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An international comparative study of end-of-life vehicle (ELV) recycling systems

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Abstract End-of-life vehicles (ELV) have become a global concern as automobiles have become popular worldwide. An international workshop was held to gather data and to discuss 3R policies and ELV recycling systems, their background and present situation, outcomes of related policies and programs, the framework of recycling and waste management, and case studies on related topics in several countries and regions, as well as the essential points of the comparison. Legislative ELV recycling systems are established in the EU, Japan, Korea, and China, while in the US, ELV recycling is managed under existing laws on environmental protection. Since automobile shredding residue (ASR) has a high calorific value and ash content, and includes heavy metals as well as a mass of unclassified fine particles, recycling ASR is considered highly difficult. Countries with a legislative ELV system commonly set a target for recovery rates, with many aiming for more than 95 % recovery. In order to reach this target, higher efficiency in ASR recovery is needed, in addition to material recycling of collectable components and metals. Environmentally friendly design was considered necessary at the planning and manufacturing stages, and the development of recycling systems and techniques in line with these changes are required for sound ELV management.

Keywords End-of-life vehicle · ELV · Recycling · International comparison · Automobile shredder residue · ASR

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Introduction

End-of-life vehicles (ELV) have become a global concern as automobiles have become popular worldwide. Automobile ownership worldwide has been increasing at a higher rate than the global population and reached more than 1 billion units in 2010 [1]. This trend is especially notable in Asia and in Central and South America. Along with the number of owned automobiles, the generation of ELV has also increased.

Since ELVs consist of more than 70 % iron, these have been traditionally traded as a valuable secondary resource, and their recycling has been conducted autonomously based on market mechanisms. However, fluctuations in the price of steel scraps and the rise in the treatment cost of automobile shredding residues (ASR) have at times pulled down ELV prices. Thus, management of ELV recycling under a legislative framework is becoming increasingly important. Currently, countries and regions with legislation on ELV recycling are still limited, e.g., the EU, the EFTA, Japan, Korea, China, and Taiwan [2]. Particularly in countries and regions where automobile ownership is rapidly increasing, there is the urgency to develop a legal framework for ELV recycling. In addition to iron, base metals such as copper and zinc, as well as rare metals such as platinum and palladium, are used in the manufacture of automobiles. There is also a demand for the collection of valuable metals as secondary resources.

The treatment of ASR has also become a significant issue even in countries with ELV recycling legislation and systems. While ELV recycling targets are mandated under ELV recycling legislation, realizing these targets by collecting only metals is difficult and the recycling of ASR has become indispensable [3]. The recycling of ASR is becoming increasingly important in the total ELV recycling lately, since the types of materials in ASRs have become diversified due to the employment of lightweight materials to improve fuel efficiency, and the advancement of computerization of automobiles. The development of ASR recycling techniques is urgent, because treatment and recycling of ASR is difficult as it has high calorific value and high ash content, and also contains nonsegregable fine particles [4, 5]. Heavy metals and flame retardants with persistent organic pollutants (POPs), often remain in ASR and may induce unintentional generation of POPs during the thermal treatment processes. This is also the reason why recycling ASR is difficult [6].

This study aims to examine the characteristics and effectiveness of legislative systems for ELV recycling in several countries and regions. Moreover, this study also intends to discuss the future development of ELV recycling systems by reviewing the characteristics of ASR and existing techniques for the 3Rs (reduce, reuse, and recycle).

Study methods

A workshop entitled "International Workshop on 3R Strategy and ELV Recycling 2012" was held in Nagoya, Japan, from September 19-21, 2012. The purpose was to gather data on 3R policies and ELV recycling systems in the EU, the US, and Asian countries (China, Indonesia, Korea, Vietnam and Japan), and to summarize essential points of the comparison. Data gathered during the workshop included: the background and present situation of the 3R policy and the ELV recycling system, the framework of recycling and waste management, outcomes of related policies and programs, and case studies on related topics. The participants invited were policy makers or those who have relevant experience in waste management, researchers, and automobile manufacturers. Participants were from Belgium, Germany, Italy, the United States, Australia, China, Indonesia, Korea, Vietnam, and Japan.

Results and discussion

Global trend in automobile ownership and generation of ELV

Automobile ownership (including cars, buses and trucks, based on 2010 records) and the estimated generation of ELV are listed in Table 1. Automobile ownership worldwide exceeded 1 billion in 2010. The EU and the USA accounted for 50 % of this total number, each having 270 million and 240 million units, respectively. In newly industrialized countries such as China and India, the number of automobiles is rapidly growing. It was reported that automobile ownership in China has reached more than 100 million in 2012 [17]. Another report forecasted automobile ownership worldwide to reach 2.4 billion in 2050 [18]. Therefore, taking effective measures for ELV recycling/treatment is an urgent requirement throughout the world, especially in newly industrialized and developing countries.

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Table 1 Global and country/state estimates of automobile ownership and ELVs. Countries with automobile ownership of more than 10,000,000 units of and a positive calculated ELV in 2010

Country/state	Automobile ownership (units)[a]	Deregistered automobiles (units/year)[b]	Number of ELVs (units/year)[c]
European Union[d]	271,319,000	14,077,000	7,823,211
(Germany)	(45,261,188)	(2,570,137)	(500,193)
(Italy)	(41,649,877)	(1,835,293)	(1,610,137)
(France)	(37,744,000)	(2,002,669)	(1,583,283)
(England)	(35,478,652)	(1,810,571)	(1,157,438)
(Spain)	(27,750,000)	(996,718)	(839,637)
Russian Federation	41,224,913	300,000	Not available
USA	239,811,984	20,419,898	12,000,000
Canada	21,053,994	1,321,658	1,200,000
Brazil	32,100,000	1,058,064	1,000,000
Japan	75,361,876	4,080,000	2,960,000
China	78,020,000	6,000,000	3,506,000
Korea	17,941,356	849,280	684,000
Australia	15,352,487	600,311	500,000
Subtotal	792,185,610	57,921,599	29,673,211
Global total	1,016,763,420	15,805,275	40,176,051[e]

[a] Data from the Japan Automobile Manufacturers Association Inc. (2012) [7]. Values in () are not included in the subtotal

[b] Indicates (number of automobiles without owners in the previous year + number of new automobiles in the market this year) − number of automobiles without owners this year. However, the global total is a reference value since the estimated numbers of deregistered automobiles (increase in the number of automobiles with owners of the said year surpassed the number of automobiles for sale in the same year) in some countries were negative. The number of automobiles in Japan, where the estimated number of deregistered buses and trucks was negative, was from actual values in 2011 based on Yoshida and Hiratsuka [8]. For the same reason, data on China was based on Zhou and Dai [9]. Moreover, EU data was an estimated value of EU25 [10]

[c] The number of ELVs was summarized from data below. The subtotal does not include values in ( ). EU, Eurostat [11]; USA, Jody et al. [5]; Canada, Automotive Recyclers of Canada [12]; Brazil, Adcley Souza [13]; Japan, Yoshida and Hiratsuka [8]; China, Xiang and Ming [14]; Korea, Oh [15]; Australia: Environment Australia (2002) [16]

[d] EU + Liechtenstein, Norway

[e] The subtotal of ELVs was multiplied with the ratio between the global total number of owned automobiles and the subtotal of the number of owned automobiles in each country, excluding Russia

The generation of ELVs was estimated at 40 million, which accounts for 4 % of total automobile ownership. ELV is defined as the deregistered car that will undergo treatment/recycling through appropriate processes within the country. Data on ELV generation are cited from official reports. In EU member states, Japan, and Korea, reports on the number of ELVs are mandatory under their legislative ELV recycling systems, while the numbers in other countries are usually reported by the recycling industry which plays the main role in the ELV recycling processes. Meanwhile, the number of deregistered automobiles in Table 1 was calculated using statistical data. The number of deregistered automobiles was obtained by subtracting the number of owned automobiles at the end of a said year from the sum of newly sold automobiles in the same year and the number of owned automobiles at the end of the previous year. A comparison between these figures indicates that in general, there are more deregistered automobiles than ELVs. This is because deregistered automobiles include: used cars for export, unregistered cars used within private sites, or cars illegally dumped as waste.

Basically, the generation of ELVs depends on the number of deregistered automobiles, while the latter is related to the number of registration and the life duration of automobiles. In addition, the trend in the number of automobile registrations is influenced by the economic growth and the penetration level of automobiles in the market. One estimation of deregistered automobiles in countries with comparatively high automobile ownership rates indicated that in the EU, 14 million and 16.6 million cars were to be deregistered in 2010 and 2020, respectively (the number of car per capita: 502 cars/1,000 people) [10]. These values were calculated using the economic growth rate and the probability of the emergence of the deregistered automobiles based on the Weibull distribution function. It is presumed that in several countries, the difference between the estimates of deregistered automobiles and the number of ELVs may be due to the exportation of deregistered automobiles [19]. Yano estimated the ELV generation in Japan (the number of car per capita: 576 cars/1,000 people) by applying the life duration of automobiles to the Weibull distribution function [20]. The calculation revealed that the number of ELVs would slightly decrease from 4.2 million to 3.7 million in the 2000s and will reach 2.9 million in 2020. The trend and forecast on the automobile ownership in China (the number of car per capita: 47 cars/1,000 people) are shown in Table 2 [21]. In China, cases where deregistered automobiles were traded in the used car market, and ended up running on public streets are also reported. Moreover, dismantling by the car owners themselves is often seen in China. Therefore, it was assumed that the actual situation of ELV generation and the reported number of ELVs by recyclers are inconsistent [22]. Presently, the establishment of a legislative ELV recycling system is in progress in China, and it is estimated that ELV generation will reach 99.5 million in 2020 [14].

The discussion above revealed that the number of automobile ownership in the world would continue growing in the future, as well as the number of deregistered automobiles. However, it may be assumed that the rate of increase in the number of deregistered automobiles would vary among countries due to differences in the prevalence rates of automobiles. Also, the ratio between the numbers

Table 2 Forecast of Vehicles in China [21]

	Total number of vehicles (million)	Increase in number of vehicles (million)	Total number of ELVs (million)	ELV ratio to total number of vehicles (%)
2015	95.38	14.91	6.44	6.7
2017	112.72	16.91	7.78	6.9
2020	141.03	20.05	9.95	7.1

Based on China Automotive Technology and Research Center (CATARC)

of deregistered automobiles and ELVs would be unique to each country. For example, in Japan and the EU, where one out of every two persons owns an automobile, the increase in the number of deregistered automobiles would be relatively slight; while in countries like China where the automobile market is growing rapidly, the number of deregistered automobiles would also increase. Although the management of ELV is required in every country, it is notably important in countries and regions which have growing automobile markets.

ELV recycling flow

The recycling flow of ELVs turned out to be almost identical in many countries, regardless of the existence of a legislative management system. The general ELV recycling flow under legislative management systems in the EU and Japan are shown in Fig. 1. The process of ELV recycling starts with dismantling. At this point, components containing hazardous substances such as lead batteries, mechanical oils and refrigerant gases are collected first, and then recyclables and valuable materials for secondary use, including engines, tires and bumpers are collected. In the case of Japan, the collection of refrigerant gases and air bags are legally mandated [24]. In the US, voluntary collection of components containing mercury, such as switches, is operated during the dismantling stage [5]. In China, components collected at the dismantlers are very often re-sold or recycled as secondary products [14]. The weights of ELV after dismantling are reduced to 55–70 % of the original weights in the EU and Japan. An exhaustive collection of material is significant in order to reduce the amount of ASR and to avoid hazardous substance contamination in ASR.

Car hulks left after the dismantling process are put into shredders. The shredded materials are separated by air classifier, and ASR (Light) is taken out. Subsequently, irons and non-ferrous metals are separated by magnetic separators or non-ferrous metal collectors. The remnants of these processes are ASR (Heavy). The percentages of irons and non-ferrous metals in a vehicle mass are 36–70 % in the EU, and 50–55 % in Japan, respectively. The amounts of ASR (Light + Heavy) are reported to be 12–32 % in the EU, and 17 % in Japan.

In the EU, ASR is in many cases landfilled at the final landfill sites. It was a similar situation in Japan prior to the enactment of the Law for the Recycling of End-Of-Life Vehicles. However, after the enforcement of the said Law, which mandates the recycling of ASR, material separation of secondary resources, collection of slags by melting furnaces, and energy recovery have become more common. As a result, it is reported that 15–16 % of components and

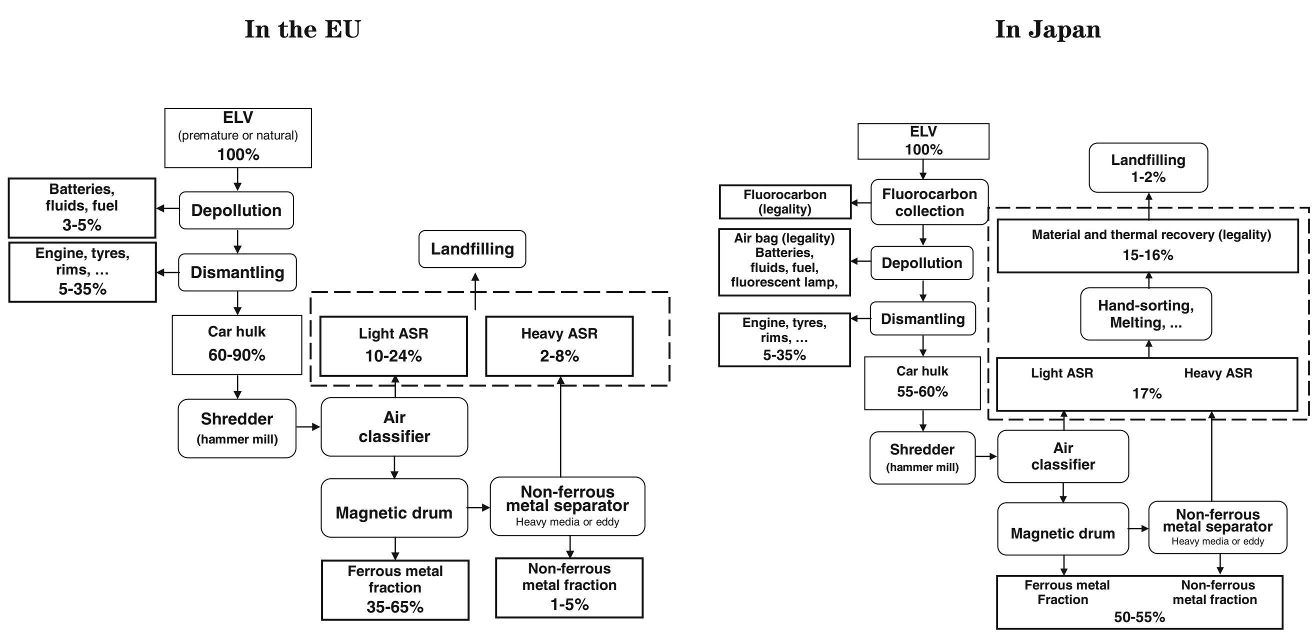


Fig. 1 Schematic diagram of the typical processing of an ELV. *Left* EU, Vermeulen et al. [23]. *Right* Japan, Yoshida and Hiratsuka [8]

materials are collected, and only 1–2 % of the total ELV mass are landfilled. In the EU, applicable techniques for the direct collection from ASR was studied in order to meet the target of 95 % reuse and recovery by 2015 [23, 25].

International comparison on ELV management

Table 3 shows the comparison of ELV management systems in several countries. The ELV management systems shown here are categorized into two parts. One is the direct management system based on legislation (the EU, Japan, Korea, and China in Table 3), and the other is the indirect management system based on market mechanisms and environmental regulations (the US in Table 3).

In the EU, the EU-Directive 2000/53/EC on ELVs was enacted in 2000 [26]. It aims to control the generation and disposal of wastes from automobiles and to enhance environment-consciousness among parties involved in ELV treatment, through the promotion of reuse, recycling and collection of ELVs and their components. The Directive is based on the subsidiary principle and the extended producer responsibility principle [27]. According to the subsidiary principle, EU member states must establish their national legislations on the ELV recycling system. The Directive also sets recycling targets for different phases. Member states are required to meet the targets, while car manufacturers and importers shoulder the expense of recycling under the extended producer responsibility. Targets that member states must meet for "reuse and recovery" and "reuse and recycling" rates are: 85 and 80 %, respectively, by 2006; and then 95 and 85 %, respectively, by 2015. The index of "reuse and recovery" includes energy recovery in addition to "reuse and recycling". Hence, in other words, the energy recovery is accepted up to 5 and 10 % for the 2006 and 2015 targets, respectively. Furthermore, the desirable rates of final disposal are less than 15 and 5 % for the 2006 and 2015 targets, respectively.

In Japan, the Law for the Recycling of End-Of-Life Vehicles was enforced in 2005 [24]. With the need to reduce ASR due to shortage of final disposal sites, as well as the prevention of illegal dumping and unsound treatment of ELV driven by fluctuations in the steel scrap market, the act intends to set down appropriate roles among related players to promote sound treatment and recycling of ELVs [28]. The act characteristically specifies components/materials to be recycled, stakeholders that will shoulder recycling costs, as well as the development of an information management system. Recycling targets are separately determined for airbags, refrigerant gas and ASR, and not for the whole ELV. Furthermore, an environmentally sound treatment of the fluorocarbons is required by law. The recycling rates for airbags and ASR from 2015 are 80 and 85 %, respectively. With regards to the recycling of ASR, thermal recovery is acceptable and no provision was set regarding its recovery rate. Car manufacturers and importers are responsible for the recycling of air bags and ASR, and the sound treatment of fluorocarbons; however, recycling fees are paid by buyers at the time of purchase, and these fees are deposited into the deposit management entity. In order to ensure proper implementation of fees deposited, an electronic management manifest system was developed to enable the confirmation of the actual progress of the ELV recycling at each stage of the process.

In Korea, the Act for Resource Recycling of Electrical and Electronic Equipment and Vehicles [30] was enforced in 2008. Prior to this act, the Korean government had been employing EPR (Extended Producer Responsibility) on its waste management policy. This act further enhanced the EPR policy, which evolved into the Integrated Product Policy through the introduction of the Eco-assurance System [31]. The Eco-assurance System requires both preventive and follow-up management: the former is to ensure environmentally friendly design and manufacture of products, while the latter is to conduct environmentally sound management of wastes [33]. Under this act, the responsibility for ELV recycling is placed on all the stakeholders involved, including manufacturers, importers, dismantlers, shredders, ASR recyclers and refrigerant gas processors, and the recycling rate is mandated [15]. The recycling rate is issued as prescribed by presidential decree. "The material recycling and energy recovery" target is set at a minimum of 85 % by 2014 (including energy recovery of less than 5 %), and at least 95 % after 2015 (including energy recovery of less than 10 %). When the ELV recycling cost exceeds the price of the ELV, the excess cost is shouldered by the manufacturers and importers. Also, the manufacturers and importers must submit information on recycling performance to the Korea Environment Corporation (KECO), and such data is then reported to the government, accordingly.

In China, the End-of-Life Vehicle Recycling Regulations enacted in 2001 established an ELV collection system with the purpose of preventing accidents caused by the use of refurbished or overage vehicles. For this purpose, management rules involved the restructuring of dismantlers and the improvement of their abilities. The reuse of the five major assemblies (i.e., engines, steering, transmissions, axles, and frames) was prohibited to prevent traffic accidents caused by the improper use of these components. In 2006, the Automotive Products Recycling Technology Policy was promulgated, under which the responsibilities of manufacturers and importers to promote ELV recycling were clarified, and substances used in car manufacturing that will be controlled and prohibited were stipulated in consideration of environmental protection. This technical

Table 3 A comparison of the ELV management methods in various countries and regions

	EU	Japan	Korea	China	US
ELV management system	Law Directive 2000/53/EC Of The European Parliament And Of The Council of 18 September 2000 on end-of life vehicles (enforced in 2000) [26]	Law Law for the Recycling of End-of-Life Vehicles (enforced in 2005) [24]	Law Act for Resource Recycling of Electrical/ Electronic Equipment and Vehicles (enforced in 2008) [30]	Law End-of-Life Vehicle Recycling Regulation (enforced in 2001) [34] Automotive Products Recycling Technology Policy (declared in February 2006) [35]	Related law [5] Resource Conservation Recovery Act Clean Air Act, etc.
Background of the management system	Measures for increasing ASR [27] Measures for abandoned automobiles Environmental measures of dismantling sites	Lack of final disposal sites [28] Illegal dumping of ASR [29] Effective use of resources [29]	Measures for ELVs [31] Effective use of resources Management of information on ELVs	Measures for illegal assembly [22] Effective use of resources Measures for recycling economy	Strict implementation of regulations [5] Environmental conservation measures associated with ELV recycling
Parties responsible for recycling costs	Automobile manufacturers and importers (if the recycling incurs cost), finally users	Users	Automobile manufacturers and importer (if the recycling incurs cost), finally users	No regulation (traded as a valuable secondary resource)	No regulation (traded as a valuable secondary resource)
Target automobile	M1, N1	All vehicles (including buses, trucks, etc.), with the exception of two-wheeled vehicles	M1, N1	M1, M2, M3, N1, N2, N3	No regulation
Recycle target	[26] Until 2006: Reuse + Recovery: 85 % Reuse + Recycle: 80 % Until 2015: Reuse + Recovery: 95 % Reuse + Recycle: 85 %	[24] Airbag: 85 % ASR: 70 % (from 2015 onwards) 50 % (2010 to 2014) 30 % (2005–2009)	[15] Until 2014: Material + energy recovery: 85 % (of which energy recovery rate is within 5 %) After 2015: Material + energy recovery: 95 % (of which energy recovery rate is within 10 %)	[35] Possibility of recycling: 2010: about 85 % (material recycling of 80 % or more) 2012: about 90 % (material recycling of 80 % or more) 2017: about 95 % (material recycling of 85 % or more)	[36] No specific goals (95 % of ELVs enter the recycling route, of which 80 % of the materials are recycled)
Information management	Issuance of Certificate of Destruction (CoD), monitoring of target values by the government	Electronic manifest system	Intensified collection of information on deregistration and recycling	Issuance of ELV collection certificate [34]	Information collection management by recycling industry groups
Characteristic of the system	Based on the subsidiarity principle and the principle of Extended Producer Responsibility [27] Regulation to prohibit inclusion of heavy metals (mercury, cadmium, hexavalent chromium, lead) Domestic laws are being enforced but the manner of operation varies with country.	Automobile manufacturers and importers take responsibility for the recycling No target for the recycle rate/ recovery rate regarding the total automobile weight. Thermal recovery is recognized in ASR recycling.	Based on the Extended Producer Responsibility (EPR) [32] System planning adjusted to fluctuations in ELV price is being done. Operated under the Eco-assurance system [32, 33]	In the End-of-Life Vehicle Recycling Regulation, ELV management is being done with the aim to prevent accidents resulting from illegal remodeling and use of aging automobiles. [21] The recycle of the 5 components (engine, steering, transmission, axle, and frame) is prohibited by the above mentioned law but the ban was partly lifted based on the Regulation of Remanufacturing of Pilot Automotive Parts (enforced in 2008) [14]	There is no regulative system that directly manages ELV on the national level [5] Under the Anti-Car Theft Act (1992), information on vehicles collected by recyclers is managed by the National Motor Vehicle Titling Information System. The Automotive Recycling Association of the ELV recycling industry operates an information website for related regulations to attain stricter compliance. [37]

M1, 4-wheeled vehicles with seating capacity of nine or less, including passenger vehicles; M2, seating capacity of nine or more, vehicle weight under 5,000 kg; M3, vehicle with seating capacity of nine or more, vehicle weight over 5,000 kg; N1, freight vehicle with maximum load capacity under 3,500 kg; N2, maximum load capacity of 3,500 kg or more, freight vehicle weight under 12,000 kg; N3, freight vehicle with maximum load capacity of 12,000 kg or more policy also sets the following recycling targets for ELV: about 85 % (or at least 80 % material recycling) by the year 2010; about 90 % (or at least 80 % material recycling) by the year 2012; and about 95 % (or at least 85 % material recycling) by the year 2017. The Management Regulations on ELV Collection and Recycling is scheduled to be released in the near future [21]. In 2008, the Regulations of Remanufacturing Pilot of Automotive Parts was issued with the aim of carrying out a trial program on the production of secondary products from used components including the five major assemblies. This effort contributed to improvement of the recycling rate during the dismantling stage [14].

In the US, ELV recycling operates autonomously based on the market mechanism. ELV recycling has been promoted by the Automotive Recyclers Association (ARA). Although there is no mandatory recycling target, the rate of material recycling was reported to reach 80 % [36]. More emphasis is placed on the promotion of environmentally sound management at the dismantling or recycling facilities under this system than in an integrated management system. In particular, dioxins, furans, polycyclic aromatic hydrocarbons (PAHs) and greenhouse gases require monitoring. It would also be considered important to take sound measures for the control of hexavalent chromium and mercury, as well as brominated flame retardants and phthalate compounds that require careful monitoring for their hazardousness [5]. The ELV recycling program is, therefore, the subject of strict monitoring under environmental laws. Among the relevant regulations are the Resource Conservation and Recovery Act (RCRA), the Clean Air Act (CAA), and the Clean Water Act (CWA). In addition to federal laws, state governments also impose their own regulations. Thus, ARA disseminates complementary information to ELV recyclers regarding the latest environmental regulations at the state level through an electronic database [37]. Currently in most states, ASR is classified as a non-hazardous waste and ends up in a landfill. However, its potential for environmental risk has become a growing concern [36]. For example, hazardous substances such as heavy metals and brominated flame retardants in landfilled ASR may pollute the groundwater.

Presently, one region and five countries have developed a legislative ELV recycling system, the EU and the European Free Trade Association (EFTA), Korea, Japan, China, and Taiwan. Russia, India, Mexico, Turkey, and Vietnam are making preparations for the introduction of such a legislative management system ([2] and data added by the authors). In Russia, although the law on recycling tax for imported cars was enacted in September 2012, this policy is also viewed as an act to protect their national automotive industry rather than to promote ELV recycling [38]. By contrast, countries that have no direct regulations on ELV management are the US, Canada, and Australia.

In most cases, attempts to introduce a mandatory ELV management system are intended to bring in the concept of EPR to ELV management, and to make clear the responsibility of stakeholders. The driving forces behind these efforts are the concern for the hazardous characteristics of ASR, the lack of final disposal sites and the corresponding rise in the treatment cost of ASR that would result to a high ASR recycling cost, consequently exceeding the price of ELV. In other words, a legislative system tries to ensure ELV recycling that is otherwise dismissed under the market mechanism. In a country that promotes ASR recycling under the market mechanism, ASR recycling cost is presently so low that it seems unlikely that the treatment and recycling costs in total would exceed the price of ELV. In Japan, the treatment cost of ASR is approximately over US$200 [39]. However, the environmental risks of ASR have reportedly come to be recognized in the US [36], which may increase ASR recycling costs in the future. In Canada, although no legislative ELV management systems have ever been established, it may be necessary to introduce a mandatory system to implement measures to prevent environmental pollution by lead batteries, refrigerant gases, switches containing mercury and mechanical oils, as well as the increase in operators with improper treatment facilities [40].

Countries with a legislative ELV system commonly set a target for recovery rates, with many aiming for more than 95 % recovery. In order to reach this target, higher efficiency in ASR recovery is needed, in addition to material recycling of collectable components and metals [23, 25]. It is notable that Japan has set a separate target for ASR recovery since the enactment of the ELV recycling law. This law requires mandatory ASR recycling and requires users to bear the responsibility for the cost.

Properties of ASR

The properties of ASR are reviewed from research literatures that are summarized in Table 4. Regarding metals/minerals, ASR contains high amount of inorganics and the amounts of Si, K and Ca are of percent levels. Fe and Cu, which make up the car body and the electrical components, are also present in small percentages. In addition, Cr, Ni, Pb and Zn contents in ASR are high. The Hg concentration was 0–3 mg/kg. Regarding elements, C content was the highest at 17.5–90 %, and this may have come from various polymers in ASR.

With regards to organic halogen compounds, the amount of PBDEs, or one of the brominated flame retardants, was high at 110,000–310,000 μg/kg. The amount of HBCD, another flame retardant used for car materials, was 990–5,700 μg/kg. Also, the amount of PCBs was highest at 78,510 μg/kg. With regards to PCBs, Low POP Content is

Table 4 Characterization of ASR

Item	Unit	ASR (range)	Reference
Heavy metal and mineral			
Ag	mg/kg	<0.26	[5]
Al	wt%	0.16–10	[6, 45, 50, 52, 53, 59, 60, 62, 66, 86, 96, 100]
As	mg/kg	0–63	[3, 5, 6, 48, 55, 56, 62, 67, 81, 83, 84, 102, 104]
Ba	mg/kg	28–38.9	[5]
Ca	wt%	1.49–13	[6, 53, 54, 62]
Cd	mg/kg	0–200	[3, 5, 6, 41, 42, 45, 48, 55, 56, 62, 66, 67, 72, 81, 83, 84, 86, 102, 104]
Cr (total)	mg/kg	0.2–11,000	[3, 5, 41, 42, 45, 48, 50, 55, 56, 59, 62, 66, 67, 72, 81, 83, 84, 86, 102, 104]
Cr VI	mg/kg	<0.05–4.6	[3, 6, 62, 67, 84]
Cu	mg/kg	3.543–60,000	[3, 5, 6, 41, 42, 45, 47, 48, 50, 53, 56, 57, 59, 62, 66, 67, 72, 81, 83, 84, 86, 102, 104]
Fe	mg/kg	1,400–697,300	[6, 45, 47, 50, 53, 59, 60, 62, 66, 72, 86, 100]
Hg	mg/kg	0–3	[3, 5, 6, 42, 48, 52, 55, 62, 67, 81, 83, 84, 87, 104]
K	wt%	0.1–0.6	[6, 62]
Mn	mg/kg	700–1,100	[48, 50, 66]
Na	wt%	0.8–5.7	[6, 62]
Ni	mg/kg	34.8–4,000	[3, 41, 42, 45, 48, 50, 52, 56, 59, 62, 66, 67, 72, 81, 83, 84]
Pb	mg/kg	0–53,000	[3, 5, 6, 41, 42, 45, 47, 48, 50, 53, 55–57, 59, 62, 66, 67, 72, 81–84, 86, 87, 102, 104]
Sb	wt%	0.04	[6]
Se	mg/kg	<0.01–1.3	[3, 5, 6, 48, 67, 84]
Si	wt%	2.1–12.9	[6, 72]
Sn	mg/kg	54.6–169	[3]
Ti	wt%	0.9	[72]
Zn	mg/kg	0–33,100	[3, 5, 42, 45, 47, 50, 56, 57, 59, 62, 66, 67, 72, 81–84, 86, 87, 100]
Element			
C	wt%	17.5–90	[5, 43–46, 55, 57, 62, 67, 72, 78–82, 85, 95, 99, 103]
H	wt%	1.3–12	[5, 41–46, 55, 57, 62, 67, 72, 78–82, 85, 95, 99, 103]
N	wt%	0.5–4.5	[5, 41–46, 55, 57, 62, 72, 78–80, 82, 85, 95, 99, 103]
O	wt%	0–30	[5, 41–44, 46, 55, 62, 72, 79, 80, 85]
F	wt%	0.0–1.5	[62, 67, 72]
Cl	wt%	0–5	[5, 6, 42, 44, 45, 50, 51, 53, 54, 56, 57, 60–62, 67, 72, 79, 80, 82, 85, 103]
Br	mg/kg	300	[6]
S	wt%	0–1	[3, 6, 41–45, 48, 51, 53–58, 60–62, 67, 72, 78, 79, 81, 82, 95, 99]
P	wt%	0.7	[72]
Dioxin-related compounds and brominated flame retardants			
PCDD, PCDF	ng-TEQ/g	0.00252–0.38	[3, 6, 29, 67, 81]
D.L.-PCBs	ng-TEQ/g	0.014–0.027	[6, 29]
PCDDs/DFs + D.L.-PCBs	ng-TEQ/g	0.027	[6]
PCBs (total)	μg/kg	1.7–78,510	[3, 6, 29, 48, 62, 67, 81]
PCN	μg/kg	13–47	[29]
PBDDs/DFs	μg/kg	10–120	[6, 29]
MoBrPCDDs/DFs	μg/kg	ND-15	[6, 29]
Brominated diphenyl ethers	μg/kg	310,000	[6]
PBDEs	μg/kg	110,000–310,000	[29]
Tetrabromobisphenol A	μg/kg	220–15,000	[6, 29]
HBCD	μg/kg	990–5,700	[29]
TBP	μg/kg	68–180	[29]

Table 4 continued

Item	Unit	ASR (range)	Reference
Composition			
Fabric, fibers	wt%	1.61–42	[42, 55, 65, 67, 68, 74, 77, 99]
Plastic	wt%	5.3–70	[6, 41, 42, 49, 50, 52, 55, 63–65, 67–77, 85–94, 96–101]
Rubber	wt%	1.42–55	[5, 6, 41, 42, 49, 50, 52, 55, 63–65, 67–75, 77, 86–94, 96–101]
Textile	wt %	3–36.1	[6, 50, 52, 63–65]
Metals	wt%	0.3–26.9	[5, 6, 41, 49, 50, 52, 55, 63, 64, 67, 69–71, 73, 75, 86–94, 97, 98]
Paper	wt%	0.27–0.94	[6, 63, 100]
Polyurethane foam	wt%	0.26–43	[5, 6, 41, 50, 52, 55, 65, 67–69, 73, 94, 97, 98]
Wood	wt%	0.01–10.1	[6, 52, 63–65, 98–100]
Glass	wt%	0–40	[6, 49, 55, 67, 68, 71, 72, 74, 75, 77, 85, 96, 98, 100, 101]
Wire	wt%	0.4–5	[6, 50, 52, 63, 65, 67–69, 71–73, 77, 94, 97–100]

set at 50 ppm under the Basel Convention on the Control of Transboundary Movements of Hazardous Wastes and their Disposal [105]. ASR may be possibly treated in an environmentally sound manner as a waste contaminated with PCBs.

The direction of ASR management

Although recycling of ASR is important to the overall flow of ELV recycling, it is considered very difficult since ASR has a high calorific value and ash content, and also contains heavy metals and fine particles that are hard to separate [4], [5]. In this regard, ASR recycling in the EU has taken two directions: (1) intensive dismantling involving the separation and collection of materials at the dismantling stage; and (2) post-shredder treatments (PSTs) involving the collection of materials from ASR after the shredding stage. Intensive dismantling would reduce the generation of ASR as well as its hazardousness. Kohlmeyer [106] summarized the two systems of intensive dismantling and PSTs for different types of materials in Fig. 2. She also pointed out that the computerization of vehicles would be an issue to tackle in the near future with regards to improving ASR recycling. With intensive dismantling, plastics and glass undergo material recycling processes, while in the PSTs, plastics are used in thermal recovery, and glass ends up in final disposal sites as a backfilling material. Regarding the metals in the Shredder Light Fraction (SLF), their separation before shredding would take place during intensive dismantling, while in PSTs, they are separated from the SLF. According to Vermeulen et al. [107], although intensive dismantling would be effective in protecting the environment, its economic efficiency is unreliable due to the rise in labor cost and the drop in the price of collectable materials, hence the application of PSTs is necessary to meet the EU regulation.

In China, although the reuse of the five major components had been traditionally prohibited for safety reasons,

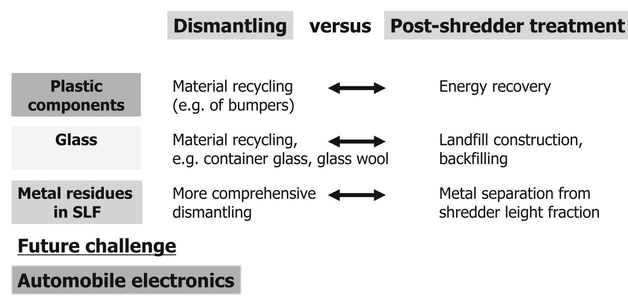


Fig. 2 Points of Discussion for the Advancement of ELV recycling [106]

collection and recycling (or rebuilding) of these components as secondary products are recently being attempted [14]. Also, advancement of mechanization and increasing the collection efficiency at the dismantling stage can be seen [108]. However, taking into account the rapid increase in ELV generation and the rise in labor cost in the future, it may be necessary to develop a strategy for a mechanized shredding process and for the management of ASR [21, 22].

In Japan, the thermal recovery of ASR is commonly practiced, and the total recovery rate is approximately 99 % [8]. While this is due to a recycling system that incorporates cost incentives and promotes transparency of information, regulation permits the thermal recycling of ASR mixed with other wastes. Because the treatment cost is shouldered by users, high treatment performance is ensured and this is thought to be a main contributory factor to the improvement of facilities for the thermal recovery of mixed ASR in Japan.

In the design of automobiles, greater fuel efficiency and improved running performance are aimed for with the reduction of body weight and the computerization of the control systems. Also, development of electric and hybrid cars are taking place at a rapid pace, with the aim of breaking dependency on fossil fuels. Such changes in the material composition of vehicles have not only resulted in better quality cars, but also in the increased use of plastic materials in vehicles. The use of rare metals and hazardous substances for computer related components have further made ASR recycling difficult. Kohlmeyer [106] summarized the supply risks and countermeasures concerning the critical raw materials used in electric cars in Table 5. Kohlmeyer warned that in 2030 demands for the production of dysprosium, a rare earth compound, would become six times higher, and may bring about a significant environmental impact. She also pointed out that the amount of copper that will be used per vehicle would increase from 25 to 75 kg, and that gold, silver and palladium would be in short supply despite the increased demand. In order to overcome these challenges, she suggested the following mid- and long-term measures as efficient and important. That is, to include electro-mobility as a sustainable means of transport, to develop a motor that does not rely on permanent magnets, to develop a more environmentally friendly method of mining essential metals, and to promote recycling. She explained that research in these areas is in progress in Germany.

Trends and effectiveness of the treatment of ASR

In countries with legislative ELV recycling systems that mandate a target recycling rate of 95 %, ASR treatment is an important process to achieve this. Table 6 shows ASR recycling techniques in Japan [109]. In Japan, the recycling rate of ASR is directly stipulated, and a number of ASR recycling techniques were put into practical use in conformity with the enactment of the Law for the Recycling of End-of-Life Vehicles. The act also permits thermal recovery as a recycling method with no regulation as to the maximum rate of thermal recovery. Hence, a large number of recycling methods that are in use involve thermal recovery, which aims for the collection and utilization of metals and slags.

Table 7 shows the techniques for ASR in the EU [23]. Passarini and Santini [110] has conducted analysis based on the Italian ELVs recycling campaign. They pointed out that, in order to achieve the EU target of 95 % recycling rate by the year 2015, additional recycling of 5–10 % based on ELV mass would be necessary. This would require the recycling of ASR that presently is mostly landfilled in the final disposal sites. Since the EU has set the rate of energy recovery to be within 10 % for its 2015 target, the recycling of ASR must be conducted through other ways than energy recovery. Thus, methods to collect the remaining metals in ASR, and techniques to collect separately various plastics for material recycling are being introduced. Regarding the recycling of plastics in ASR, feedstock recycling, pyrolysis, and gasification are being developed. Needless to say, direct thermal recovery techniques are also used for plastics, and are incinerated with other wastes or used as fuel in the non-ferrous refining industry. In the EU, Directive 2000/76/EC for the incineration of waste prescribes that when the chlorine content in the waste exceeds 4 wt%, the incineration temperature must be kept at

Table 5 Critical raw materials for electric vehicles [106]

Outlook on supply risks 2030	
Rare earths	Dysprosium demand 2030 for E-vehicles: 6-time global production
	High environmental impact
Copper	Up from 25 to 70 kg copper per vehicle
Precious metals	Several grams of silver, 100 mg gold and palladium
	But: Less platinum/palladium, if no more catalysator
Lithium, cobalt	Batteries: LFP: Li, NMC: Li + Co
Gallium, germanium, indium	Increasing competing applications (LED, photovoltaics)
	Gallium demand 2030: 1.4-times of global production
Challenges for action	
Include electro-mobility in sustainable transportation concept	
Resource efficiency: electric motors with little or no permanent magnets	
Promotion of more environmentally sound mining of critical metals	
Recycling: effective and important in the medium term.	
Research for recycling in Germany	
→ Batteries: e.g. LithoRec and LiBRi → Electric motors: MORE—Recycling of motors	

Table 6 ASR recycling technology in Japan [109]

Type of technology	Summary
① Alternative fuel + material recovery (7 facilities)	Utilization of existing facilities of material manufacturing industries such as non-ferrous metal refineries; the use of combustible component parts in ASR as alternative fuel, and recovery of metals like copper
② Thermal disposal + thermal recovery + material recovery (6 facilities)	Thermal recovery in the form of electricity or steam from continuous boilers operated by thermal disposal; recovery of metal resources and slag by treatment of the incinerated ash in melting furnaces
③ Gasification + gas utilization + material recovery (5 facilities)	Production of readily available fuel gas after modifying and refining gas generated from gasification of ASR; regarding the residues, either to utilize it as carbon material for industrial purpose or melt it and recover the metal resource and slag
④ Gasification + thermal recovery + material recovery (8 facilities)	Thermal recovery/electricity generation in continuous secondary combustion furnaces/boilers after gasification of ASR; regarding residues, these are melted to recover metal resource and slag
⑤ Separation of materials + alternative fuel (7 facilities)	In addition to various separation processes, technology to recover a specific single material

Table 7 ASR recycling technologies in EU

Secondary recovery of ASR
Physical and mechanical upgrading of ASR: air classification, magnetic separation, eddy current separation, screening, screening, optical sorting, manual sorting, drying, float/sink separation, froth flotation, thermo-mechanical sorting, wet grinding, hydrocyclone, static, hydrodynamic separation tanks, heavy media separation
Advanced secondary recovery of ASR: upgrading to fuel, Incorporation into manufactured products
Direct ASR-to-energy applications
Co-incineration with other waste streams: grate furnace, fluidized bed combustor, rotary kiln, cement kiln
The use of ASR as fuel in metallurgical processes: blast furnace, pyro-metallurgical non-ferrous metal production processes
Thermo-chemical treatment of ASR
ASR as feedstock for the thermo-chemical treatment
ASR pyrolysis
ASR gasification

Based on Vermeulen et al. [23]

1,100 °C for more than 2 s to decompose the hazardous organic chlorine substances. Techniques on the dechlorination of ASR are being developed to meet this regulation [23].

Since ASR contains various substances, it is important to consider the environmental impact of POPs in ASR or those that are unintentionally produced during ASR treatment. Specifically, the control of POPs contained in the residues is the main point of consideration in ASR management. Osada et al. [6] carried out a test of melting ASR by using a shaft-type direct melting furnace to determine the behavior of BFRs and PBDD/DFs and the distribution of heavy metals in the slag and fly ash. Table 8 shows the concentrations of dioxin-related compounds and BFRs in a full-scale ASR melting plant. Exhaust gas sampled at the outlets of the combustion chamber and of the gas cooler were found to contain small amounts of BFRs and dioxin-related compounds. The exhaust gas sampled at the outlet of the catalytic reactor contained 0.15 ng/m^3 N of PCDD/DFs, 0.20 ng/m^3 N of PBDD/DFs, and 28 ng/m^3 N of TBBPA. The TEQ value derived from PCDDs/DFs and dioxin-like PCBs detected in the final emissions was 0.0014 ng TEQ/m^3 N. Neither MoBrPCDD/DFs nor PBDEs were detected in the exhaust gas sampled at the outlet of the catalytic reactor. The slag and metals discharged from the melting furnace contained few dioxin-related compounds or BFRs. However, concentrations of PBDD/DFs were 30 ng/g, 0.2 ng/m^3 N and 0.26 ng/g in the ASR, the final gas emission and the fly ash, respectively. This was equivalent to a total release of 0.014 ng/g of ASR (a total reduction of 99.9 %) with 79 % of the emission released as fly ash. No PBDD/DFs were detected in the slag

Table 8 Behavior of BFRs and PBDD/DFs during ASR treatment [6]

	ASR (ng/g)	Slag (ng/g)	Metals (ng/g)	Fly ash (ng/g)	Exhaust gas (conversion for O_2 at 12 %)		
					Combustion chamber (ng/m^3N)	Gas cooler (ng/m^3N)	Catalytic reactor (ng/m^3N)
PCDDs/DFs[a]	0.97 (0.0043)	0.27 (0.00086)	1.1 (0.0038)	99 (1.6)	0.28 (0.0016)	–	0.15 (0.0014)
Co-PCBs	30 (0.023)	0.027 (0.00023)	0.03 (0.00019)	4.6 (0.070)	0.17 (0.000019)	–	0.16 (0.000026)
PCDDs/DFs + Co-PCBs	(0.027)	(0.0011)	(0.0040)	(1.7)	(0.0017)	–	(0.0014)
PBDDs/DFs[b]	30	N.D.	N.D.	0.26	0.12	N.D. (0.09)[c]	0.2
MoBrPCDDs/DFs[d]	N.D.	N.D.	0.03	44	N.D.	–	N.D.
Brominated diphenyl ethers[e]	310,000	0.1	0.2	2.8	2	24	N.D.
Tetrabromobisphenol A	15,000	0.07	0.05	0.29	14	13	28
PCBs[f]	270	0.091	0.15	22	1.5	–	2.6

The values indicated in () are WHO-TEF (1998) conversion values, the units are ng-TEQ/g or ng-TEQ/m^3N

– not analyzed

[a] 4–8 chlorinated

[b] 4–8 brominated

[c] Including those lower than the lower limit of determination and those higher than the detection limits

[d] 3–7 chlorinated

[e] 1–10 brominated

[f] 1–10 chlorinated

or metals. The total amount of PBDEs released was 170 ng/g of ASR, which means that 99.9999 % of the input amount was decomposed, with 71 % of the total released as fly ash. Based on these results, it may be concluded that the DMS method is effective for the decomposition of BFRs, such as PBDEs and TBBPA, as well as of PBDD/DFs and PCBs.

Comparative life cycle assessment (LCA) of ASR recycling methods

For the improvement of the ELV recycling rate, it is important to apply appropriate techniques in ASR recycling. This is commonly recognized in many countries and regions [15, 107, 110]. Although techniques for the final disposal, energy recovery, and resources collection are being implemented in ASR recycling, it is also important to apply one that has the least environmental impact.

Ciacci et al. [88] conducted a Life Cycle Assessment (LCA) of five scenarios of ASR treatment using Eco-indicator'99. Eco-indicator'99 is an integrated environmental impact assessment model developed in the Netherlands, which enables single scoring at the endpoint. In the study, scenario 1 puts the ASR generated after the shredding process in the final disposal; scenario 2 collects nonferrous metals from the ASR and puts the residues into final disposal; scenario 3 incinerates the residues described in scenario 2 along with other municipal solid wastes (MSW) for thermal recovery. These three ASR treatment methods are actually in practice in Italy. Scenario 4 separates plastics according to types from the residues described in scenario 2, using them as recycled materials, and puts the remaining residues in the incinerator together with other MSW in the same plant as in scenario 2. Scenario 5 gasifies the ASR described in scenario 2 to produce synthetic gas, and then converts the synthetic gas to methanol. Scenarios 4 and 5 are Post Shredder Technologies (PSTs) that are still being developed, and currently there are no plants in Italy where they are being carried out.

LCA results are shown in Fig. 3. In Eco-indicator'99, environmental impacts at the endpoint are first integrated into the three indicators, and weighted scores are then evaluated to estimate the Damage score. The three indicators are: Disability Adjusted Life Year (DALY), the potentially disappeared fraction of plant and species (PDF, m^2 year), and the resources (the additional energy necessary for the mining of resources, MJ surplus). The Damage score for scenario 1 was estimated to be the worst of all the scenarios. The DALY score for scenario 1 was high, which may have been due to the carcinogenetic risk of the landfilled plastics at the final disposal. For scenario 2, risk on human health was expected to be the same as in scenario 1,

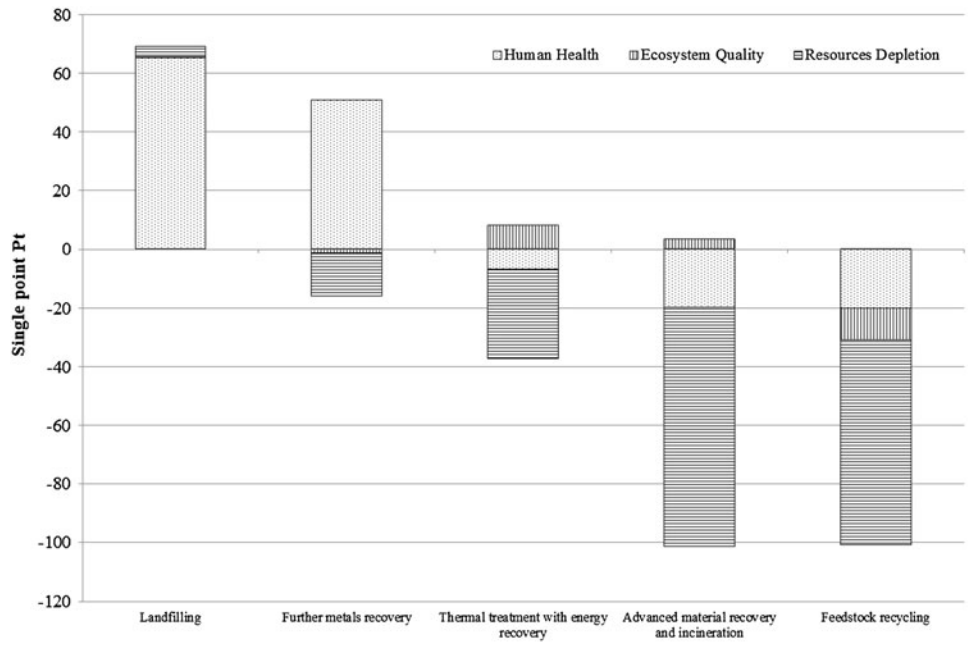


Fig. 3 *Bar* chart showing total damage scores using the Eco-indicator'99 method at each end point [88]

while the non-ferrous metals collection process contributed to improving the resources score. The PDF score was estimated to be highest for scenario 3, presumed to be due to the impact of the effluent gas emission from incineration. In scenarios 4 and 5, the impact on resource consumption was largely avoided by the collection of plastics. In scenarios with non-ferrous metals collection, resource scores prevailed over the other scenarios even though mining of non-ferrous metals require large amount of energy, indicating the significance of the non-ferrous metals collection process.

Furthermore, the five scenarios were compared to the European targets for the year 2015 under Directive 2000/53/EC on ELV. It was thought that a more than 85 % "reuse and recycling" rate would be achievable by scenarios 4 (86.9 %) and 5 (85.8 %), and a more than 95 % "reuse and recovery" rate would be achievable by scenarios 3 (96.5 %), 4 (97.6 %), and 5 (96.4 %).

Vermeulen et al. [111] conducted a sustainability assessment on four ASR treatment scenarios using seven sustainability indicators: energy intensity, material intensity, water consumption, land use, global warming, human toxicity, and treatment cost. The four ASR treatment scenarios were: "landfill", "recycling and landfill", "energy recovery and landfill", and "recycling, energy recovery and landfill". The recycling method in this study included the collection of iron, non-ferrous metals, and plastics separated according to material. Short (100 years) and long (60,000 years) term assessments were carried out. The impact scores of evaluation categories for each scenario using landfill as a baseline are as shown in Fig. 4. Damage scores were then calculated using these impact scores. Comparison of environmental scores in each scenario revealed that "landfill" scored the highest, followed by "energy recovery and landfill", "recycling and landfill," and "recycling, energy recovery and landfill", in decreasing order. It was estimated that the recycling combined with energy recovery would satisfy the European Targets of 85 % "reuse and recycling" rate and 95 % "reuse and recovery" rate at 88.4 and 98.5 % for the former and the latter, respectively. These results on LCA all indicate that promoting material collection and energy recovery from the residues would minimize the total environmental impact of ASR recycling.

Issues on current recycling systems

The following issues regarding ELV management in Korea have been pointed out [15]. Currently, it is considered difficult to meet a 95 % target rate after 2015 because of the undefined takers of responsibility for the achievement of the target, inadequate recyclers who are incapable of carrying out sound recycling, and the improper treatment of ASR and refrigerants (CFCs) that commonly take place. Under the Korean ELV recycling system, recyclers assume the responsibility of carrying out recycling if the ELV is economically valuable. On the contrary, manufacturers assume such responsibility if the recycling incurs cost. This two-sided characteristic of the system makes it unclear whose responsibility it is for achieving the target. In addition, less valued or costly materials are likely to be avoided during the dismantling process, since those components that are of higher value are preferentially separated. This tendency ends up to a lower recycling rate.

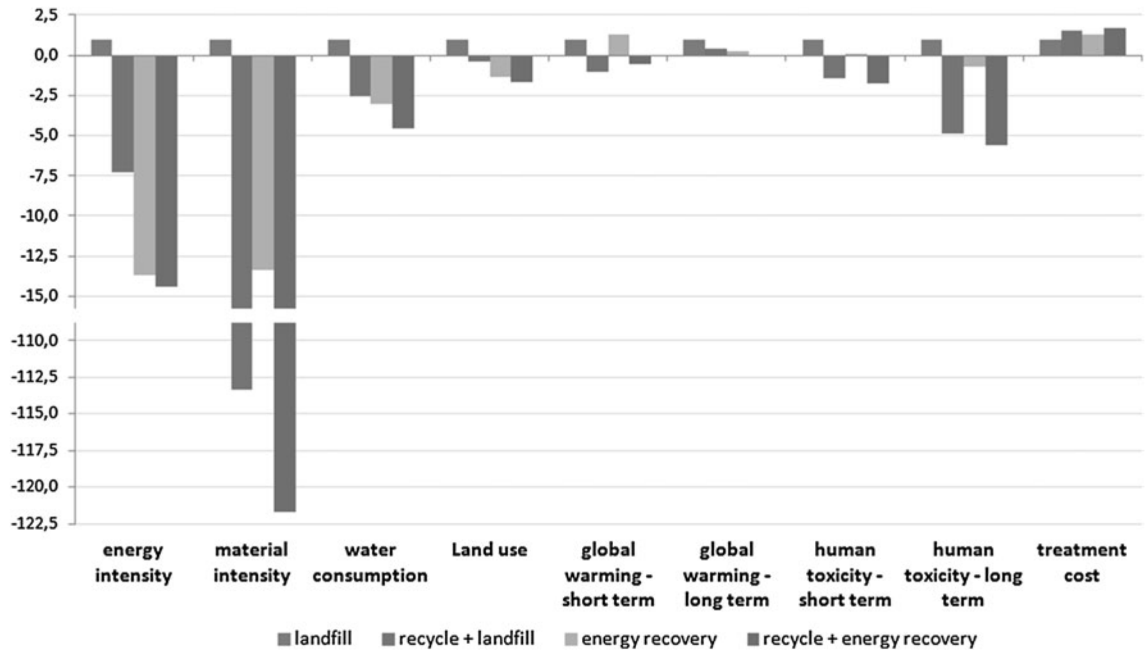


Fig. 4 Sustainability assessment of ASR treatment strategies, graphically presented with landfill set at 1 (100 %) [111]

Table 9 Reforming the recycling system to achieve a recycling rate of 95 % by 2015 [15]

Present	Near Future
Dispersion of responsibility	Centralization of responsibility (car maker/importer)
Small car recycling company	Reinforcement of criterion of ELV recycling company for improvement of facilities
No registration company for ASR recycling	Encouraging registration by clearing the payer
No registration company for recycling and treatment of refrigerant gases	Encouraging registration by clearing the payer and role of each body (collection by ELV dismantling Co.,) responsibility of treatment by car maker

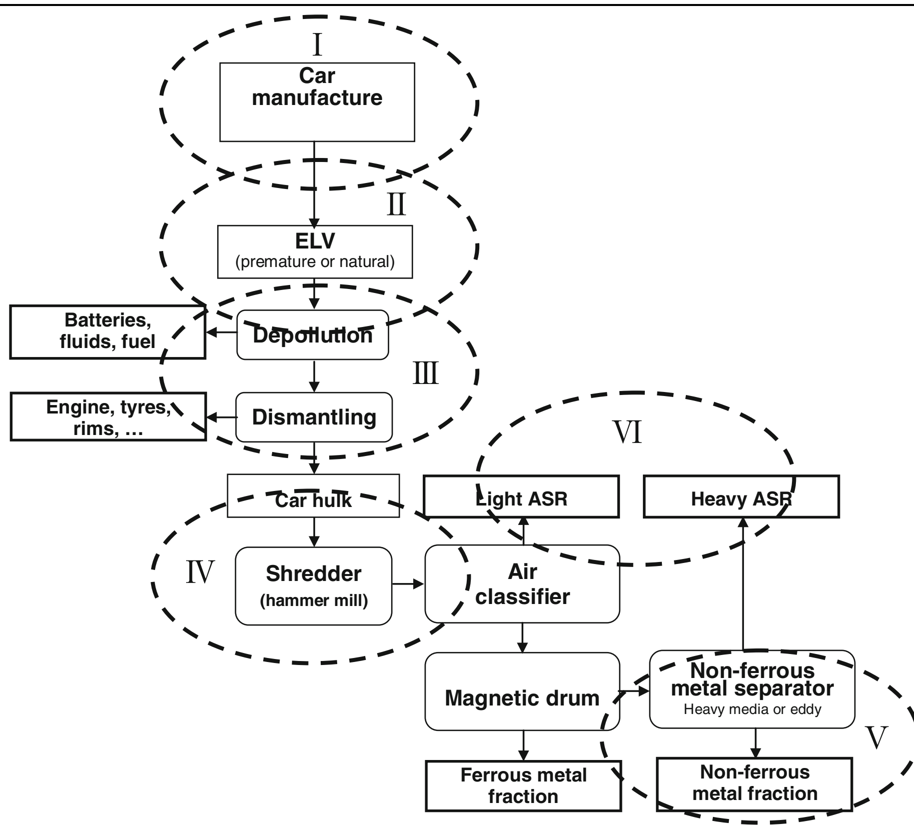
Moreover, it is assumed that CFCs are illegally discharged in the air due to the absence of sound treatment facilities. Sound recycling would be difficult for small recyclers, since the collection cost of ELV is expensive. Besides, the cost of recycling would be expensive if it is entrusted to a company that adheres to environmental criteria. The Korean government recognizes that it is necessary to take various measures to achieve the 2015 target (Table 9), aiming at integrating the responsibility for the ELV recycling system, and at clearly defining the roles of the related stakeholders. Those involved in ELV recycling in other countries and regions should study Korea's experience on how it conducted a sound analysis and improvement of its plans.

In China, several problems on ELV recycling are reported. Cases reported are: ELVs ending up in the used car market and are being used illegally; improper recycling processes that are causing serious environmental pollution at the facilities; and illegal extension of the life time of a vehicle without permission; and illegal remanufacturing. Such cases were pointed out to occur in the absence of a comprehensive management system [21].

In Japan, even though the mandatory target under the Law for the Recycling of End-of-Life Vehicles is already

Table 10 Challenges for ELV management and direction of systems/technologies

Stage	Challenges	Direction of systems/technologies
Stage I	Prevention of hazardous substances	1. Restriction of the use of hazardous substances, and the development of alternative materials
Designing/manufacturing of automobile	Sufficient dismantling information	2. Labeling of components for identification
	Promotion in recycling components/materials	3. Shift to materials that are highly recyclable
		4. Consideration of environmental impact of increasing electronic components and reducing vehicle weight
Stage II	Reliable collection of scrap cars	1. Integration and centralization of the management of scrap cars
Collection of ELV	Prevention of illegal dumping	2. Utilization of the electronic information system
	Prevention of illegal use	3. Clarification of division roles among stakeholders
		4. Providing the public with information on the automobile recycling system
Stage III	Promotion of component reuse	1. Develop the market for components for reuse
Dismantling	Promotion of component/material recycling	2. Stricter system for collection of hazardous substances and appropriate treatment
	Proper treatment of hazardous substances	3. Modernization and automation of dismantling
	Maintenance of a safe working environment during dismantling	4. Fulfillment of related regulations and their stricter enforcement
	Maintenance of a sound dismantling environment	5. Modernization of the dismantling industry and thorough registration system
	Prevention of sharp rise in the cost	
Stage IV	Keeping treatment capacity	1. Stabilization of the scrap market and its cooperation with the system
Shredding	Avoidance of geographic skewness	
Stage V	Intensive separation of materials	1. Automation of the separation labor
Post-shredding 1	Prevention of sharp increase in costs	2. Development of separation techniques
	Maintenance of separation working environment	3. Clarification of parties responsible for the cost of handling and ensuring transparency of information on the treatment
Stage VI	Promotion of thermal recovery	1. Development of the thermal recovery technology
Post-shredding 2	Prevention of secondary pollution	2. Clarification of parties responsible for the cost handling
		3. Conducting of environment monitoring



attained, some issues were pointed out [112]. Firstly, a management system for distinguishing between a used car and an ELV would be necessary in order to ensure proper delivery of ELV from the owner to the recycler, and to enable timely measures against illegal dumping or treatment. It would also be desirable to promote the reuse of components without compromising car safety. In addition, it would be necessary to come up with flexible measures on the ELV recycling system that can always efficiently function and address shifts in the car structure, components and the material composition along with the emergence of new models such as hybrid cars.

Direction of ELV management

In many countries and regions, the establishment of legislative ELV recycling systems has brought about progress in the management of ELV. Yet a host of challenges must still be tackled to realize better operation of the systems or to achieve the mandatory targets. Table 10 summarized the current issues of ELV recycling systems in the countries and regions with legislation on ELV recycling. Issues at each stage in the ELV recycling process were shown. The table also shows the direction towards which ELV management systems and techniques should be geared in the future.

In ELV recycling, enhancing the capability and efficiency of dismantling and ASR treatment is essential. Hence, it is of great importance to consider the environmentally friendliness of automobiles during the designing and manufacturing stages. While it goes without saying that the use of hazardous substances must be avoided at the designing stage, labeling and sharing information on dismantling among related role players are necessary in order to ensure the accuracy and speed during the manual processes at the dismantling stage. Regarding the recent advances of automobiles, e.g. the computerization or the reduction in body weight for safer and environmentally friendly automobiles, it is necessary to forecast the outcome at the ELV stage and to incorporate requirements from the environmental perspective at the designing stage.

During the dismantling stage, the concept of the 3Rs, the waste hierarchy in a Sound Material-Cycle Society, should be a prerequisite. Detaching reusable components and the expansion of the market for second hand products is desirable, provided that the safe and proper functioning of second hand products can be assured. Securing the health and safety of the working environment in dismantling facilities is also necessary, which may require more effort from the industry to modernize in order to improve the compliance level. The management of the 3Rs, as well as the protection of health and safety in the work environment during the dismantling stage could gain higher efficiency and transparency by the implementation of an information management system.

In the shredding and ASR treatment stage, the potential hazardousness of ASR can cause recycling/treatment cost to rise sharply. In order to define clearly the responsibility for the recycling/treatment cost, and to prevent illegal handling, securing transparency regarding cost information is necessary. It is also necessary to view ASR as a valuable resource. Since ASR contains various depleted resources, the development of technologies to extract these resources from ASR is expected.

Conclusion

We have compiled the data on ELV recycling systems of the world and examined the similarities and differences among those systems. In this section, we would like to state some of the key points in our study. The following four points require in-depth discussion: (1) how to address thermal recovery, (2) insights by LCA, (3) how to handle ASR, and (4) importance of DfE. Conclusions for points (3) and (4) are provided in this section. However, as for issues (1) and (2), we only describe the result and discussion as our study still cannot draw a clear conclusion. We will make them clear in our future study.

1. Expected increase in ELV with the growing car ownership worldwide and importance of promoting ELV recycling

Under the current situation where automobile ownership reached 1 billion units in 2010 and is still growing, ELV management is of importance in terms of resource conservation, waste management, and traffic safety that involves human lives. The automobile is relatively expensive among household goods, and its life duration is difficult to determine. The use of ELV must be strictly avoided to maintain traffic safety. Therefore, the coordination and cooperation between the automobile registration system and the ELV recycling system should be established to promote the sound recycling of collected ELV under the 3R concept.

In countries and regions with growing automobile markets, establishing collection and recycling facilities of ELV is an urgent issue. Basically, the ELV recycling process consists of dismantling, shredding and ASR treatment. However, various recycling techniques exist and these contribute to the efficiency of the recycling system. For example, exhaustive dismantling would decrease the recycling cost of ASR. It is important to recognize that ELV recycling systems can be modified to fit the situation in each country.

2. Countries with legislative ELV recycling systems and the importance of legislation

In countries and regions with legislative ELV management systems, such as the EU, Japan, China and Korea, although there are similarities in their legislation, the operation and the effectiveness of their systems differ. By contrast, in the United States where no direct legislation on the management of ELV exists, ELV recycling/treatment is strictly being managed through environmental protection regulations, and it is currently assumed that ELV recycling is taking place at the same level as in the EU. This is because the price of ELV is relatively high compared to its treatment cost. In the future, possible fluctuations in market prices of ELV due to changes in the value of ASR as a hazardous waste or as a depleting resource also need to be taken into account. Advanced and flexible measures are needed in designing effective recycling systems.

3. ASR management points, its hazardousness and its value as a resource

The treatment of ASR is one of the most important processes in ELV management. The hazardousness of ASR as well as its value as a source of depleting resources needs to be addressed. International regulations on ASR treatment are expected to become stricter in the years to come, as can be seen in the emerging demand for the international regulation of brominated flame retardants, the treatment of components containing mercury in line with the treaty on the control of mercury, the control on unintentionally produced POPs during the heating processes. The detoxification of ASR through applicable techniques will continue to increase in significance. Also, the need to develop techniques to extract the valuable materials from ELV is urgent, due to the undoubtedly increasing social demand for the conservation of depleting resources.

4. Measures to be taken regarding the move towards computerization of new models of automobiles

The use of automobiles has some degree of impact on the environment. Taking into account the protection of air quality, the control on greenhouse gas emission, and the avoidance from the effects of fossil fuel depletion, further advancement of the computerization of automobile control systems and the reduction in their body weight may be expected. This would result in higher composition of plastics and aluminum due to a shift from iron. Also, nonferrous metals such as copper and rare metals would be used more frequently. The decrease in iron content may possibly lower the recycling rate. It may also become difficult to collect most of the rare metals by magnetic selection, and thus the need to develop collection techniques after the shredding process may be urgent. It would be also necessary to come up with flexible measures on the ELV recycling system new models such as hybrid cars and electric cars.

5. Worldwide flow of ELV and the importance of further comparison within the international framework

The difference between the number of deregistered cars and ELVs is strongly related to the international market of used cars. The gap in these numbers is not small. Meanwhile, in countries which import and utilize used cars there is inadequate information and technology on ELV management, or their ELV recycling system is undeveloped. As both new and used automobiles are globally distributed, it may be possible to reach a global consensus on the rules for ELV management systems and on their operation at the national level. In the future, an international comparative study regarding ELV recycling systems in a wide range of countries and regions may be conducted. Efforts to share information and to promote adequate ELV recycling systems must be continued.

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