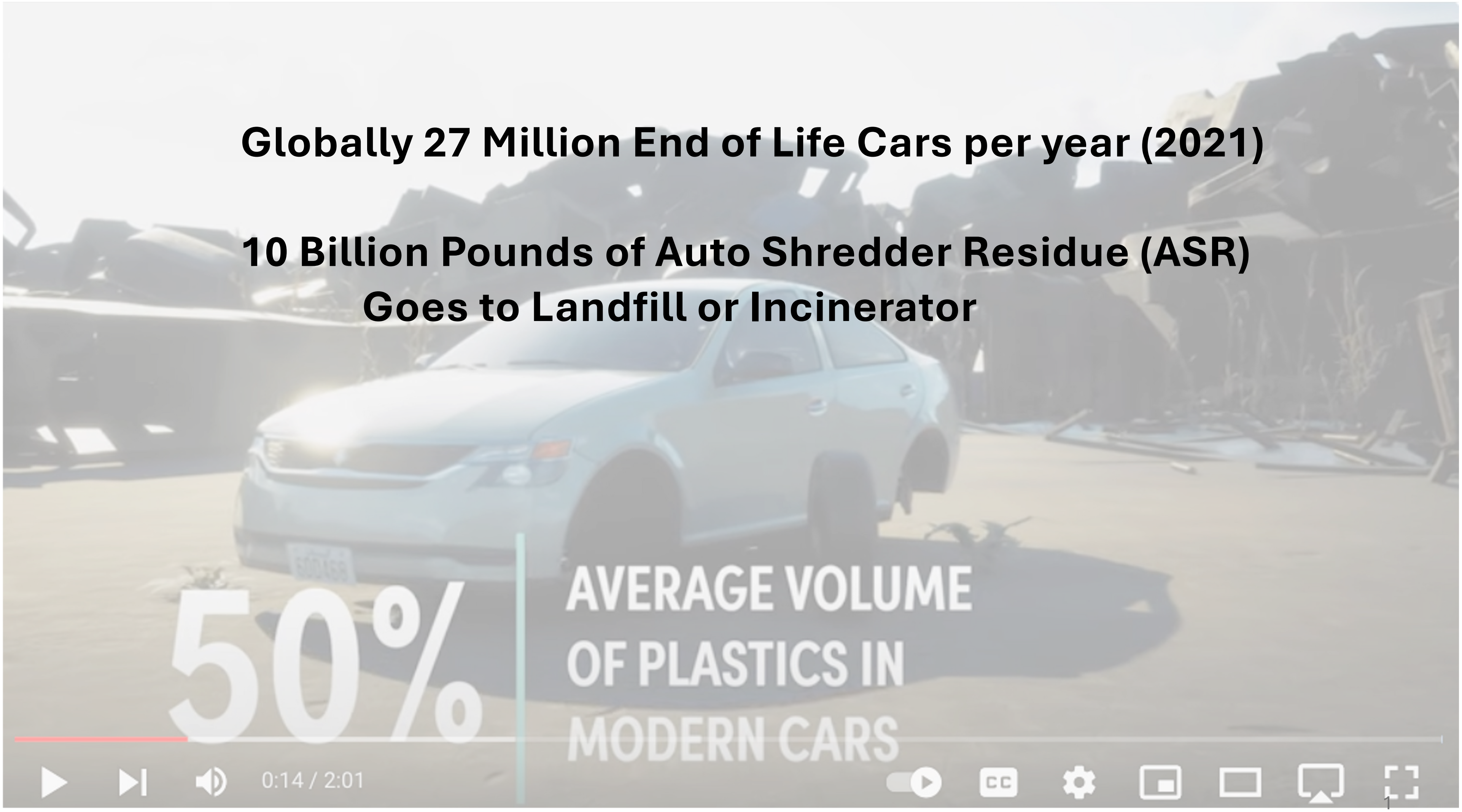
Globally 27 Million End of Life Cars per year (2021)

10 Billion Pounds of Auto Shredder Residue (ASR) Goes to Landfill or Incinerator



Eastman Chemicals Promo Video

One Car => 4,000 lbs of waste

80% metal and glass

20% Automotive Shredder Residue (ASR)

5 million tons in the US per year

Seat fibers from a crushed vehicle which will become ASR. Photo credit: Padnos

Auto Shredder Residue (ASR). Photo credit: Pandos.

Ford 2023 85% of plastic in their cars is recycled

Volvo promises in 2025 25% recycled plastic

Renault as some models with 30% and some with 90% recycled plastic

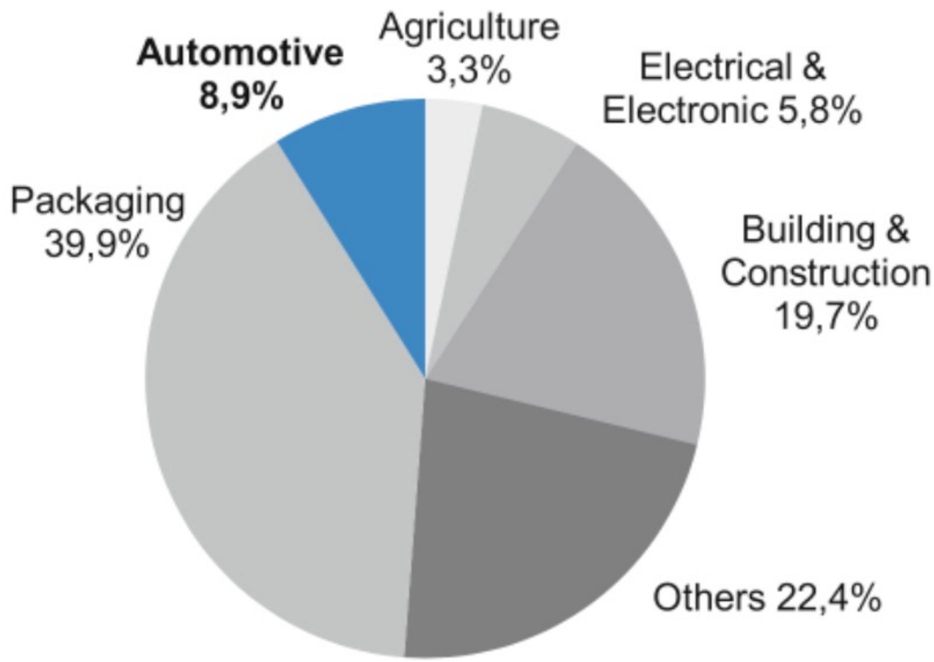


Fig. 3.4 Plastics Demand by Segment in the EU-28+N/CH in 2015 (total of 49 Mt, 'others' include consumer and household appliances, furniture, sport, health and safety,…), adapted with kind permission from PlasticsEurope (PlasticsEurope 2016, p. 17)

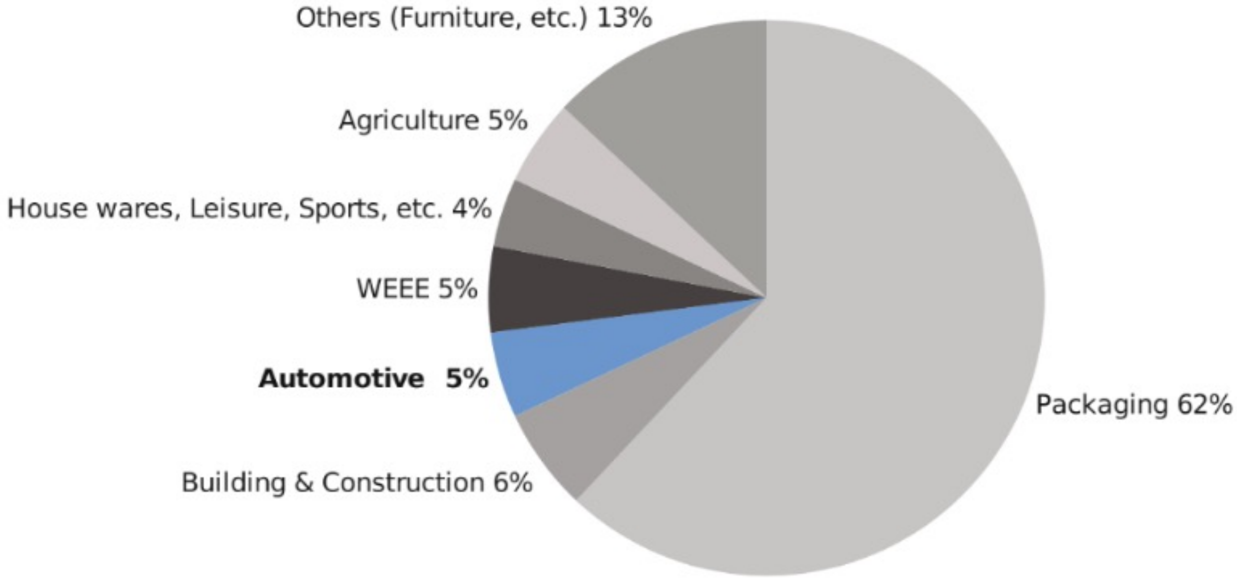


Fig. 3.10 Proportions of Plastics Waste in the EU-27+N/CH in 2008, adapted with kind permission from European Commission DG ENV et al. (2011, p. 66) cited after PlasticsEurope (2009)

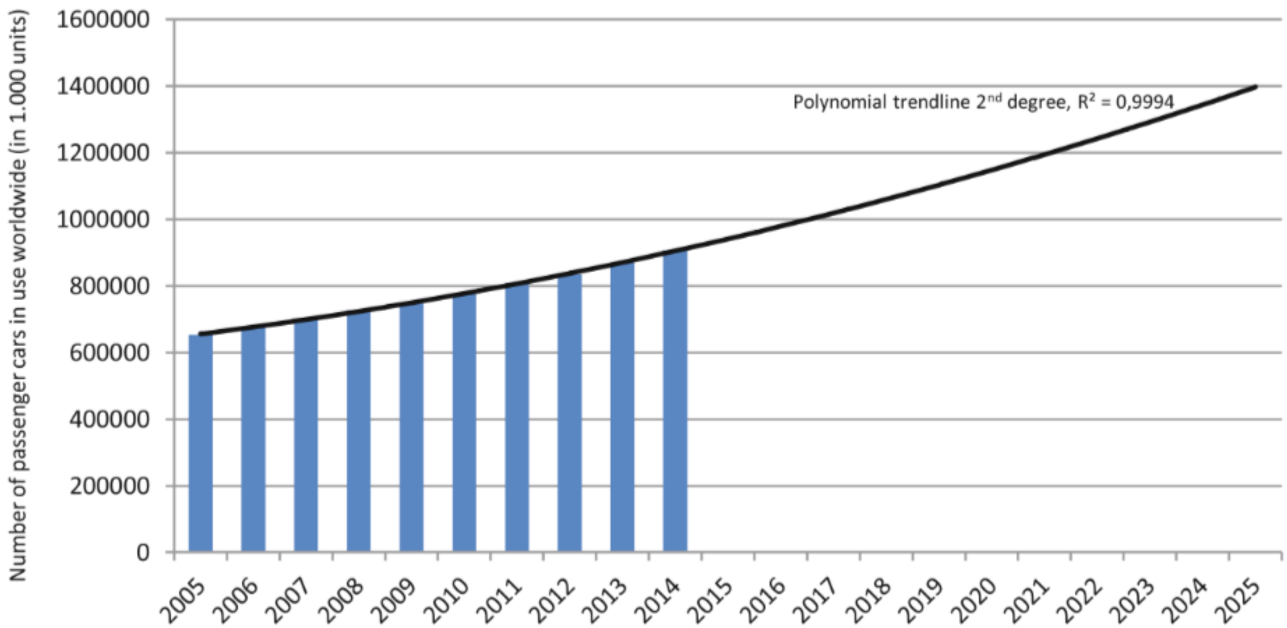


Fig. 3.16 Passenger cars in use worldwide, adapted with kind permission from OICA (2016a), modified by adding a polynomial trendline

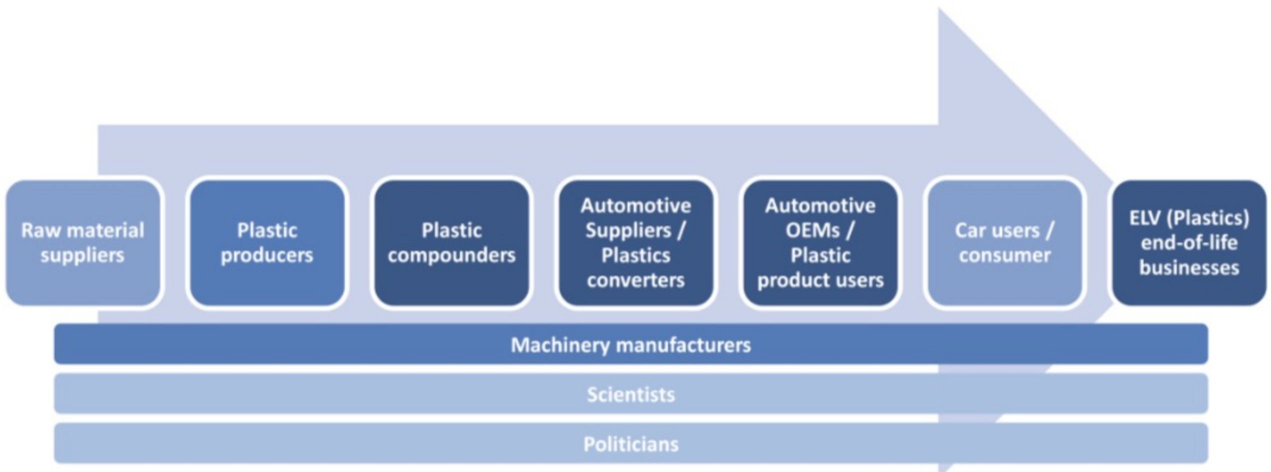


Fig. 6.3 Value chain of automotive plastics

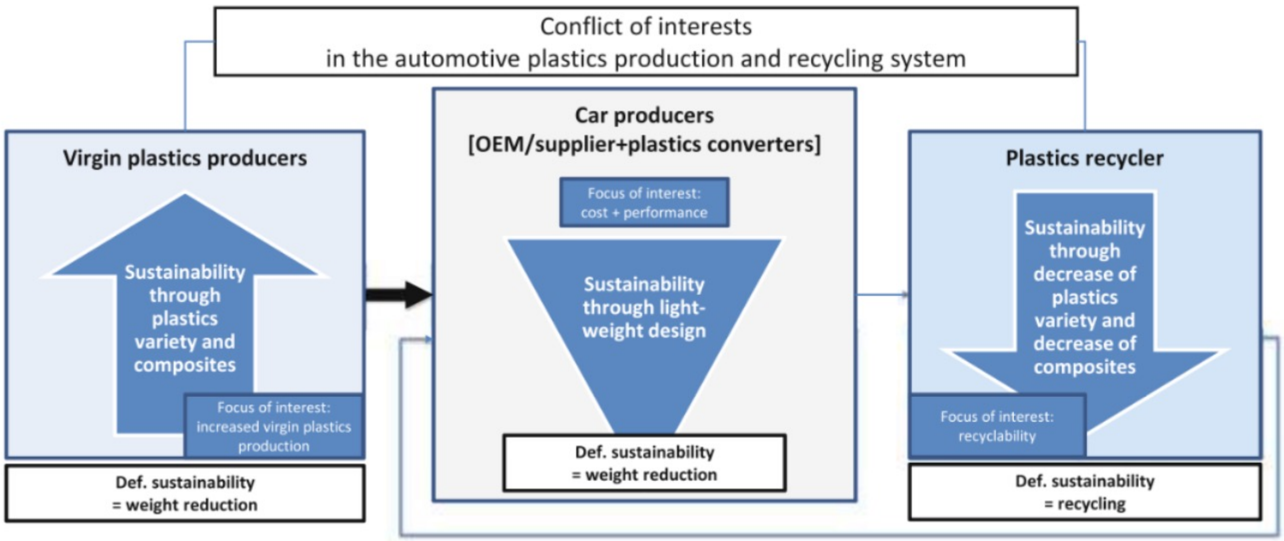


Fig. 7.1 Conflict of interests concerning automotive plastics, validated with experts

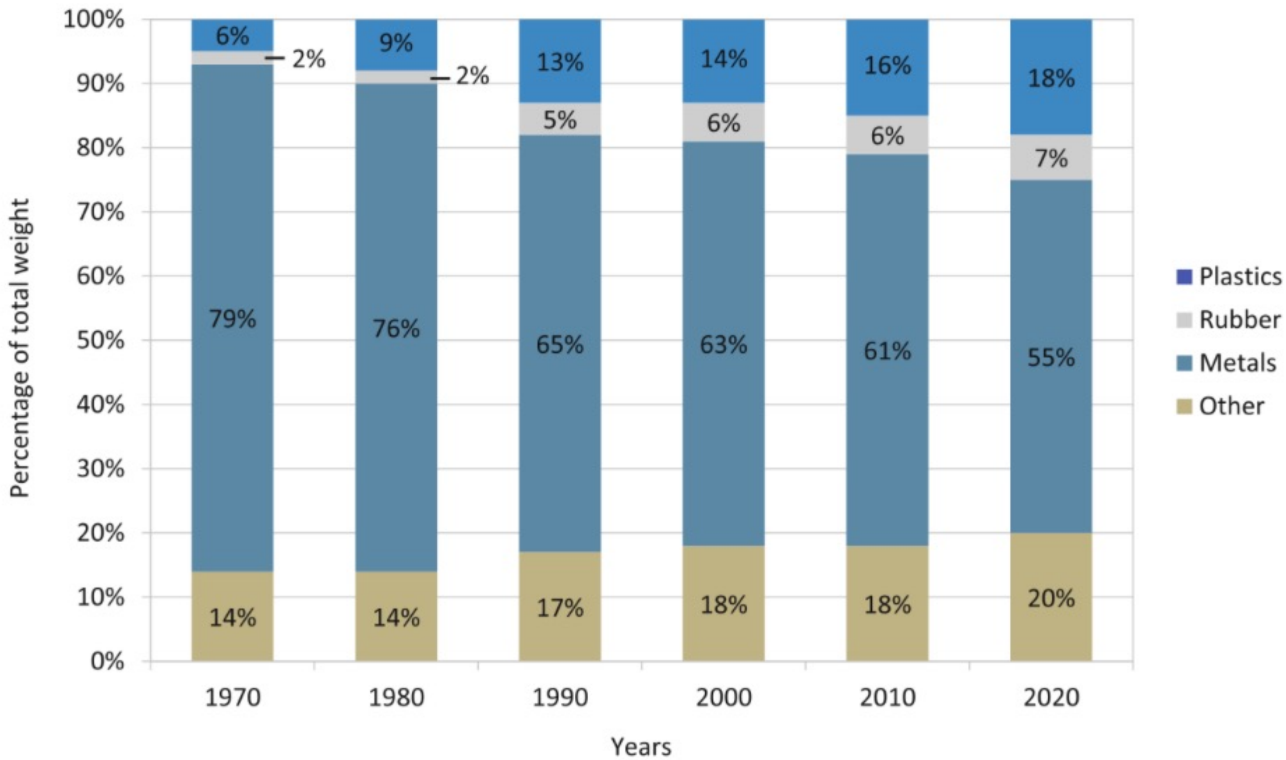


Fig. 3.17 Automotive materials development, adapted with kind permission from Weill et al. (2012, p. 2), modified by the author. (Color figure online)

Table 3.4 Plastics used in a typical car, used with kind permission from EuPC (2013)

Component	Main types of plastics	Weight in av. car (kg)
Interior trim	PP, ABS, PET, POM, PVC	20
Seating	PUR, PP, PVC, ABS, PA	13
Bumpers	PP, ABS, PC/PBT	10
Under-bonnet components	PA, PP, PBT	9
Upholstery	PVC, PUR, PP, PE	8
Dashboard	PP, ABS, SMA, PPE, PC	7
Electrical components	PP, PE, PBT, PA, PVC	7
Fuel Systems	HDPE, POM, PA, PP, PBT	6
Body (incl. panels)	PP, PPE, UP	6
Lighting	PC, PBT, ABS, PMMA, UP	5
Exterior trim	ABS, PA, PBT, POM, ASA, PP	4
Liquid reservoirs	PP, PE, PA	1
Total		105

SMA styrene maleic anhydride; PPE polyphenylene ether; UP Urethane plastic; ASA Acrylonitrile styrene acrylate

Fig. 3.18 Automotive plastic types, used with kind permission from PlasticsEurope (2013b). All rights reserved

Table 3.3 Most prominent plastics and their estimated percentages in terms of weight used in a typical car, based on PlasticsEurope (2013a) and Weill et al. (2012)

Plastic type	Acronym	% by weight	kg (224 kg total per car)
Polypropylene	PP	28.6	64
Polyurethanes	PUR/PU	17.4	39
Polyamides	PA	11.9	27
Polyethylene	PE-HD/MD/LD/LLD	9.7	22
Styrenic copolymers	ABS, ASA, SAN	5.3	12
Polyvinyl chloride	PVC	3.8	9
Others		23.3	51

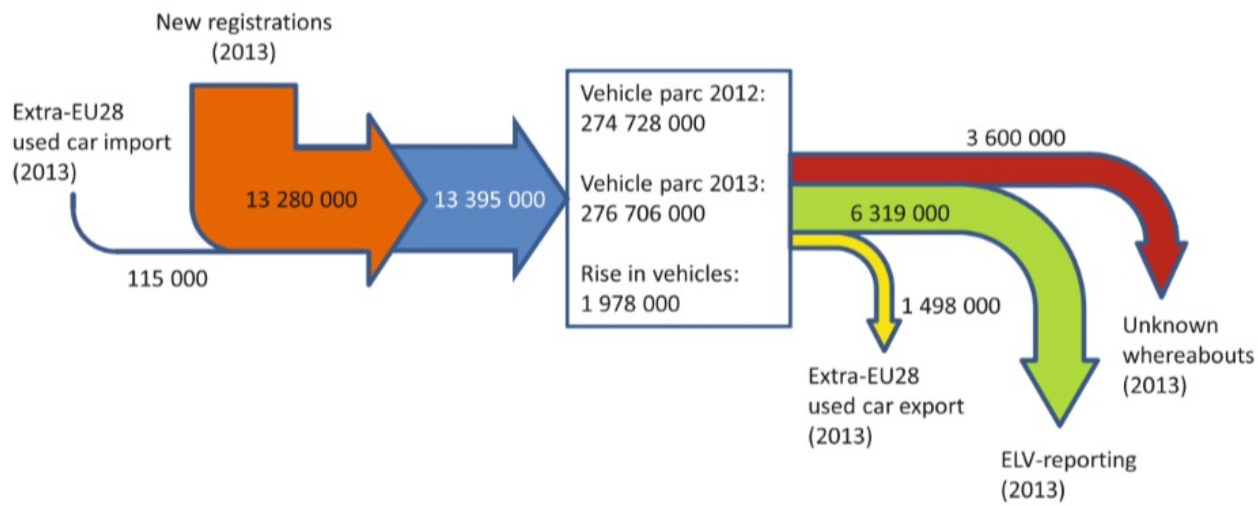


Fig. 3.19 Automobile streams in the EU-28 in 2013 (M1+N1 vehicles), reproduced from Oeko-Institut e.V. et al. (2016) (CC BY-SA)

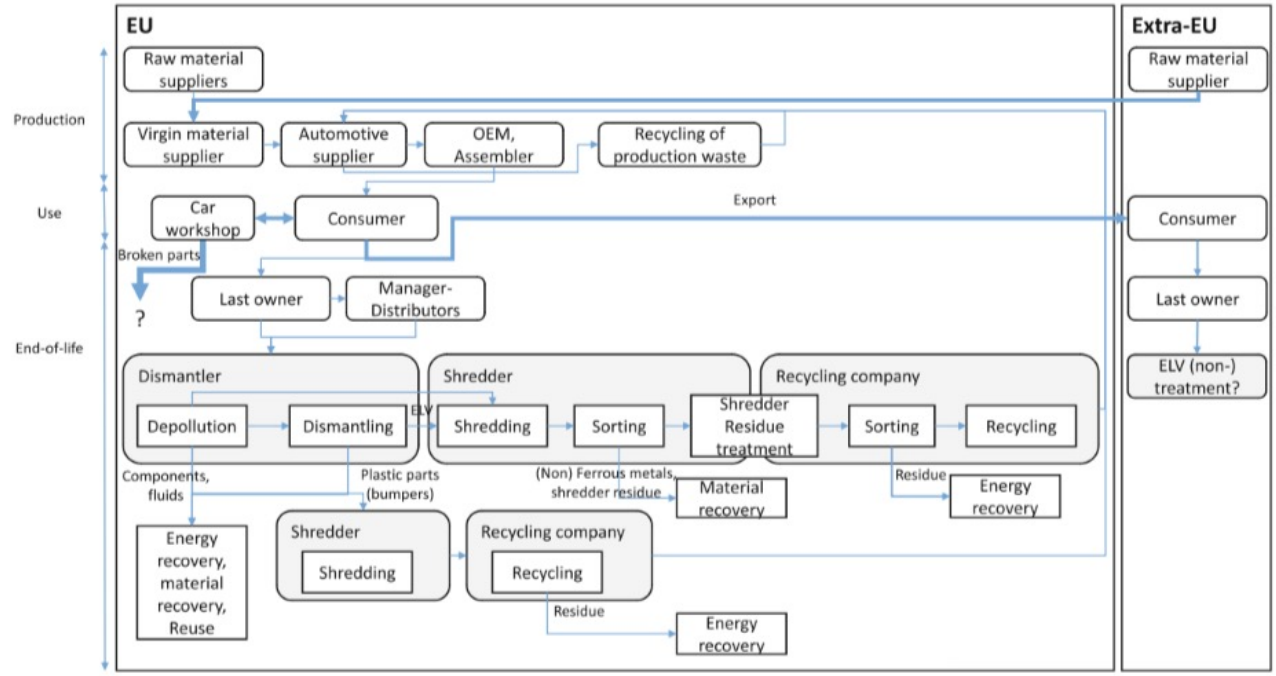


Fig. 3.20 The car life-cycle in the EU with the focus on ELV treatment, adapted with kind permission from Kanari et al. (2003), Maudet et al. (2012)

Two ways to shred a car

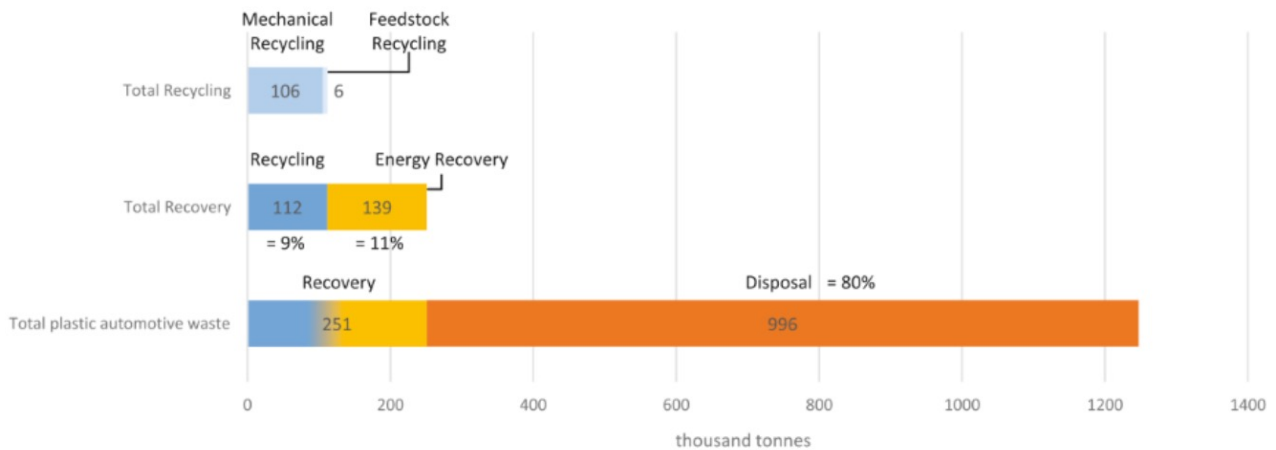


Fig. 3.21 Treatment of total automotive plastics waste in EU-27+N/CH in 2008, adapted with kind permission from European Commission DG ENV et al. (2011, p. 86)

Table 3.5 Plastics content in a 2015 ELV, estimation (European Commission DG ENV et al. 2011, p. 125)

	%	kg
PP	42	44.63
PU	11	11.69
PA/PC	8	8.50
ABS	7	7.44
PVC	7	7.44
Other	12	13.81
Total	100	106.26

Table 3.6 Usage of recycled plastics in car fleets in Europe (BMW Group 2015; Daimler AG 2015; PSA Groupe 2015; Fiat Chrysler Automobiles Group [FCA] 2015, p. 64; Volkswagen AG 2015; Nissan Motor Corporation 2016, p. 138; Renault Group 2015, p. 16; General Motors 2015; Ford Motor Company 2016)

OEM	Proportion of recycled plastics
FCA Group (Fiat/Chrysler)	34.9% (avg. 2015)
BMW Group	No clear indication (up to 20% in 2014)
Nissan Motor Corporation	No clear indication (13% in the best performing model)
PSA Group (Peugeot/Citroen)	No clear indication
Renault SA	No clear indication
Ford Motor Company	No clear indication
General Motors Company	No clear indication
Volkswagen Group	No clear indication
Daimler AG	No clear indication

Table 3.7 ELV-Directive (European Union 2000, p. 38)

	As of Jan 1, 2006	**As of Jan 1, 2015**
Reuse and recycling (%)	80	85
Reuse and recovery (%)	85	95

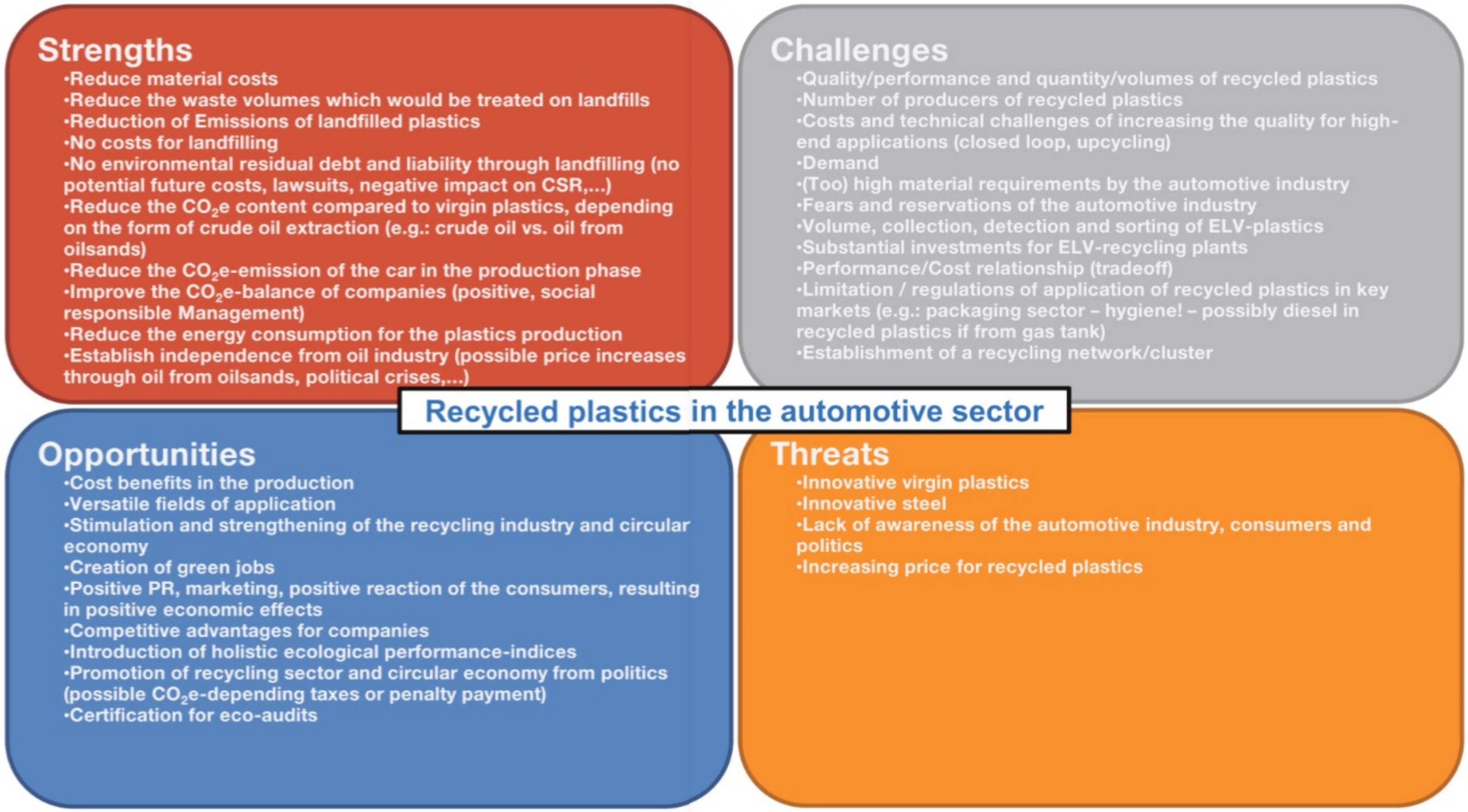


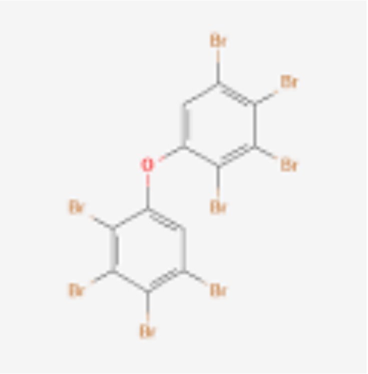
Fig. 5.1 SCOT analysis of the usage of recycled plastics in the automotive sector, developed with experts

Automotive Recy
Plastics, and Sust
The Recycling Ren
David Schönma

Table 5.1 Overview of future perspectives concerning recycled plastics in the automotive sector - Literature sources: Sperling and Gordon (2009); Weill et al. (2012); Heuss et al. (2012); BMW Group (2015); Daimler (2015); Fiat Chrysler Automobiles Group (FCA) (2015); Ford Motor Company (2016); General Motors (2015); Nissan Motor Corporation (2016); PSA Groupe (2015); Renault Group (2015); Volkswagen (2015); European Commission (2011, 2014a, b, c); European Union (2013); PlasticsEurope (2016)

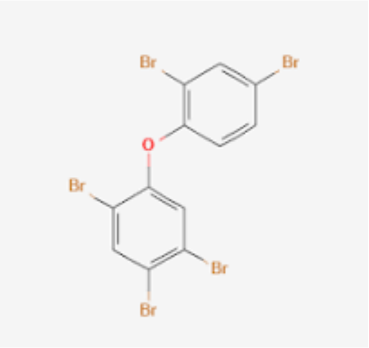
Source			
Prognosis	**Literature**	**Survey**	**Expert workshops and interviews**
Number of cars will increase worldwide	X (=confirmed)	0 (=not asked)	X
Car weight will decrease	X	0	X
Share of plastics in cars will increase significantly till 2020	X	X	X
Innovative metals (High strength steel, aluminium, magnesium,…) will increase	X	0	X
Holistic life-cycle thinking will increase	X	0	X
Political incentives for circular economy will increase	X	0	X
Increasing share of recycled plastics in new cars and car parts till 2020		X	X
Demand for more sustainable materials will increase till 2020		X	X
Marketing with recycled plastics will be beneficial in 2020		X	X
Hierarchy of ELV treatment in 2020: 1. Rank: Mechanical recycling 2. Rank: Thermal energy recovery 3. Rank: Chemical recycling 4. Rank: Landfilling		X	X

Automotive Shredder Residue, ASR (25% of End-of-Life Vehicles (ELVs))



May/probably contain bromine flame retardants (BFRs)

a. Hexabromodiphenyl ether and heptabromodiphenyl ether (also known as octabromodiphenyl ether or commercial **octaBDE** which is a commercial mix of several types of BDEs); used as a flame retardant for some acrylonitrile-butadiene-styrene (ABS) thermoplastics particularly for those used for **electronic goods** such as computer monitor and television casings, photocopiers, microwave ovens, laptops, and printers. Also used in coatings and lacquers, and in polyurethane foam for auto upholstery.



b. Tetrabromodiphenyl ether and pentabromodiphenyl ether (also known as commercial **pentaBDE**); used predominantly in **polyurethane foams for vehicles seats** and fittings and foams used for furniture, mattresses, carpet underlay, and electronic equipment.

BFRs are toxic and pose a risk of causing adverse effects to human health and the environment. They are capable of **long-range transport, persist in the environment, and bioaccumulate in human and animal tissue.**
They have the potential to be **transformed into brominated dioxins** when burnt at low temperatures or when the chemicals break down. This can occur during handling, recycling or disposal. The brominated dioxins are **extremely toxic and carcinogenic**.

Automotive Shredder Residue, ASR (25% of End-of-Life Vehicles (ELVs))

- ASR contains a variable mix of thermoplastics, rubbers, thermosets, foam, felt, fiber, glass, metal (copper), stones, mud, wood, water, dirt
- Unpredictable, useless extraneous material
- Hazardous substances: Mercury, Lead, Cadmium, PCBs, BFRs
- ASR is classified as hazardous
- ASR is being landfilled
- Sorted resins are eligible for recycling, most for pyrolysis or incineration

Recycling plastics from automotive shredder residues: a review

Alfons Buekens · Xujian Zhou

J Mater Cycles Waste Manag (2014) 16:398–414

Automotive Shredder Residue, ASR (25% of End-of-Life Vehicles (ELVs))

- Average at 13.7 years we reach ELV
- Transfer of ELV from affluent to Africa, Asia, Eastern Europe
- Scrap yard for cannibalization (systematic or upon demand)
- Car wrecks are depolluted by removal of fluids, catalytic converters, batteries, PCBs
- Systematic dismantling (rare) bumpers, cushions,
- Shredder (1950s to now) result in fist size metal, fine shredder dust (aluminum/magnesium/plastics), dense shredder dust
- Fiber glass bodies, hybrid and EVs are a problem for conventional shredders

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Automotive Shredder Residue, ASR (25% of End-of-Life Vehicles (ELVs))

- Switzerland, Japan and later the Netherlands pioneered pyrolysis for ASR. EU followed.

- ELV Directive of the European Parliament and of the Council of 18 September 2000 on end-of-life vehicles 2000/53/EC [10, 11, 16];
- Directive 2000/76/ EC (December 4, 2000) on the incineration of waste [17];
- Directive 1999/31/EC (April 26, 2000) on the disposal of waste in landfills [18].
- EU Regulation on Registration, Evaluation, Authorisation, and Restriction of Chemical substances (REACH, 2007) [19, 20], to protect people and the environment from chemical hazards, impacts the potential recycling of automotive materials.

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Automotive Shredder Residue, ASR (25% of End-of-Life Vehicles (ELVs))

EU regulations:

- **Carmakers** must reduce their use of hazardous substances (mercury, hexavalent chromium, cadmium, or lead) when designing and producing vehicles.
- **Producers** must use International Organization for Standards (ISO) guidelines for labelling and identification of vehicle components suitable for reuse and recovery and meet the costs for collection and recovery.
- EU Member **States are required to establish collection systems** for ELVs and ensure that all vehicles are transferred to authorised treatment facilities, through a system of vehicle deregistration based on a **certificate of destruction.**
- The last holder of an ELV may dispose of it **free of charge** (free take-back).
- Vehicle **dismantlers must obtain permits** to handle ELVs.
- **Storage and treatment of ELVs are strictly controlled** through de-pollution procedures and **designated parts removal** requirements (cf. 2006/12/EC [21]).
- **Vehicle manufacturers** compile data and report regularly to the authorities designated.
- Every 3 years **Member States** are required to report to the European Commission on implementation.

ELV Directive (2000/53/EC) is the first **Extended Producer Responsibility** Law (EPR)

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Automotive Shredder Residue, ASR (25% of End-of-Life Vehicles (ELVs))

In the EU ASR is classified as hazardous waste.

Most ASR is landfilled

To a rising extent energy is recovered, mainly by co-combustion with municipal solid waste [22] or in cement kilns.

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Automotive Shredder Residue, ASR (25% of End-of-Life Vehicles (ELVs))

Japan:
Retrieve CPCs, airbags, and ASR
Car producers own recycling companies
Consumers pay at purchase for recycling

South Korea:
Car producers and importers responsible for ELV

US:
“Product Stewardship” calls for ”shared responsibility”. No mandates.
Some industrial groups have formed to address the problem, ASR hasn’t been specifically addressed

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Automotive Shredder Residue, ASR (25% of End-of-Life Vehicles (ELVs))

Car Crushing

Decontamination: Removal of fluids and batteries etc

Flattening: crushing of car

Bailing: Ship bails to shredding plant (hopefully)

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Automotive Shredder Residue, ASR (25% of End-of-Life Vehicles (ELVs))

Shredding Process

Remove Recoverable Parts: wheels and tires, steering columns, fenders, radios, engines, starters, transmissions, alternators, selected plastic parts and components, air bags, glass, foams, catalytic convertors, mercury switches, bumpers, cushions, dashboards

Shredder: fist size wrinkled plates of steel and light fluff (**ASR** and light weight metals) and heavy fluff (steel fragments and other metals)

Light fluff: magnetic separation followed by eddy current separators for aluminum and other nonferrous metals.

Heavy fluff: sink float separators for different metals and plastic-coated wires etc.

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Automotive Shredder Residue, ASR (25% of End-of-Life Vehicles (ELVs))

0.7 to 25 % moisture
18 to 68 % ash
14 to 30 MJ/kg for fuel

plastics (ca. 38 MJ/kg)
rubber (23 MJ/kg)
textiles (17 MJ/kg)

ASR Composition:

Residual ferrous and non- ferrous metals (5–23 %),
plastics (20–49 %),
rubber (3–38 %),
textile and fibre material (4–45 %),
wood (2–5 %),
and glass (2–18 %)

ASR Classification:

•Light fluff, generated during shredding, following spontaneous air classification (75 % of ASR; 10–24 % of the ELV)
•Heavy fluff, remaining after metal separation from the heavy shredded fraction (25 % of ASR; 2–8 % of the ELV)
•Fine soil and sand are sometimes reported separately, but usually part of the heavy ASR (\2.5 % of the ELV)

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Table 1 Composition of ASR, light and dense fraction [25]

	[45]	[6]	[40]	[46]	[47]	[48]	[49]
(a) Composition, as wt%, of ASR, according to the origin: light fluff							
Metal	1–1.7	21	8.8	2.5	3.7	0.3	
Wire	2.9–3		4.7	1	2.2		0.5
Rubber	3.8–4	3.1	2.6	3	8.8	10.3	4.1
Textile	37.5–39.6		36.1	32.5	26.2	8.3	7.9
PUR foam	6.6-20.6		35.3	8			3.8
Plastic	16.1–24.1	31.8	11.7	9	46.1	11.0	8.7
Wood	0.03–0.4			1	2.7	0.6	
Paper	0.8–1.0				0.8		
Soil/sand	6.4–21.6				4.3		
Glass	0	2.3		43 (minerals)			
Others	2.7–6.2		0.8		5.2	69.5 (<10 mm)	75 (fines)
(b) Composition, as wt%, of ASR, according to the origin: heavy fluff							
Metal	0.2–1.4	1.6		5		0.7	
Wire	7.0–12.7			3			0.7
Rubber	14.1–17.3	9.3		55		43.7	44.8
Textile	7.7–11.6			3		10.5	10.5
PUR foam	0.9–2.8						3.3
Plastic	23.8–30.9	8		19		32.6	29
Wood	0.06–0.7			7		4.7	5.6
Paper	1–2.5						
Soil/sand	7.6–12.3			8 (minerals)			
Glass	8.3–11.0	9.4					
Others	4.6–4.0					7.8	6.1 (fines)

Recycling plastics from automotive shredder residues: a review

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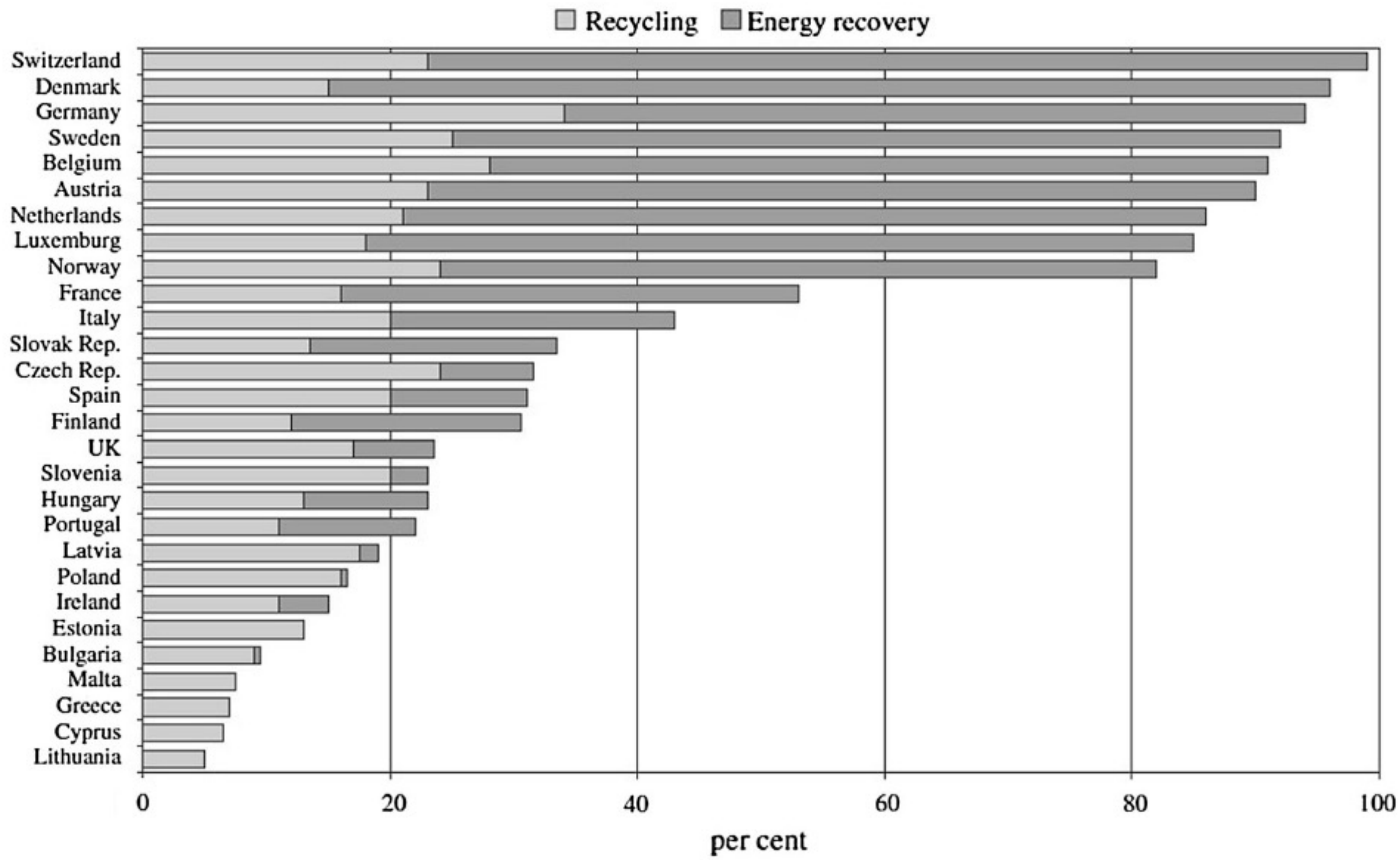
Fig. 1 Recycling of general plastics in various European countries [51]. Recycling rate, mechanical recycling; energy recovery rate, thermal recycling



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Automotive Shredder Residue, ASR (25% of End-of-Life Vehicles (ELVs))

Sorting of ASR

- liberate large pieces of metal,
- the mixed plastics are classified and a light fraction is sorted out.
- subsequent wet separation allows sorting it into different subfractions, graded according to their density.
- then the ABS-PS (styrenics sinks in water) and PE-PP concentrates (polyolefins float) are mechanically and thermally dried.
- remaining metal and other conductive contaminations are subsequently separated, using hamos electrostatic separators.
- downstream electrostatic separators convert the ABS-PS or PE-PP mixtures into separate fractions.
- if required, light-colored plastics fractions can be produced using optical-electronic sorting.

WEEE-plastics can be treated similarly

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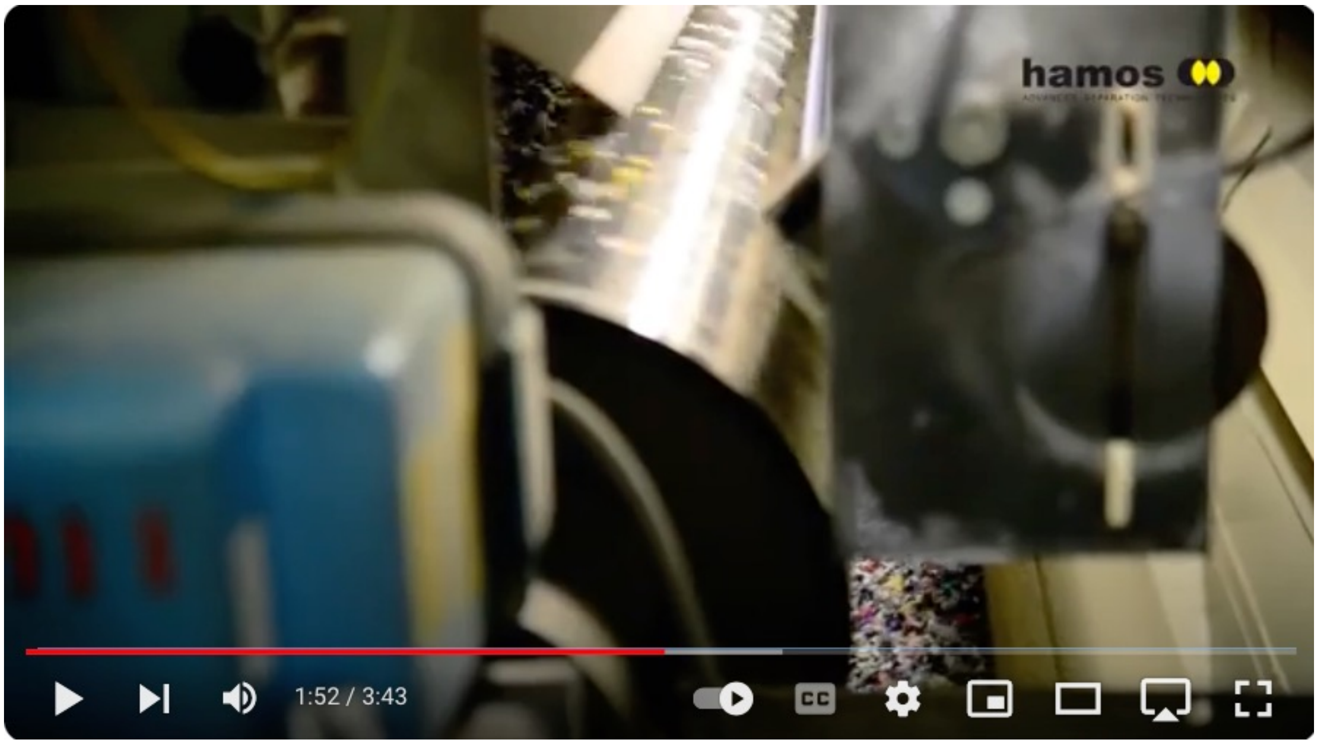
Automotive Shredder Residue, ASR (25% of End-of-Life Vehicles (ELVs))

https://www.youtube.com/watch?v=bmk-lQieQdg



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Automotive Shredder Residue, ASR (25% of End-of-Life Vehicles (ELVs))

Co-incineration with limited addition of few per cent ASR to another main-stream is feasible without violating emission standards.

ASR typically contains significant amounts of chlorine (Cl), sulphur (S), nitrogen (N), and a wide range of heavy metals.

Table 2 ASR contaminants [58]

Compounds	PCDD/Fs	Dioxin-like PCBs	PCB	PAHs
Concentrations	242–329 ng I-TEQ/kg	481–631 ng I-TEQ/kg	13–15 ppm	37–140 ppm

Polychlorinated dibenzodioxins PCDD
Polychlorinated dibenzofurans

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Polychlorinated biphenyls

Automotive Shredder Residue, ASR (25% of End-of-Life Vehicles (ELVs))

- Heavy metals of miscellaneous origins.
- Various paint pigments, plastics additives, and corrosion products bring in a number of heavy metal compounds;
- brominated flame retardants (BFRs), e.g. from printed circuit boards or car cushions are routinely accompanied by antimony oxides.
- Mercury used in switches, relays, and gas discharge lamps,
- Shredding a single lead battery would impregnate a lot of ASR with lead and its oxides.

zinc (Zn, 2.10 %),
copper (Cu, 1.85 %),
lead (Pb, 0.26 %),
chromium (Cr, 0.16 %),
nickel (Ni, 0.12 %),
antimony (Sb, 230 ppm),
cadmium (Cd, 77 ppm),
mercury (Hg, 3 ppm)

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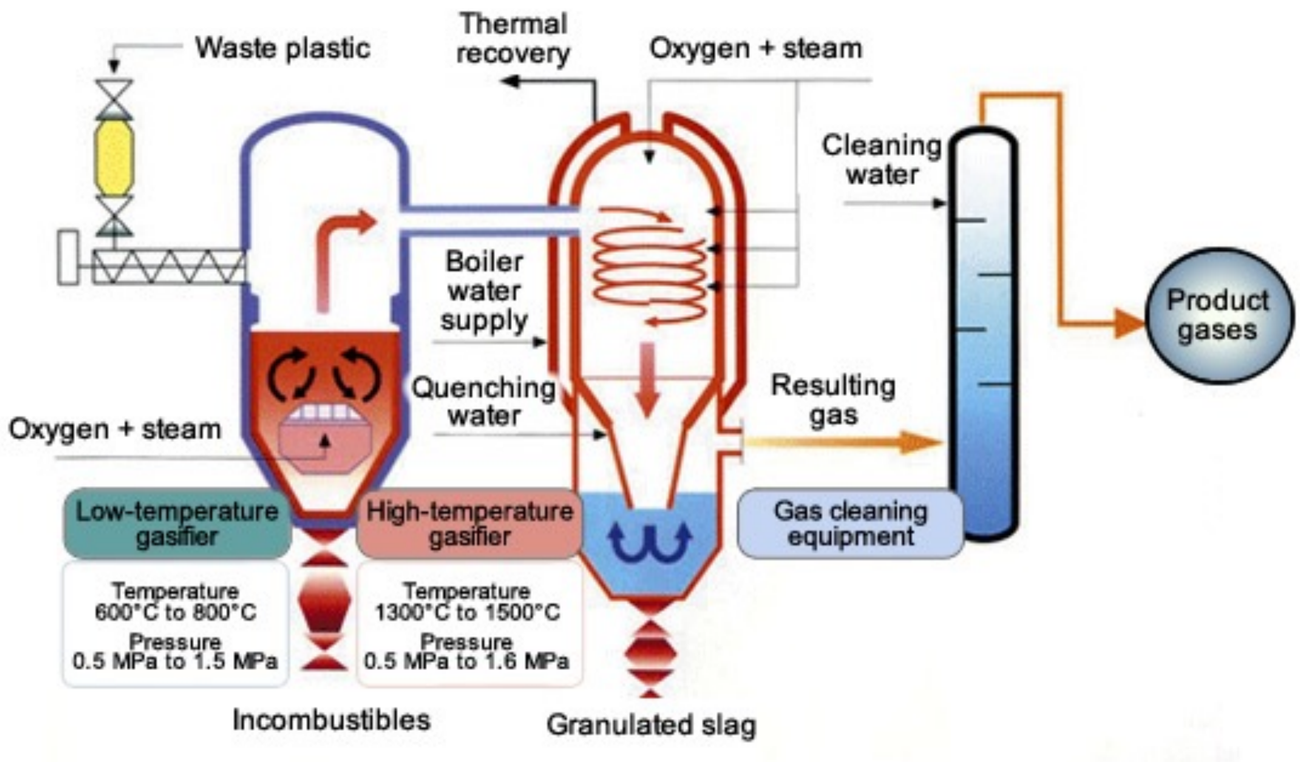
Pressurized twin internally circulating fluidized-bed gasification system (PTIFG)



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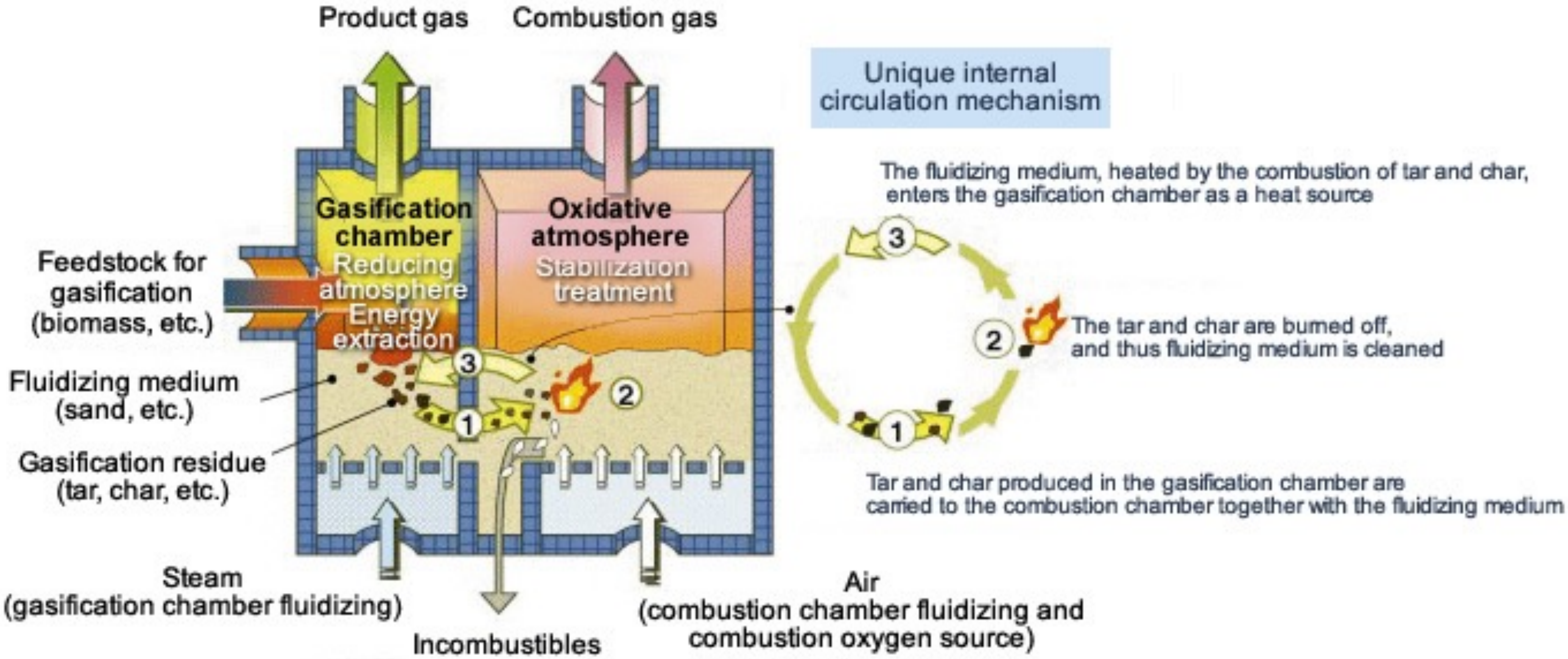
https://www.eep.ebara.com/en/business_technology/technology_3.html

Internally circulating fluidized-bed gasification



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Automotive Shredder Residue, ASR (25% of End-of-Life Vehicles (ELVs))

ASR Incineration

- burning ASR directly, recovering some supplemental metal from incinerator residue and possibly even from fly ash.
- technical and environmental factors.
- Tested in 1980s with Belgian shredder enterprise (IWONL/IRSIA R&D-project), but due to its high calorific value and melting characteristics the ASR burned too fiercely, leading to uncontrollable combustion, local lack of oxygen, agglomeration of burning ASR, and carry-over of unburned fines

Recycling plastics from automotive shredder residues: a review

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Automotive Shredder Residue, ASR (25% of End-of-Life Vehicles (ELVs))

- Co-incineration can be conducted in a wider range of incinerator categories, such as mechanical grate furnaces, fluidised bed and vortex combustors, rotary kilns, and cement kilns.
- Such solutions are called **Solution by Dilution** by operators of duly licensed hazardous waste incinerators.

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Gasification of ASR:

1.Fluidized bed gasification (Winkler, Leuna Werke, Germany) at unusually low temperature (750–900 °C). An air factor was used of 25–40 % of the stoichiometric combustion air requirements: partial combustion of char supplies the heat required for autothermal operation. Gasification of carbon with steam or carbon dioxide is still slow below 850 °C. Yet, operating temperatures are restricted by weakening of the ash, leading rapidly to loss of fluidization. Air as gasification agent introduces large amounts of nitrogen in the producer gas, thereby reducing the calorific value of generator gas.

2.Vertical shaft gasifiers (Lurgi, Frankfurt) operate in counter-current, with rising gasification products and the charge gradually descending towards the hearth at temperatures up to 1200 °C. Air is replaced as a gasification agent by a balanced mix of oxygen and steam. Ash is tapped periodically as molten slag, unless gasification temperature is severely limited.

3. A rotary kiln can be used, operating at a higher ratio of (volume reacting gases)/(volume of the charge) and adding tumbling action to the charge. The Landgard partial oxidation plant of Monsanto (Baltimore, MI, USA) was scaled-up too rapidly from pilot to full-scale and fell victim to sequentially occur- ring operating problems, starting with shredder explosions, solidification of stored shredded fuel, clogging of the slag tapping hole, etc.

4.Co-current flow combustion of pulverized fuel (Koppers-Totzek). The reactor is simply a combustion chamber, into which several pulverized coal burners inject their incomplete combustion products. Temperatures of 1400–1600 °C are reached, so that tar conversion and a fully slagging operation is ensured.

5.Montecatini, Texaco, and Shell all developed processes for converting heavy fuel oil (or any pumpable fuel), injecting these together with oxygen and steam into a combustion chamber at sufficiently high temperatures. Their designs differed mainly in the methods used to separate soot particles and to recover sensible heat from the gas.

Recycling plastics from automotive shredder residues: a review

Alfons Buekens · Xujian Zhou

J Mater Cycles Waste Manag (2014) 16:398–414

Automotive Shredder Residue, ASR (25% of End-of-Life Vehicles (ELVs))

Pyrolysis to monomer
Polymerization of reactive monomers, such as vinyl compounds or olefins and dienes, or gradual polycondensation to form polyesters and polyamides, is thermodynamically favored at low temperature. With rising temperature this trend gradually reverses and monomers become more stable than their polymers.

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Mechanical Separation:

Table 3 Overview of some post-shredder technologies [25]

	Argonne	Galloo	MBA-polymers	Salyp process	Stena	R-plus (WESA-SLF)	VW-Sicon
Separation techniques							
Air classification	X	X	X		X	X	X
Magnetic separation	X	X	X	X	X	X	X
Eddy current separation	X	X	X	X	X		X
Screening		X		X	X	X	X
Trommel separation	X	X		X	X		
Optical sorting				X			X
Manual sorting				X	X		
Drying						X	
Sink/float separation		X		X	X		X
Froth flotation	X						
Thermo-mechanical sorting				X			
Wet grinding			X				
Hydrocyclone			X				
Static separation tanks		X					
Heavy media separation					X		

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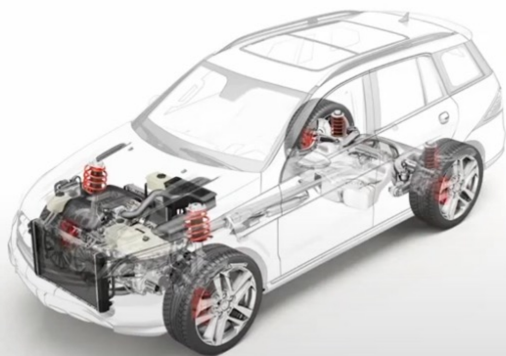
Circular Economy in the Automotive Industry
CLARIOS
THE
CIRCULAR
IMPERATIVE
The Path to an Automotive
Circular Economy
Adam Muellerweiss
Chief Sustainability Officer

Internal Combustion

Average Age: **12.2 years**
Expected Life: **200,000+ miles**
Annual End-of-Life: **14 million cars**



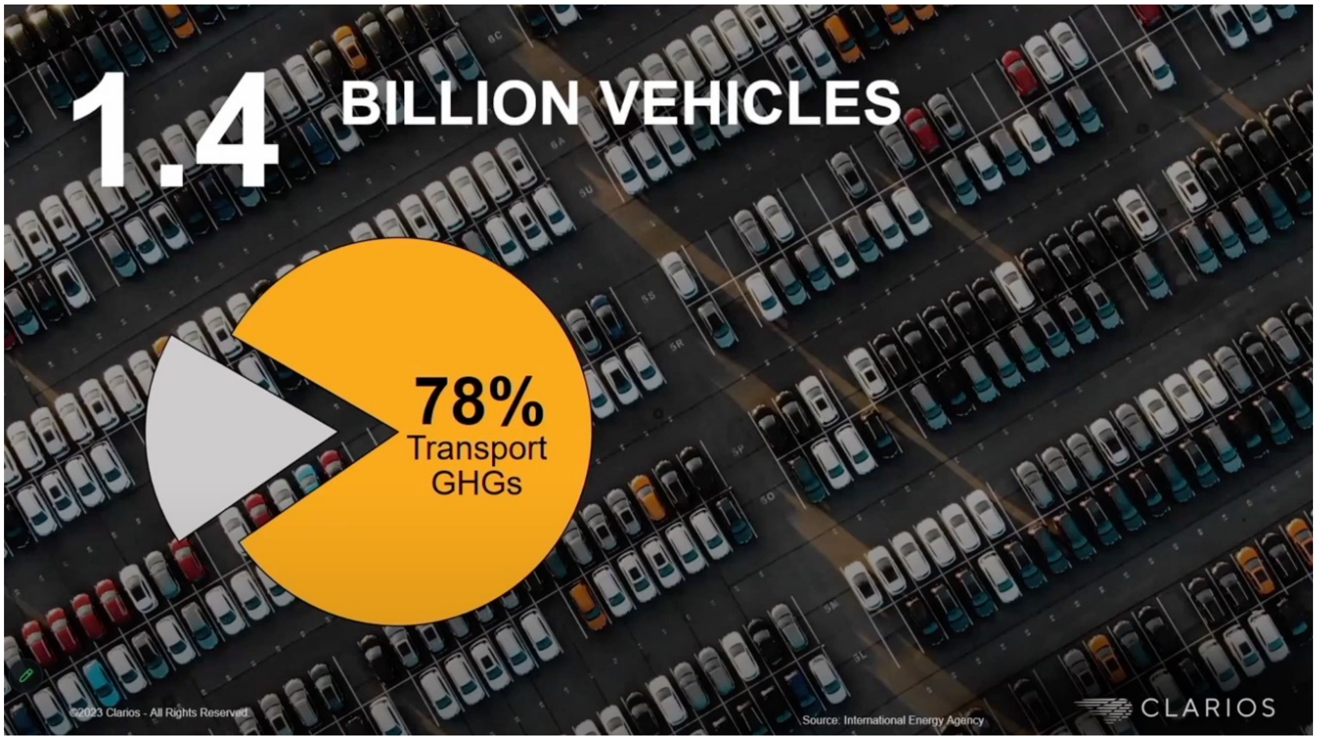
Electric

Average Age: ***3.8 years. . .***
Expected Life: ***250,000+ miles***
Annual End-of-Life: ***TBD***

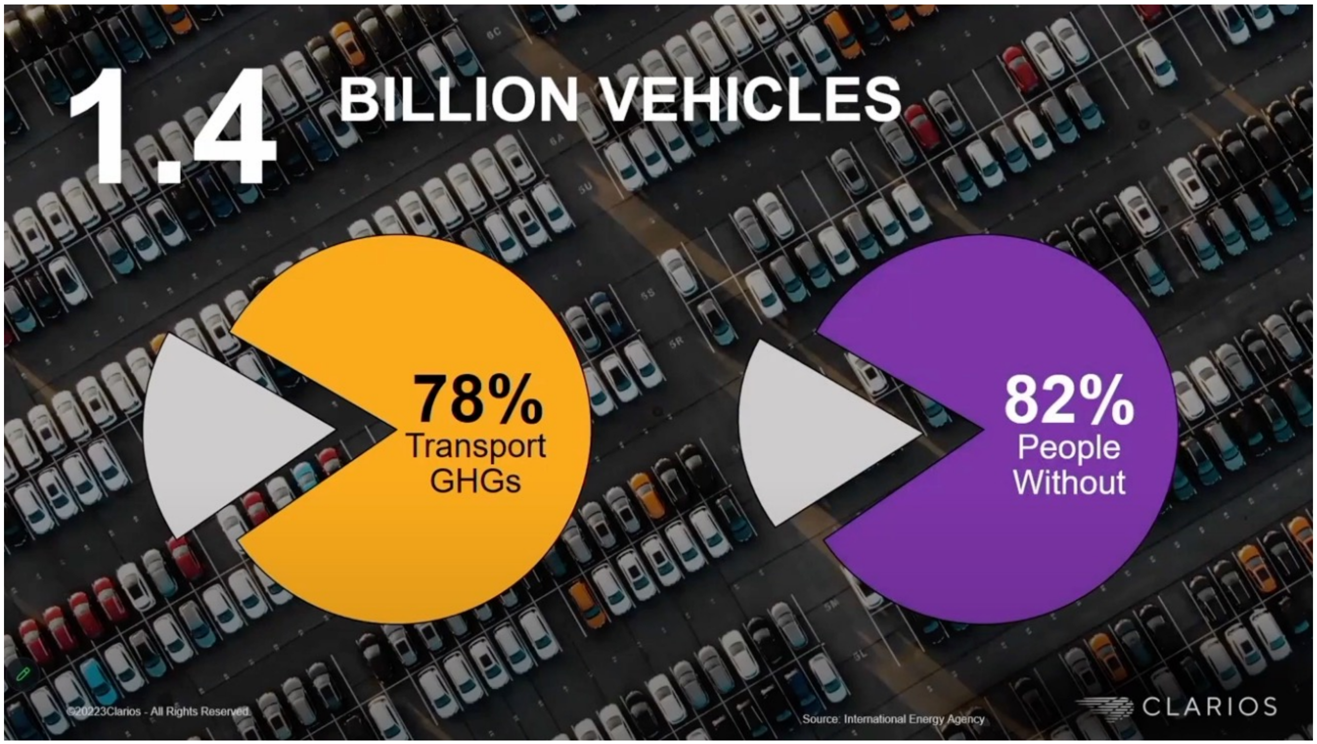
Source S&P Global, Automotive Recyclers Association, Clarios

CLARIOS

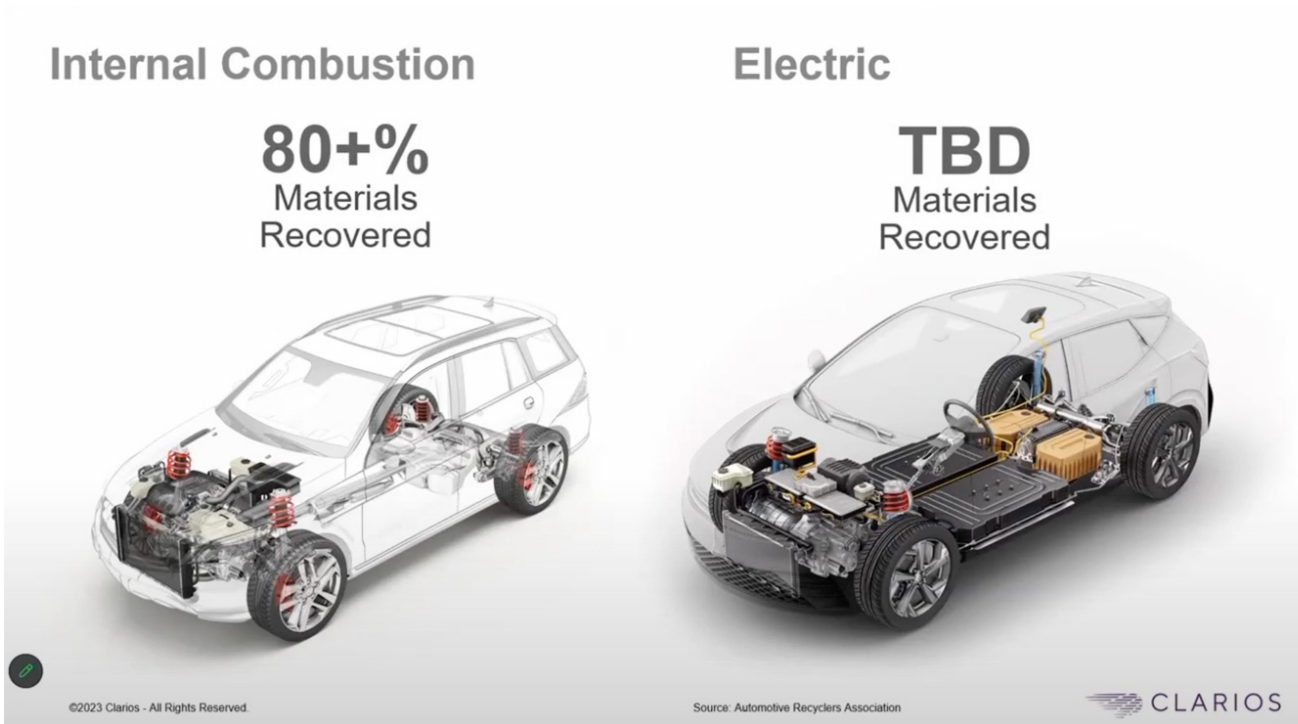
World



Greenhouse gas emissions



Population with no car


Internal Combustion
80+%
Materials
Recovered
Electric
TBD
Materials
Recovered
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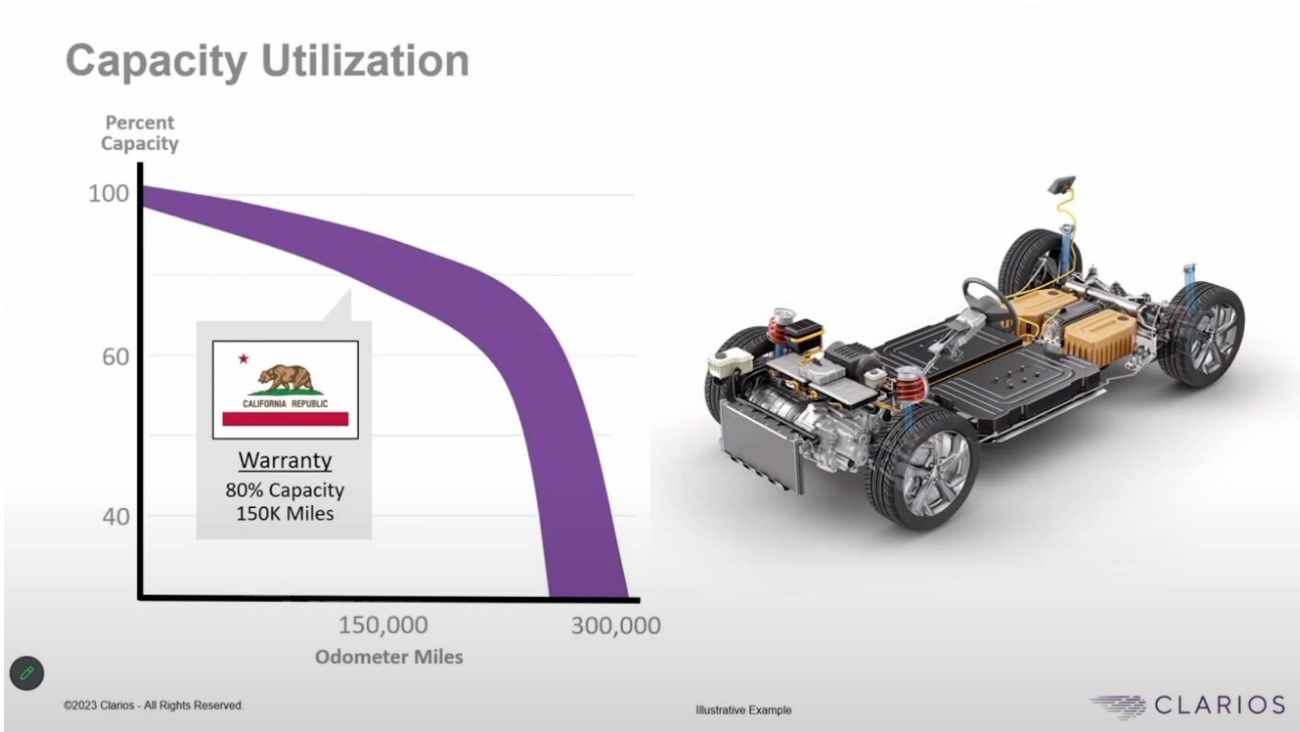
Source: Automotive Recyclers Association
CLARIOS


Capacity Utilization
Percent Capacity
100
60
40
CALIFORNIA REPUBLIC
Warranty
80% Capacity
150K Miles
150,000
300,000
Odometer Miles
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Illustrative Example
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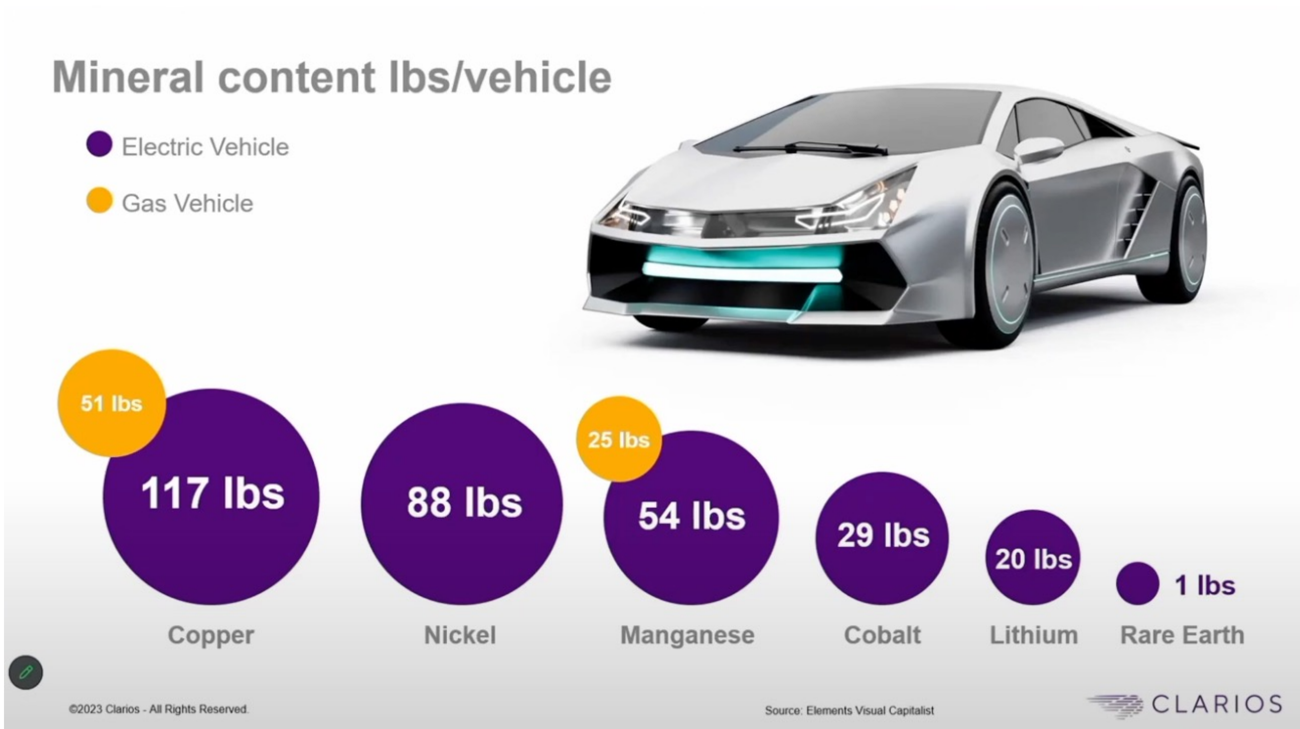
Mineral content lbs/vehicle
Electric Vehicle
Gas Vehicle
51 lbs
117 lbs
Copper
88 lbs
Nickel
25 lbs
54 lbs
Manganese
29 lbs
Cobalt
20 lbs
Lithium
1 lbs
Rare Earth
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Source: Elements Visual Capitalist
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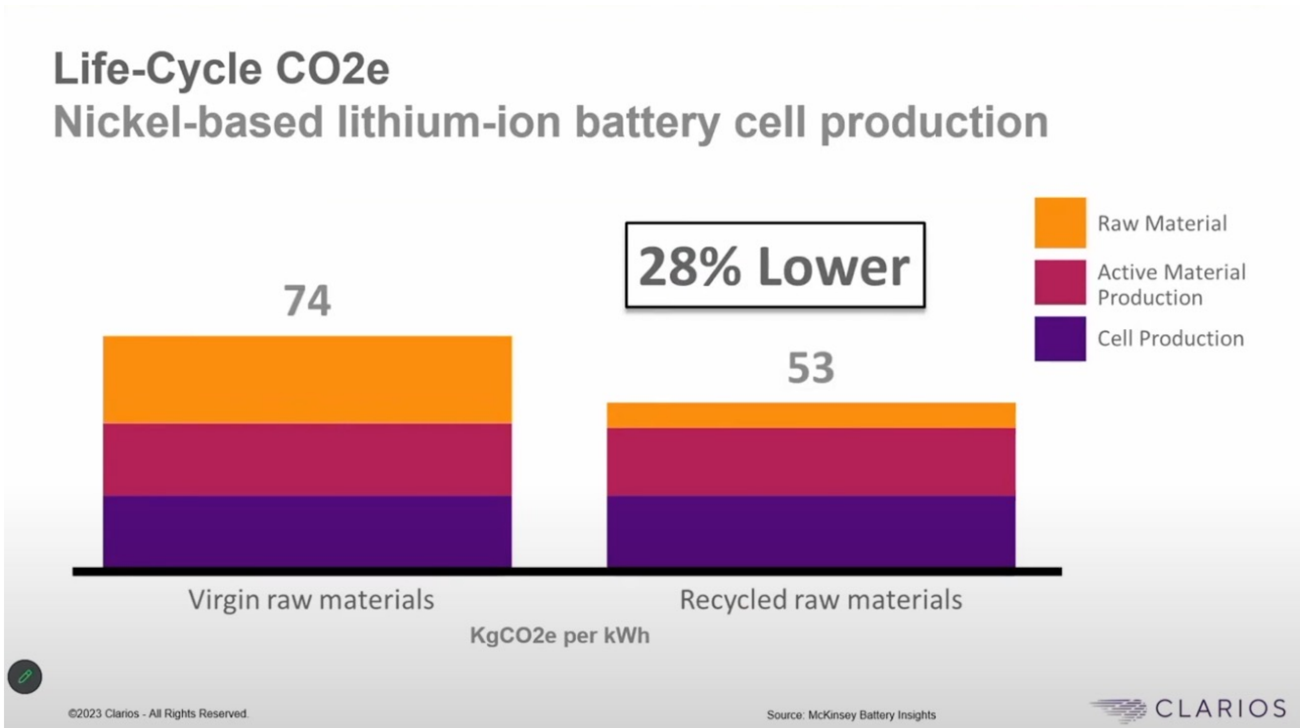
Life-Cycle CO2e
Nickel-based lithium-ion battery cell production
28% Lower
74
53
Raw Material
Active Material Production
Cell Production
Virgin raw materials
Recycled raw materials
KgCO2e per kWh
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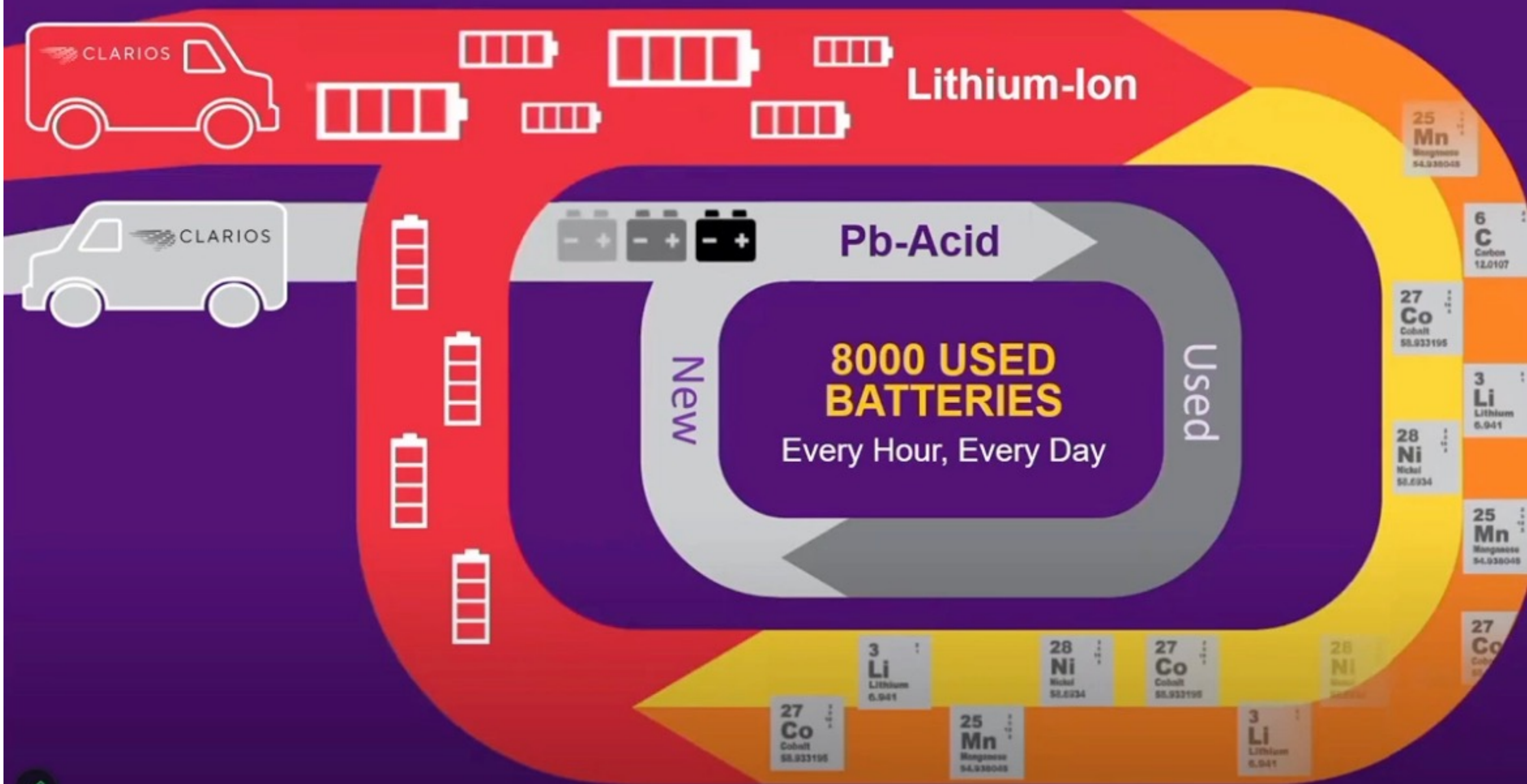
Source: McKinsey Battery Insights
CLARIOS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Lithium-Ion
Pb-Acid
New
Used
8000 USED BATTERIES
Every Hour, Every Day

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Responsible Battery Coalition®

GLOBAL BATTERY ALLIANCE

BATTERIES POWERING SUSTAINABLE DEVELOPMENT

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From most recycled
to most circular

[Are EVs more circular that ICEs?]