- RµPERT ("Rubber Product Enhanced Recovery Technology") project is a TSB funded collaboration between Imperial College London and industry aimed at developing microwave-induced pyrolysis as an economically and environmentally sustainable waste tyre management solution. The goal of the project is developing a process based around a unique microwave furnace and used to produce a carbon-rich material to be used in tyres as a recycled filler.

Anyway, both of projects develop also the energy recovery of the ELT with gasification and pyrolysis technologies.
Other European events have been useful to gather news and information on waste management. One of these has been the IARC (the International Automotive Recycling Conference), that is the main European and worldwide event completely focused on the automotive recycling. During the last event kept in Budapest on March 22th 2012, specific topics on the ELT management were in agenda. ETRMA showed the latest news on the tyres markets and the different European systems of ELT management [20] Besides, during the last days of the Conference, a visit was arranged at the Euro-Novex Kft [21], company focused on the treatment and recycling of rubber. Indeed the visit concerned the plant (capacity with 34000 tons/year) managed by Euro-RUBBER Kft, company of the Group in charge of producing rubber granulates in Újszilvás, in Hungary.

Energy Recovery technologies of ELT

ELTs have a similar calorific value as a high quality coal, with the advantage that the emissions of (heavy) metals are much lower and so they are used as an alternative to fossil fuels, mainly in cement kilns and thermoelectric power stations. Other ways to energy recovery from ELTs are their burning in dedicated incinerators or breaking down by pyrolysis with recovery both of materials and energy as well.
The use of ELTs within cement kilns is already widely applied mainly thanks to the material composition since the steel content of the tyres, providing an essential source of iron, avoids the need for shales and clays and reduces the amount of oxides of nitrogen formed in the process. Besides, controlling the high temperature (around 1500°C) within the kilns, it is possible to optimize the tyres combustion, reducing solid waste as well. Shredded tires can be fed into the kiln by

insufflation, that is, blowing shreds into the discharge end of the kiln. Such a technology is already mature and research concerns further process optimizations increasing production capacity and reducing energy consumptions and costs.

A recent survey by the Portland Cement Association (PCA-2008) on 31 cement kilns in the U.S. highlighted that the use of Tyre Derived Fuel (TDF) reduces the quantities of coal, coke, and/or natural gas needed for kiln operation and reduces the quantity of iron that must be added with the raw materials [22]. Data for particulate matter, NOx, SO2, dioxin-furans, and CO (Figure 13) confirm that kilns firing TDF had emissions approximately one-third of those kilns firing conventional fuels such as coal, coke, and natural gas. As a matter of fact the emissions of particulate matter from TDF-firing kilns were 35% less than the levels reported for kilns firing conventional fuels.

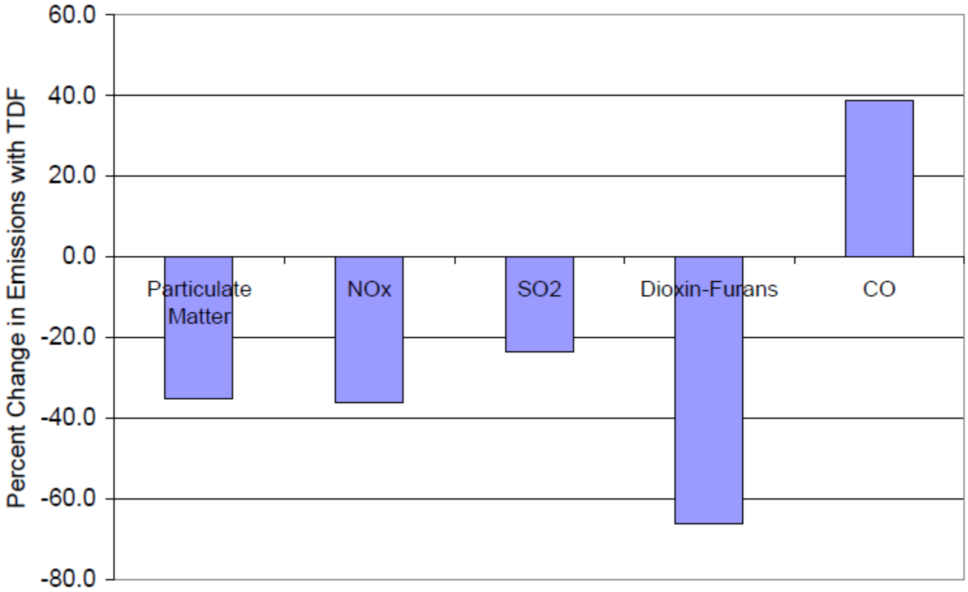


Figure 13 - Emission changes associated with TDF firing (Ref. Portland Cement Association 2008)

Another energy recovery technology is the pyrolysis, that is a process of thermal decomposition in an inert atmosphere which yields gas, oil, steel and carbon char which can be used to strip 90% of hydrocarbons from liquid effluent.

The oil and gas can be used as fuels within the pyrolysis system, or for an adjacent heat and power system. Compared to recovery of energy by direct burning, pyrolysis is a self-contained process which avoids the release of large volumes of combustion gases. This saves on the cost of cleaning or "scrubbing" systems needed with normal incineration to remove pollutants from the gases. It also means that the process can be controlled to recover products for resale.

The char produced can normally only be used for industrial processes. However, if microwave technology is used then the carbon black produced is of higher quality and has a wider variety of applications including reuse in new tyre manufacturing. Combination with microwaves is a research field investigated by the Imperial Collage London, who presented results of the RμPERT project during the last Ecomondo Fair.

Eventually, a summarizing overview on the benefits and disadvantages of the main technologies and applications of materials from ELT recovery is shown in Table 4 [23].

Application/Product	Benefits	Disadvantages
Alternative Fuel (Cement kilns or power stations)	• Conserve natural resources; • High calorific value; • Large volume potential	• Measuring equipment required to control emissions • Needs generally shredded tyres; • Costly to install and operate.
Steel electric arc furnace and foundery kilns	• Total and complete recovery of tyre components: carbon, steel, rubber • Replace high cost carbon	• Measure equipment required to control emissions • Needs generally shredded tyres • Costly to operate.
Landfill Engineering	• Lightweight, low density fill material; • Good load bearing capacity; • Lower cost compared to gravel; • Does not need a well-qualified labour;	• Potential leaching of metals and hydrocarbonates; • The steel cord in the tyre could puncture the lining; • Compressibility of the tyre;
Light weight or drainage fill	• Reduced unit weight compared to other alternatives; • Flexible, with good load bearing capacity; • Good drainage;	• Potential leaching of metals and hydrocarbonates; • Deformation under vertical load, when a proper soil cover thickness is not used; • Difficulty in compaction (need to use more than 10ton roller, six passes, 300mm lift)
Erosion control	• Low density which allows free floating structures to act as wave barriers; • Tyre bales are lightweight and easy to handle; • Durability;	• Tyres should be securely anchored to prevent mobility under flood conditions; • Tyres can trap debris, (needs maintenance); • Anchors can shift over time due to wave action rendering tyre structures insecure; • Water action and tyre buoyancy makes the positioning of any permanent protection below the surface very difficult; • Ultimately such tyres to become again waste to eliminate
Thermal Insulation	• Low thermal conductivity; • Overall lower cost than traditional materials;	• Compressible; • Relatively new product, producers will to need convince the construction industry of its suitability;
Noise Barriers	• Lightweight, and can therefore be used in geologically weak areas where traditional materials would prove too heavy; • Free draining and durable;	• Needs monitoring to avoid accumulation of debris; • Visual impact;
Rubber modified asphalt	• Increased durability • Surface resilience • Reduced maintenance; • Increased resistance to deformation and cracking; • More resistant to cracking at lower temperatures; • Aids in the reduction of road noise;	• It is very sensitive to changes in conditions during mixing i.e. requires expert knowledge; • Difficult to apply in wet weather; • Not applicable when ambient or surface temperatures are less than 13º C; • Possible occupational health problems due to emissions; • It cannot be reprocessed like traditional asphalt

Application/Product	Benefits	Disadvantages
Rubber modified Concrete	• Lower modulus of elasticity which reduces brittle failure; • Increased energy absorption making them suitable for use in crash barriers etc; • Suitable for low weight bearing structures; • Can be reprocessed by grinding and mixing again with cement	Relatively new product, producers will to need convince the construction industry of its suitability;
Train and tram rail beds.	• Longer life span compared with timber (20 year for rubber beds and 3–4 for wood or asphalt); • Environmentally safe; • Better flush with road; • Use chips/shreds as vibration damping layer beneath sub-ballast	• More expensive than traditional material; • Relatively new product, producers will need to convince industry of its suitability;
Outdoor sport surfaces (equestrian, hockey and soccer) or Artificial turf	• Skid resistant; • High impact resistance • Durable; • Highly resilient; • Easy maintenance; • Independent of irrigation;	
Play grounds and sports surfaces	• Smooth with consistent thickness; • High impact resistance; • Durable; • Will not crack easily; • Available in various colours;	
Asphalt and bitumen modification for road applications	• Increased durability • Surface resilience • Reduced maintenance; • Increased resistance to deformation and cracking; • More resistant to cracking at lower temperatures; • Aids in the reduction of road noise; • Substitutes virgin materials, like styrene-butadienestyrene • Significant environmental benefits documented with respect to global warming potential, acidification and cumulative energy demand.	• It is very sensitive to changes in conditions during mixing i.e. requires expert knowledge; • Difficult to apply in wet weather; • Not applicable when ambient or surface temperatures are less than 13º C; • Possible occupational health problems due to emissions; • It cannot be reprocessed like traditional asphalt.
Indoor safety Flooring	• Skid resistant; • High impact resistance; • Durable; • Available in various colours; • Easy maintenance;	• More expensive than conventional alternatives; • Colours may be limited; • Limited market.
Shipping container Liner	Possible use with other packaging problems;	More expensive than conventional alternatives;
Conveyer belts	Possible use as conveyer belt at supermarket stills ;	• More expensive than conventional alternatives; • Cannot be used where belt is subject to large stresses, since it may be prone to failure;

Application/Product	Benefits	Disadvantages
Footwear	• Water resistant; • Long life span; • By varying the thickness of the sole the use of the footwear can be changed;	Could be more expensive to manufacture than conventional product;
Carpet underlay	• Easy to use; • Recyclable; • Conserves natural resources	Limited industrial production.
Roof tiles	• Looks like traditional tile; • Durable (40 to 50 years warranty US and Canadian tiles); • Lighter; • Cheaper long term cost;	Limited industrial production.
Floor tiles	• Resilient; • Skid resistant; • High impact; • Easy maintenance; • Recyclable;	Limited industrial production.
Activated carbon (carbon black)	Preserves virgin material ;	• Very expensive process as it needs pyrolysis; • Very energy intensive; • Low grade activated carbon; • Still in the research stage;
Live stock mattresses	• Long life span; • Easy to disinfect; • Reusable; • In the long term it is cheaper than alternatives	• Could be more expensive to manufacture than conventional mattresses; • Market potential unknown;
TPE Thermoplastic Elastomers	Similar properties to typical elastomeric materials;	Very limited existing sites.
Pyrolysis	Reutilizes the sub products of pyrolysis (oil and gas);	• Limited capacity because of operational problems caused by tyres; • Very limited existing sites; • The sludge originating from the process contains metals and other wastes, which for the moment is deposited in abandoned mines, poses an environmental problem;
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Reference: Adapted from the Questor Centre (2005), Hylands & Shulman (2003) and Aliapur (2004.)

Table 4 - Recovery and disposal of waste pneumatic tyres: benefits, disadvantages, prevention and control

Conclusions

The state of the art of the ELT management in Europe and worldwide and the state of the art of the recycling and recovery possibilities are very wide and well knows. The most important added value of this deliverable is to study the different experiences and share these knowledges inside the TyRec4Life partnership.

The second important conclusion of this deliverable is that from 2011 also in Italy started the Producer Responsibility system for ELT. Therefore it becomes more and more important to have a well done management of the ELT flows and, according the European waste hierarchy, to increase the market demand of recycled rubber product starting mainly from asphalt rubber application.

As a matter of fact, such an application shows remarkable advantages:

- It is an industrial solution that ensures the recycling of important rubber volume;
- it gives important environmental improvement in comparison with other recycling/recovery options and mainly with abusive landfilling as well;
- it allows excellent technical performances (safety, acoustical,...);
- it ensures similar economics in the middle term and better economics in long term, considering also the maintenance costs.

Moreover, the recycling and recovering of ELTs is also a strategic issue in order to reach the 2015 European target on the End of Life Vehicles (85% by weight of reuse and recycling; 95% by weight of reuse and recovery), due to the fact that tyres represent around the 3% of the weight of a whole vehicle.

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