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ALUMINIUM, RECYCLING AND TRANSPORTATION

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ABSTRACT

Transportation is the largest market for the aluminium industry. Lightweighting, recyclability and rapidly escalating energy and fuel costs are further driving the adoption of light metals in new vehicles. A survey of common aluminium automotive components and their alloys is presented.

Issues relating to aluminium, recycling and transportation explored include:
1. How prompt scrap generation and closed-loop recyclability of prompt scrap is affecting the selection of materials and alloys as well as forming and joining methods for automotive manufacture
2. A sustainable global material recycling system and a sustainable Al recycling system do not require closed-loop recycling of individual products or alloys
3. The need for alloying element and impurity management in the Al recycling system
4. Effect of different recycling regulatory regimes in the European Union (EU) and North American (NA)

The globalisation of automotive manufacturing and the shift of metal production and the manufacturing base from Europe and North America to the developing world affect the demand for Al scrap and thus for Al recycling. The life cycle of automotive Al is followed in NA, EU 15 and in new EU members, as used automobiles are exported, scrapped, de-polluted, stripped of reusable components and shredded to liberate the materials, and as the aluminium is sorted out and recycled. Current status and development of various scrap upgrading techniques is presented. Finally the effect of the substances of concern on the material recycling system is explored.

1. REDUCE! REUSE! RECYCLE!

For a generation “REDUCE! REUSE! RECYCLE!” was the rallying cry for environmental sustainability. These 3 Rs are always presented in order of importance, and their importance is readily acknowledged. However, applying the 3Rs to the end-of-life vehicles (ELV) and the systems for dealing with them generates a number of paradoxes.

REDUCE

Reducing the environmental lifetime footprint of a vehicle is the most important, universally accepted goal. Fuel energy savings, obtainable through vehicle downsizing and lightweighting, impact CO_2 emissions, global warming, and resource conservation much more than total recycling of all materials in the automobile. In 1975 the US established Corporate Average Fuel Economy (CAFE) standards for passenger cars and light trucks in an effort to double new car fuel economy by model year 1985. However, the response of many North American (NA) consumers was to switch to large vans and pickup trucks not covered by these standards.

Such consumer material greed is spreading. The EU 15 is now EU 25, making it easier for another 100 million Eastern Europeans to join the consumer rat race. Many of them are busy trading in their four-cylinder Ladas and Skodas for six-cylinder used BMWs and Mercedes. The leaders in this race, however, are the 1.5 billion Chinese and 1 billion Indians. All major automotive companies are building car assembly plants in both countries; Japanese, European and American parts suppliers have rushed to supply technology and investment to build a supply chain that last year converted steel, aluminium, magnesium and plastics into over five million vehicles in China and another million in India. This, combined with the Japanese and Korean total production of 14 million vehicles, already surpasses NA or EU vehicle production. At present it’s Asia that holds the title as the largest auto manufacturer – and the lowest cost and largest volume producer of steel, aluminium, magnesium and zinc. REDUCE doesn’t seem to be any more important for Asia’s nouveau riche than for North American or European consumers. Tata in India is building full-size Safari SUVs for the domestic market and GM Hummers are being imported into Beijing.

REUSE

ELVs are collected by dismantlers for the re-manufacture and reuse of parts that extend the useful lifetime of the vehicle fleet currently on the road. Reuse recovers the value of the components. Used or re-manufactured parts stripped from a 2000 VW Golf hulk are sold back to the customer for a total of well over 10,000 €, which is probably more than the car’s new price in 2000. Parts for older models are even more expensive. In practice, not all the reusable parts are removed from each vehicle. Industry computer databases can track the demand for used parts by year, make and model and the dismantlers remove only the parts that can be sold (at a profit). Used components provide a large enough margin to pay for collection, dismantling, de-pollution, repair and re-manufacture. In NA ~12,000 dismantlers are feeding an industry of over 75,000 re-manufacturers, machine shops, and auto service and repair garages. Auto manufacturers participate in this industry through the service departments of their dealer networks, which supply OEMs and re-manufacturers with parts removed during servicing. In servicing the global fleet of more than half a billion vehicles, the reuse-remanufacturing industry has an enormous impact on extending vehicle life and thus preserving environmental resources. However, since long vehicle life impacts negatively on the profits of auto and original equipment manufacturers, reuse tends to get little publicity and hence attention from the public or the regulators – even though its globally distributed economic impact outweighs that of the concentrations of car assembly plants.

For complex assembles like automobiles, the cost of disassembly exceeds the materials value of recovered components. Hence disassembly is limited to removal of parts for reuse and to de-pollution, unless it is mandated by regulation. Car hulks, first stripped of marketable used parts, must be de-polluted by the dismantler before being flattened for shipment to material recycling plants. Any dismantled parts not saleable in the after market or rejected by re-manufacturers, are also crushed and baled separately by scrap category for shipment to material recyclers.

RECYCLE

Post-consumer recycling really starts when flattened hulks and crushed baled parts are sent to the recycler. The recycler separates the commingled materials and renders them suitable for reprocessing into a new generation of materials and makes the residue inert and safe for disposal.

For vehicles, recycling is the “R” that has the smallest impact on both their environmental footprint and on global economics, yet this R attracts the largest amount of publicity and regulatory attention.

At a value of 150€ per hulk for shredded scrap concentrate, the 10,000,000 hulks (de-polluted and stripped of re-usable parts) generated each year in EU provide 1.5 billion € per year as a vehicle contribution to the EU scrap-shredding and material-recovery industry. In NA, such an amount fuels a self-sustaining market-driven recycling system. In EU, the de-pollution, treatment and disposal fees enable the operation of technologies that otherwise would not make any economic sense.

But what is recycling? Recyclability, recycled content, recycling rate, recycling, recovery and residue disposal all come into play.

Recyclability

Recyclability refers to the potential of a given product to be recycled. The US Federal Trade Commission (FTC) and EU ELV directive prescribe different theoretical calculations of recyclability. The FTC number is the percentage by weight of the material that is currently being recycled, which includes metals, fluids (less fuel), and batteries. The EU guidelines include the FTC-listed materials, plus fuel (counted as 90% of a full tank), plastics that could be recycled, and up to 10% of the vehicle weight for energy recovery. These idealized calculations do not take into account material losses in the recycling process due to the size reduction, incomplete separation, melt losses or chemical degradation. They also do not consider if there is a market for the recyclables. In municipal waste recycling, there are many examples of theoretically recyclable plastics being segregated and collected, only to be later landfilled as no infrastructure for reprocessing the material existed and there were no markets for the recycled product. Automobile tires, for example, continue to accumulate in significant amounts, even though the majority of scrapped tires is burned as tire-derived fuel and there is well-developed technology for producing tire chips and crumb rubber and potential markets that theoretically could consume the whole recycled supply. The FTC and EU recyclability numbers do not reflect or measure the actual recycling that takes place.

The EU directive targets 85% material recycling plus energy recovery from an additional 10% of vehicle weight by 2015. This would require 85% recyclability and 95% recyclability or recoverability for all new vehicles. Such specific targets have undesirable side effects. This could prevent lightweighting of a vehicle by substitution of Al or Mg for steel. Since both Al and steel are fully recyclable, one would expect no interference from the directive, yet when US FTC and EU recyclability calculations were applied to the Toyota Pirus for steel and Al body-in-white (BIW) options, the steel-bodied Pirus satisfied the EU directives, while the Al-bodied option calculation gave lower recyclability numbers. In going from steel to Al, the total weight was lowered by a reduction in the recyclable portion, leading to an overall reduction in the calculated "recyclability." What is the long-term effect? The efforts for lightweighting and reductions in vehicle fuel consumption are stifled. There is absolutely no effect on real recycling since the same non-recyclables need to be disposed of for both options.

A better way to view recyclability is: the total market volume of potential options for scrap of a given composition – the purer the scrap, the more of it can be sold to batch various alloy compositions. Pure metal from primary smelters can be considered the most recyclable metal composition. However, when there is no market for the secondary material, the recycling system is not sustainable and the scrap has to be considered non-recyclable.

Recycled Content

Recycled content depends on the compositions of the desired alloy and of the scrap. Higher element concentrations in the alloy permit use of more scrap. If the scrap is purer than the alloy, then it can be batched from 100% scrap. Some alloys are specifically designed to be batched with high recycled contents. For aluminium alloys, the three most common examples are:

- 380 series foundry alloys: an average composition of today's scrap mix of all common alloys
- 3105 painted sheet alloy: an average of low copper and zinc wrought alloy mix
- 3004/3104 can body alloy: a prime diluted composition of can body and can lid mix.

Combined global shipments of these alloys and their variants are ~ 10 million tonnes creating a market for the recycled content in these alloys that exceeds the global supply of manufacturing and post-consumer Al scrap. Their compositions are given in Table 3 and more details are available from http://www.matweb.com.

Recycling rate and fraction recycled are ill-defined, nebulous concepts when applied to a class of long-lifetime post-consumer products like vehicles. While there are statistics on the number of ELVs processed, vehicle lifetime statistics are uncertain. In NA, many no-longer-registered vehicles are not immediately scrapped and spend years in backyards and farm fields, and later in dismantling yards. These are not disposed of, they are just retired and join the growing pool of reusable and recyclable materials in consumers' hands. The number of vehicles available for recycling is unknown, and thus the fraction of the number of available ELVs actually recycled, i.e. the recycling rate, cannot be determined.

Fraction Recycled

Fraction recycled is the weight fraction of the recycled ELVs that ends up in recycled products. This can be determined during a recycling process test by a material mass balance. Unfortunately, it is impractical to operate the entire recycling system in a mass balance test mode

at all times. An occasional test will demonstrate the recyclability potential of the best recycling process in the high-recovery test mode. This will have little relation to the material losses from the small shredders or scrap processors who optimise their processes for high throughput and high product grade to maximize profits. A better measure of fraction recycled would be:
(weight recycled)/(weight recycled + loss to the landfill)

The weight recycled is known from the recycling plant output, and the loss to the landfill can, and should, be statistically monitored for all landfills by sampling the residue shipped there.

Recycling

Recycling, the act of material recovery from scrap, depends on the existence of a complete recycling system. This includes legislation, regulation, education, collection, technology, and, finally, a market for all types of recovered scrap. All these components need to be present for an efficient recycling system.

Recovery

EU waste directives draw the line at conversion of waste into fuel when defining recycling. If heat/energy is the only useful output from waste treatment, the EU defines that as recovery. EU values it less than recycling. By 2015, the ELV directive will allow 10% of ELV weight to be burned to recover heat. Burning waste to generate heat is equivalent to burning fuel. Therefore, the economic value of the energy generated by combustion is that of the fuel that would generate the same heat output. EU regulators, however, prefer to support complex pyrolysis and hydrocracking plants to convert SR into fuel oil instead of concentrating on efficient combustion and emission controls for cement kilns and waste-to-energy plants.

The EU use of the term recovery to mean generation of heat is confusing. This term is more generally used in chemistry and industry to designate component yield defined as: weight of the component reporting to the product divided by the component weight in the feed stream of any separation step. Hence, generally, reference to “recovered plastic” does NOT imply that the plastic was burned.

Waste Disposal

Both EPA and EU regulators consider anything that crosses the fence of a landfill as being disposed of and not recovered. This includes alternative daily landfill cover (ADLC). Required daily cover consists of a ~20 cm layer of dimensionally stable, inert, water permeable material for every 2 m of municipal solid waste (MSW) infill (10% of landfill volume). In the US, daily cover requires hauling ~15 million tonnes of sandy soil to the landfill or an alternative daily landfill cover. SR has been long approved as an ADLC in the US Even if all of the US SR were used as ADLC, it could supply only 2.5 million tonnes or 15% of the daily cover required by EPA regulations.

As ADLC replaces the cover layer, it does not take up volume reserved for infill waste. Also, it saves the landfill operator the costs of digging and hauling sandy soil to the landfill. An even greater value is its use in control of disease vectors – rodents and birds that feed on MSW. In spite of these advantages, ADLC does not qualify as a value-added product, even though the materials it replaces (sand or tarps) do qualify. Other landfill construction materials such as clay and geotextiles are not classified as disposed-of waste.

The ELVs contribution to shredder residue disposed in EU contains little metal and only about 1,000,000 tonnes/year of plastics and rubber. This pales in comparison with 13,000,000 tons of plastic used for packaging, and 5,000,000 in electrical and electronic waste, and 3,000,000 in demolition waste. Clearly increasing the 15% plastic packaging recycling rate by 10%, a reasonable goal for EU, has more impact than complete recycling of all plastics from vehicles. The US is even more wasteful, SR also contains 1 million tonnes of plastic and rubber, but landfills receive 30 million tonnes of plastics and rubber while recovering only a dismal 5%. Technically, an increase in plastics recycling from MSW is an easier task than from SR because a much larger fraction of MSW plastic is mono-material, while the majority of plastics in SR are usually filled or reinforced and contain fire retardants.

2. Al SCRAP VALUE

Recycling for material recovery captures the value of the material in which it re-enters the production stream. Aluminium recovered as oxide from dross could replace bauxite in the Bayer process, recovering the cost of bauxite mining and red-mud disposal. Recycled secondary ingot, when it replaces prime in alloy batch formulation (whenever scrap is in short supply), has a value near the cost of prime metal. Good portions of sheet recovered from scrap coil and used as sheet retain the value of the rolling, heat treating and finishing, which usually doubles the prime value. More often prompt/home scrap is remelted and only the metal value is recovered. The large difference in the value of semi-products and prime ingot gives significant economic advantage to production and manufacturing methods that generate little scrap. Net-shape casting/finish machining usually produces less process scrap than extrusion/hydroforming, which in turn gives less scrap than sheet blanking/stamping/trimming. Sheet process and manufacturing scrap can match or even exceed the finished component weight. Thus, the manufacturer purchases sheet twice the weight of product, at a cost of twice the prime price. The manufacturer gets credit for a weight of scrap equal to the weight of product, priced at discount to prime – a significant consideration when choosing among materials, alloys and forming methods.

In all but the most exotic Al alloys, the value of the alloy is dominated by the cost of prime, there is usually only a little difference in ingot value that depends on the alloy composition. Therefore, at a re-melt/billet/sheet ingot casting plant, it is often more practical to combine scrap from several alloys to batch another alloy with the widest composition limits rather than try to recycle each type of scrap back into the same alloy.

As the markets for secondary products made with secondary foundry, and sheet alloys expanded to include engine components, beverage can and house siding, post-consumer Al scrap is now in short supply and high demand. Secondary foundry ingot sells near the price of much less alloyed prime wrought alloys. This exposes the fallacy of the desirability of maximizing scrap destination in the following widely publicized recycling hierarchy:

1. recycle to a similar application (closed loop: wrought to wrought)
2. recycle to a less demanding application (wrought to cast)
3. recycle to a precursor ($Al(OH)_3$)
4. use as a reactant (Al deoxidant, thermite)
5. recover energy content (in WTE combustion)
6. landfill

In the case of metals, nearly all recycling involves batching an alloy melt from a number of available scrap categories, prime and hardeners. The Al market values all alloys at a similar price, because they all use some prime in the batch formulations. At the stage of intermediate scrap products, there are some differences. Baled mixed old scrap can be bought from a junkyard at a discount of ~1 €/kg to prime. Alloy-segregated manufacturing scrap costs ~0.15 €/kg more than mixed old scrap because secondary smelters have the option of closed-loop batching the segregated scrap into the same alloy, using it to sweeten a secondary Al alloy, or using it as a hardener for batching another alloy from primary Al. Secondary smelters blend the various scraps in appropriate proportions to minimize the prime diluent requirement for the alloy batch. The way secondary smelters maximize profit is to put the lowest grade scrap in the alloy with the widest composition limits in a value-added application, rather than upgrading the scrap to make it compatible with alloys with tight composition limits.

Secondary smelters, however, value a secure supply, consistency and ease of handling more than high purity. They pay a premium for clean, shredded mixed-alloy Al recovered from shredder nonmagnetic metal concentrate over alloy-segregated scrap. Shredded Al scrap usually sells just about at the alloy ingot price, less the costs of melting, alloying and casting.

As long as there is a scrap shortage, and continued demand for highly alloyed casting alloys, there is no economic incentive to spend resources to segregate scrap by alloy grouping to find alternative markets for Al scrap. On the contrary, it is the few large markets for alloys with wide composition limits that enable the sustainability of the Al recycling system. The prime-based, low- and narrow-composition limit alloys also play a critical role in maintaining this sustainability. Aluminium associations and secondary producers are fond of pointing out that recycled aluminium has the same properties as the same alloy batched from prime. The key caveat is that the recycled alloy meets the same composition and particulate content limits, in spite of the dreaded impurity pickup that leads to an increasing elemental concentration spiral. It is the presence of the higher purity alloys in the scrap that dilutes the alloying and impurity elements and reduces the amount of prime that needs to be in the batch to meet alloy composition targets.

One could consider recycling the Al metal content of shredder fines, sink-float plant water treatment sludge or dross fines by acid leaching and converting the Al metal values to $Al(OH)_3$. However, in such a case this “product” would recycle to the alumina refinery to be purified by the Bayer process together with bauxite. The recovered value would not even cover the cost of shipment of fines or $Al(OH)_3$ solution to an alumina refinery. On the other hand, destructive reactant uses such as steel deoxidants, which are lower in the recycling hierarchy, sell at ~50 €/tonne premium to LME prime.

At least for scrap Al, there is very little correlation between the recycling hierarchy, the environmental impact, and the market value of the product.

3. REQUIREMENTS FOR A SUSTAINABLE Al RECYCLING SYSTEM (Optimised for low cost and maximum profit)

A sustainable Al recycling system, optimised for low cost and maximum profit requires the following:

A low-cost system for ***managing the alloying elements*** in scrap and using these elements to alloy new metal is needed for recycling system sustainability. A sustainable system consumes all available Al scrap. The current alloying element management system consists of source segregation of prompt and manufacturing Al scrap, manual grouping of old Al scrap by type at the junkyard, and recovery of mixed alloy Al scrap from shredder residue. This low-technology system is already sustainable. High-technology solutions for particle sorting of Al scrap and grouping it by alloy family and for particle-by-particle batching of target alloys exist, but await their turn for wide deployment for a time when the supply of low-grade mixed alloy scrap exceeds the demand for secondary alloys, and rising wage rates in Asia make it uneconomic to hand classify the shred.

The scrap source feed needs to contain ***recyclable***, relatively pure PRIME alloys for diluting impurity pickup and allow batching of SECONDARY alloys with high ***recycled content.*** There is no benefit to the recycling system in trying to put recycled content in every item and every component. The real constraint is that the ***markets*** for all scrap-derived products consume all the available scrap.

In separating recyclable materials from scrap, each separation needs to add value, and only a small fraction of the scrap feed can end up as residue, otherwise the processing cost per tonne of output quickly escalates, making recycling uneconomic. Added value of any separated product indicates a market demand for that product. Products should be targeted for existing markets, otherwise a lot of market development will be necessary.

Actual ***recycling*** requires: a complete system of scrap collection + de-pollution, shredding + scrap processing, and remelt + alloying plants and low transportation costs between them + markets for all the secondary products.

Optimisation of the recycling system for low cost is aided by an ***unrestricted flow*** of scrap concentrates and recycled products. An example of flow between geographic regions is low-cost transport of scrap to Asia. This allows the use of low-cost labour for manually intensive sorting and brings scrap metal to this new centre for secondary metal production and product manufacturing. For a current example of flow between markets, Al recovered from shredder concentrate is a mixture of metal from vehicles, buildings, machinery and appliances. Foundry alloys are batched from this shred and segregated manufacturing scrap with no regard for the source industry. This avoids development, capital and operating costs of setting up closed-loop recycling of prime alloys.

Conversely, wrought-cast separation of Al alloys and alloy-sorting technology is already producing 3105 building siding and 3104 can body alloys from the aluminium recovered from auto-shredder metal concentrates. Such a separation will direct 3XXX, 5XXX and 6XXX alloys from automotive scrap into building and packaging products; it will also increase Si, Cu, and Zn content and decrease the Mg content and overall quantity of the shred bound for foundry alloys. This will delay the date when recycling system sustainability considerations will dictate substantial recycled content in some sheet and extruded automotive components. The challenges (i.e. time, costs, risks and cultural shock) associated with the development of a system to produce specification wrought automotive materials with high recycled content are significant. Producers of prime metal and semi-products are in no mood to initiate such development when wrought market penetration is <10% with sluggish increase.

The ability to trade scrap between market segments is not a bonus, it is a necessity – and a current reality. Multiple buyers of scrap-derived product for competing applications make the system robust, as a downturn in one market may coincide with an upturn in another.

Closed-loop recycling within a market segment, an alloy, and especially a product, however, is not a requirement of a sustainable recycling system. Such a practice increases recycling costs and makes the system less able to deal with changing market conditions. Current regulations do not explicitly require closed-loop recycling, but separate EU directives dealing with ELVs, electrical and electronic scrap, municipal waste, and construction and demolition waste, each assigning the responsibility and costs associated with product recycling to the manufacturers, all lean to the used beverage can (UBC) closed-loop recycling model. This is an undesirable development being copied throughout the world.

4. Al AND TRANSPORTATION

Figure 1 shows the vehicle share of global Al consumption, use and recycling. Transportation is already the largest market for the aluminium industry, using ~6 million tonnes in 2004. Shipments of semi-fabricated Al (castings, extrusion and sheet) are well over 9 million tonnes for transportation. The difference is the manufacturing scrap (borings, trim, and skeleton scrap). At ~ 3 million tonnes, that is more than is recovered globally from all ELVs and constitutes ~30% of the semi-product shipments to vehicle component manufacturers, or ~45% of Al used in vehicles. Most of it can be source segregated by alloy enhancing its recyclability. Automotive castings are the base market for the Al secondary industry. These use up ~4 million tonnes of post-consumer and manufacturing Al scrap in secondary foundry alloys. Automotive castings and other secondary alloys are currently consuming Al scrap from all scrap market sources with little need for additional alloy grouping. Eventually, as the largest market and scrap producer, transportation will have to consume the majority of its own scrap in order to sustain the Al recycling system. Alloy grouping will be required once the volume of sheet components exceeds what can be consumed by castings in transportation and other markets. However, the penetration of sheet and extruded aluminium into the transportation market is slower than expected by the Al companies due to material cost premium over steel, higher fabrication and assembly costs for an Al body structure, Al cost fluctuations and increased competition from high-strength (HS) steel, plastics and composites. This slow expansion of sheet and extrusion use in cars, combined with an explosion of new car production in Asia and a concurrent expansion of demand for secondary castings, is delaying the time when alloy grouping will need to be widely implemented.

There is a number of estimates of current aluminium use in an average automobile, for example the EAA breakdown for 1000 kg of a European car is given in Table 1.

Table 1: Average Al content per 1000 kg of a 2004 European car*

System	**Components**	**Al (kg)**
Power unit	Engine & transmission	67
Suspension and chassis	Axels, cradles, subframes, wheels, brakes, arms	30
Body	BIW, hood, doors, decklid, fenders, roof, liftgate	12
Equipment	Seats, bumpers, heat exchanger, steering column & wheel, dash board support	18
Total		**125**

* European Aluminum Association – http://www.aluminium.org/

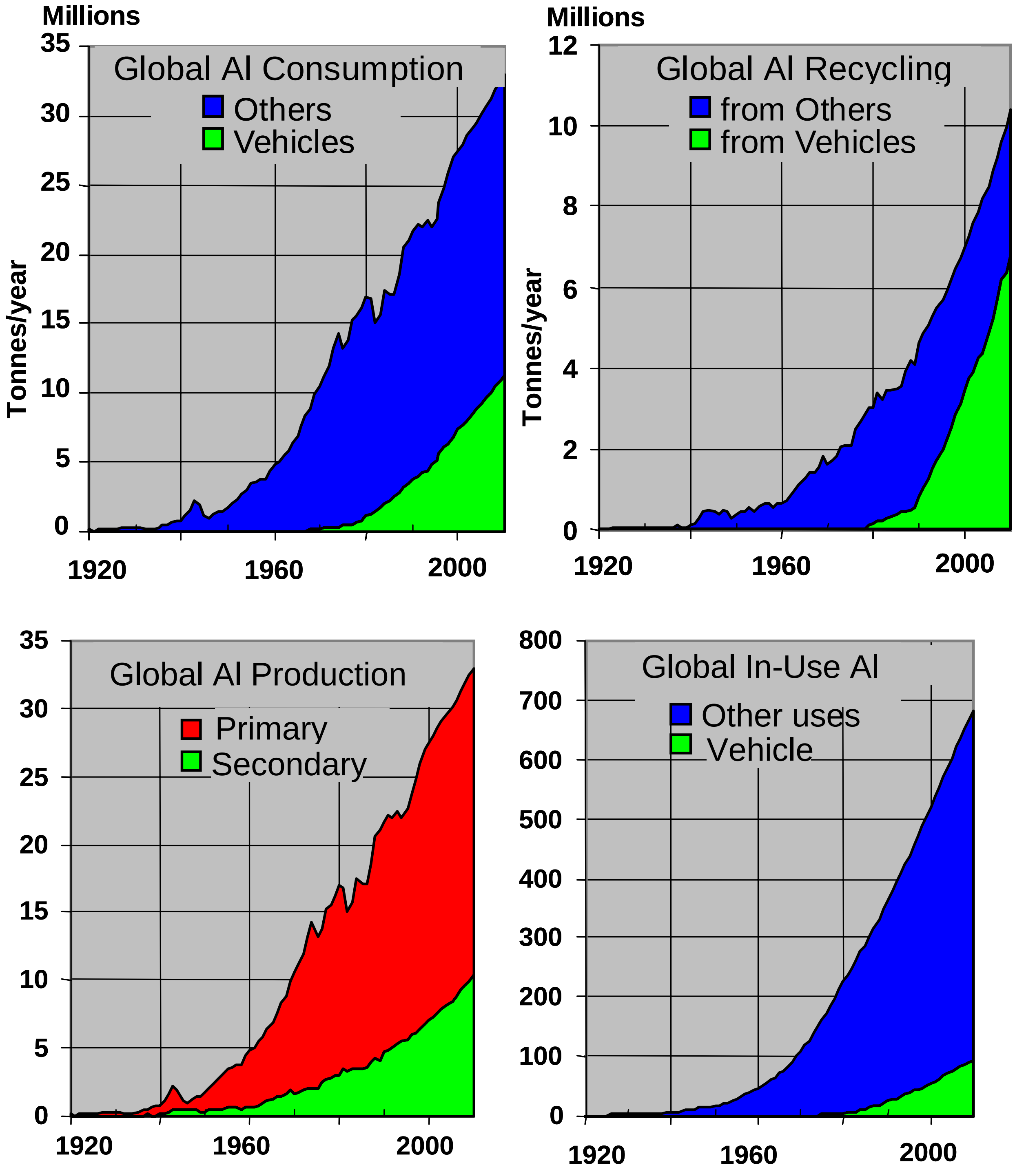

Figure 1: Global Al consumption, production, recycling and the vehicle share of the Al market

For some components, the market share is substantial. The uses are pistons, heat exchangers, engine blocks, and wheels. This compilation is useful in predicting the quantity of Al metal that will be available for recycling in 10-15 years. More detailed information is given in Table 2, which compiles the typical alloys for each application and the typical weight of Al in each component. The Audi A2 and A8 give a good idea of the upper limits of Al usage in a small and large car, respectively 258 kg and 546 kg. Table 3 gives the maximum concentration limit for the major alloying elements in common automotive alloys. Armed with this type of information, it is possible to consider strategies for impurity and alloying element management in the Al recycling system dominated by the transportation sector.

Table 2: Aluminium automotive components

Component	**AA Alloy(s)**	**Forming Tech.**	**Typ. Weight**
Al intensive car**			**1003 kg**
Motor**			**178 kg**
Drive train**			**58 kg**
Engine block	380, 383, 384	cast	15-30 kg
Transmission housing			10-15 kg
Differential housing			5-10 kg
Intake manifold			5-10 kg
Engine head Crank case	319, 356	cast	10-20 kg
Pistons	High alloy 12-22Si	cast	300-500 g
Bumpers	6061, 7003, 7108, 7029	extruded	3-5 kg
Radiators, oil coolers	(1100, 3003) + 4147	brazed sheet	1-2 kg
Chassis**			**222 kg**
Wheels	A356.2	cast	5-8 kg
	5754	stamped plate	
	6061/6082	forged	
Suspension, chassis, wishbones control arms subframes	356 EN AC-AlMg5Si2Mn	cast	wishbone 2-3 kg subframe 12-17 kg axel 6-11 kg contr.arm 3-4 kg
	6082	extruded/forged	
Body**			**338 kg**
Closures, skin sheet inner stiffeners	6016, 6022, 6111	stamped sheet	fenders 2-3 kg/m^2
			hood & trunk lid 7-12 kg 4.8 kg/m2
	5052, 5182, 5754, 6111, 6181		liftgate 10-13 kg door 11-15 kg
Body structure 200-300 parts	5182, 5754	stamped sheet	150-250 kg total
	6061, 6082	extruded & hydroformed	
	356 EN AC-AlMg5Si2Mn*	cast	
Interior**			**149 kg**
Seats	5454, 5754	stamped sheet	Front 6-8 kg Back 13-18 kg
	6061, 6082	extruded	

*EN AC-51400, ** Including non-Al components

Table 3: American Aluminum Association maximum concentration limits of common automotive alloys and key secondary alloys in other major Al markets*

AA Alloy	**Si**	**Cu**	**Mg**	**Mn**	**Zn**	**Fe**	**Other**
Transportation							
A319.0	6.5	4.0	0.1	0.5	3.0	1.0	
356.0	7.5	0.25	0.45	0.35	0.35	0.6	
A356.2	7.5	0.1	0.45	0.005	.005	0.12	
380.0**	**9.5**	**4.0**	**0.1**	**0.5**	**3.0**	**2.0**	
384.0**	**12.0**	**4.5**	**0.1**	**0.5**	**1.0**	**1.0**	**Ni 0.5**
390.0	18.0	5.0	0.65	0.1	0.1	0.5	
1100	0.5	0.2			0.1	0.5	
3003	0.6	0.2		1.5	0.1	0.7	
4032	13.5	1.3	1.3		0.25	1	Ni 1.3
5052	0.25	0.1	2.8	0.1	0.1	0.4	
5454	0.25	0.2	3.0	1.0	0.25	0.4	
5754	0.4	0.1	3.6	0.5	0.2	0.4	
5182	0.2	0.15	5.0	0.5	0.25	0.35	
6008	0.9	0.3	0.7	0.3	0.2	0.35	
6060	0.6	0.1	0.6	0.1	0.15	0.3	
6061	0.8	0.4	1.2	0.15	0.25	0.7	
6022	1.5	0.11	0.7	0.1	0.25	0.2	
6111	1.1	0.9	1.0	0.45	0.15	0.4	
6181A	1.1	0.25	1.0	0.4	0.3	0.5	
6016	1.5	0.2	0.6	0.2	0.2	0.5	
6082	1.3	0.1	1.2	1.0	0.2	0.5	
7003	0.3	0.2	1.0	0.3	6.5	0.35	
7108	0.1		1.4		5.5	0.1	
EN AC-51400DF	2		5	1			
Packaging							
3004/3104**	0.6	0.25	1.3	1.5	0.25	0.8	
Building products							
3105**	0.6	0.3	0.8	0.8	0.4	0.7	

*http://www.matweb.com, **secondary alloys

5. CAR DESIGN AND Al RECYCLING

While it may be imprudent to burden the car designer with the responsibility for recycling of all components of an ELV, there are some simple considerations at the design stage that can make the aluminium recycling system more efficient.

Key structural components should be designed for a maximum property-to-weight ratio to maximize the benefits of lightweighting and lifetime fuel use reductions. This is easiest to achieve with prime alloys. For example, reduce the weight of: AlSi – A356 wheels, AlSiMg – 6061,6082 extrusions, AlZn – 7108, 7003 bumper and structural extrusions, AlMg – 5754 sheet structural stiffeners or AlMn–3003/AlSi-40XX brazed heat exchangers. Prime alloys typically have low impurity element concentrations and thus are a very desirable source of diluent in the shredded scrap mix and help in managing and balancing the alloying elements and impurities in the scrap.

Some high-volume components should be designed for high recycled content to provide the required market for a sustainable recycling system. Engine and transmission castings already can have nearly 100% recycled content, mainly due to the dilution effect of purer scrap alloys from other, often non-automotive components. Structural castings are another desirable example. In the aluminium-intensive vehicle (AIV), there is an increasing use of structural thin-wall castings in suspension components and structural pillars in BIW. Foundry alloys have higher alloying element concentrations and lower formability requirements than stamped sheet components. This allows higher recycled content and provides a continuing market for recycled aluminium. Structural castings are designed to consolidate several joined stamped metal components. This reduces the number of multi-material joints, adhesives, and fasteners. In the future there may be a need to put recycled content into an Al wrought component. 6111 skin sheet is the most promising target application as this is the wrought alloy with widest composition limits for all the common alloying elements.

Alloy selection for both prime and secondary alloys needs to consider eventual recycling. Uni-alloy vehicles are not desirable, but where possible the part count and the number of materials/alloys in any one part should be minimized. Alloys should be chosen from the standard alloy families based on the common alloying elements (Al, AlCu, AlMn, AlSi, AlMg, AlMgSi, and AlZn). Exotic alloying elements should be avoided. Exotic alloys can have enticing properties. For example, the addition of lithium gives high specific stiffness, and tin enables super-plastic forming. However, the concentration limits for these elements in common alloys is <0.05%, and a small number of components with exotic alloying additives can poison the aluminium recycling system. Lithium can be refined out (at a cost), but tin, nickel and other “noble” metals can only be diluted. Alloy designers should work on standardizing the cast structure modifiers in the AlSi foundry alloys. The West uses Sr, Ca, and Na additives, while Asia uses Sb. The systems are incompatible as the combination of additives precipitates out. Millions of Asian-built ELVs are shredded in the West with local ELVs, increasing the treatment costs for secondary foundry alloys.

Auto designers aim at producing stiff strong assemblies that do not come apart while in use. Design for ease of dismantling is, as it should be, far down on the priority list. However, recycling could be facilitated by generation of mono-material pieces on shredding. This can be achieved without sacrificing strength or stiffness by consolidating components and reducing the number of permanent joints between different incompatible materials. Attaching the closure sheet to inner stiffeners by hemming is ideal. Joining incompatible alloys by welding or using self-piercing rivets, however, reduces the yield of wrought alloys on separation from the mixed alloy scrap, thus reducing the value of the Al scrap. Plastic snap fasteners that attach the headliners to the sheet metal are shredder- and recycling-friendly, as they break or unfasten when shredded.

6. ALLOYING ELEMENT AND IMPURITY MANAGEMENT IN THE Al RECYCLING SYSTEM

Without upgrading, the average post-consumer shredded Al scrap chemical composition can be used only in 38X foundry alloy compositions. At present these alloys can consume all the available Al recovered from the post-consumer shredded scrap. Higher strength and ductility automotive casting applications demand purer 319, 356 or 51X alloys that require segregated scrap or prime. These alloys are now batched from process and manufacturing scrap (often of non-automotive origin). Transportation market share of the higher purity foundry alloys and of the prime wrought alloys is increasing and it is predicted that sometime in the future, the 38X alloy market will be to small to accept all the Al recovered from post-consumer shredded scrap.

In the future, post-consumer Al shred will need to be grouped so that it can be batched into other product alloys (diluted with prime or segregated prompt scrap). Composition correlated particle grouping and dilution/hardening with metal of known composition are the most cost-effective methods of impurity management. Currently global prime metal production is over 30,000,000 tonnes while recycling recovers 7-8 million tonnes of manufacturing and post-consumer Al scrap that is traded on a scrap market. This gives ~ 4:1 possible dilution ratio of scrap with prime. This is sufficient for many years, especially when combined with alloy grouping by particle sorting. In-house remelt, prompt semi-production and manufacturing scrap streams illustrated in Figure 2 combine to be larger than the post-consumer scrap flow. These prompt-scrap recycling loops have a significant impact on the relative economics of the materials competing for the various applications. Their impact is through the increase of the effective energy requirement and the melt losses associated with production of the final finished weight of the Al component. For example, near-net-shape casting gives foundry alloys a significant advantage over stamped sheet alloy components, which generate scrap at direct chill ingot casting, hot and cold rolling, blanking, and stamping stages. During production and component manufacture, the alloys are known, and it is usually feasible to maintain source segregation of the scrap by alloy. Source segregation is always less expensive than subsequent sorting of the combined scrap mix. Source segregation of prompt scrap is pretty universally practiced in semi-production facilities – rolling mills, extrusion presses and foundries. Source segregation of scrap by alloy in product manufacturing is much more rare and much of the manufacturing scrap is sold commingled on the scrap market. The exception is skeleton blanking scrap at the stamping plants, where it is now becoming more common for the rolling plant remelt to buy back the scrap.

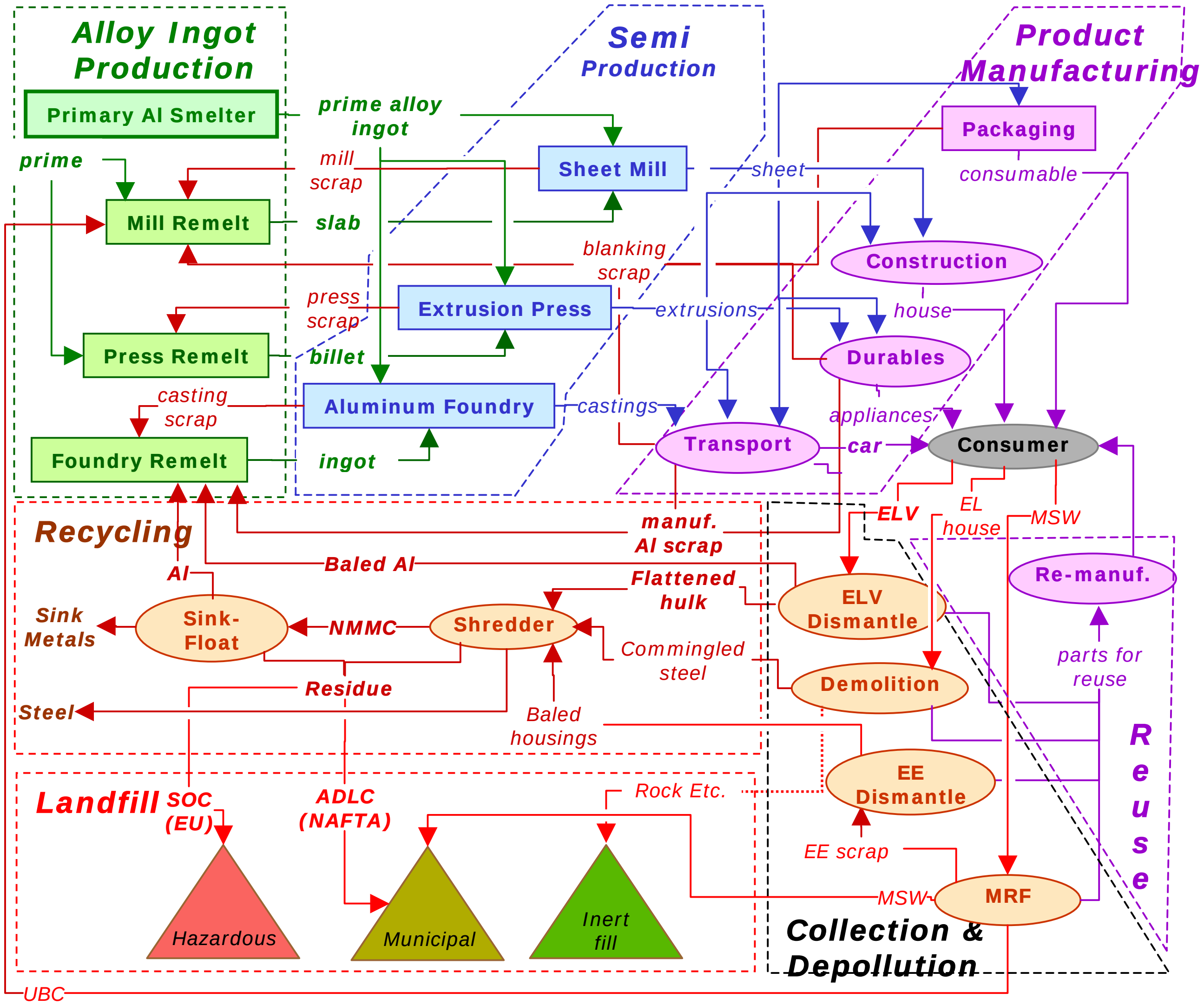

Figure 2: Scrap Flows in the Al Production and Reuse and Recycling

7. CURRENT INTEGRATED MATERIAL RECYCLING SYSTEM

Figure 2 summarises the Al portion of the current integrated material production, product manufacturing, use, reuse, de-pollution and recycling system. In terms of volume, Al is a small fraction of the system. Steel, plastics, building construction materials, are all produced in larger volumes and combine into complex assemblies. These are nearly always composed of several materials and more variants – alloys, resins, fillers/reinforcements, additives. The aluminium components are usually a minor fraction of the final assembled vehicle, building, machine, or packaged product. Just as assembly and construction must deal with all the component materials, so does post-consumer disassembly and recycling. Whereas the recycling of production and manufacturing scrap can concentrate on a few known aluminium alloys, the post-consumer recycling system must, as it is already set up to do, process and recycle all the commingled material components of the end-of-life durables, vehicles, and buildings.

There is specialization in the collection and de-pollution part of the cycle because there are completely different reuse/re-manufacture markets for buildings, electronics and vehicles.

However, when material recycling comes into play, the comparatively lower recovered material value limits the amount of economically justified disassembly.

After being de-polluted and stripped of spare parts by a dismantler in a junkyard, vehicle hulks are flattened, and unusable dismantled parts and collected scrap are baled according to ISRI scrap categories for ease of transport to the material recycler. Metal containing commingled scrap is sent to a steel shredder, while bales of segregated metal may be sold directly to remelt facilities. UBC and mixed-low-copper bales go to the remelts at sheet ingot cast houses; press scrap and alloy-segregated extrusions go to remelts feeding extrusion billet casters; and any more highly alloyed or mixed-alloy categories go to remelts casting foundry alloy ingots. Vehicle hulks and any other scrap that contains commingled materials is shipped to steel shredders equipped with hammer mills, often referred to as auto shredders.

Hammer mill shredders are designed for processing various types of steel scrap. They shred any metal-containing item or debris regardless of the source of the scrap bundle. ELV hulks are frequently a minor fraction of the shredder feed. Consistency of the steel product is the most important product quality and economic consideration for the shredder. This is frequently achieved by concurrently feeding the shredder a mix of various types of scrap materials. Segregation of the feed to achieve desired scrap material concentrations in the nonmagnetic and nonmetal concentrates has been repeatedly suggested by the downstream processors of the shredder residue, but this seldom makes any economic sense to the shredder as it tends to impact negatively on the consistency of the steel product.

Only a minor fraction of the total recycled aluminium passes through the shredders. Globally, approximately 2.5 million tonnes of Al is recovered from the shred. This compares with and is included in 7~8 million tonnes of post-consumer and manufacturing Al scrap traded by the brokers, and over 20 million tonnes of in-house casting, prompt semi-fabrication and take-back manufacturing scrap.

The shredder’s main product by weight is steel, but the nonferrous metal content is also economically important. Currently, the value of Al in an ELV, as secondary ingot, matches that of steel. With increasing light metal content of the automobile, light metal value will soon dominate the economics of material recovery from shred. There is as much plastic and rubber in a new car as light metal. The potential value of the plastics sorted out of vehicle scrap is set by the value of the virgin resins they would replace, with prices nearly at par with those of light metals. However, to realize that value, markets for secondary plastics need to be further expanded. Plastics recycling has to deal with a more complicated case of “substances of concern” (SOC), which include PCBs and brominated fire retardants (BFR) (see section 9.)

The North American post-consumer metal recycling industry consists of more than 10,000 scrap collection and dismantling yards, about 200 scrap shredders, close to 10 sink-float plants, and one aluminium sorter (Huron Valley Steel Corp.). Collection is widely distributed in individual localities. This layer is controlled by small, usually family-run, enterprises. The decreasing number of plants in the sequence reflect the removal of the recycled materials from the shrinking mixed recyclable stream and the highly mechanized, productive shredding, material separation (sink-float) and scrap-sorting plants (see Table 5). The material volume is steadily reduced as the de-polluted vehicle hulks stripped of reusable parts are flattened, transported to shredders, and converted to fist-sized pieces. Shredders recover steel and may skim off a portion of aluminium with an eddy current separator. They in turn sell the nonmagnetic metal concentrate to sink-float plants to float aluminium and sink metals and separate both from fines and nonmetallic particles.

Al is mainly marketed to NA secondary Al smelters, while mixed sink metals are put in shipping containers and exported to China and India for manual sorting. Huron Valley Steel in the US and Galoo in EU each have a nonmagnetic metal sorting plant capable of separating Al, Mg, Cu, Zn, brass, stainless steel, and lead—a highly mechanized and highly productive system. However, it is currently more profitable to sell the mixed sink metals to Asia for hand sorting there than to sort the sink metals and market the products in North America.

In 2004 NA shredders processed ~20 million tonnes of ELV hulks. They and downstream processors recovered ~15 million tonnes of steel, ~1 million tonnes of Al and ~0.5 million tonnes of other nonferrous metals from the ELV hulks. The ELV-sourced portion of SR totalled ~2.5 million tonnes, containing ~1 million tonnes of plastic and rubber and was mainly used in municipal landfills as ADLC. To put that in perspective: The municipal solid waste landfilled in 1750 landfills in US totalled 164 million tons in 2003. It included: no ELV hulks, 16 million tons of consumer durables (mainly electrical appliances and electronics), 31 million tons of plastic and rubber, 9 million tons of steel and 2.5 million tons of Al, including 1.4 million tons of Al cans. (US produced 2.5 million tons of prime Al in 2004). The ELV SR plastic and rubber contribution is only 3% of the plastic and rubber in MSW and 0.6% of the MSW. In 2003, 5% of the MSW plastics were recycled (mainly as plastic bottles: PET 25% and HDPE 31%). The point to all these statistics:

1. US throws out as much Al as it produces.
2. US throws out more Al beer cans than there are plastics in shredder residue.
3. The value of steel, aluminium and plastics that are produced just to replace what was discarded in US MSW is ~US$40 billion.
4. The value of these materials as recovered scrap products is ~US $16 billion, that is ~US $100/tonne of MSW.

Those are big numbers that should be able to economically justify a substantial increase in recovery of recyclables from MSW. The SR is an insignificant portion of the total problem; it serves a useful function in a landfill as daily cover and is technically and economically a very difficult fraction to recycle. In NA, market drive will dictate a solution that will involve recovering more of the easiest and/or most profitable waste components – metals, compostables, wood, paper, and glass and plastic containers

first and then piggy-backing the more challenging separations into the MSW processing plants. Once the material components in waste are liberated and sized to enable recovery of profitable components, the incremental cost to attempt more challenging separations such as sorting and recovering plastics from the mixed shred may be economically justifiable. Table 4 demonstrates that, under the current NA system, there is no economic incentive for such recovery if the recovery of plastics and rubber results in having to dispose of the residue in a hazardous waste landfill.

Table 4. Scrap Material Value Per Tonne of ELV

	kg	IN SHREDDER CONCENTRATE		AS REPLACEMENT MATERIAL	
		€/kg	€	€/kg	€
Metal recovery only					
Ferrous metals	700	0.20	140	0.30	210
Aluminium & nonferrous	60	0.75	45	1.50	120
Plastics & inorganic residue NA	240	(0.01)	(2)		(2)
Total NA	1000		183		328
Plastics & inorganic residue EU	240	(0.25)	(60)		(60)
Total EU	1000		125		270
With plastics & rubber recovery					
Recycled as plastic	80	0.30	24	1.50	120
Recycled as fuel	80	(0)		0.25	20
Rust & inorganic residue	80	(0.25)	(20)		(20)
Total	1000		189		450

In Europe there is a similar recycling industry structure with the addition of a more vertically integrated ownership, and regulations through EU directives that cover separately packaging and municipal waste, electrical and electronic waste, construction and demolition waste, and ELVs. In each of these areas, responsibility is placed on the manufacturers to design recyclable products and take responsibility for their recycling. These regulations tend to artificially generate separate parallel recycling systems because vehicle manufacturers do not want to be responsible for complications of C&D or EEE wastes and volume of MSW.

Table 4. further demonstrates that in EU, where SR is banned from municipal landfills, the production of plastic and RDF precursor concentrates at the shredder could increase the value of shredder products by 64 €/tonne or ~50% – a potentially economically worthwhile project.

The life cycle of the aluminium through this recycling system is completed in a secondary smelter – a remelt plant where scrap is converted into an alloy melt and then shape cast, or cast as foundry alloy ingot, extrusion billet, sheet ingot slab or a continuous strip. The secondary smelters least-cost-batch the alloy composition maximizing the content of the scrap from lowest cost sources and minimizing the amount of prime diluent. Painted scrap such as siding and UBS are decoated, and the borings and turnings are de-oiled to reduce melt losses. Al recovered from nonferrous shredder concentrate typically contains ~15% painted metal that is relatively thick gauge. Much of the paint is chipped or worn off during shredding and downstream segregation. As a result, when this material is continuously fed into a sidewell melter equipped with vortex submergence feed well, significantly higher melt recoveries (~95%) are achieved than when similar scrap is fed as bales into the melter side well. Melt safety is also improved as shredding opens the closed containers that may cause molten metal explosions.

Table 5. Al scrap segregation and upgrading processes

Separation	Process	Products	% of UO Feed	% of Shredder Feed
Fe separation	Magnetic	▪ Steel shred		▪ 55%*
Metal-nonmetal separation	Size screening	▪ <5 mm fines – dirt		▪ 15%*
	Density – air suction/elutriation	▪ Light – fluff ▪ Denser concentrate	▪ 10% ▪ 90%	▪ 3%* ▪ 27%
	Conductivity – eddy current (ECS)	▪ Non metal ▪ Conductive concentrate	▪ 67% ▪ 33%	▪ 15%* ▪ 12%
	Density–sink-float	▪ Non metal ▪ >1 g/cm^3 concentrate	▪ 50% ▪ 50%	▪ 6%* ▪ 6%
Al-other metal separation	Sink-float and ECS	▪ Al ▪ dense metal mix ▪ Nonmetal	▪ 60% ▪ 30% ▪ 10%	▪ 2.4% ▪ 1.2% ▪ 0.4%*
	Jig and ECS	▪ Al grain (>5<10 mm) ▪ Dense metal mix grain ▪ Nonmetal grain	▪ 60% ▪ 30% ▪ 10%	▪ 1.2% ▪ 0.6% ▪ 0.2%
Wrought/Cast Al sort	Particle sorting	▪ Cast Al concentrate ▪ Wrought Al concentrate	▪ 70% ▪ 30%	▪ 2.9%* ▪ 1.3%
Ave. atomic weight sort	Dual energy x-ray absorption based particle sorting	▪ Al+AlMg+AlSi ▪ AlCu+AlZn	▪ 90% ▪ 10%	▪ 1.2%* ▪ 0.1%*
Chemical-composition-based Al alloy batching	Laser-induced breakdown spectroscopy based particle sorting	▪ Targeted Al product batch composition		
Wet density sort	Kinetic density separation	g/cm3 ▪ <1.0 organic (float) ▪ >1<1.75 rubber, plastic ▪ >1.75<2.5 rock, Mg ▪ >2.5<4 Al, rock, ins wire ▪ >4 Cu, Zn, Pb, St. steel		

*Output

This global recycling system description still does not reflect the additional geographical and geopolitical constraints and does not follow the cars through this maze.

The new automobile is first leased or purchased. After 3~4 years it enters a used car market coming off the lease or helped by an inducement of an expensive re-qualification inspection in Japan. If used cars were not exported, there would be no effect on the global life cycle. However, convoluted customs regulations dictate a very specific migration route for a significant fraction of the used cars. The countries with large new car production capacity either ban or impose high custom duties on used car imports. Countries with no significant car industry buy up the used cars. Used cars from Japan migrate to the Asian mainland, while Western European used cars go to the Middle East and Eastern Europe. The break-up of the USSR and acceptance of Eastern Europe into the EU could open the floodgates to used car imports into this region. In a short time span, the Ladas, Skodas, Trabants, Czajkas, etc., may be replaced by used VWs, Audis, Opels, Volvos, BMWs, and Mercedes. Thus, Western Europe may export a significant portion of its car recycling issues to Eastern Europe and the Middle East in the same way as Japan is exporting its recycling issues to mainland Asia with its used cars. This system makes even more sense when one considers that the infrastructure for repair, remanufacture and reuse of old components is well developed in Eastern Europe.

The burden of SR disposal and the opportunity for profit from resource recovery is being exported from the EU 15 to the new EU partners. The market for used Lada or Skoda parts in the EU 15 does not exist, but in a few years the new EU partners may start to supply used/ remanufactured parts to the EU after market. What is needed there is the infrastructure to deal with the short-term spike in supply of ELVs. They all need to be de-polluted, shredded to liberate the materials, and then separated into steel, nonmagnetic metal concentrate, and nonmetal residue in accordance with the EU ELV directives. There is a good market in Eastern Europe for scrap steel. The generation of cars that will be initially shredded will have low Al content, but should be rich in zinc and copper and there is a high market demand for such a shredded mix.

The shift of the global manufacturing base to Asia brought that area economic growth, wealth and an explosion of domestic Asian markets, producing hunger for energy and resources. Since secondary material sources can save up to 95% of the capital and energy requirements of prime metal production, Indian and Chinese scrap buyers are willing and able to pay premium prices for scrap in the EU and NA markets.

While China and India are encouraging new car production and discouraging used car imports, they are short of raw materials and rich in inexpensive labour. Their regulations, high custom duties on prime and sorted metals, 15% VAT refunds to government licensed scrap importers and artificially low value of the Chinese Yuan, all conspire to give a very significant purchasing advantage to the Asian scrap buyers. They can pay premium prices for mixed nonmagnetic metal concentrate, and for products of sink-float separation: light (Al and Mg) and dense (Zn, Cu, brass, stainless steel) mixtures.

Mixed metal scrap shreds are hand sorted into parent metal categories, and feed Indian and Chinese secondary nonferrous metal industries, which in turn feed their manufacturing plants making goods for export back to EU and NA, closing the global material loop. As the domestic Chinese and Indian markets grow at an explosive rate, the loop is already becoming a one-way drain.

The hand-sorting process for the shredded metal has been mechanized in US and Europe, but in the low-wage, low-capital-investment, incentive-fed Asian climate, hand sorting is at present more economic. This situation is not likely to last long as Chinese wage rates are already rising and the Asian hunger for high tech gadgets is well known.

8. SCRAP PROCESSING TECHNOLOGIES

Dismantling and De-pollution

Parts are removed from ELVs and other consumer durables manually (with power tool assistance). Such dismantling is justified by parts re-build and reuse or by de-pollution. De-pollution removes dangerous/toxic substances such as liquids (e.g. gasoline, oil, coolants, and refrigerants), air bag propellants, and lead batteries. There is a further list of "substances of concern" that are banned from construction of new automobiles that include Cr^{6+}, Hg, Cd, Pb, PCBs. Dismantling of components in ELVs containing these SOC elements/substances is either impractical or not required when they are readily separated from the shred.

Transportation

Transportation is an integral and economically important part of the global recycling system. It links geographically distributed collection and dismantling with shredding and recycling that is geographically concentrated within a continent, and with the intra- or inter- continental transport of recyclable material concentrates and segregated material scrap to downstream scrap concentrate processors or to the secondary re-processors – remelts in the case of Al.

Baling or flattening densifies the scrap to reduce the per-tonne transport costs. De-polluted car hulks are flattened for transport to shredders on flatbed trucks. Flattening terminates any possibility of further dismantling downstream.

Shredding also densifies scrap and allows preparation of various recyclable concentrates with sufficient value to make long-distance transport economic, and to satisfy the Basel Convention, which bans the trans-boundary shipment of wastes for disposal. Shredded scrap concentrates can be handled in bulk and loaded into self-dumping bulk carrier trucks, or standard multi-modal shipping containers. Bulk carriers and re-usable shipping containers have revolutionized long-distance hauling of raw materials and manufacturing goods enabling the development of global markets. Transport vehicles and shipping containers are reusable and all have to complete a round trip after arriving in EU or US loaded with cars or other manufactured goods. Container ships need ballast to maintain stability on stormy seas. Solution? Scrap concentrates, are loaded into the containers and onto the ships. Since the round trip has been pre-paid by the manufactured goods, the trip back for scrap is often cost-free, allowing China and India to buy secondary raw materials in Europe and North America.

Shredding

Hulks are shredded for material recovery in hammer mills designed for shredding low-grade steel scrap. A steel shredder consists of a rotor with 4 rows of swinging ~100-kg hammers spinning on a horizontal axis. A 5,000 – 6,000 kW hydraulic or electric motor drives the rotor. A feed roll forces the steel scrap or a car hulk into the path of swinging hammers and the shredded scrap is discharged through a grate with ~10 cm openings. Such a large shredder snacking on up to three car hulks per minute can output 360,000 tonnes in a year in a single-shift 40-h/week operation.

Shredding is essential for efficient scrap sorting. The process efficiently liberates mono-material pieces from complex assemblies of several material types. Size reduction generates a predictable size and shape of particles enabling efficient mechanized bulk material handling in bins and conveyors. Shredding densifies the product enabling cost-efficient storage and transport of the relatively low-value scrap. Mono-material pieces of uniform size enable mechanical material separations. Dismantling and shredding are complimentary. Even mono-material dismantled parts need to be shredded for cost-efficient handling, storage, transport, and material recovery.

Separation of Al

Separation of Al from the shred is accomplished by first separating the steel on a pair of drum magnets arranged in series. Shredded pieces need to be picked up by both drums to be diverted to the steel product stream, which at that point still contains rust, foam and carpeting. These are cleaned out of the product through air elutriation in a Z-box separator – steel slides down the Z while the fluff is entrained in an air stream and carried off to be dropped out in a cyclone separator.

The dense nonmagnetic fraction contains aluminium and other nonmagnetic metal shred. The shredder feed concentration varies between 0-10 % Al depending on the type of scrap being shredded and which parts were dismantled upstream. Removal of 2/3 of the weight as steel triples the nonmagnetic metal concentration in the residue, but 20-30% metal concentration is still insufficient for economic long-distance transport of the SR to the sink-float plant, which needs only metals. Concentration of metals to 50%~60% can be accomplished with negligible loss of metal yield by screening and eddy current separation. The SR is screened into three size fractions: fines, small and large fractions. Oversize is re-shredded. Fines contain mainly inorganic dirt, sand, pebbles, glass and rust. There is a small proportion of metal and plastic in the fines, but this is too small to consider recovery. The two larger fractions are passed separately over a system of eddy current separators. These are fast rotating multi-pole permanent magnet drums that generate a sinusoidaly varying magnetic field at the headpulley of a wide-belt conveyor on which the shred is distributed in a monolayer. The varying magnetic field induces an electric current in conductive (metal) particles; this generates an induced magnetic field that repels the metal particles over the splitter. The distance that the particle is thrown scales with the ratio of electrical conductivity to density. Thus the Al tends to be thrown the furthest. Some shredders add a second splitter that allows them to collect a portion of Al as product, which can be nearly 100% metal and >95% Al particles. This product can be marketed directly to some secondary smelters that invested in their own Al upgrade circuit. The “over first and under second splitter” fraction can meet the 50-60% metal content target without forcing metal into the SR residue. This fraction is sold and shipped for wet separation at sink-float plants.

The nonmetals, poorly conducting paramagnetic stainless steel and some lead all fall short of the splitter into the SR nonmetallic concentrate. A recent price increase for nickel and thus stainless steel made it economically attractive for shredders to invest in eddy current coil (ECC) sensor particle sorters. These can detect and tell the difference between stainless steel, lead and nonmetal. Selected particles are then deflected out of the SR stream, falling off the conveyor headpulley by a blow bar making a stainless steel shred product.

Sink-float plants consist of a dry upgrade and sizing circuit similar to that at the shredder, followed by sequential separation in three wet separations at fluid densities of 1, 2.2, and 4.5 g/cm^3 respectively. The dense liquids are slurries of magnetite and ferrosilicon. Wood, foam, polyolefins float in process water; plastics, rubber, Mg and hollow Al float in magnetite slurry; and Al, rock, insulated wire float in ferrosilicon slurry, while dense metals (Cu, brass, SS, Pb and Zn) plus some dense slag rock and ferrite magnets sink.

The Al is separated from the magnetite slurry float fraction on an eddy current separator circuit and is then dried for shipment to the secondary smelter. The product is clean, having been washed and dried. It is then ready for melting. The melt composition average tends to remain consistent over time, and that, combined with ease of continuous mechanized scrap handling and feeding, makes it an ideal product for secondary smelters batching foundry alloys.

Upgrading Al Scrap

Al alloy grouping and batching of selected alloy compositions by sorting Al shred has been shown to be technically feasible at an industrial scale by Huron Valley Steel custom-built particle sorters. These processes, listed in Table 5, include separation of wrought Al from cast, grouping by alloy family and particle-by-particle batching of a selected product alloy composition. WTE Corp is also active in particle sorting of shredder scrap using LIBS chemical analysis.

As mentioned above, in the present economic climate, further upgrading Al shred after production of mixed alloy clean Al product makes no economic sense.

Technical developments in material segregation technologies

New developments aim at capital and operating cost reductions in the metal-nonmetal separation, in recovery of plastics and rubber and the treatment of residue fines.

Improvements in dry density separation may allow the elimination of the wet slurry sink- float processes that require high capital cost of closed-loop process water treatment systems. Sand fluid beds were shown on laboratory scale and on small throughput plant scale to be capable of separation of organics from metals and of light from dense metals.

Improvements in air knife and ballistic separators allow a more precise density cut between wood+rubber+plastic and foams+textiles+foils. Rare earth magnets that made eddy current separators practical are now being applied to magnetic headpulleys and drum magnets that improve separation of weakly magnetic particles and those with small magnetic attachments.

Quantum improvements in computing power, digital imaging and machine and other imaging area or line scan sensors are fuelling development of sensor-based particle sorters.

The sensors include.

- colour and hyperspectral (IR through UV) imaging
- imaging visible reflection spectroscopy
- reflection and transmission, visible and x-ray imaging
- image-based 2- and 3-D size and shape imaging
- eddy current coils with increased spatial resolution and conductivity sensing precision
- X-ray fluorescence
- Laser-induced breakdown plasma spectroscopy (LIBS)

These sensors are married to fast particle diversion systems. The industrial ones use air jets arranged in blow bars. Particle sorters with multiple blow bars have now been industrially demonstrated enabling multiple output streams from a single particle sorter, significantly simplifying sorting plant flowsheets. Particle sorters have been industrially applied to colour sorting of dense nonferrous metals from each other (Zn/Cu/brass), and in removing impurities from stainless steel separated from the SR stream by the ECC sorter. Shape and size imaging sorters sort out coins from the metal shred. The first industrial plant to sort secondary wrought alloys from Al shred using LIBS analysis has been in operation since 2004. SILAS project in EU is aiming to improve on this technology for wide commercial implementation.

There are also improvements in the wet density separation. Kinetic density separation utilizes the differences in particle terminal settling velocity in water to separate particles into up to six output streams. This allows combination of all media plant separations into one process vessel and eliminates magnetite and ferrosilicon media losses. This will allow the building of smaller, economic wet density separation plants.

Hydrocyclones and sorting centrifuges have been used for density separation between different types of plastic. Productivity and selectivity of the separation have been improved by drastically increasing the apparent gravitational force field. While this technology is not necessary for coarse separation between metals and nonmetals, it may be useful in separating residue fines by density into organics, light metals, sand, rust and dense metals and washing out the SOCs.

9. SUBSTANCES OF CONCERN - THE TAIL THAT WAGS THE RECYCLING DOG

It is the SOC shredder residue tail that wags the recycling dog. De-pollution before shredding is key; complete dismantling of banned components does not take place in practice during de-pollution, and SOCs are diluted in the shred. Further, as the time goes on and we find out more about man's impact on the environment, more substances, some already in wide use, are being added to the SOC list. As their use is banned in new products, the scrap that contains them becomes instantly non-recyclable. Because shredder feed is a mixture of scrap from various products, the SOCs from all kinds of consumer durables and demolition residue find their way into the shred. Buildings and some consumer durables have very long useful lives and the SOCs banned now will continue to plague the recycling system for decades.

Metals of interest on the SOC list include Cr^{6+}, Hg, Pb, and Cd. Of these only Cr^{6+} is present in the conversion coatings on some painted Al products. On melting it is either trapped in dross as oxide or is reduced as impurity in Al. In either case, Al recycling removes Cr^{6+} contamination from the recycling loop. Impurity pickup in the recycled Al melt is an issue from the point of limiting the range of possible secondary alloy compositions, but it is not related to SOCs or environmental concerns.

As steel, Al, other metals and remaining recyclable materials are separated, the SOCs tend to concentrate in the residue. EPA regulates air and water emissions from scrap processing plants as well as the leachable content of the solid residue destined for landfills. After removal of Al and other nonferrous metals, SR is treated to convert water-soluble lead sulphate contamination from lead-acid batteries into an insoluble lead phosphate. Treated SR passes EPA leachability tests qualifying it for municipal landfills. It is approved in most states for use as an ADLC, and hence receives preferentially low tipping fees. NA recyclers worry that removing too many recylables from the residue will concentrate the SOCs to the point where the SR will no longer satisfy the EPA leachability criteria, and will be redirected to much more expensive hazardous landfill.

In the EU, regulators already consider shredder residue too hazardous for municipal landfills so that reducing the quantity of solid residue is economically paramount. Recyclers charge treatment fees that cover disposal costs as hazardous waste. Their profit comes from reducing the weight landfilled at minimum processing costs. Conversion of organic content to CO_2 and adding solid inorganic residue to cement by combustion in a cement kiln is the least-cost, most convenient way of dealing with the problem. Proponents of this RDF solution claim that that the CO_2 generation should not be credited to this scenario because in the absence of RDF, the same amount of CO_2 would be produced by other fossil fuels. It is of interest that in spite the waste minimization and recycling objectives of both EPA and EU regulators, the economic realities of both EU and NA recycling systems do not maximize the financial benefits of recycling plastic and rubber from SR.

The SOCs have a potential to dictate the recycling products, process technology as well as the economics of the entire recycling system, for example:

In NA, products containing >2 ppm PCB are banned from commerce. This will help to remove PCBs from any new consumer products, but blind application of that ban to trade in shredder concentrates would cripple the entire material recycling system as the shredder could not sell nonferrous concentrate to the sink-float plant, and solvent extraction of PCBs from the entire shredder residue would be impractical, uneconomic and environmentally harmful.

Brominated fire retardants are another example. Tetra- and penta- bromides were found to be released, transported in the environment and to accumulate in the food chain. As a result, their production is being phased out and new cars are being specified by the manufacturers to be tetra- and penta- bromide free. However, the current fleet of half a billion vehicles, houses and consumer durables all contain these compounds, hence the recycling system will have to deal with them for the next 50-100 years.

10. SUMMARY

The environmental benefits of in-use fuel savings due to car lightweighting far outweigh the environmental cost of total energy use in Al production and Al automotive component fabrication.

Reuse of automotive components recovers ~100X the value of the Al material in the component.

Value of any Al alloy converted to a secondary ingot or billet is nearly the same because it is set by comparison with its replacement – prime Al.

The NA reuse/recycling system is market driven and fully funded from the income from reused components and recycled materials. Economics dictate what is recovered and what is disposed of.

The EU ELV directive and MSW landfilling regulations dictate the structure of the EU recycling system with more extensive dismantling, and earlier adoption of recycling or energy recovery of rubber and plastic from shredder residue, than is likely in NA.

A modern, shredder-equipped, recycling system is able to exploit the urban mine for recycling of secondary materials, reducing the need to extract increasingly scarce raw materials and to produce prime metals and virgin plastic resins.

All technology necessary to ensure sustainable, nearly complete recycling of Al from vehicles and other products exists and technology development continues to reduce costs and improve material recoveries. Research and development now focus on the recovery of organic recyclables from the residue and environmentally sound treatment of what is left.

Sustainability of the current Al recycling system depends on the continued large market for the few secondary alloys and the dilution of the impurity pickup with alloy segregated prime alloy scrap or prime Al. Development of high-technology methods to further upgrade Al shred continues. The real economic incentive and the Al recycling sustainability issue will come up again when post-consumer mixed-alloy Al scrap supply exceeds markets for composition compatible secondary alloys.

11. GLOSSARY

ADLC	Alternate daily landfill cover
AIV	Aluminium-intensive vehicle
BIW	Body-in-white – car structure including frame, passenger cage, engine compartment and trunk, and usually excluding closure panels – fenders, doors, hood and decklid or liftgate.
BFR	Brominated fire retardant
C&D	Construction and demolition
EC	Eddy current (induced in a electrically conducting particle in a varying magnetic field)
ECS	Eddy current separator (a spinning rotor with rows of magnets)
ECC	Eddy current coil sensor
EEE	Electrical and electronic equipment
EPA	US Environmental Protection Agency
FTC	US Federal Trade Commission
ISRI	Institute of Scrap Recycling Industries, Inc.
MSW	Municipal Solid Waste
LIBS	Laser Induced Breakdown Spectroscopy – elemental analysis method
OLD SCRAP	Post-consumer scrap
OEM	Original equipment manufacturer
PCB	Polychlorinated biphenyls
RDF	Residue-derived fuel
Semi-product	Plate, sheet/foil coils and extrusion profiles
SOC	Substances of concern, including those with toxic, mutagenic, carcinogenic properties, biochain accumulation, ozone depletion, global warming potential, etc.
SR	Shredder residue
SS	Stainless steel
UBC	Used beverage can
UO	Unit operation
WTE	Waste-to-energy (incinerator with heat recovery)

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