DEVELOPING A TECHNOLOGY ROADMAP FOR AUTOMOTIVE LIGHTWEIGHTING METALS RECYCLING

FINAL REPORT OF WORKSHOP

Held at the United States Council for Automotive Research LLC (USCAR) Offices
Detroit, Michigan, on September 24, 2008

Workshop was co-sponsored by the U.S. Department of Energy, together with USCAR and Argonne National Laboratory.

Workshop Summary Report was compiled for the Energy Systems Division, Argonne National Laboratory, Director Edward Daniels, by John Green, JASG Consulting, under sub-contract # 8F-02061.

Report dated December 2008

CONTENTS

FIGURES

TABLES

DEVELOPING A TECHNOLOGY ROADMAP FOR AUTOMOTIVE LIGHTWEIGHTING METALS RECYCLING

1 OVERVIEW

The U.S. Department of Energy (DOE), together with the Vehicle Recycling Partnership LLC (VRP) of the United States Council for Automotive Research LLC (USCAR) and Argonne National Laboratory, sponsored a one-day workshop on issues related to automotive lightweighting metals recycling technology on September 24, 2008, at the USCAR offices in Southfield, Michigan. The objectives of the meeting were to identify and prioritize R&D technology needs related to automotive lightweighting metals recycling that would enable and further promote the future use of lightweighting metals in automotive applications.

1.1 WORKSHOP OBJECTIVES

The primary objective of the meeting was to facilitate a technology interaction and exchange among the automotive companies, metals suppliers and recyclers, and the DOE national laboratories and academia that would result in the development of a technical roadmap to guide future R&D investment. The meeting was to cover the following automotive lightweighting metals in decreasing order of priority: aluminum, magnesium, titanium, and metal-matrix composites. Although the initial objective of the workshop was to explore issues with a future time horizon of 25 years, the workshop focused almost exclusively on near-term (less than 10 years) issues and R&D needs.

Secondary objectives of the meeting were to evaluate and identify expected significant losses in the life cycle of these lightweighting metals, primarily in the automotive sector, and then identify technology and R&D needs and priorities that can cost-effectively minimize these losses to ensure optimal materials use and recycling.

1.2 PARTICIPANTS

The group of about 35 subject matter experts from both the United States and Canada included

- Representatives from the original equipment manufacturers (OEMs) of Chrysler LLC, Ford Motor Company, and General Motors Corporation;

- Representatives from Argonne National Laboratory, Oak Ridge National Laboratory, and Pacific Northwest National Laboratory (PNNL);

- Representatives from the Canadian Centre for Mineral and Energy Technology (CANMET) and the Canadian AUTO21 project;

- Representatives from the Center of Automotive Research (CAR), Institute of Scrap Recycling Industries (ISRI), and other recycling and scrap shredding companies, as well as the Automotive and Light Truck Committee of the Aluminum Association; and

- Aluminum industry participants from Kaiser Aluminum, Inc., and Aleris, Inc.

A participant list is included in Appendix A.

The workshop consisted of a mix of formal presentations by subject matter experts and facilitated discussions from the participants to identify the challenges to the effective recycling of lightweight materials and the R&D priorities. Slides from the presentations are included in Appendix B.

2 BACKGROUND

Over the past decade, the quantity of light metals used in vehicles has continued to increase and is projected to grow further. For example, surveys by the Ducker Company show that the amount of aluminum in the average North American vehicle has grown from about 80 lb in 1974 to 327 lb in 2007 and is projected to reach 374 lb by 2015. Traditionally, the purpose of using light metals has been to reduce vehicle weight, increase fuel efficiency, improve vehicle performance, and enhance safety.

More recent growth in the use of light metals in automotive manufacturing has been in response to rising fuel costs as U.S. automakers look to provide consumers greater fuel efficiency and to meet more stringent Corporate Average Fuel Efficiency (CAFE) regulations passed recently by Congress. With the development of alternative propulsion systems (such as plug-in hybrids and electric drive vehicles), the trend to lightweight vehicles is expected to continue. In preparation for the influx of lightweighting materials, the workshop was timely as the world strives to attain more sustainable mobility.

2.1 BACKGROUND ON LIGHTWEIGHTING AUTOMOTIVE METALS

As a prelude to the detailed presentations and discussions, it is instructive to consider general information about the commodity light metals under consideration — namely, aluminum, magnesium, and titanium. Metal matrix composites (MMC) do not lend themselves to this comparison because they are so variable; for example, the reinforcing phase may be several different compounds of differing size, shape, and morphology. They are more in the nature of specialty materials than commodity metals. Also, the anticipated use of MMC is expected to be limited, as compared to the use of light metals in the next 25 years.

A comparison of the general features of aluminum, magnesium, and titanium is shown in Table 1. Note that the global supply of aluminum is much greater (~40 times) than the global supply of magnesium, which, in turn, is about five times more available than titanium. The issue of light metals supply will be important in the case of widespread application in an industry as large as the automotive industry. In the case of aluminum, the only commercially viable process is the Bayer-Hall-Heroult process from bauxite ore, which is widely distributed. By contrast, magnesium can be obtained from several different ores and by thermal reduction (Pidgeon process) or electrochemical reduction. Titanium can be obtained from either rutile or ilmenite ores by the Kroll process, in which magnesium is consumed to reduce $TiCl_4$ (titanium tetrachloride) to titanium “sponge.” All three metals have densities considerably lower than steel (~7.9 g/cc) and will positively impact the lightweighting of vehicles.

Recently, China has developed a dominant position in the production of magnesium and, to a lesser degree, of aluminum. Russia is the largest producer of titanium. Regarding recycling, aluminum has a mature secondary industry, and about one-third of all aluminum production is from recycled material. In contrast, magnesium has only a fledgling secondary industry, while titanium conducts a lot of dismantling and reuse by salvage from planes in desert “graveyards.” Aluminum alone is traded on the London Metal Exchange (LME).

2.2 GENERAL PRESENTATIONS

The participants were welcomed by Dr. Claudia Duranceau, Ford senior research recycling engineer and member of the VRP Engineering Project Oversight Committee, and by Dean Paxton of PNNL (on behalf of Joe Carpenter of the DOE Office of Vehicle Technologies). Duranceau opened to say that the VRP wanted to achieve a roadmap that would aid understanding of the state of the art of lightweighting metals — especially aluminum and magnesium — but the discussions also explore the possible use of titanium and MMCs in the future.

The aim of the workshop and subsequent discussion was to uncover key technology gaps and prioritize future R&D. Paxton indicated that from the DOE perspective, the 2010 goals of the FreedomCAR and Fuel Partnership are to achieve a 50% reduction in the weight of vehicle structure and subsystems, increased affordability, and an increased use of recyclable materials. With regard to the latter, cost is the major challenge that must be overcome, and it was pointed out that recycling might provide a significant beneficial impact on the cost of lightweighting metals.

Jay Baron, president of the Center of Automotive Research (CAR), provided an overview of future automotive trends. He cited the increasing pressures on the OEMs as a result of fuel prices, requirements for reduced emissions, higher lightweighting metals costs, and the need to retool facilities for the production of smaller vehicles. He noted the trend toward lower volumes per vehicle nameplate and that more niche vehicles are being built on global platforms to extend program life and use production capacity. Trends in material use show that the use of high-strength steel, aluminum, and plastics is increasing primarily at the expense of mild steel. Baron also said that the bulk of these materials is recycled — present estimates for recycling in the

TABLE 1 Current Status and Comparison of Automotive Lightweighting Metals, September 2008.

Topics	Aluminum	Magnesium	Titanium
Global annual supply (MT)	39,000,000	750,000–1,000,000	~150,000
Supply: US Canada	~3.6 MMT(with 1.5 shut) ~3.0 MMT	~ 50,000 MT (U.S. Mag) Becancour closed; Haley — moved to China	~50,000 MT (three U.S. plants)
Ores	Bauxite — well distributed	Dolomite, Magnesite, Brucite, Carnellite	Rutile, Ilmenite
Production	Bayer refining and Hall Heroult reduction only viable process	Carbothermic Reduction or Electrochemical Reduction	Kroll Process; New processes under development
Sources	China (~50% global prod.), Russia, Canada, U.S, Brazil	China (~85% global prod.), U.S., Israel, Brazil; U.S. supplies tight -- anti-dumping levies restrict imports	Russia (~30% global prod.), U.S.
Density, g/cc	2.7 (comparison to steel ~ 7.9)	1.7	4.5
Major Uses	Transportation, ~ 35%, of which 80% is for castings of engine blocks and powertrain components; the rest between extrusion and bodysheet	Alloying element for aluminum alloys (~42%); major automotive use is for die-casting	Aerospace (76%); Major automotive use is for mufflers
Recycle	One-third of Al production is recycled; mature secondary industry	20,000 MT from old scrap. Fledgling secondary industry	Limited post-user recycle; extensive process scrap recycle: planes in desert “graveyards” are valuable for salvage of parts
Supply Issues	China starting eight new smelters in Fall 2008 (1.5 MMT new prod.) under recession conditions: Chinese dominance coming?	Chinese dominant in supply; Used in 5xxx, 6xxx Al alloys.	Cyclic industry that depends on aerospace economic cycles.
Distribution	Free market pricing; LME trading	Pricing supply controlled; not on LME	Pricing supply controlled; not on LME

United States are 97% for steel and 90 - 95% for aluminum — but that recycling is complex and driven primarily by market demand in North America. A key issue, according to Baron, is that recycling is not just recovering the materials, but doing so in a way that preserves as much material value as possible. He mentioned that some 84% of the average vehicle is presently recycled; later, an ISRI representative suggested this number is closer to 75%.

The complexity of vehicle propulsion systems will increase greatly in the future with a gradual phase-out of gasoline engines and the growth of hybrid, clean diesel, and flex-fuel propulsion systems. Baron mentioned that the complexity of technical issues is enormous. There is no single technical solution; instead, there are multiple technology options with unknown future costs and synergies. No single company has the capabilities and resources to explore all of the options, nor can a company afford to make an erroneous selection in the marketplace. Because all of the producers have finite limits of financial and technical resources, he advocated increased collaboration between the OEMs in USCAR and the transplant auto producers (such as Nissan, Honda, and Toyota) as a means to mitigate the technical and financial risk. (See the detailed charts of the specific presentation for additional information.)

Boyd Davis, president of Kingston Process Metallurgy, Inc., and speaking on behalf of Peter Frise, Director of AUTO21, echoed the benefits of collaboration in describing the activities of AUTO21, the Canadian automotive R&D collaboration. The program enables extensive collaboration between industry and academia. The program has enabled an effective and more relevant concentration of R&D for the auto industry among the Canadian universities. Davis mentioned that the AUTO21 program had recently been reauthorized for the next seven years. He also mentioned that about 500 students were involved in all facets of the program, which bodes well for the auto industry in the future.

Adam Gesing, president of Gesing Consultants, Inc., provided an overview of light metals in current post-consumer metal recycling systems. He noted that the content of light metals, especially magnesium, is expected to increase. He stressed that market needs drive much of what actually is sorted and sold back to the industry. Currently, much of the nation's post-shredder scrap is exported to China for hand-sorting and remains in use in China. Thus, much of the scrap supply is not available in this country, and the energy content of the scrap material is also lost.

With regard to scrap sorting and the growing use of magnesium, he indicated that a key need is to separate the aluminum and magnesium recycle streams. Separating the streams would have the benefit of growing a stronger secondary magnesium industry; at present, only a fledgling secondary industry exists. If the aluminum and magnesium streams are not separated, magnesium has to be removed subsequently by fluxing, which results in losses of both aluminum and magnesium. Accordingly, a separation of both streams will optimize the recovery of both metals. Gesing emphasized that one needs a complete system for recycling — it is not feasible to "cherry pick" a particular metal or alloy out of the system — without a plan to treat the bulk of the waste. He also noted that more than 40% of magnesium is used as an alloying addition to aluminum alloys, and about 10% is used for steel desulphurization. Figure 1 (slide 17 in Gesing's presentation) depicts the flow of light metals in the current car-recycling system.

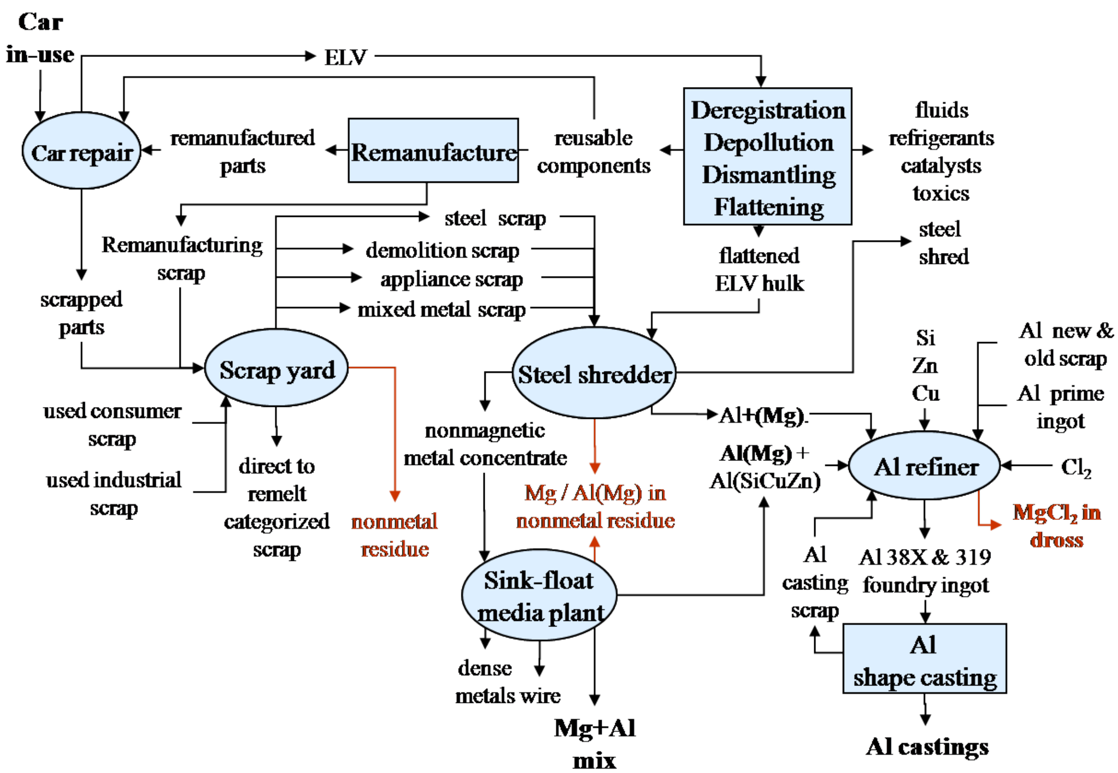


FIGURE 1 Light Metals in the Current Car-Recycling System. (Slide 17, Gesing)

2.3 METAL-SPECIFIC PRESENTATIONS

Specific presentations were made for aluminum by Doug Richman of Kaiser Aluminum, on behalf of the Auto and Light Truck Committee of the Aluminum Association; for magnesium by Bob Powell of General Motors; and for titanium and MMC by Curt Lavender of PNNL, to discuss the trends in automotive applications in each case and highlight any technology gaps and R&D needs. These presentations were then followed by two presentations focused on recycling and melting process developments for aluminum (Ray Peterson, Aleris International, Inc.) and magnesium (Boyd Davis, Kingston Process Metallurgy, Inc.), respectively. The formal presentations were then followed by a wide-ranging discussion among all participants. This discussion prioritized the technology gaps and R&D needs that had been identified.

3 TRENDS AND TECHNOLOGY GAPS

3.1 ALUMINUM

In the case of aluminum, Richman explicitly addressed many of the limitations and constraints called for in the guidance for the meeting (see Appendix B and his presentation for details). According to Richman, energy and emissions savings of 95% are driving recycling, in comparison to deriving the metal from the ore. Accordingly, metal suppliers will attempt to use as much recycled material as possible. The objective is to recycle the metal with a minimum loss of value. Chart 12 of Richman's presentation illustrates a recycled "materials value" pyramid for aluminum. Unfortunately, the value of aluminum from shredded auto hulks is reduced by some 30%, as compared to pure ingot.

Richman also indicated that in 2005, the average vehicle contained about 7.7% aluminum for an overall total of ~5 B (billion) lb of metal. By 2015, the average vehicle is estimated to contain about 10%, or ~6 B lb of metal that will be available for recycling. The vehicle components with the greatest share of aluminum are heat exchangers and pistons (100%), transmission casings (98%), cylinder heads (85%), and engine blocks (65%).

A major technology gap in the recycling of aluminum alloys is the buildup of iron impurities that arise as a result of the wear of processing equipment and machinery. This iron content compromises mechanical and corrosion properties of the recycled material. A process to remove iron dissolved in molten aluminum would be a huge benefit to the quality of the aluminum recycle stream. Likewise, it is important to minimize the use of dissimilar metal fasteners, design more monolithic components, and reduce the use of paint coatings and adhesives as much as possible. Finally, Richman noted that alloying additions of lithium from certain high-strength alloys, and various particulates from MMCs, are most detrimental to the quality of recycled aluminum.

3.2 MAGNESIUM

Concerning magnesium, Powell noted that it has many similarities with aluminum, but the total use of magnesium in automotive applications is at least 20 times lower than the total use of aluminum. Recent comparative numbers for the General Motors vehicle fleet were cited as 325 lb for aluminum and 14.8 lb for magnesium for the average vehicle. Magnesium is mostly employed as die castings, and little wrought material is used. Magnesium has been demonstrated as a suitable replacement for other metals instrument panels, transfer cases, seats and their tracks, and steering wheels. Galvanic corrosion can be a problem with magnesium, and so designers have to be aware of this issue. Corrosion can be controlled by reducing the impurity contents of the metal, specifically the iron, copper, and nickel values (and this needs to be reduced significantly to < 0.04 weight percent for iron and to ~15 ppm for Cu and Ni) so that the quality of the oxide film is not compromised for corrosion resistance. This reduction of impurities in magnesium is at least an order of magnitude greater than the needed reduction of iron impurities in aluminum; most iron specifications for aluminum alloys call for an iron impurity level of <0.4

weight percent. Powell noted that a key need for magnesium is to get more successful demonstrations and applications of the metal.

The recycling of magnesium is hampered by the considerable reactivity of the metal with oxygen and moisture and will be made more complex by the inclusion of creep-resistant alloys in powertrain applications. These latter alloys derive their higher-temperature creep resistance through the alloying of calcium, strontium, and rare earth elements, which will be detrimental to the overall quality of the recycled metal. Almost certainly, these alloys would need to be separated from the general magnesium recycled stream.

3.3 TITANIUM

In discussing the use of titanium, Lavender noted that the overall market is again smaller than that for magnesium, and much smaller than the market for aluminum. Titanium is prepared by the Kroll process, which consumes magnesium in the reduction of titanium tetrachloride, and so cost is a major issue. To date, cost has limited its automotive applications to components like springs, valve trains, and fasteners in some niche vehicles. Overall, the cost is prohibitive for any widespread application in automotive use. This situation is not expected to change until a new lower-cost preparation process emerges. Several processes are being explored, but none has yet showed sufficient promise for commercial development.

Lavender indicated that titanium is extensively recycled in the aerospace industry (e.g., by e-beam melting), and because of its high cost, in-process scrap is 100% recycled. In this sense, titanium recycling is a mature industry. Care is required to control the interstitial content of carbon, oxygen, and hydrogen because these elements can influence mechanical and corrosion properties. Also, alloy traceability (especially in regard to aerospace applications) is enforced and is most sophisticated. In other industries, titanium recycling is not commonly practiced.

3.4 METAL-MATRIX COMPOSITES

With regard to metal-matrix composites, Lavender noted that these materials are more specialty materials, but not in any sense commodity metals. Further, the complexity of the field is enormous, because both the matrix and the reinforcing phase can be varied. Also, the reinforcements can be particulate, fibrous, or even woven fabric and of variable size and orientation. An aluminum alloy matrix reinforced with silicon carbide particles at the 20% level (6061/SiC/20p – T6 in the terminology that has developed to describe these composites) has been used in niche automotive applications. Pistons and connecting rods have been developed, and the Chrysler Prowler vehicle had brake rotors fabricated from these materials, but there have not been any applications in large volume. It was noted that the reinforcing phase would probably end up in dross; it would be a risk to metal quality in aluminum recycling, and so no aluminum recycler is likely accept the MMC material for processing.

4 PROCESSING ISSUES AND R&D NEEDS

Peterson and Davis discussed the processing issues with the recycling of aluminum and magnesium, respectively. As for aluminum, Peterson mentioned that 30% of the domestic aluminum supply is recycled material, but that in the case of Aleris International, Inc., this number is as high as 70%, since Aleris does not produce primary aluminum.

4.1 ALUMINUM

Peterson noted that recycling is successfully practiced with the automobile industry. For example, post-consumer scrap is the largest source of input for some automotive cast alloys (e.g., 380, 383, 319 alloys). The key is to be able to blend scrap sources of "known" composition. To this end, he suggested that the automotive industry evolve toward using fewer, but more compatible, alloys as an aid to subsequent recycling. It is interesting to note the Aluminum Industry Technology Roadmap published by the Aluminum Association in February 2003 highlighted this point as a performance target for the industry by 2020. Specifically, the Roadmap in Exhibit 5-2 on p. 38, called for the "development of a unified body sheet alloy for inner and outer applications."

The most important processing issues in recycling are to optimize metal recovery and to lower production costs. Metal recovery centers on reducing the oxidation losses during melting by using improved burners, minimizing turbulence, and using cover gases, for example, while production costs can be impacted by lowering energy costs, increasing throughput, increasing furnace size, and decreasing labor costs. Also, as a critical R&D need, he mentioned that a cost-effective alternative process to chlorine fluxing for magnesium removal would be most beneficial.

As an example of a successful industrial interaction from a prior DOE roadmap, Peterson reviewed progress on a development project, sponsored by DOE Industrial Technologies Program, between Apogee, General Motors, and Aleris. This project has improved the transport of molten metal so that energy input and melt loss have been reduced, metal quality enhanced, and the need for a holding furnace at the cast shop has been eliminated.

4.2 MAGNESIUM

With regard to magnesium, Davis indicated the molten metal is highly reactive and sulfur hexafluoride, SF_6, is employed as a cover gas to reduce oxidation and "runaway" vaporization. This gas is well known as a potent greenhouse gas, and so there is a critical need to identify a substitute. Sulfur dioxide, other gases, and blends of inert gases have been tried but are not as effective as SF_6 in protecting magnesium from oxidation. For specific information about the several fluxes that are employed during the handling and treatment of molten magnesium, see the presentation. Some of the fluxes are toxic and discourage the recycling of magnesium by processors.

For magnesium alloys, the control of iron, nickel, and copper impurities to extremely low levels is critical to achieving good corrosion resistance performance. In the case of iron impurity, this is controlled by additions of manganese to the magnesium melt, causing dense Fe-Mn intermetallic compounds to form and settle to the bottom of the melter. However, for nickel and copper, there is no effective way to remove these impurity elements, and they are controlled by dilution. Also, at present, there is no separation and recovery of the rare earth elements that are used to confer higher-temperature creep resistance on magnesium alloys. Technology to purify magnesium melts is sorely needed. This suggests that these creep-resistant alloys should be recycled as a separate stream (i.e., disassembled) and not be shredded and mingled with other magnesium or aluminum streams.

5 DISCUSSION SESSION

Following the formal presentations, the participants joined in a facilitated discussion to define technology gaps, R&D needs, and priorities. The participants discussed at length the suggestion from the aluminum industry to evolve to a design approach where fewer, more compatible alloys are used in vehicle assembly. This discussion grew into a more extensive debate about the importance of “designing for recycling” and included such topics as joining processes, avoiding dissimilar rivets that reduce the efficiency of sorting processes, and the use of adhesives, among others. A series of R&D needs and priorities grew out of this discussion.

Participants discussed the use of life-cycle analysis as an aid in determining the low-energy and low-cost option for recycling. This was not intended as a rigorous computation but more as a methodology to assess recycling options and to ensure that processes used in recycling do not compromise the conclusions of previously determined life-cycle analyses.

Another extensively debated topic was the issue of dismantling prior to shredding of the auto hulk. Some suggested that because much of the aluminum is concentrated in the propulsion system, it might be possible to remove this material in larger components when the vehicle is being “de-polluted.” After much discussion, the prevailing view was that because of the advances in shredder and sorting technology and the time in which a shredder can reduce an auto hulk to small, 4-in.-diameter, pieces (~40 seconds), it was considered more efficient to allow the complete hulk to be shredded and subsequently sorted.

5.1 COLLECTION OF IDENTIFIED TECHNOLOGY GAPS, NEEDS, AND PRIORITIES

In this section, we highlight the recycling technology gaps, needs, and priorities for all of the automotive lightweighting metals discussed at the workshop, both suggested by invited speakers and uncovered during the facilitated discussions.

On the topic of technology gaps, there were many suggestions throughout both the formal presentations and the informal discussions. Many suggestions focused on the theme of impurity control of molten metals. For example, issues with impurities dominated at least four distinct areas. In the case of aluminum, the iron content (and, to a lesser extent, silicon content) builds up after repeated recycling, most likely as a result of the wear of the mechanical handing systems. At present, there is no easy way to remove iron from molten aluminum, and, in practice, attaining the necessary lower values is done by dilution with prime (pure) ingot, which is expensive.

Likewise, for magnesium melts, iron, nickel, and copper impurities need to be controlled to extremely low levels to ensure adequate corrosion resistance properties of the metal. Although the iron values are controlled by the precipitation of an iron-manganese intermetallic, there is no adequate control of nickel and copper levels (other than dilution). Also, for magnesium, there is no technology for the control of the calcium, strontium, and rare earth additions critical for the high-temperature, creep-resistant alloys.

In the case of higher-performance materials, there is no economically-viable technology for the removal of lithium and scandium (originating from aluminum alloy baseball bats) from aluminum melts and for the removal of particulate material (silicon carbide, aluminum oxide, etc.) from MMC. As a result, these materials are not recycled at present. Finally, the control of interstitial impurities (oxygen, hydrogen, and carbon) in titanium is problematic.

Given the considerable numbers of technology gaps about impurity issues, workshop participants speculated that the DOE national laboratories, with their capabilities and longer-range focus, might be best suited to develop solutions to these needs.

In the area of melt treatment, several technology gaps were noted. For instance, Peterson highlighted the ongoing need for an alternative technology to chlorine fluxing of aluminum melts that would still be effective but more environmentally benign. Likewise, in magnesium melting, there is a need for an improved cover gas or mixture of gases, or some new process development, to reduce the oxidative melt losses. Also, many of the fluxes used in molten magnesium treatment are not desirable to handle and, accordingly, discourage the recycling process. With all of these issues in magnesium processing, participants speculated that a fluxless process for the consolidation of magnesium scrap could be developed.

Several other technology gaps were noted as follows:

- There is a need to get more demonstrations of magnesium applications into automobile use and thereby acquire more application experience.

- A low-cost production method for titanium “sponge” would greatly facilitate the application of this versatile metal.

- No technology has been defined to separate and recycle co-cast metals (an example is recent Novelis “Fusion” technology).

- To reduce the complexity of aluminum alloy sorting, there is a need to develop an alloy that could be used for both inner and outer closure applications.

- There is no formal mechanism or procedure of alerting the dismantlers and recycle processors of potential hazardous or safety-related issues in automobile construction. (This technology gap was highlighted when dismantlers relayed rumors of a welding torch inadvertently igniting some magnesium components during dismantling.)

During the discussion sessions at the workshop itself and at the Organizing Committee meeting held the following day, the recycling needs and priorities were debated and grouped into areas of high, medium, and low priority (Tables 2 and 3). High-priority needs were those identified as important by the majority of workshop participants, medium-priority needs were identified by a significant minority of participants, and low-priority needs were identified as being important by only a few participants. These needs are summarized in the following two tables. Note that the top priority, supported by all workshop participants, was a policy need, not a technology need.

5.2 ASSESSMENT OF LIGHTWEIGHT METALS WORKSHOP

On September 25th, the day following the workshop itself, the Organizing Committee met to review the meeting and assess the specific results of the workshop. The group included participants from the automotive companies and the Vehicle Recycling Partnership and representatives from Argonne National Laboratory.

The details of presentations were discussed, clarified, and debated again. In general, the discussions of the group served to amplify and reinforce the conclusions of the technology needs and gaps and priorities selected from the previous day.

Finally, the workshop was considered successful, and the speakers and participants were thanked for their contributions. The participants are listed in Appendix A — their efforts and support of this meeting are acknowledged by the U.S. Department of Energy, Argonne National Laboratory, and the Vehicle Recycling Partnership of USCAR.

TABLE 2 Lightweight Metals Recycling — Highest-Priority Needs

Priority	Description
TOP	Encourage auto industry collaboration. Domestic auto companies should collaborate with “transplant” companies (e.g., Nissan, Honda, Toyota, and other stakeholders, e.g. AUTO21, CANMET, among others) to facilitate the development of complex designs and propulsion systems and mitigate financial risk (see presentation by Baron).
HIGH	Develop technology to remove detrimental impurities. Detrimental impurities need to be removed from recycled metal — specifically, in aluminum, iron needs to be removed to meet a traditional melt specification of ~ 0.4 weight percent (see Richman and Peterson presentations).
	An alternative process needs to be developed to chlorine fluxing for magnesium and lithium removal.
	In scrap sorting processes, separate the aluminum and magnesium process streams and help to grow a secondary magnesium industry. In this way, eliminate both aluminum and magnesium losses during subsequent fluxing (see Gesing presentation). Also, improve separation of shredded aluminum scrap (wrought vs. cast, high iron vs. low iron, segregation of small sizes and organics [oils/plastics]).
	Develop more recycling-compatible aluminum alloys and urge automotive designers to use fewer overall alloys, that is, different heat treatments of the same alloy for inner and outer closure panels (see Peterson presentation and general discussions).
	Improve aluminum recovery through (1) improved furnace designs, (2) improved de-coating/de-lacquering processes, (3) rapid submergence technologies, and (4) improved fluxing practice (see Peterson presentation).
	Develop improved process for handling by-products (salt cake) for the recovery of constituents (aluminum, salt flux, and oxides and non-metallics).
	Lower aluminum melting costs through better energy utilization by using improved burners (see Peterson presentation) and improve delivery of molten metal (better energy efficiency)
	Adopt life-cycle analysis as a methodology to harmonize industry practices and adopt the lowest-energy processes for recycling (see discussions)

TABLE 3 Lightweight Metals Recycling — Other Priority Needs

Priority	Description
MEDIUM	Need process to recover non-Class 1 scrap
	Improve alloy methods of magnesium to reduce energy consumption
	Develop process to minimize or eliminate salt flux use in magnesium melting
	Develop processes to remove copper, nickel, and iron for higher-quality magnesium. In the case of molten magnesium, processes need to be developed to remove copper, nickel, and iron to extremely low values to ensure good corrosion resistance properties of the resultant magnesium. (see Powell and Davis presentations). Also, conduct a process demonstration to establish that the rare earth (RE) elements needed for creep resistance can be economically recycled and reused (see Powell presentation).
	Demonstrate an alternative (non SF_6) cover gas for melt processing of magnesium (see Davis presentation), Also, encourage "best practice" processing in the application of SF_6 cover gas in magnesium melting and, in the longer term, develop an alternative for SF_6. (see Peterson and Davis).
	Evaluate scrap separation procedures for co-cast aluminum alloys (from discussion in relation to Novelis co-casting technology). Regarding joining technologies, evaluate optimum sorting procedures for friction stir welded materials; evaluate procedures for adhesively bonded materials (see discussion).
	Need to investigate Mg scrap consolidation and semi-solid processing (rheocasting and thixocasting) as a way to minimize scrap generation and flux use.
	Develop information on the composition of future light-metal recycle streams to enable dismantlers and recycle processors to anticipate potential processing issues — this has safety ramifications (request from processors during discussion).
LOW	Enhance current titanium recycling by developing more rapid scrap sorting techniques; quantification of interstitial elements is an issue (see Lavender presentation).
	Conduct a cost-benefit analysis of MMC design, including recycling, to select the best MMC composition. For example, while silicon carbide may be the best reinforcement for an aluminum matrix, what is the trade-off with an aluminum oxide reinforcement from a recycling viewpoint? Silicon carbide particulate will adversely impact the quality of an aluminum melt; an alumina particle less so (item from general discussion).

APPENDIX A: WORKSHOP PARTICIPANTS

Dan Adsit
Ford Motor Company

Jay Baron
Center for Automotive Research

Noot-A-Faizen Barsha
University of Windsor

Susan Sawyer Beaulieu
University of Windsor

Bruce Cox
Chrysler Corporation

Sujit Das
Oak Ridge National Laboratory

Boyd Davis
Kingston Process Metallurgy / AUTO21

Claudia Duranceau
Ford Motor Company / VRP

Elhachmi Essadiqi
CANMET

Adam Gesing
GCI

John Green
JASG Consulting

John Havbert
Chrysler Corporation

Elizabeth Hetrick
Ford Motor Company

John Hryn
Argonne National Laboratory

Henry Hu
University of Windsor

Bassam Jody
Argonne National Laboratory

Jerry King
GM

Curt Lavender
Pacific Northwest Laboratory

Deanna Lorincz
AISI

Judge Morton
AMACOR

Ryan Ntavro
SGM Magnetics

Dick Osborne
GM

Richard Paul
Environment Management

Dean Paxton
Department of Energy

Ray Peterson
Aleris International

Carolyn Philpott
USCAR

Daniel Prophater
David Joseph Company

Tom Prucha
AFS

Jim Quinn
GM

Aldo Reti
WTE Corporation

Everett Rezendes
Ford Motor Company

Doug Richman
Kaiser Aluminum

Andy Sherman
Ford Motor Company

Phil Sklad
Oak Ridge National Laboratory

Jerry Sokolowski
University of Windsor

David Wagger
ISRI

Bing Xu
Ford Motor Company

Automotive Lightweight Metals Recycling Workshop

September 24th 2008
United States Council for Automotive Research (USCAR)
8:00 a.m. – 5:00 p.m.

AGENDA

Start Time	Topic	Speaker
7:15 a.m.	***Light Refreshments***	
8:00	Welcome and Introduction	John Green - Facilitator
8:10	Purpose of Workshop	Claudia Duranceau -VRP
8:20	DOE Expectations and Plans	Dean Paxton – DOE
8:30	Future Automotive Trends and the Impact of Recycling	Jay Baron – CAR President
9:00	Next 25 years in Automotive Lightweight Materials	Boyd Davis - Auto21 Director / Theme D
9:30	Overview of Sorting Technology and Optimum Al and Mg Recovery	Adam Gesing -Gesing and Associates
10:00	***BREAK***	
10:15	Aluminum Trends and Automotive Applications	Doug Richman – Kaiser Aluminum. Al Association Auto Light Truck Committee Member
10:45	Magnesium Trends and Automotive Applications	Bob Powell – GM
11:15	Titanium Trends and Automotive Applications	Curt Lavendar – PNL Energy, Materials and Manufacturing
11:45	Metal Matrix Composites in Automotive and Their Recycling	Curt Lavendar – PNL Energy Materials and Manufacturing
12:15 p.m.	***Lunch***	
1:00	Aluminum Recycling and Process Improvements	Ray Peterson-Aleris, Inc. Technology Director
1:30	Magnesium Recycling and Processing Improvements	Boyd Davis – Auto21 Theme D Leader/ President, Kingston Process Metallurgy
2:00	***BREAK***	
2:15	Discussion • Clarification of Issues • Identification of Technology Gaps • Establishment of R & D Needs • Prioritization of Future Technical Agenda • Suggestions for Roadmap Format	All Participants
4:15	***Summary and Wrap Up***	

VRP
VEHICLE RECYCLING PARTNERSHIP LLC

Energy Efficiency
and Renewable Energy

Argonne
NATIONAL LABORATORY

APPENDIX B:
WORKSHOP PRESENTATIONS

Paxon: DOE Perspective
Baron: Center for Automotive Research
Davis: AUTO21
Gesing: Automotive Light Metals Recycling
Richman: Aluminum Association
Powell: Magnesium Trends and Automotive Applications
Lavender: Titanium Recycling
Lavender: Metal Matrix Composites
Peterson: Aluminum Recycling
Davis: Magnesium Recycling

Lightweight Metals Recycling
- DOE Perspective -

FreedomCAR - Specific 2010 Goals:

- *Material and manufacturing technologies for high volume production vehicles which enable and support the simultaneous attainment of:*
    1. 50% reduction in the weight of vehicle structure & subsystems
    2. Affordability
    3. Increased use of recyclable/renewable materials
- Significant technical progress being made in weight reduction designs, manufacturing and validation.
- Cost is the major challenge which must be overcome.
- For most materials there are two major parts to the cost challenge: raw material costs and manufacturing.
- Recycling of lightweight alloys may provide significant impact on the cost of raw materials similar to what is experienced in the steel industry.

Automotive Lightweight Metals Recycle Workshop

September 24, 2008

Jay Baron

Center for Automotive Research

Stolen Quotes from Dr. David Cole (Chairman, CAR)

CENTER FOR AUTOMOTIVE RESEARCH

- Auto industry is not in its final form.
- Collaboration is not a natural act.
- Everyone is fast and hits hard.
- A world of vanishing boundaries.
- Not sure where we're going, but we're getting there fast.
- Good science beats good art.
- Consolidation continues.
- Change or die.
- Shrink to grow.
- Cooperation, alliances and teamwork.
- The old business model is broken.
- You don't know what you don't know

CENTER FOR AUTOMOTIVE RESEARCH

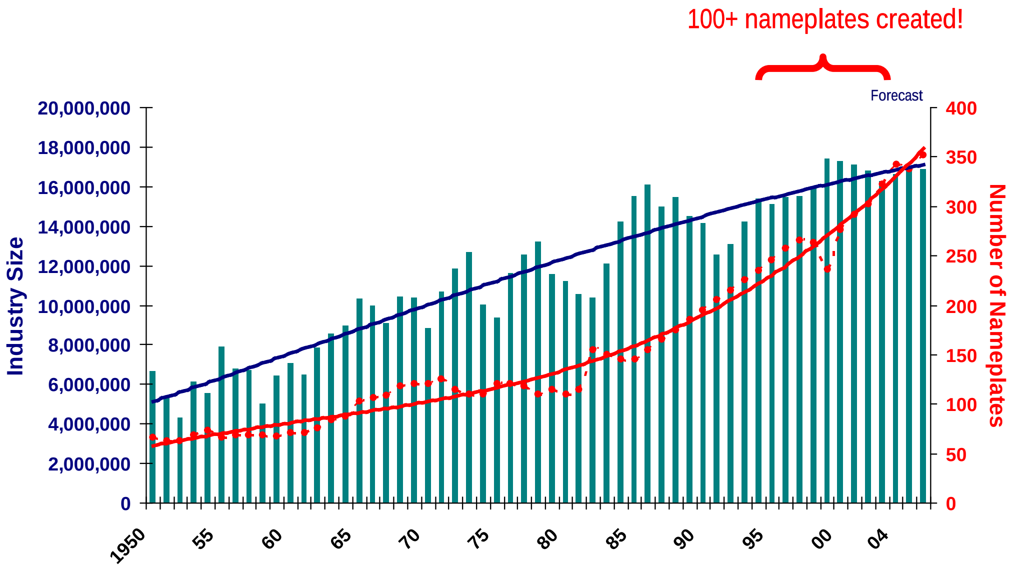
Outline

- A few significant industry trends
  (volumes, costs, demand & manufacturing flexibility)
- Technology trends and uncertainty
  - power train
  - materials
- Need for Collaborative Research
- Recycling

The Supplier Table of Pain

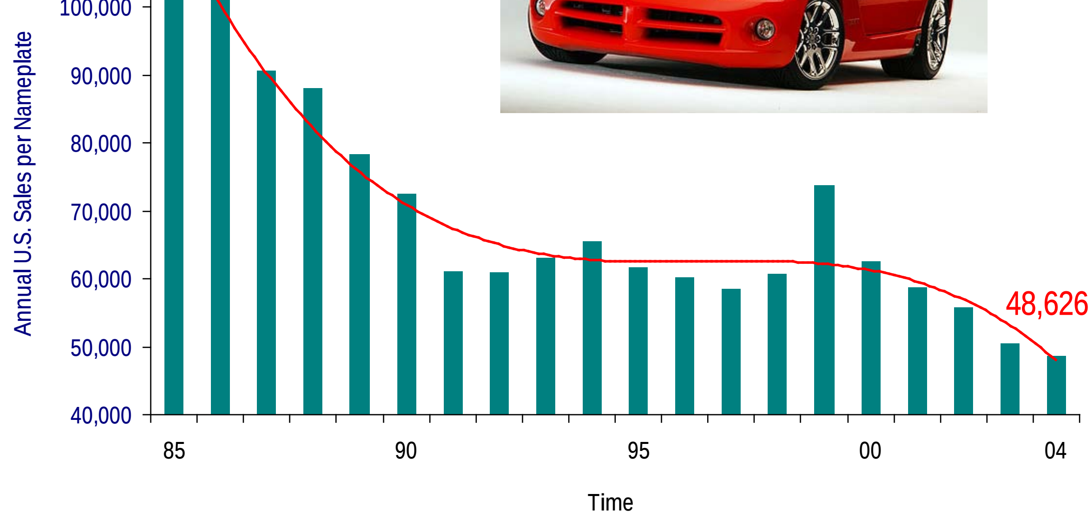
Industry PPI/CPI	1998-2008 YTD % Change
New Cars and Trucks CPI	-5.90%
Rolled Steel PPI-Commodities	+68.65%
Primary Aluminum PPI	+92.44%
Plastic Materials & Resins PPI	+79.67%
Refinery Gases (Feedstock) PPI	+487.82%
Petroleum Refineries PPI	+460.51%
Health Insurance ECI	+97.74%

Low Volume Challenge for Materials



More Nameplates and Lower Volume per Nameplate

This trend can benefit higher cost/light-weight materials in differentiating nameplates



CAR
CENTER FOR AUTOMOTIVE RESEARCH

Ford:
Global Commonization is the future

CEO Alan Mulally calls for commonization of global products

"I am really encouraged with our work to leverage the Ford brand around the world. I think we're ahead of where I'd thought we would be on coming together on global platforms - getting the volume up, the scale up, the commonality up."

- Alan Mulally, July 2007

FORD INVESTS $75 MILLION TO PREPARE MICHIGAN TRUCK PLANT FOR SMALL-VEHICLE PRODUCTION

- Ford invests $75 million in Michigan Truck's body shop to prepare for small-vehicle production.
- Conversion begins in November as large-SUV equipment is removed and transferred to Kentucky Truck Plant.
- Small-vehicle production planned for 2010
  - **80% of automation can be re-deployed in the car plant**
  - **Michigan Truck is one of three truck/SUV plants to be converted to small car production capability.**
  - **Common underbody with multiple "top hats"**
  - **Standard processes (cells, common build sequences, etc.).**
  - **Programmable tooling (robotics, etc.)**
  - **Workforce**
  - **Scope: Body Shop, Paint, General Assembly**

CAR
CENTER FOR AUTOMOTIVE RESEARCH

Year-over-Year Sales Difference
Through July 2007 to July 2008

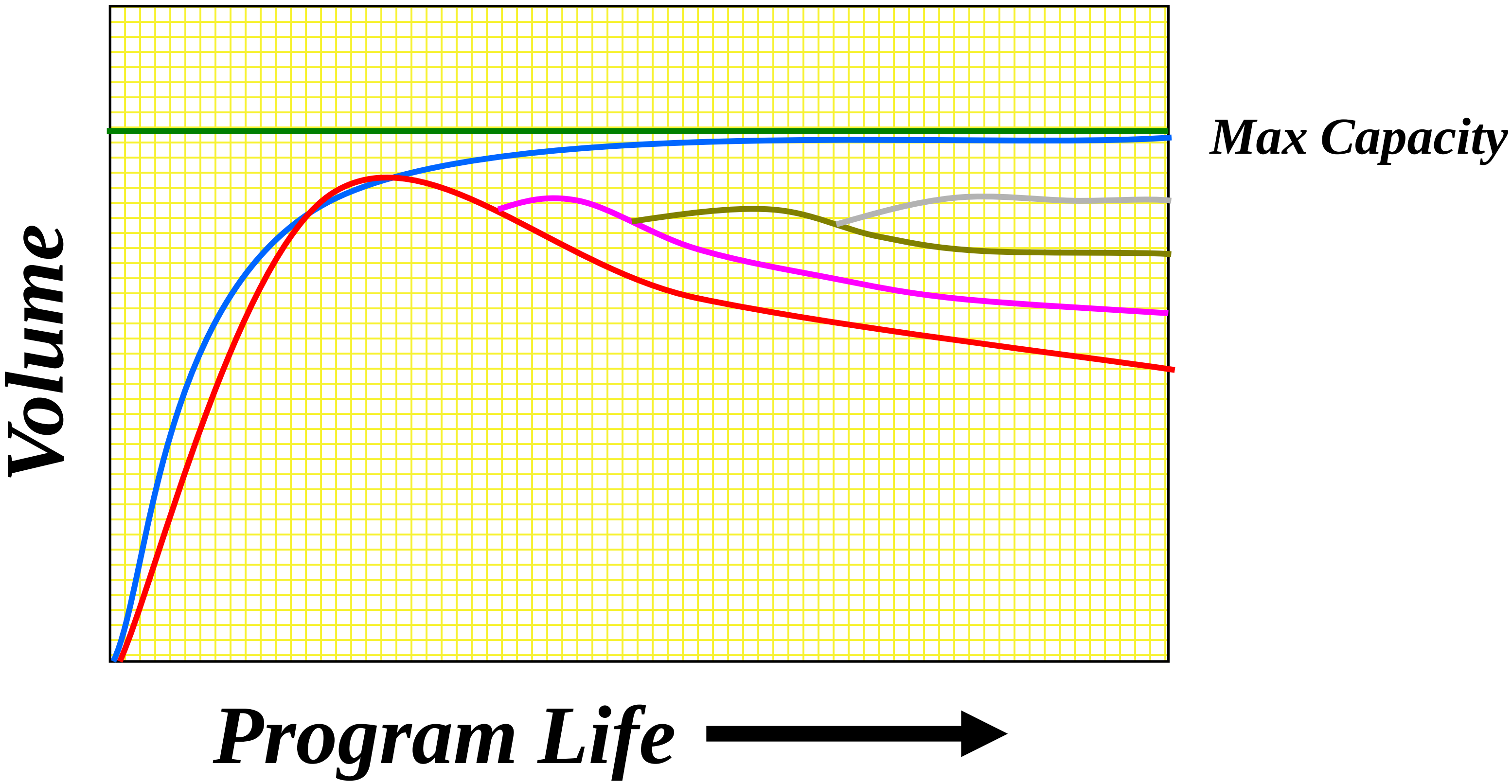
Pickup	-20.9%	-24.5%	-31.1%	-12.6%
SUV	-37.0%	-36.5%	-33.4%	-29.9%
Mini Van			-19.6%	-11.7%
Car	-6.1%	-8.7%	-19.6%	- 2.2%
CUV	-0.1%	-4.1%	15.5%	-13.4%

Sales Contraction + Sales Re-alignment

=

Retooling & Flexibility

The Opportunity



Economies of Scale: Where are they?

Has the global automotive industry experienced a recent shift in scale economies of its operational parameters

(product development, business and/or, manufacturing processes)?

- **Across time**
  (from one platform generation to the next – carry-over of parts)
- **Across regions (common components on similar platforms produced in different regions)**
- **Across platforms within a company**
  (b-segment and c-segment)
- **Across vehicle manufacturers (J/Vs)**
- **Across vehicle systems? *A diverse set of customers or a diverse set of products? (electronics)***

CAR
CENTER FOR AUTOMOTIVE RESEARCH

A New Energy Reality

Demand from Consumers

- Overall global energy demand to increase 50% by 2030
- Energy demand in developing world to increase by 70% by 2030
- $4-plus or minus per gallon gas in the U.S.

Regulation and Legislators

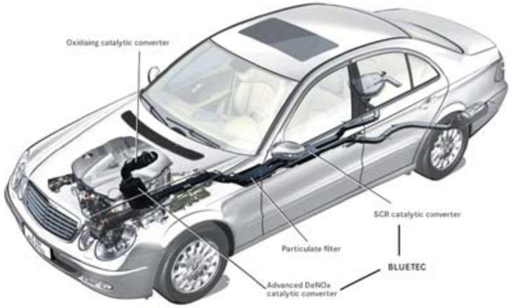
- G-8 nations have endorsed goal of reducing GHG 50% by 2050
- Obama: 80% reduction by 2050
- McCain: 60% reduction by 2050

Michael J. Stanton
President & CEO
AIAM

Diesel growth in the U.S.
- U.S. Market Share by Powertrain

	2002	2003	2004	2005	**2011**	**2016**
Dedicated Gasoline	92.7%	92.1%	92.0%	91.4%	**64.0%**	**44.8%**
Flex-Fuel (E85)	4.8%	4.6%	3.8 %	4.1%	**23.8%**	**29.8%**
Gasoline Hybrid Electric	0.3%	0.5%	1.2%	1.6%	**5.0%**	**15.0%**
Diesel	2.2%	2.8%	3.0%	2.9%	**7.2%**	**10.4%**

Source: CAR, API Report



CAR
CENTER FOR AUTOMOTIVE RESEARCH

CAR
CENTER FOR AUTOMOTIVE RESEARCH

Technologies: No Single Solution

- Power Trains
  - Fuel Cells
  - HEVs (batteries) → mild hybrids to strong hybrids
  - Diesels → Clean Diesels
- Power Train Technologies
  - CVTs, 6-speed transmissions
  - Electric power steering, brakes, HVAC (variable stroke compressors, etc.)
  - Turbo chargers
  - Cylinder de-activation
  - Direct injection
  - Variable valve timing
  - Integrated starter/generator
- Other technologies
  - Low resistance tires
  - Aerodynamics
  - Mass reduction

CENTER FOR AUTOMOTIVE RESEARCH

New Technologies Risks

- Ironically, there are too many technology options
- Multitude of technology options, each with unknown future costs and technology synergies
- Manufacturer at a competitive disadvantage if the selected technology ultimately proves to be more expensive
- Cannot afford a viable technology that does not meet customer expectations for performance
- ***Collaboration***
  (All but a very few OEMs can afford not to collaborate)

CENTER FOR AUTOMOTIVE RESEARCH

Cars, Climate Change and Policy (Drs. David Cole & Sean McAlinden)

- “Old carbon” fuels (oil) will continue to be extracted to meet global energy needs because they are cost competitive.
- Significant progress is being made in reducing fuel consumption and increasing fuel supply (biofuels).
- Advances with “new carbon” fuels (cellulosic biofuels) and Li-ion batteries reduce dependency on old carbon.
- An oil price “floor” of ~$50/barrel would sustain investment cellulosic biofuels and Li-ion batteries.

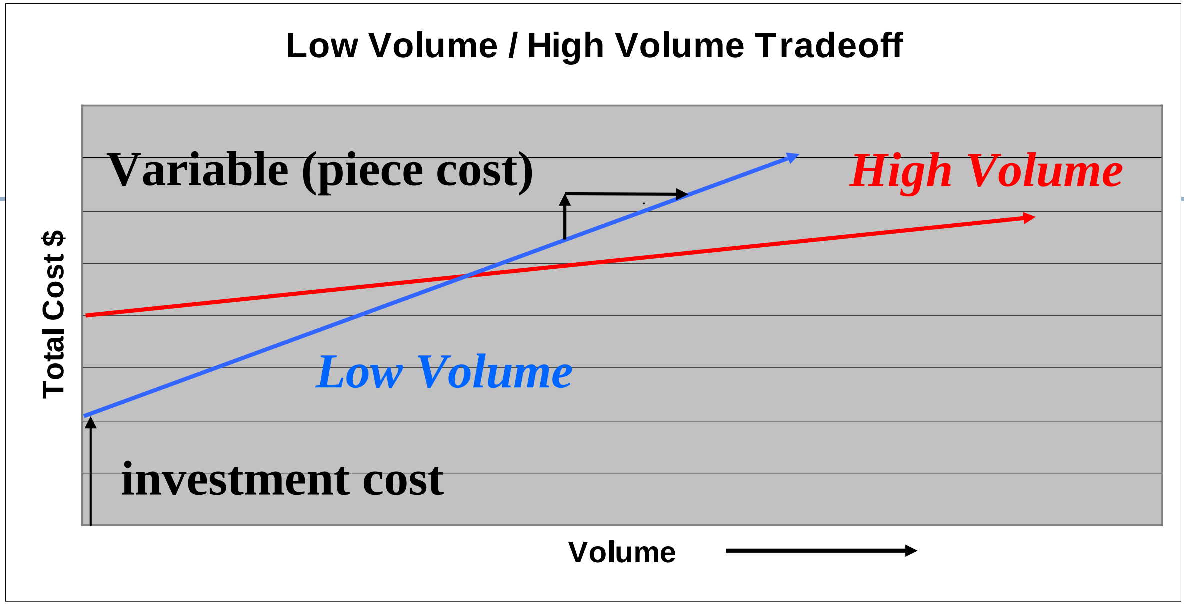
CAR
CENTER FOR AUTOMOTIVE RESEARCH

Vehicle Materials

Material	Today	5 Years	10 Years
Mild Steel	Dominate	Less dominate	No longer dominate
High Strength Steel	Some	More grades, increased use throughout body	Dominate - more grades
Boron Steel	Little (bumpers)	Introduced on crash components (pillars, rails)	Common on crash components
Aluminum	Some hoods & deck lids	Increased use on closures & components	Wide use on closures (doors) & components
Magnesium	Limited	Slight increase on components, wheels	Slight increase on components, wheels
Plastic	Mostly non-structural, fuel tanks, IPs and outer panels	More IPs, fuel tanks, outer panels and components	More IPs, fuel tanks, outer panels and components
Composites (Carbon Fiber)	Niche applications due to cost and supply	Niche applications due to cost and supply	Niche applications due to cost and supply

(yellow) Materials with increasing dominance

Polycarbonate - replace glass (rear window, sun roof, side windows)



“Material Substitution” generally understates the complexity of introducing new materials

Total Cost =

Investment (tools & engineering) + Variable (material & production)

Production Cost:

Stamping, Molding, Hydro-forming, Roll Forming, etc.

Spot Welding, Adhesive, Laser Welding, MIG Welding, etc.

Two Largest Recycled Materials in Vehicles

- Steel
  - Overall recycling rate for steel is ~97%
  - 25% of steel in each car is made from recycled steel
- Aluminum
  - Overall recycling rate for aluminum is ~90%
  - ~60% of aluminum in each car is made from recycled aluminum
  - 5% to 10% (by weight) of scrapped automobile is aluminum, but represents 30% to 50% of its scrap value

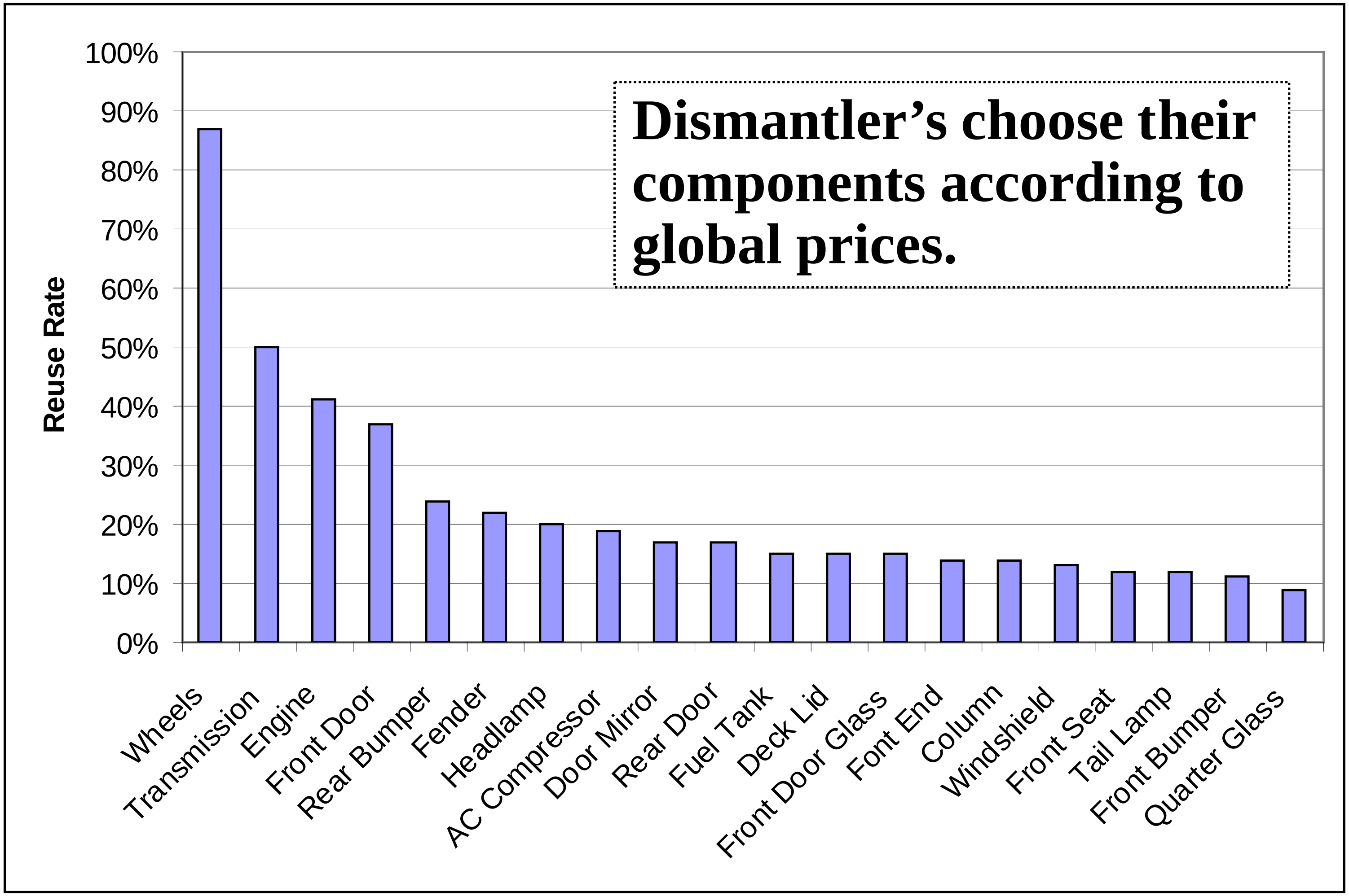
CAR
CENTER FOR AUTOMOTIVE RESEARCH

Recycling End-of-Life Vehicles

- 95% retired vehicles entered the recycling process (Ward's, 2005)
- Dismantlers remove components for reuse and prepare vehicles for shredding
- There are more than 8000 dismantlers in the US
- The market in the US is largely driven by the reuse of components
  (in Europe reuse is sometimes practiced by exporting vehicles to countries outside of the EU)
- Dismantlers are removing components for which commodity prices make separate processing economical

CAR
CENTER FOR AUTOMOTIVE RESEARCH

Component Reuse



CAR
CENTER FOR AUTOMOTIVE RESEARCH

Recycling

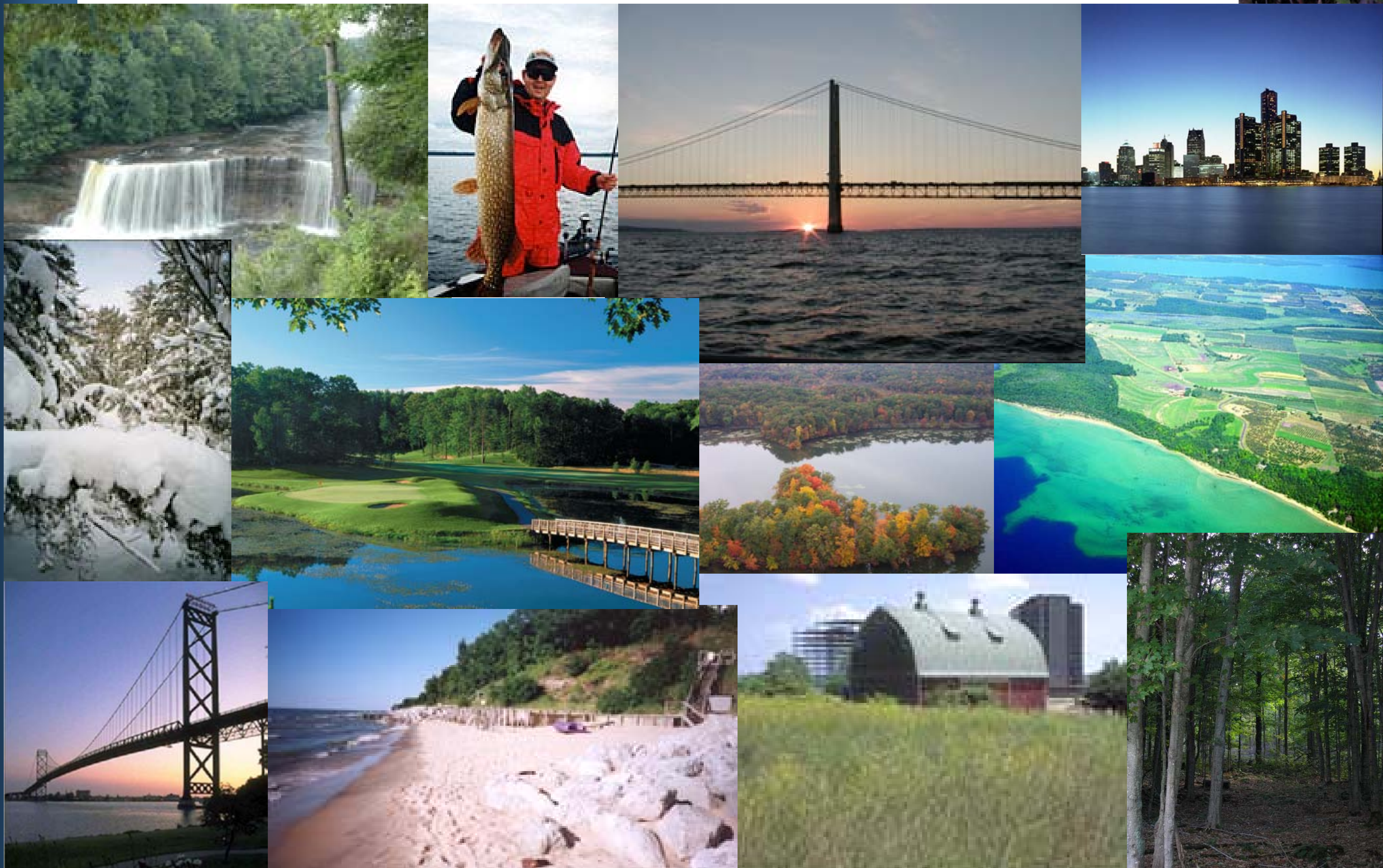
- The recycling of the metal stream is viewed as a process that is generally working well.
  (It is largely driven by economics.)
- There are about 212 shredders in the United States.
- It is estimated that at least 84% of the vehicles material content is recycled.
- Plastics pose one of the most significant challenges in vehicle recycling. Labeling plastic and designing it for disassembly helps.
- A major emphasis is on the avoidance of hazardous materials going to the landfill.

Summary Observations

- Global platforms, manufacturing flexibility and product proliferation affecting economies of scale.
- Power train complexity and future uncertainty calls for collaboration.
- Reductions in mass will continue steadily for years. The big impact on fuel economy is still power train.
- Recycling complexity will increase with more materials.
- Cooperation, alliances and teamwork (Dave Cole quote number 10).

CAR
CENTER FOR AUTOMOTIVE RESEARCH

<u>Michigan</u> is a nice place to live …



Collaborative Automotive Research and Innovation in Canada

Boyd Davis
AUTO21 NCE
Theme D Coordinator (Powertrains, Fuels, Emissions)

Sept 24 2008

Global Auto Industry Trends:

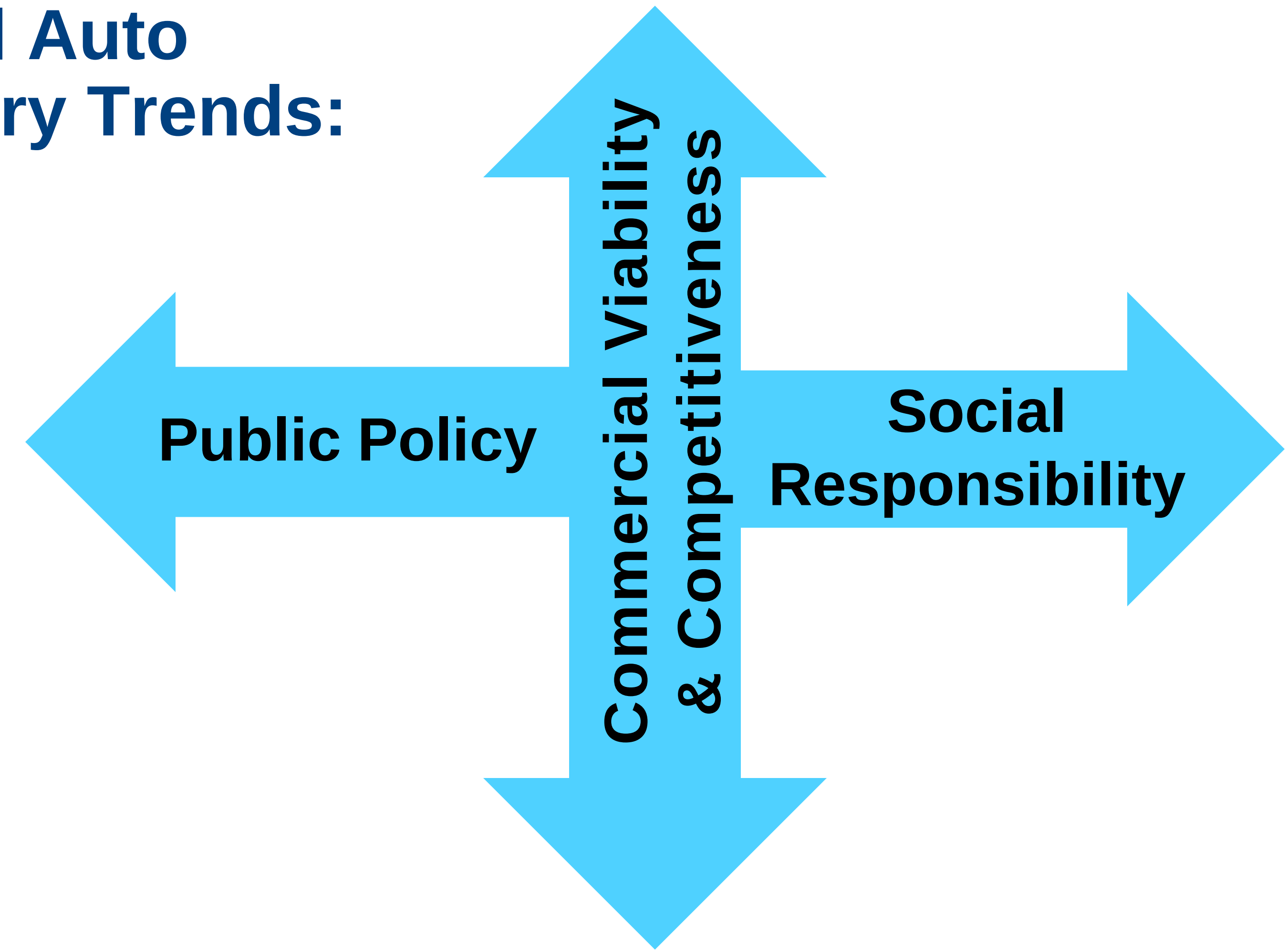
The auto industry responds to the same drivers as any other business:

- **Consumers:** ***(what do people want to buy – upon what do they place a high value?)***
- **Economies:** ***(how and where can the highest value be created using the available assets – what provides the best market opportunity?)***
- **Government:** ***(what are the public sector goals for the auto sector? Usually related to safety / environmental progress)***

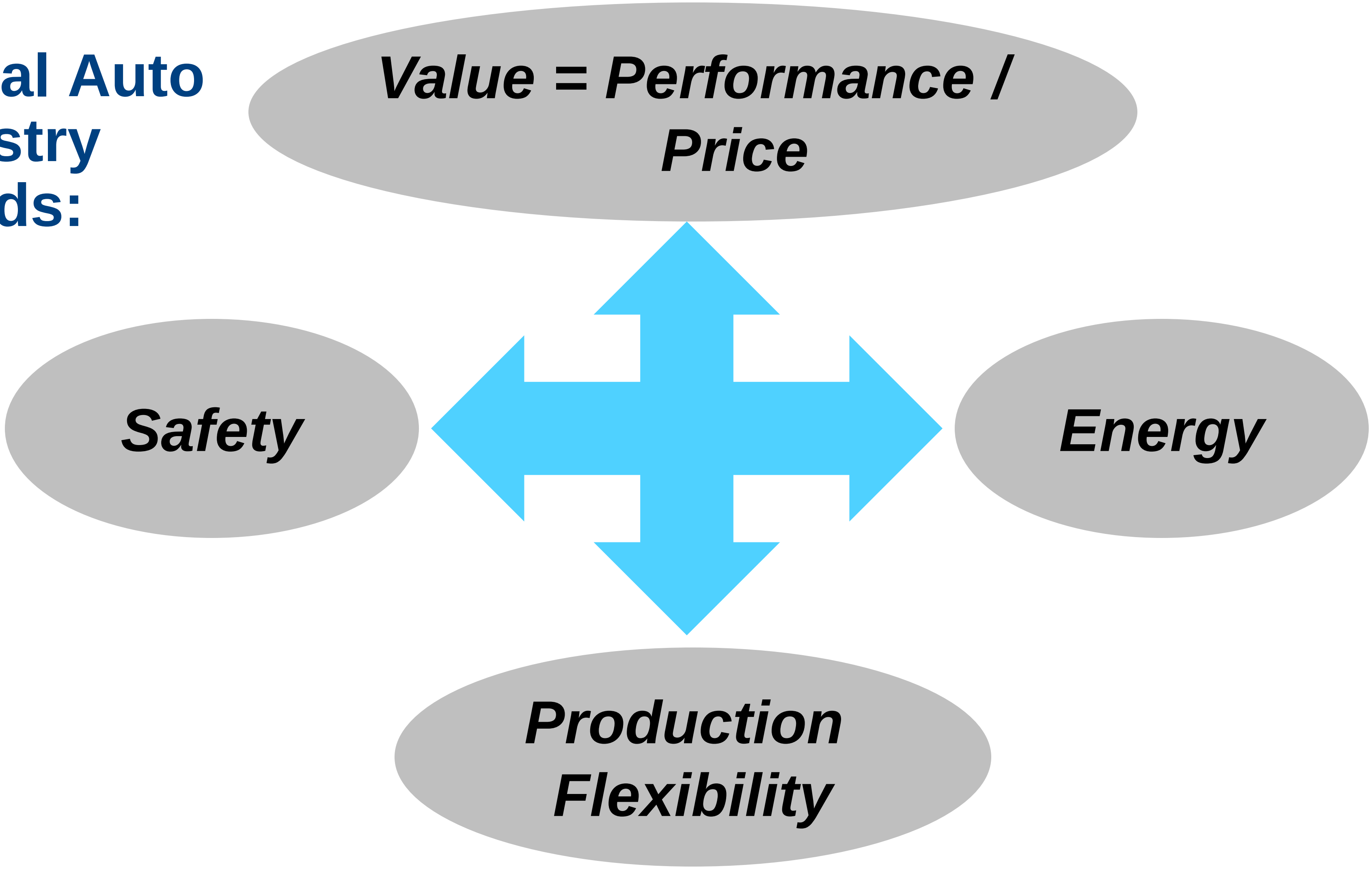
Global Auto Industry Trends:

- *These drivers can be translated into four product development targets or "vectors" that can be segregated in two axes:*
  - one axis that deals with societal and regulatory concerns;
  - a second axis relates to issues related to consumer priorities and commercial viability.
- *There is certainly cross-over between the two axes but they are distinct and both are important.*

Global Auto Industry Trends:



Global Auto Industry Trends:

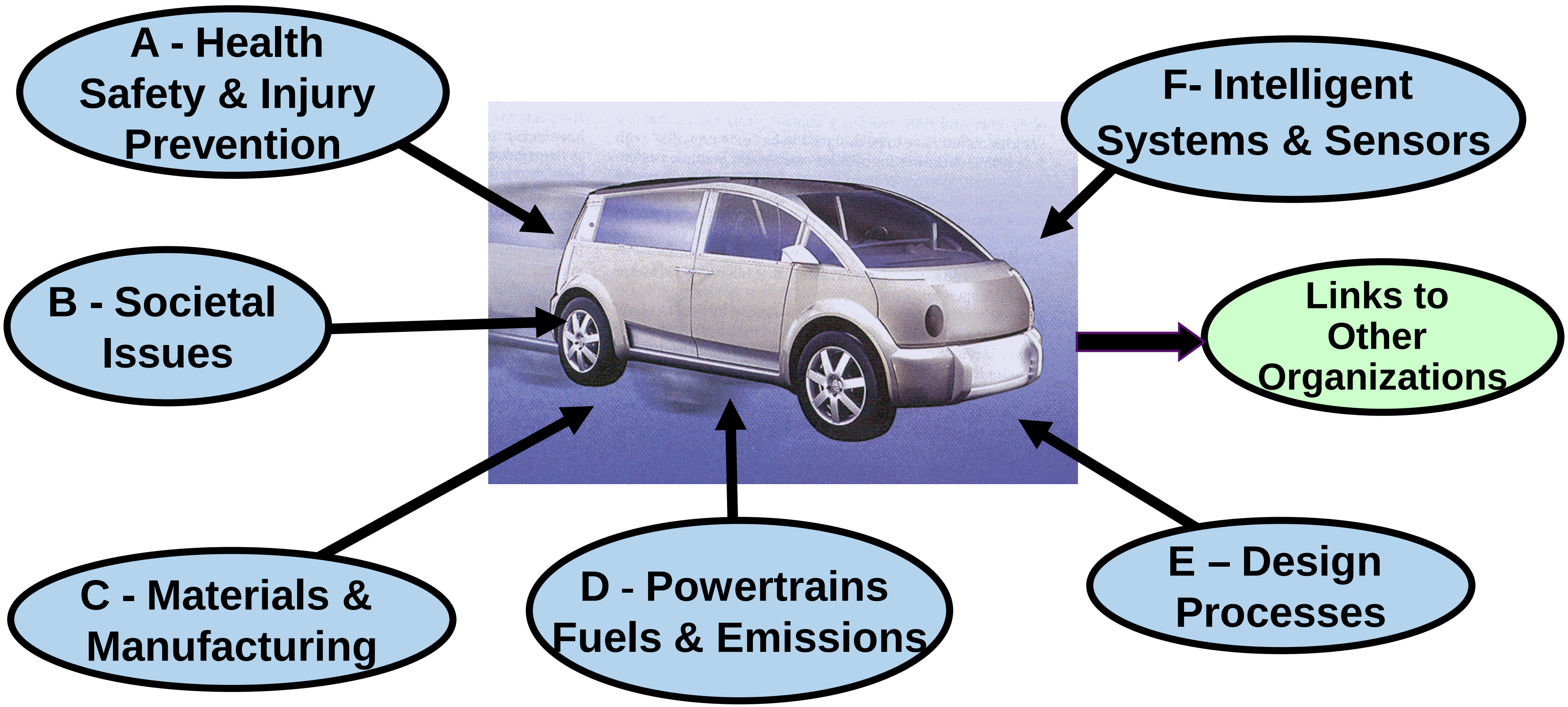


AUTO21 NCE: A network of centres of excellence built on trust, accomplishment & strong partnerships

AUTO21 – Research Program Goals

ENVIRONMENT:	Reduce the environmental impact of the manufacture, operation and end-of-life disposal of vehicles.
SAFETY/HEALTH:	Enhance the safety of workers, occupants and the public in the manufacture and use of vehicles.
ECONOMY:	Enhance the quality & performance of vehicles while reducing life cycle cost.
SOCIETY:	Enhance the economic & social benefits derived from the manufacture and use of vehicles.

Research Themes



Member Institutions (43 in all)

- Carleton University
- Centre for Addiction & Mental Health
- Concordia University
- Dalhousie University
- Ecole Polytechnique de Montreal
- George Brown College
- HEC Montreal
- Hospital for Sick Children
- IWK Health Centre
- Lakehead University
- Université de Montreal
- Université de Sherbrooke
- Univ. du Quebec a Trois-Rivières
- Université Laval
- McGill University
- McMaster University
- Queen’s University
- Ryerson University
- Royal Military College
- Simon Fraser University
- Trent University
- University of Alberta
- University of British Columbia
- University of Calgary
- University of Guelph
- University of Manitoba
- University of New Brunswick
- University of Ottawa
- University of Regina
- University of Ontario Institute of Tech.
- University of Saskatchewan
- University of Toronto
- University of Northern British Columbia
- University of Victoria
- University of Waterloo
- University of Western Ontario
- University of Windsor
- University of Victoria

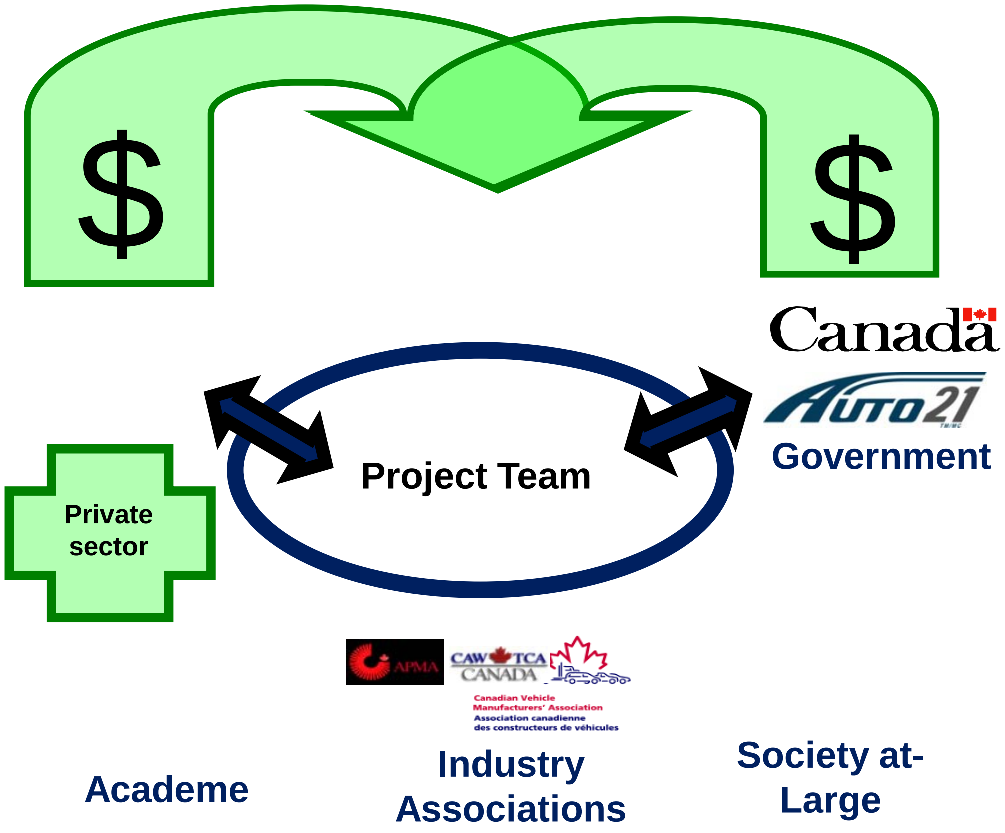
Auto21

PARTNERSHIPS (examples)

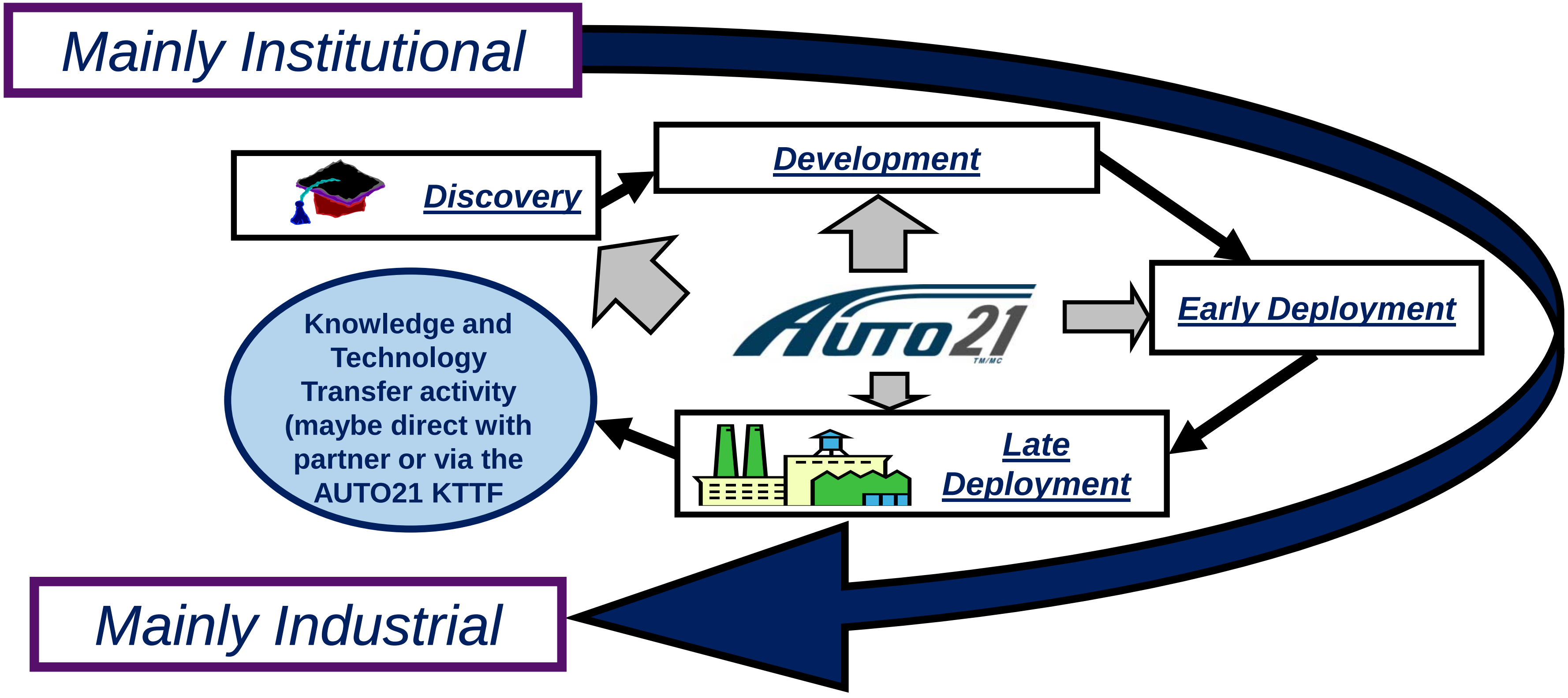
VR
ALCAN
Ford
MAGNA
A Fair Enterprise Corporation
ALCOA
TOYOTA
Bell
THE NEW CHRYSLER
GM
DUPONT
SCHUKRA
A Leggett & Platt COMPANY
ONTARIO BIOAUTO COUNCIL
ONTARIO
MATERIALS AND MANUFACTURING ONTARIO
DECOMA INTERNATIONAL INC.
Esso Imperial Oil
NRC · CNRC
Westport INNOVATIONS INC.
DOFASCO
Our product is steel. Our strength is people.
ASTON MARTIN
First Technology
Innovative Solutions
C-MAC
Weyerhaeuser
ATOFINA
stelco
APMA

AUTO21: Project Partnership Model

- Project ideas from external & academic partners.
- Partners define goals:
  - Relevance to industry
  - Academic excellence
- External + public sector funding (AUTO21)
- Solutions to technical, health or societal problems
- Rights to commercialize intellectual property (IP)
- The chance to meet the brightest new people (potential future employees).



AUTO21 – User Sector Interaction Model





AUTO21 Research Project Class Models

Discovery Projects:

- highly speculative and risky research possibly requiring development of new knowledge in several fields
- longer term or uncertain prospects for commercialization
- somewhat lower level of external support
- ➢ ***Main interaction is with research personnel in the partner organization***

Development Projects:

- less risky or speculative research with more certainty of direction and predictability of results and with a higher likelihood of commercialization on a shorter timeframe
- increased level of external support
- ➢ ***Main interaction is with development personnel in the partner organization***

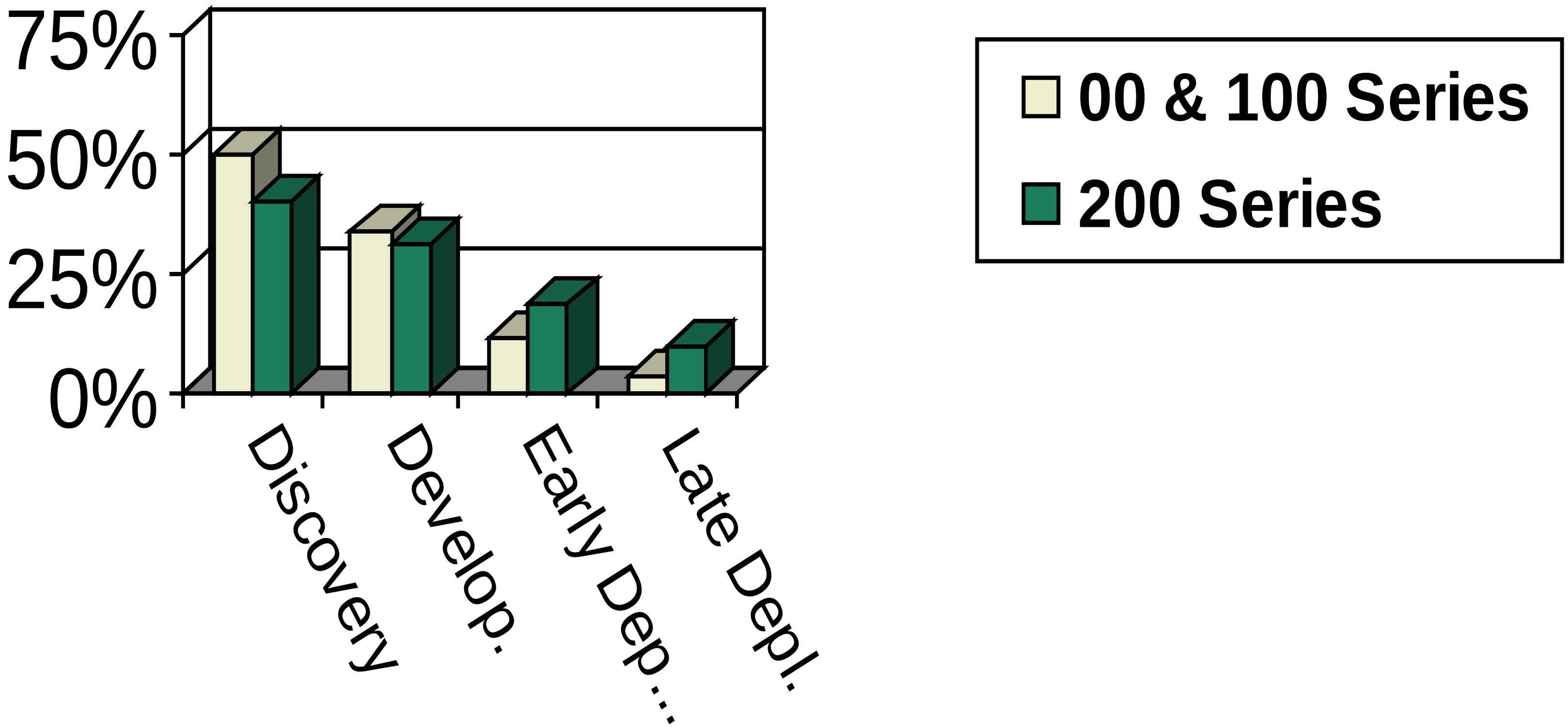


AUTO21 Research Project Class Models

Deployment Projects:

- low level of risk or uncertainty of direction and strong likelihood of commercialization likely in a relatively short timeframe
- high level of external support
- *Main interaction is with production personnel in the partner organization*

AUTO21 Project Classes – Funding Cycle 1



AUTO21 Effects Measurement Framework:

3 metrics to address 3 audiences

Academe / Researchers:

- **ACTIVITIES:** statistics reported in academic CV's including numbers of papers, book chapters, conference presentations, citations, funding from external partners etc.

Our Partners:

- **OUTCOMES:** direct results of the research such as patents, changes in methods or procedures, policies or educational curricula, HQP available for employment as a result of the Network's activities.

The Public:

- **IMPACTS:** the effect on the final product or public policy as a result of the research – i.e. the product innovations and/or the effects on quality of life resulting from the research that are visible to the public.

Key Metrics of the AUTO21 Network 2001-2008

Metric	2001	2008	% Change
AUTO21 Grant (annual)	$5.778 M	$5.8 M	0.37%
External Support	$3.03 M	c. $5.2 M	+71%
Network Researchers	193	312	+62%
Research Projects	28	54	+93%
Member Institutions	27	43	+59%
Students Registered (HQP)	163	c. 505	+210%



Developing the best people and the best technology for the future of the automotive industry

AUTO21 TM/MC

Innovation Through Research Excellence
l'innovation par l'excellence en recherche

www.auto21.ca

Networks of Centres of Excellence
Réseaux de centres d'excellence

www.nce.gc.ca

Automotive Light Metal Recycling

USCAR-VRP Automotive Lightweighting Metals Recycling Seminar
Southfield, MI
24 September 2008

Adam J. Gesing
Gesing Consultants Inc.
www.GesingConsultants.com

Contents

- Light metal (LM) recycling objectives and recommended strategy
- Market areas of interest and scrap flows between markets
- Alternative uses for primary LM ingot and recycled LM scrap
- Scrap sources and material interactions in recycling system
- Sustainable LM recycling system needs and key LM issues
- Light metals in current post-consumer metal recycling system
- New particle sorting technology
- New recycling processes
- LM recycling development needs (for afternoon discussion)

LM recycling – overarching objectives

Take concrete actions that ensure:

- Post-consumer Mg scrap does not interfere with the already well-established Al recycling system
- Post-consumer Mg is truly recycled
- Both Mg and Al recycling processes are efficient and environmentally and economically sustainable

Recommended strategy for LM recycling

- Minimize generation of production, semi-fabrication and manufacturing scrap
- Maximize scrap collection and eliminate metal scrap losses to landfills
- Minimize the cost and maximize the efficiency of metal liberation and segregation
- Minimize process losses in recycling
- Work with and improve upon the **existing** global material recycling system and scrap markets
- Promote cross-market trade in LM scrap
- Start with recycling to **existing** secondary markets and alloys
- Develop new secondary alloys and markets for scrap compositions that do not have an existing destination in the current system

Main markets for secondary Al and the most popular alloys for these markets

Market	Secondary alloy	Compatible scrap sources
Al packaging	3X04 can body sheet	Old cans, can manufacturing scrap Non-can wrought manufacturing scrap Al- and Mg-based scrap mix from 2 g/cc float fraction of a dense-media sink-float plant
Building Al	3105 painted sheet	Old Al siding Al siding and extrusion construction scrap Mixed wrought manufacturing Al scrap with low copper content Old wrought scrap
Automotive Al	38X.x casting alloys	Some 38X alloys can accept a mixture of the most common old scrap varieties without dilution, providing the Mg concentration is controlled by chlorination
	319.x casting	Tighter concentration limits on 319 increase the dilution requirement and limit the types of old scrap that can be added to a 319 alloy batch
Steel deoxidants	95% Al	This specification can be met by many mixtures of old wrought alloy scrap

Main markets for secondary Mg alloys?

Currently there are no secondary Mg alloys commercially produced from old Mg scrap!!!

Old Mg alloy scrap is consumed:

- in Al secondary smelters by chlorination out of Al foundry alloys
  ☹ **Waste**
- in steel mills for steel desulphurization
  ☺ **Recycling**

Market areas of interest

Replacement of use of prime metal in any application by scrap frees the prime metal to be used in property- and composition- critical applications such as automotive and aerospace structural components where designers prefer to use alloys batched from prime.

Hence, market areas of interest for LM-scrap-derived alloys are not limited to automotive products but should include:

For Al:

- Steel deoxidation
- Hardener compositions for LM alloying
- Extended range scrap sources for
  - foundry alloy products
  - secondary sheet and extrusion products

For Mg:

- Steel desulphurization
- Al alloying
- Common alloy Mg diecastings
- Alternative markets for creep-resistant Mg alloys

Scrap flows between markets

Use of automotive scrap in automotive alloys

- Old wrought Al scrap in auto shred is batched into foundry alloys

Use of scrap from other sources in automotive alloys

- "Auto shred" Al, the most common scrap stream used in automotive foundry alloys, is a mixture of scrap from ELVs, C&D and appliances
- "Mixed clips" scrap category, a mixture of new scrap from any sheet product or market, is often used in diluting automotive foundry alloys
- "Old Sheet," a mixture of old scrap from any sheet product or market, is used in batching automotive 38X foundry alloys

Use of automotive scrap in other alloys

- 3105 building sheet batched from Al auto shred

Production and manufacturing scrap sources

- Primary smelter dross
- Remelt and secondary smelter dross and skim
- Ingot/billet casting scrap
- Shape casting scrap
- Semi-fabrication scrap
- Manufacturing scrap

Prompt and manufacturing scrap quantity is large (~3 $\times$ old scrap).

Metal production and semi-fabrication scrap either is or should be alloy segregated at source.

Manufacturing scrap often is a simple mixture of known metals and alloys.

Scrap is usually surface contaminated: oily, lubricated or coated with paint, paper or plastic. Scrap should be cleaned, preferably before sorting, but definitely before remelting.

All metal separated from production or manufacturing scrap is already recycled, some of it closed-loop into a similar alloy.

Post-consumer LM scrap sources

	Scrap source	Scrap type
LM in EoL products	Curbside recycling and recycling depots	UBC Packaging foil
	Municipal waste dirty MRFs and RDF plants	Consumer durables – appliances
	C&D MRFs	Building scrap, siding, windows, doors Scrap machinery, process vessels & piping
	WEEE recycling depots	Electronic scrap – Al and Mg housings
	Scrap yards and ELV de-pollution dismantlers	Flattened ELV hulks Handsorted & baled, categorized LM scrap
LM commingled in shredded scrap	Steel shredders	NMMC (nonmagnetic metal concentrate) LM concentrate
LM scrap products	Dense media sink-float plants	Al and Mg-Al mixes from shredder LM concentrate
	Alloy sorting/batching plants	Al or Mg alloys batched from alloy mix

There is no post-consumer source of "automotive LM scrap" and there is no need to create one!

Material interactions in recycling system

Consumer products are a combination of:

Metal alloys	**Inorganics**	**Organics**
Steel and iron Al and Mg Stainless and superalloys Platinum and other precious metals	Glass Ceramics Silicates Concrete	Plastics Textiles Rubbers Wood Paper Etc.

Collected scrap streams are usually a combination of products from different markets – ELVs are usually commingled with C&D scrap, appliances and scrap from dirty MRFs and RDF plants.

A sustainable recycling system cannot cherry pick selected materials but should collect, separate and recycle as much as practical.

For least-cost, sustainable recycling, you need:

- ***markets*** for all scrap-derived products
- ***recyclable***, relatively pure PRIME alloys
- SECONDARY alloys with high ***recycled content***
- ***unrestricted flow*** of metal scrap between markets
- low-cost ***technology*** and system for managing alloying elements in scrap and using these elements to alloy new metal
- a complete ***recycling*** system

LM recycling system needs

The current market for Al secondary alloys exceeds the total supply of post-consumer Al scrap.

Al scrap shortfall is supplied by prime and new scrap.

There is **no** current recycling system need to:

- develop new Al secondary alloys, or
- new markets for these alloys, or
- divert post-consumer scrap to alloys currently batched from prime and new segregated scrap

There are no Mg secondary alloys currently produced from post-consumer Mg scrap. Old Mg scrap, when recovered, is used for steel desulphurization in Asia.

Mg alloy content of old LM scrap will soon exceed Mg demand for steel desulphurization.

There is an **imminent** recycling system need for:

- separation of Mg alloys from old LM scrap
- development of markets and applications for secondary Mg alloys

Summary

Key Issues

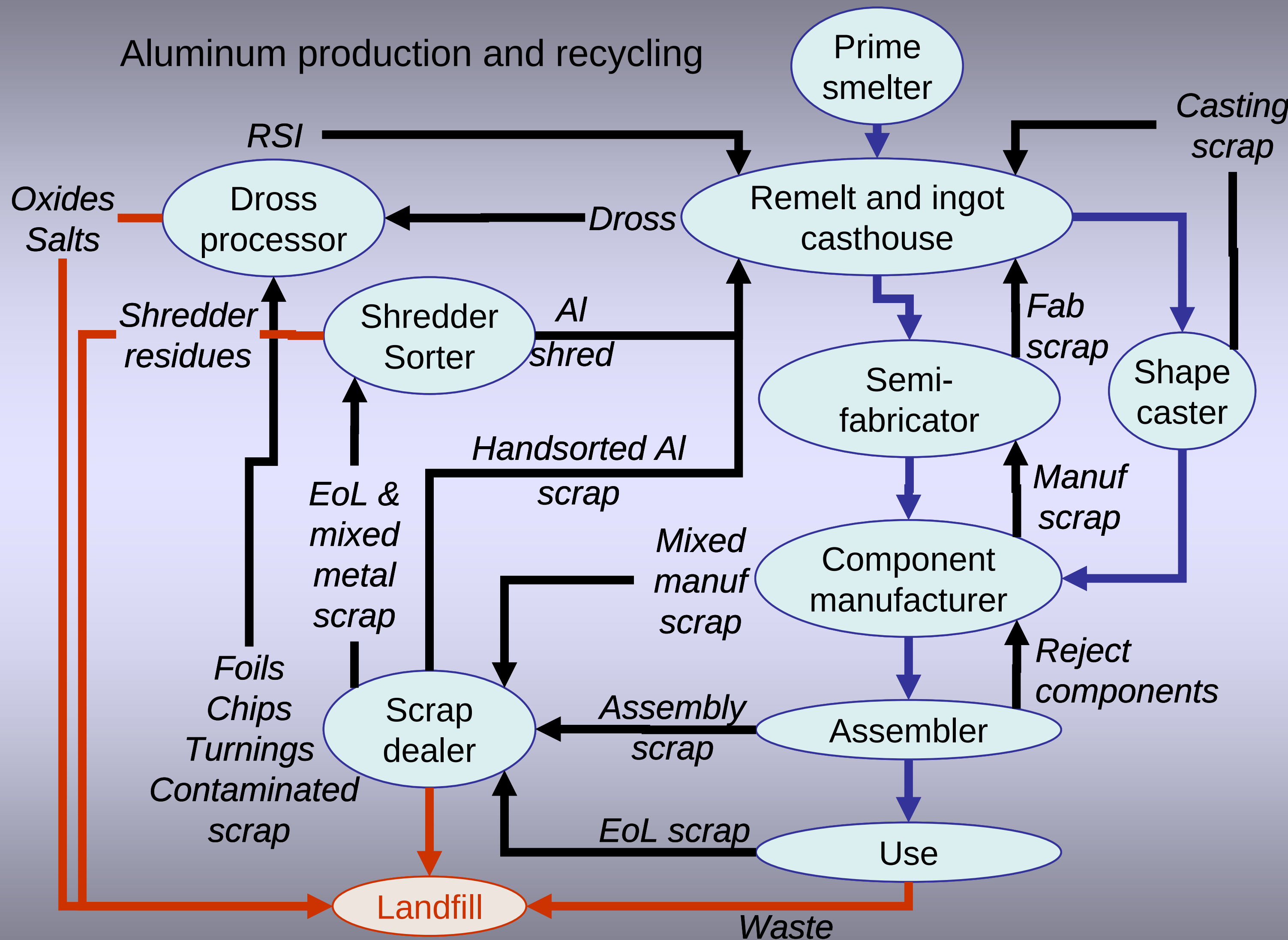
- Increasing LM content of new automobiles
- Increasing proportion of Mg
- Interference by Mg in Al recycling system

Key required actions

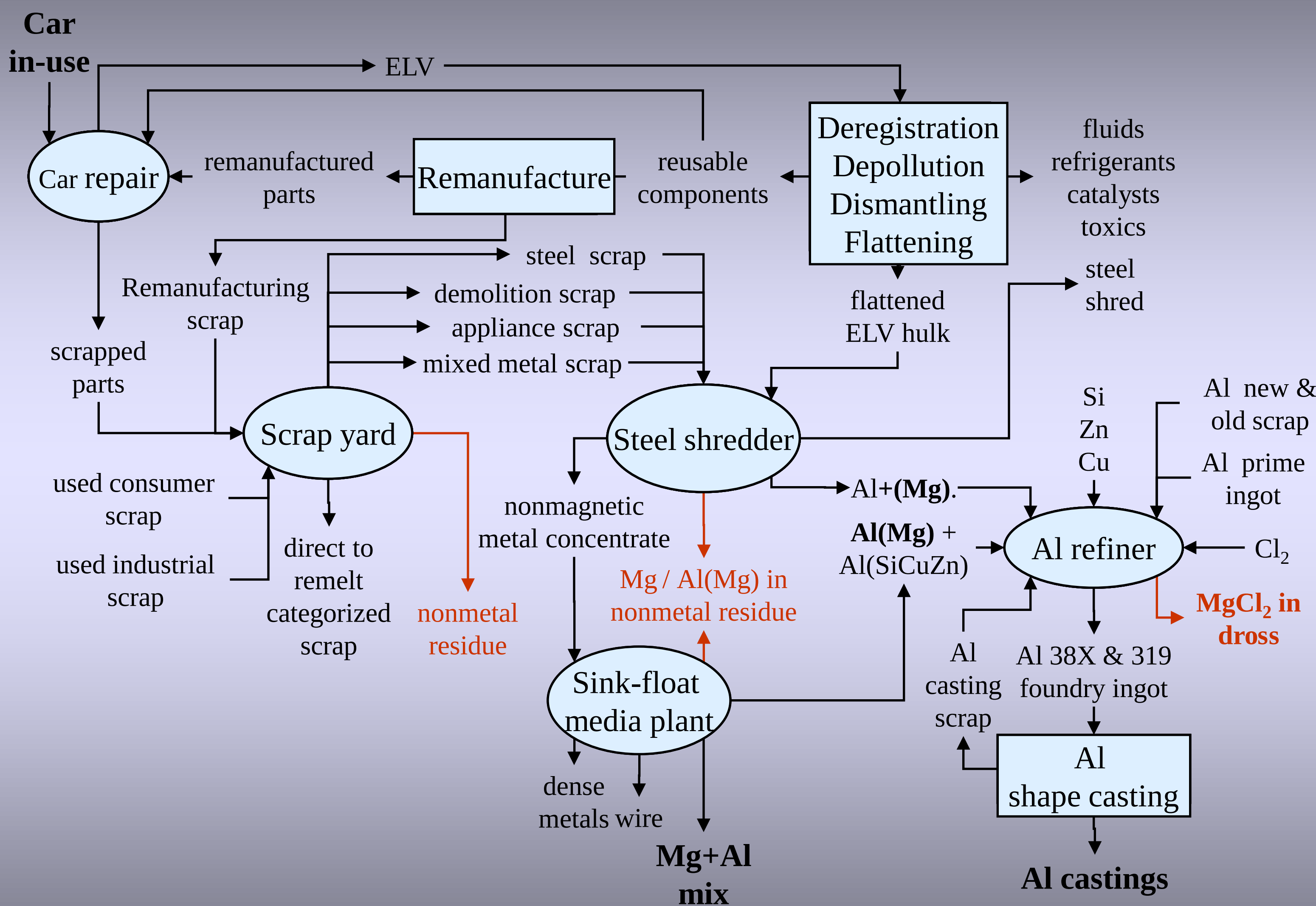
- Separate Mg from Al scrap
- Batch secondary Mg-AZ91 from old Mg scrap

Light Metals in Current Post-Consumer Metal Recycling

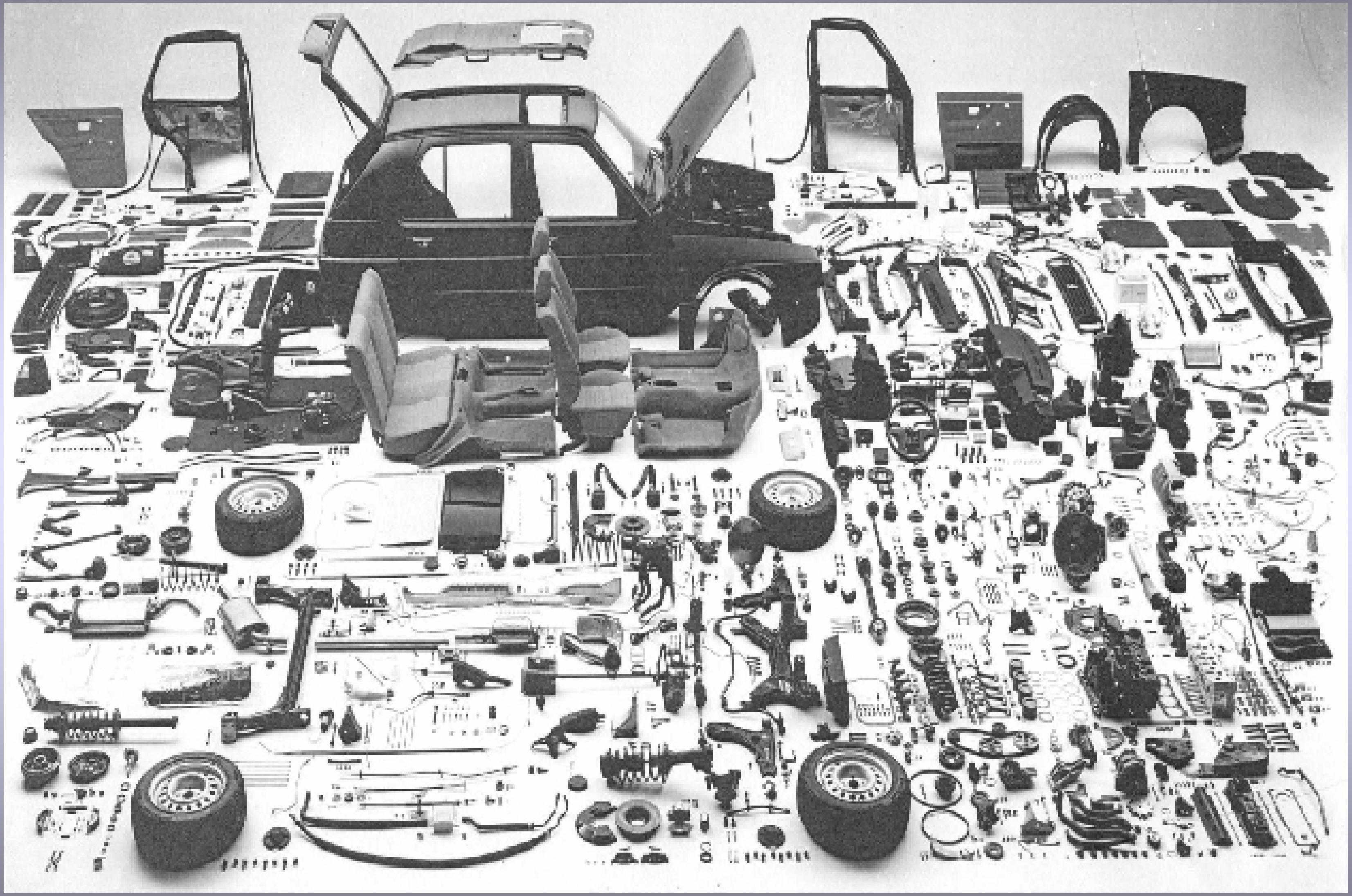
Scrap flows in the LM production and recycling system



Light metals in the car recycling system



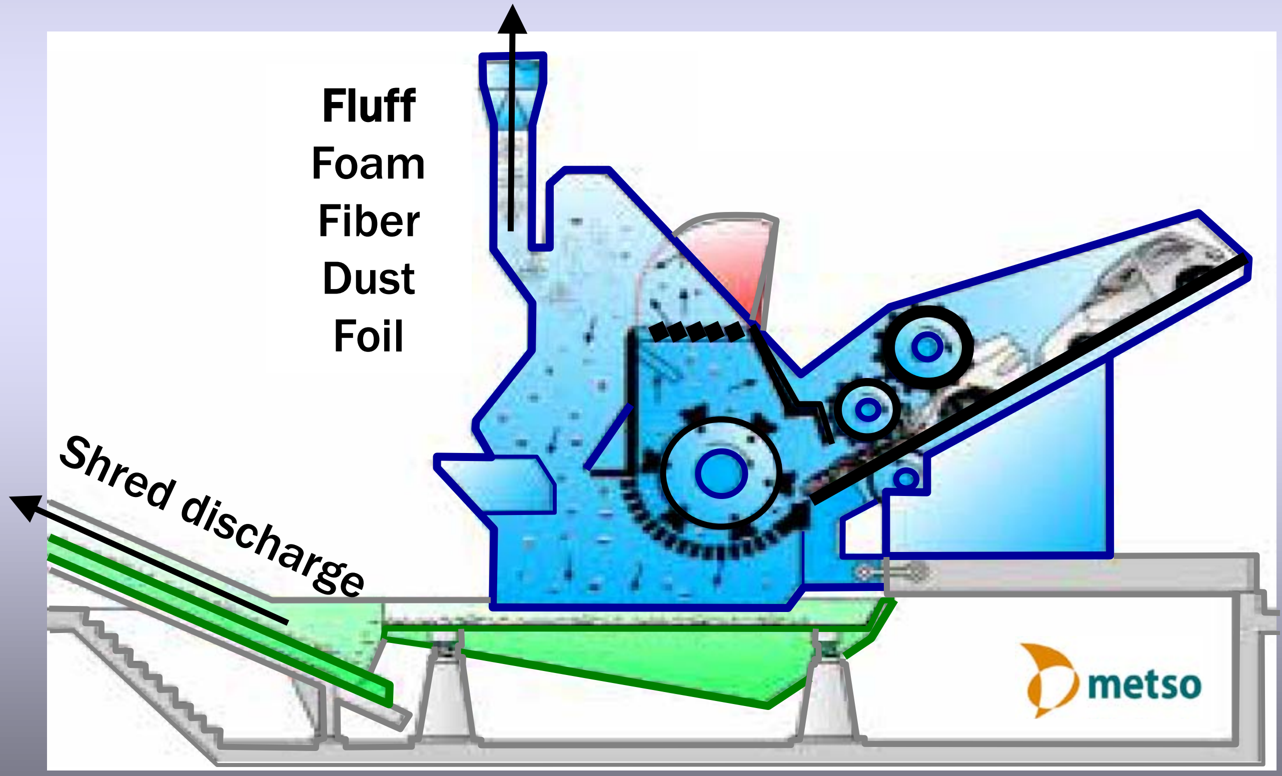
Dismantling for material recycling? – Too costly!



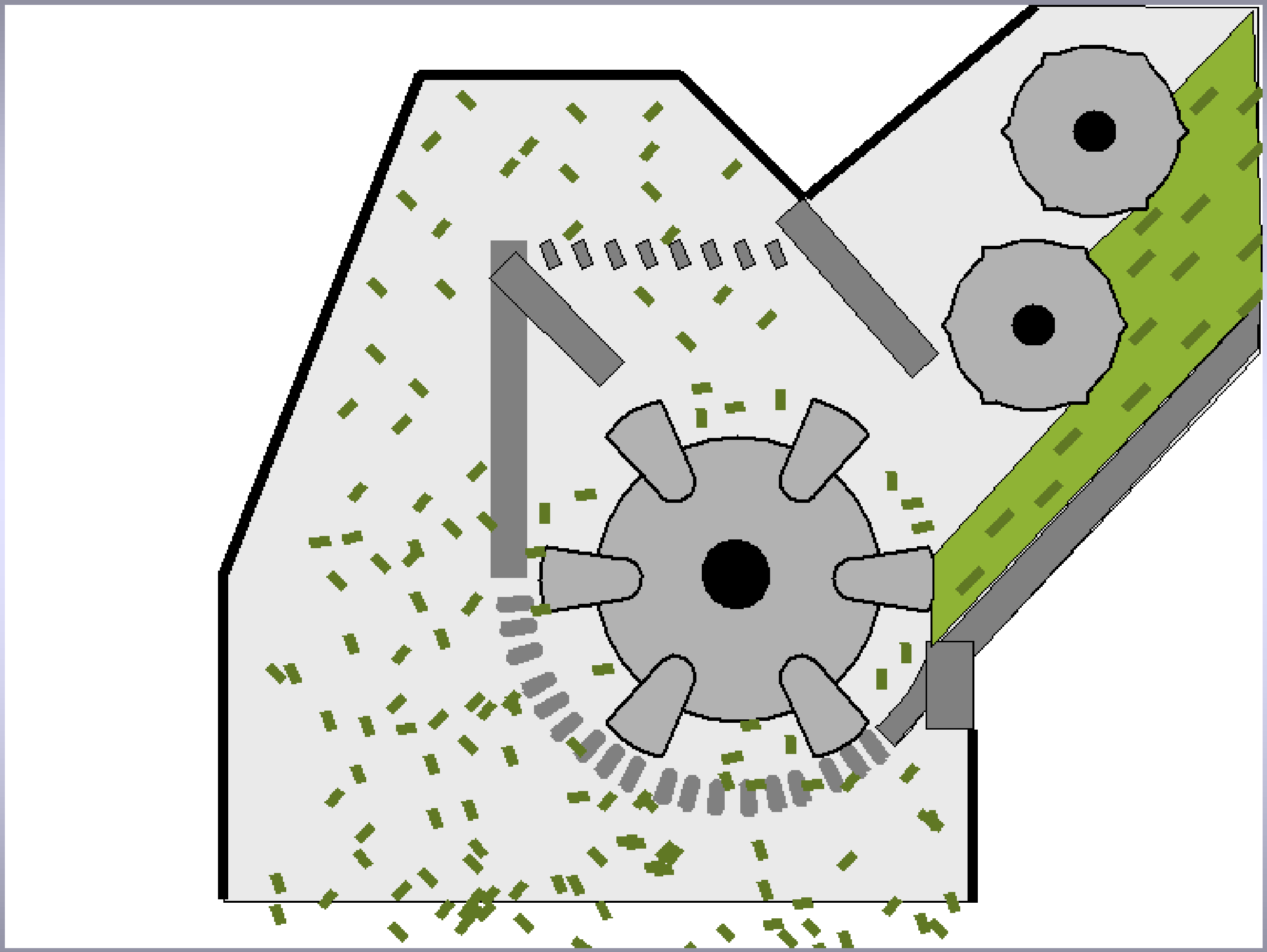
Shredding alternative

Shredding, the cost-efficient alternative to dismantling:

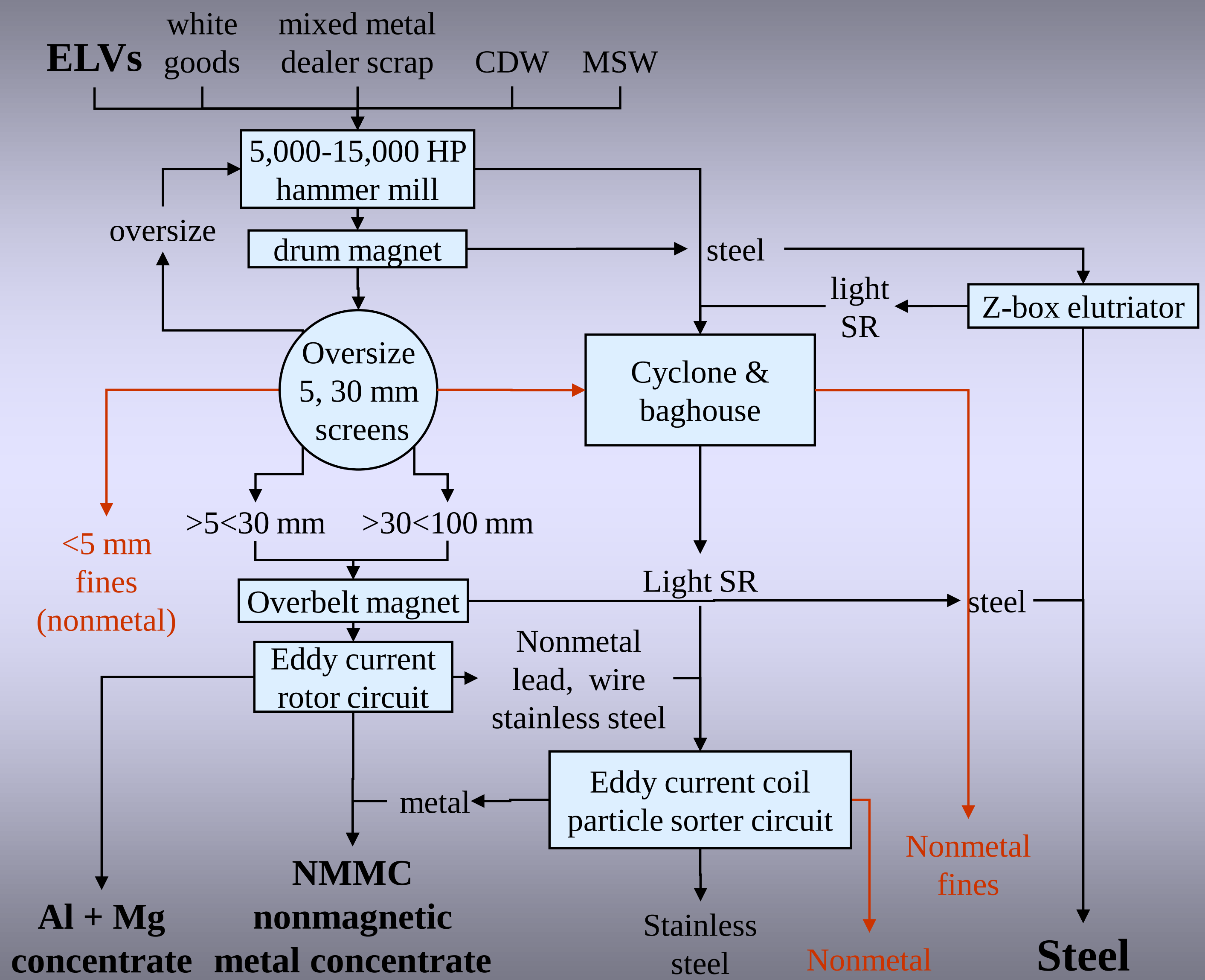
- liberates mono-material particles
- increases the bulk density
- permits mechanized material handling and storage



Hammer mill shredder



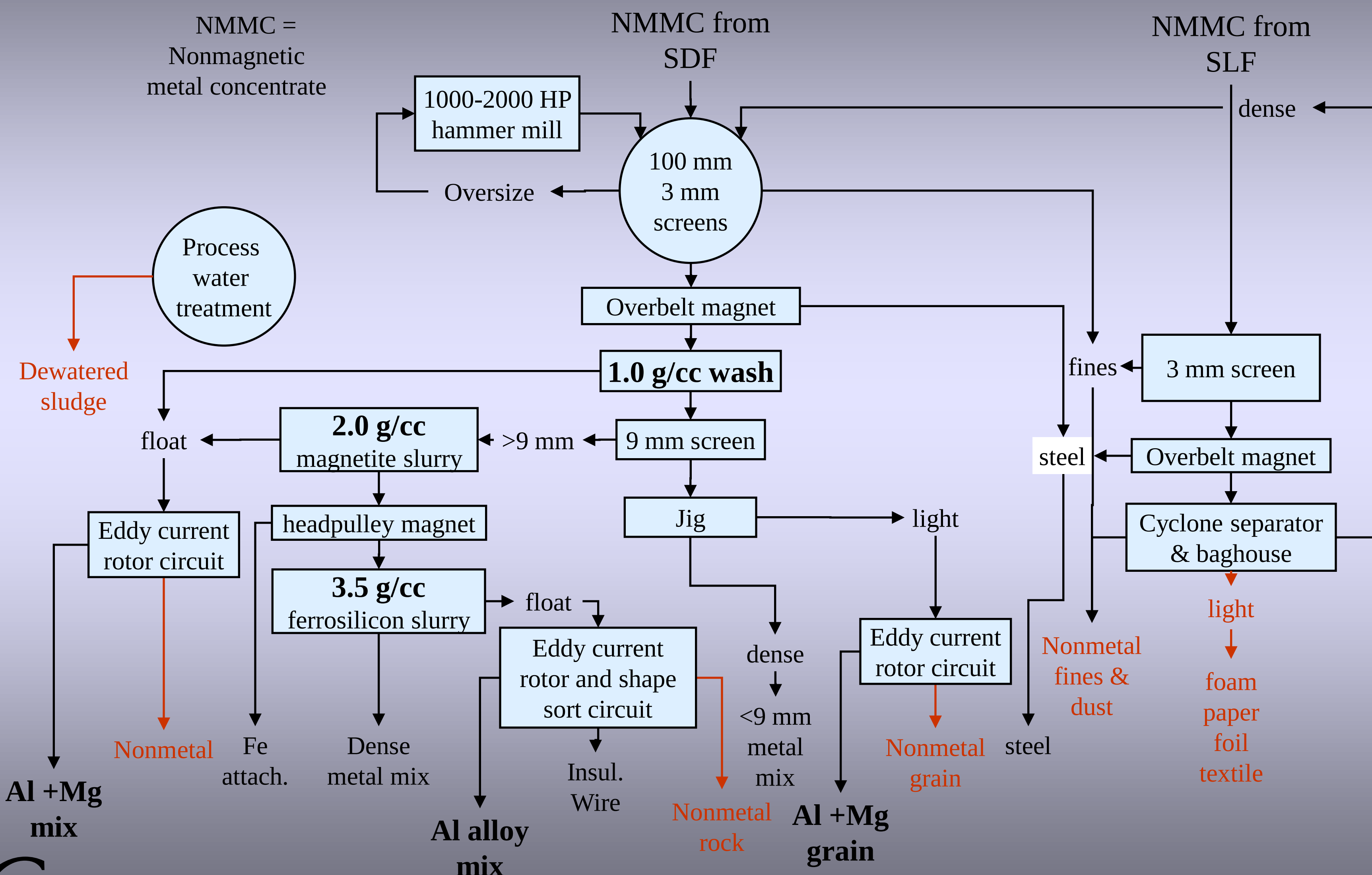
Primary shredding plant



Nonmagnetic metal concentrate (NMMC)

- NA supply ~1,000 kT of NF metal/year, growing quickly
- 20-95% metal
- 60-70% Al in metal (~600 kT/year)
- 30-50% wrought in Al (~200 kT/year)

Sink-float dense-media plant



Al mix from dense-media float fraction

Scrap sorting plant (current technology)

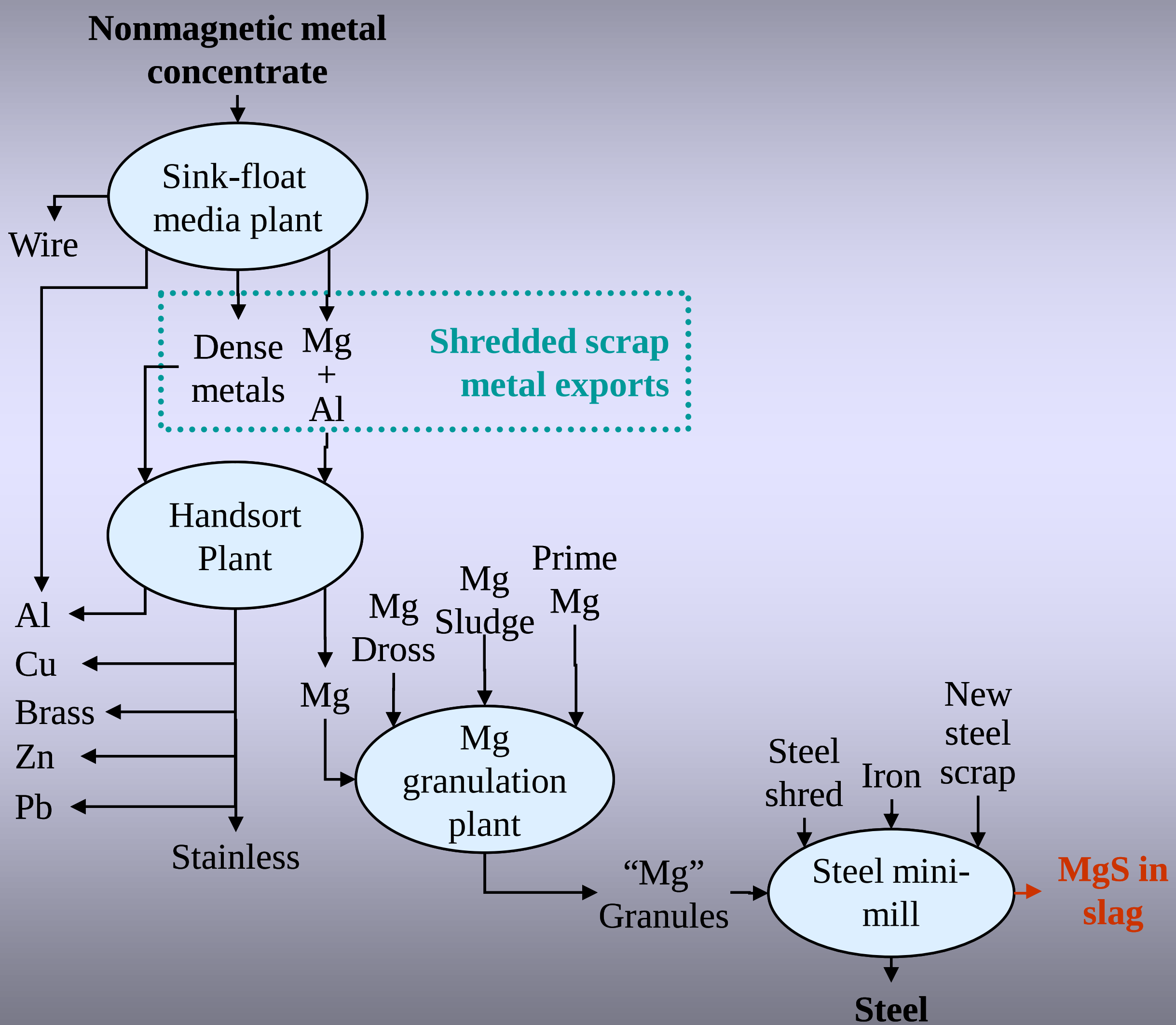
Dense metal mix (dense media sink)

Dense metal mix (dry sort)

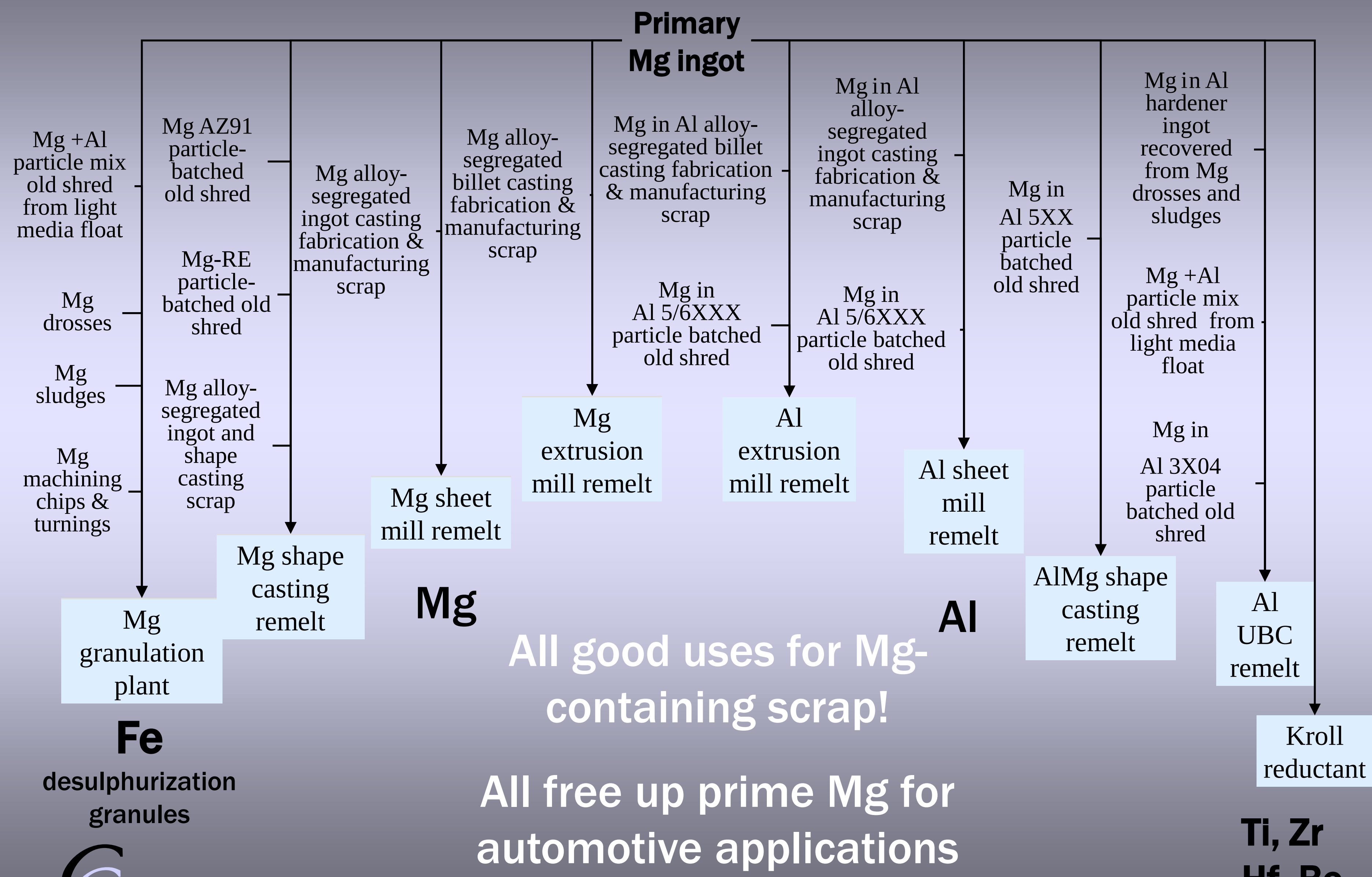
Al + Mg (light media float)

Al | Mg | Cu | red brass | yellow brass | Zn | stainless steel | lead | wire | nonmetal | steel

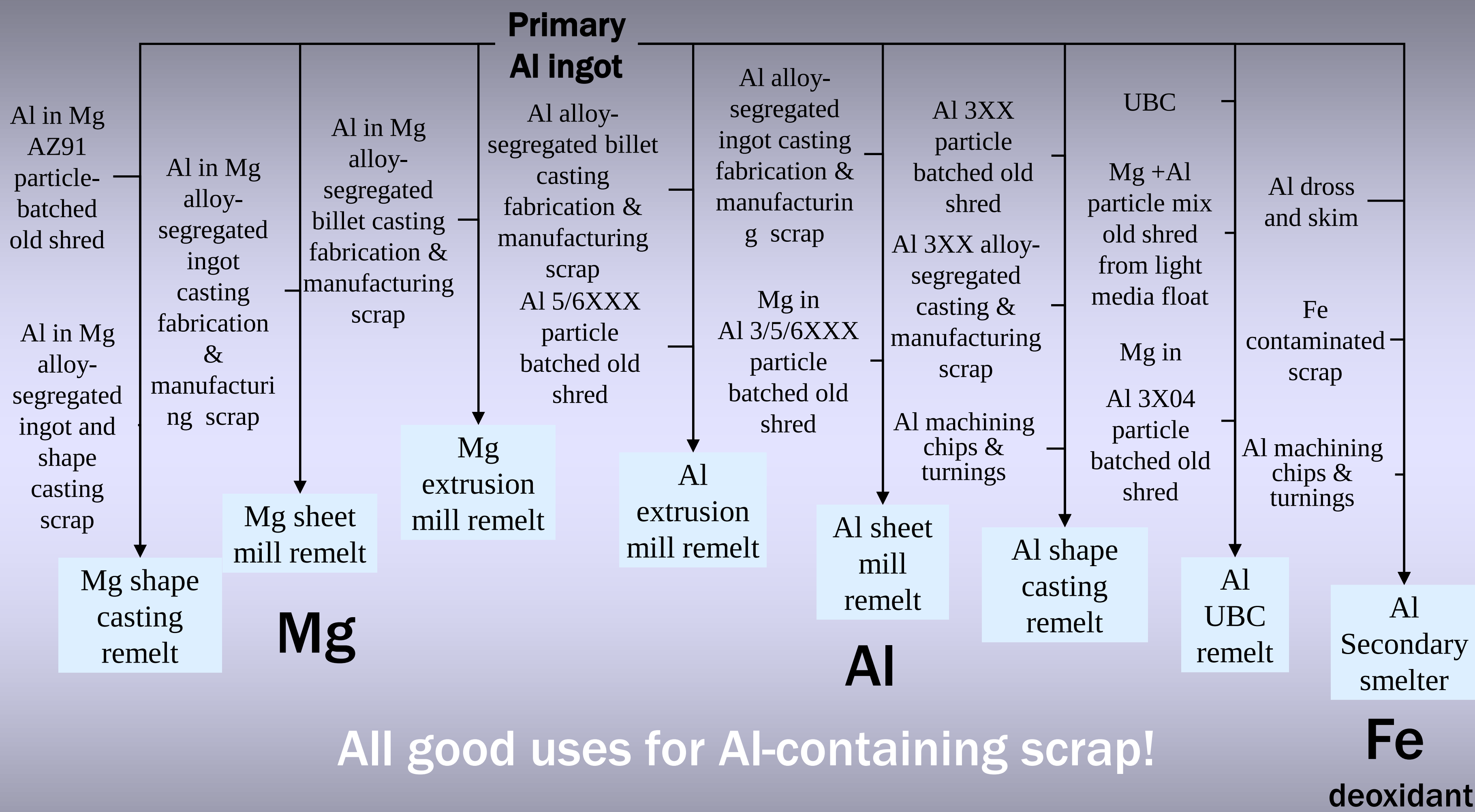
Recovery of old Mg for steel desulphurization



Alternative uses for primary Mg ingot & recycled Mg



Alternative uses for primary Al ingot & recycled Al



All good uses for Al-containing scrap!

All free up prime Al for automotive applications

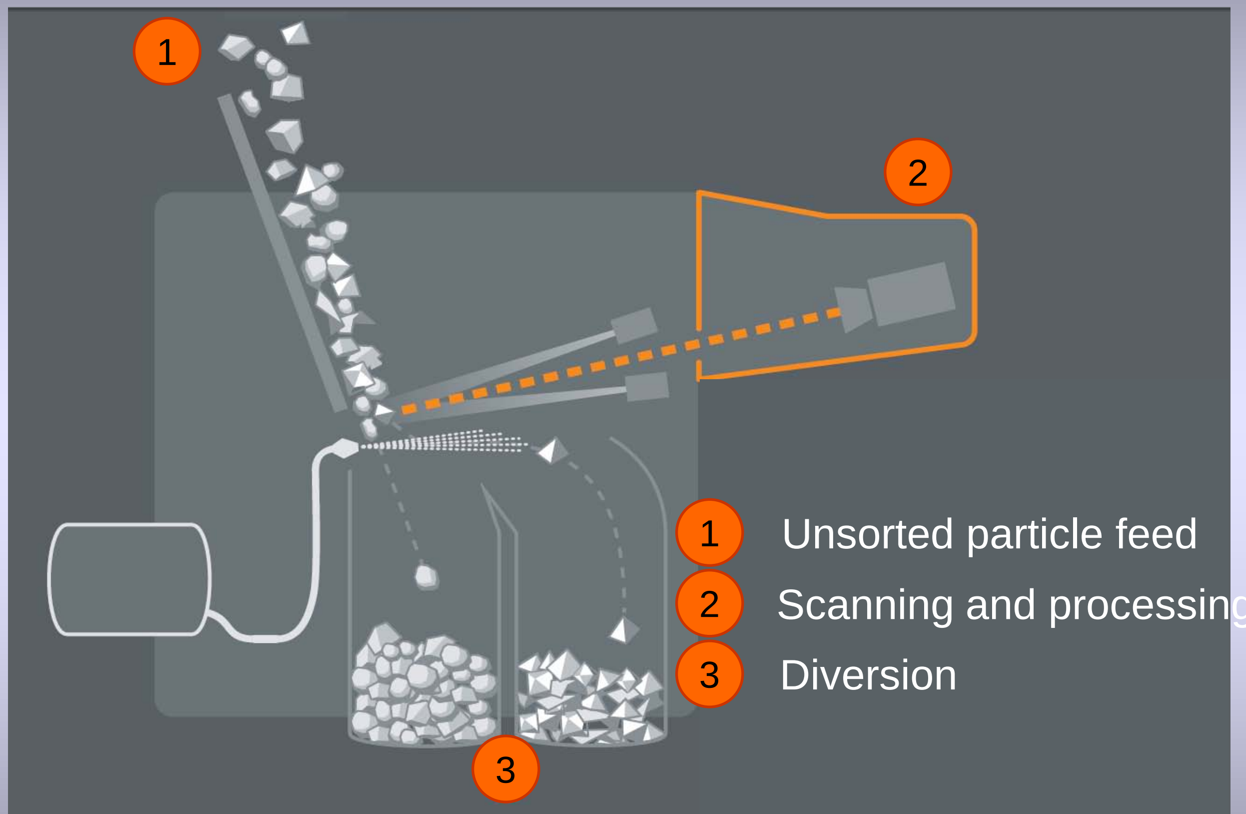
GESING CONSULTANTS INC

New Technology

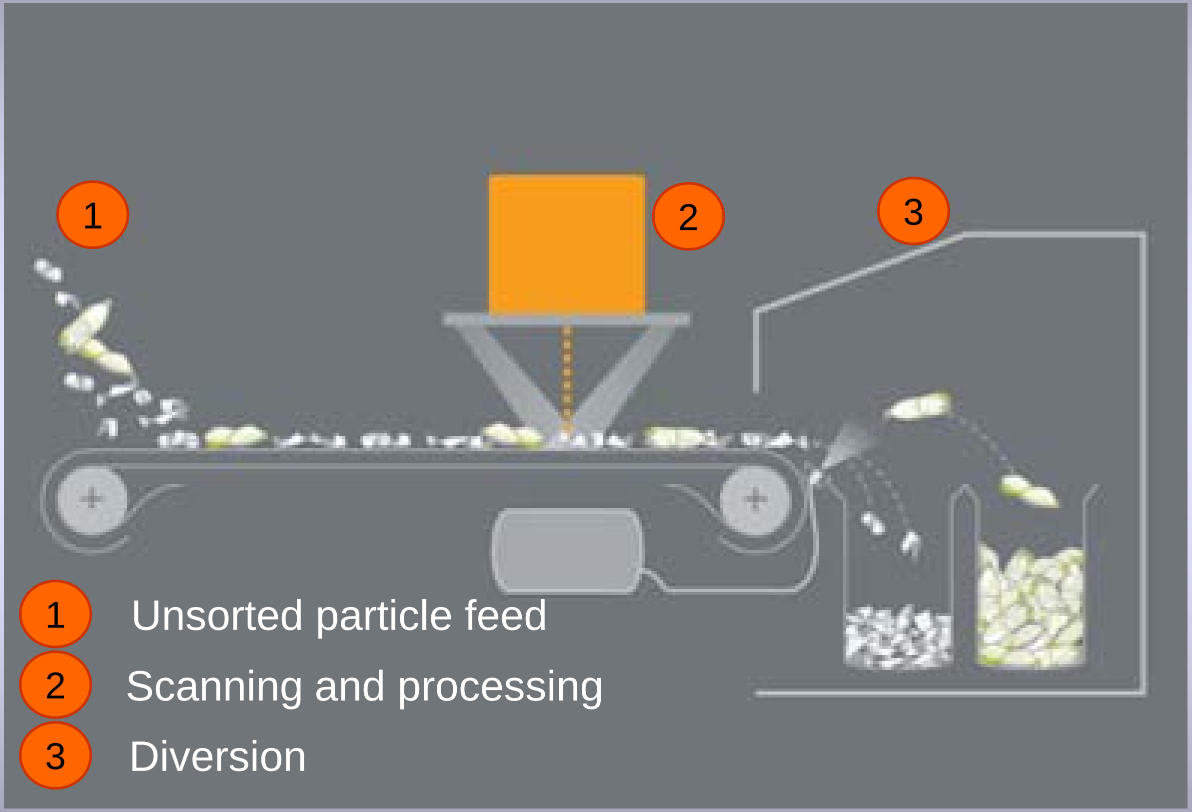
Sensor-based metal scrap particle sorting

- Sensors
- Commercial sorters
- Sorter capabilities

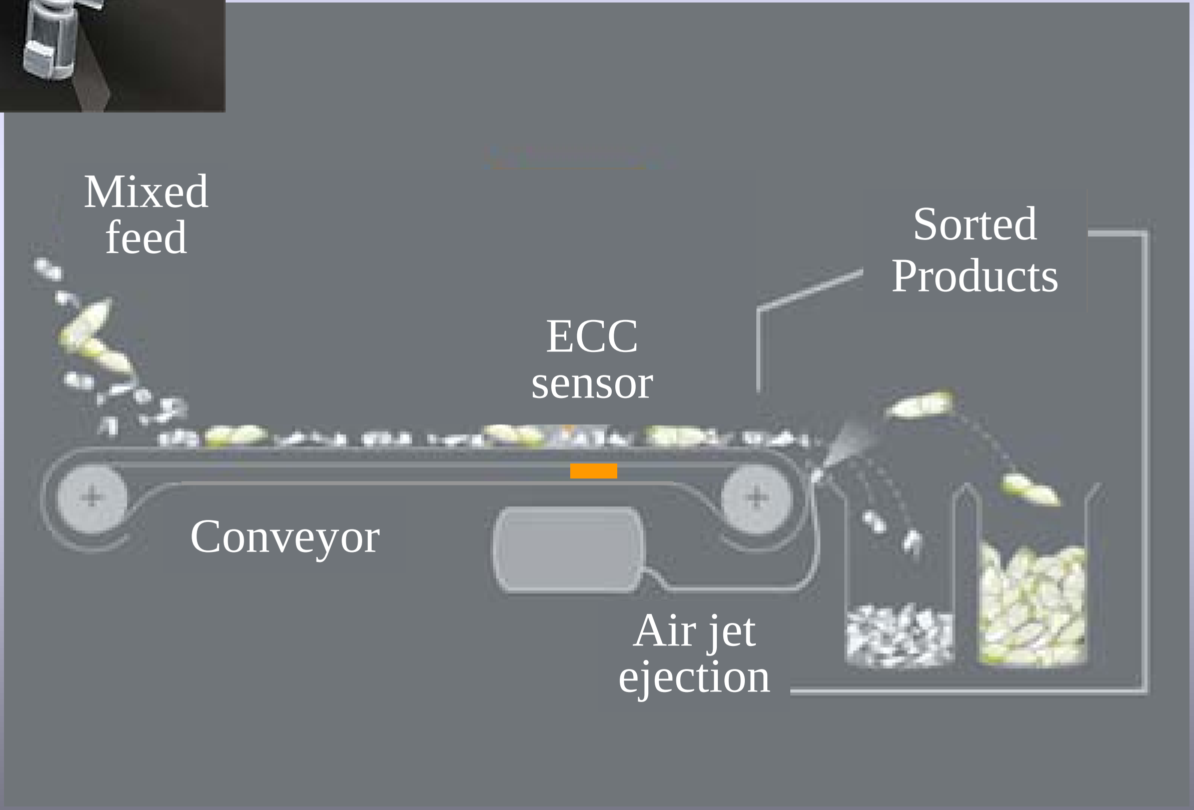
Chute type particle sorter



Belt type particle sorter



Finder Eddy-current coil sensor sorter

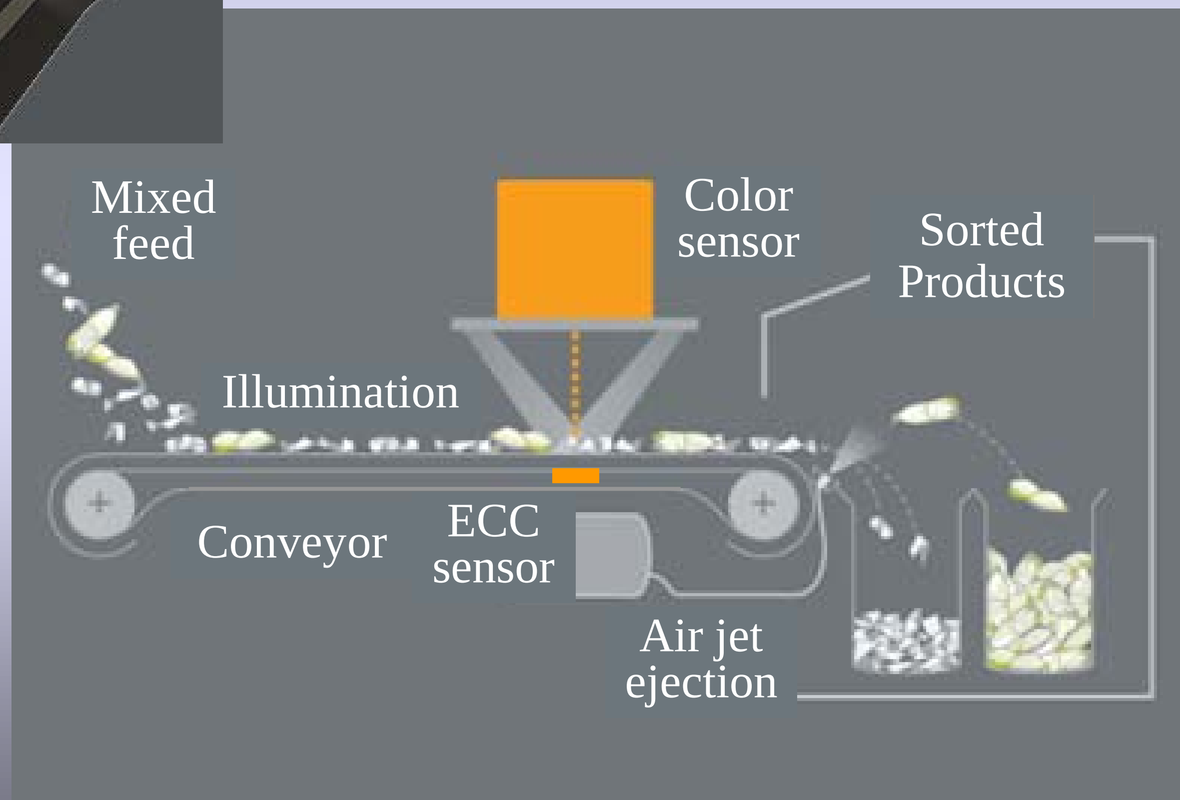


Find metal in residue

and/or

separate stainless steel

CombiSense Color and ECC sensor sorter

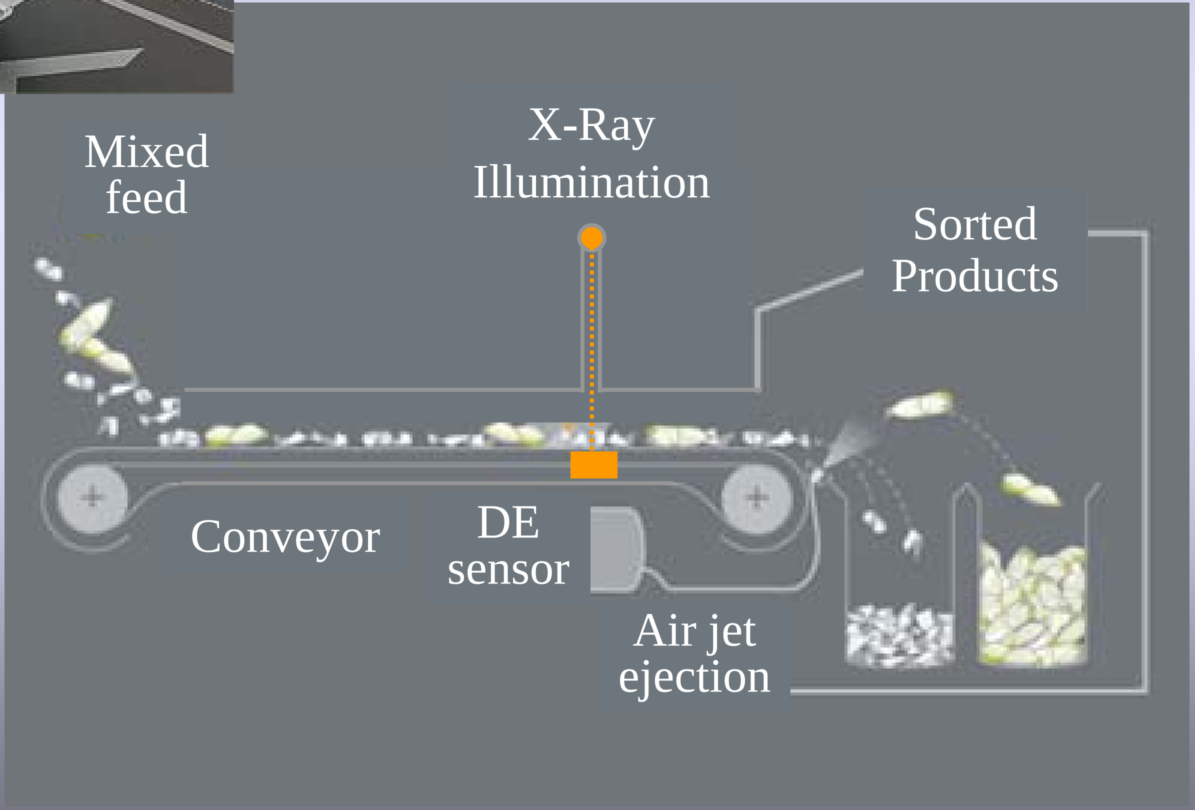


Separate Cu, brass, Zn, stainless steel, nonmetal

or

Al, Mg and nonmetal

X-Tract dual energy x-ray transmission sensor sorter

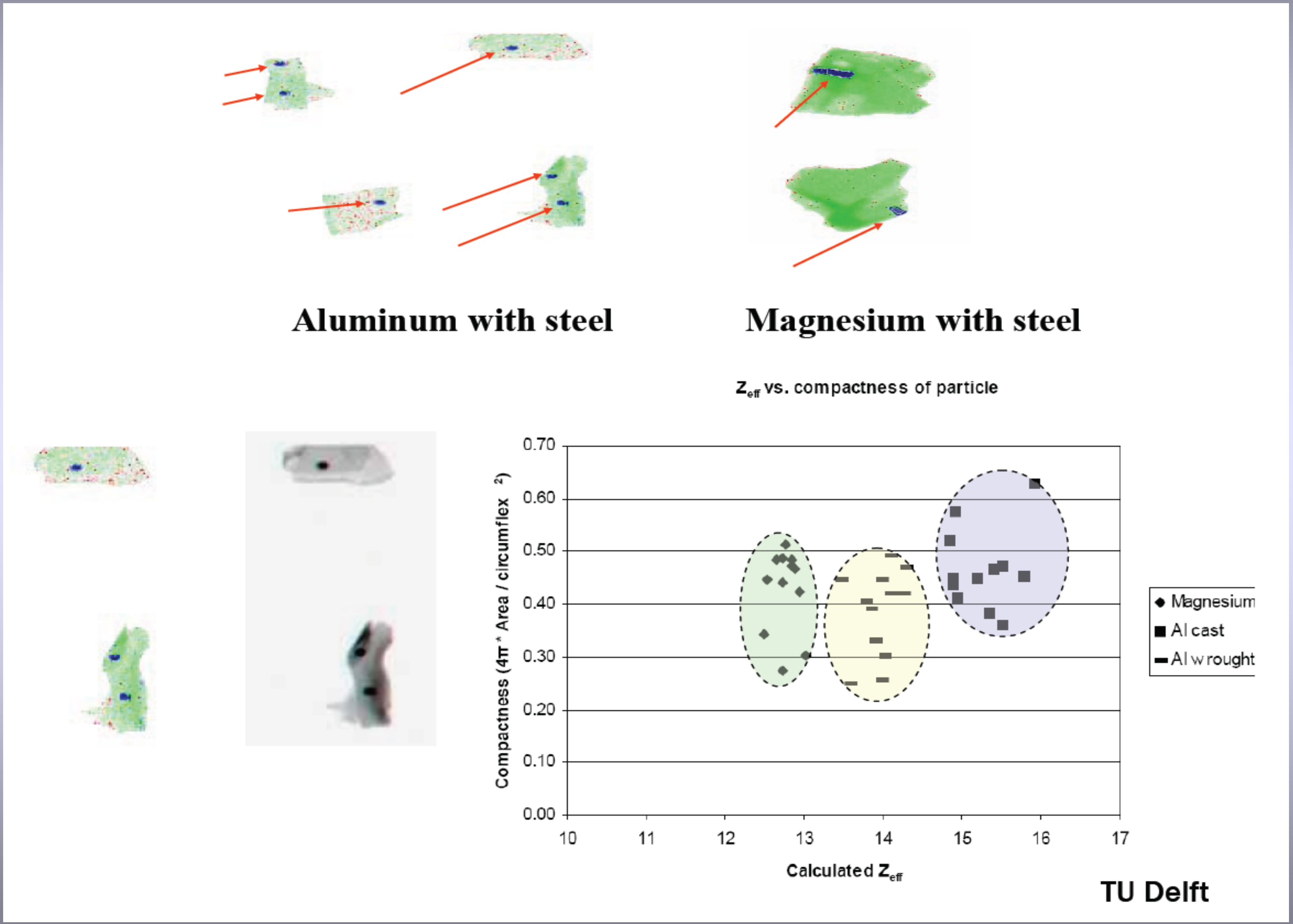


Identify contaminants,

attachments,

separate LM from DM

DE-XRT identification of Al and Mg



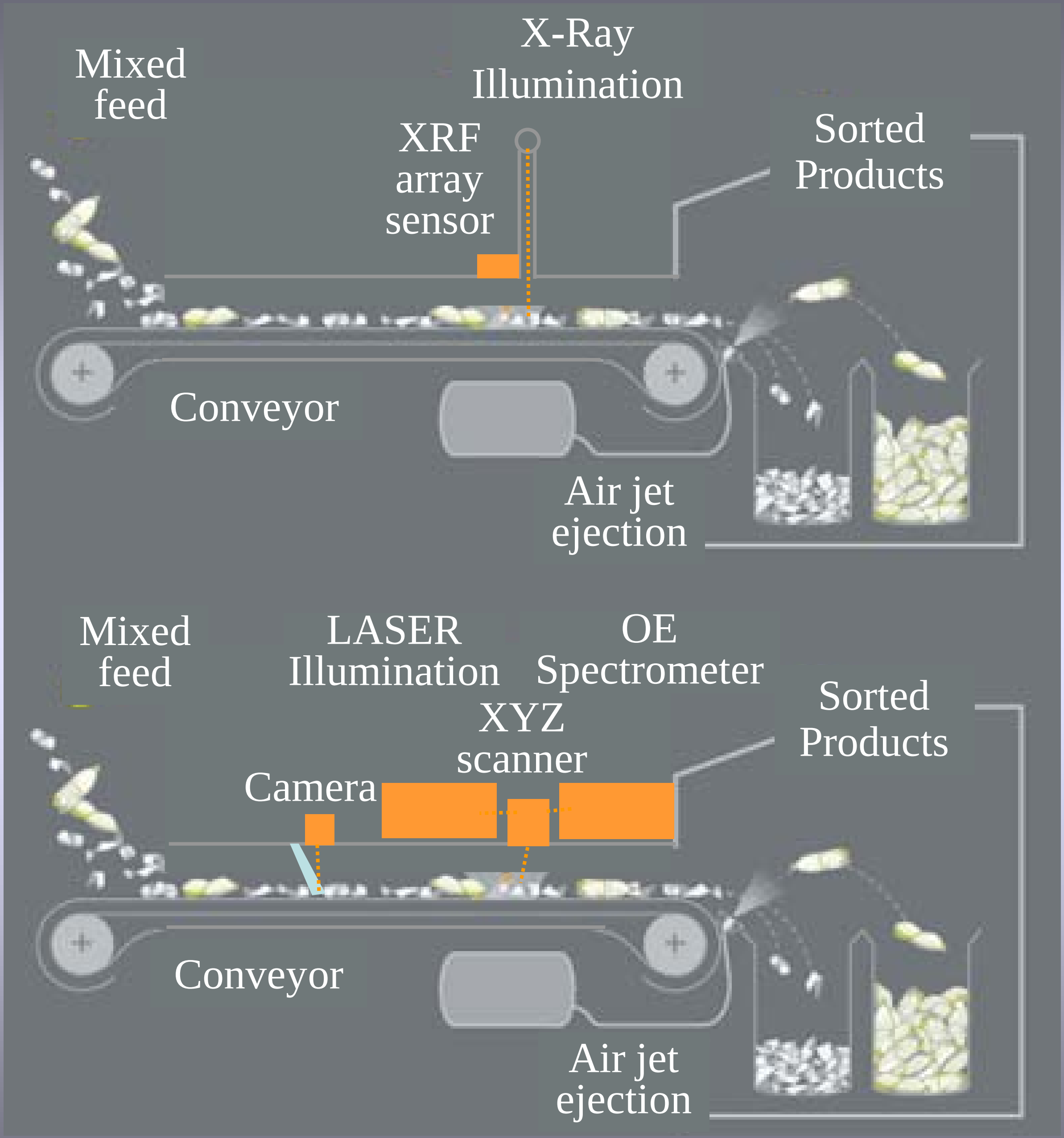
Elemental concentration sensor sorters

XRF sensor

Alloy sort based on analysis of dense elements

LIBS sensor

Alloy sort based on analysis of all elements, light and dense

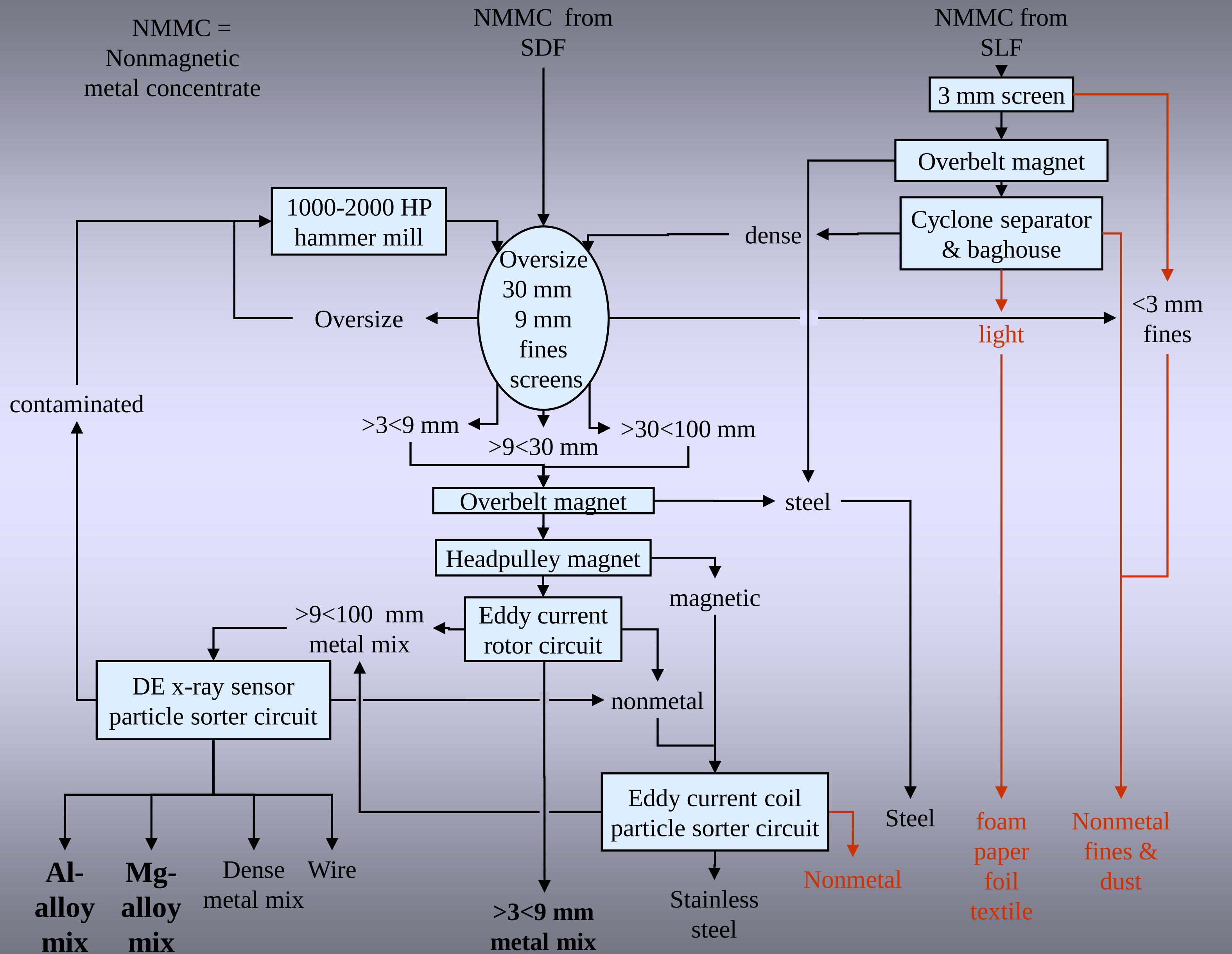


New recycling processes

Shredder residue dry sorting plant
LM alloy batching/sorting plant
Shredded LM scrap cleaning

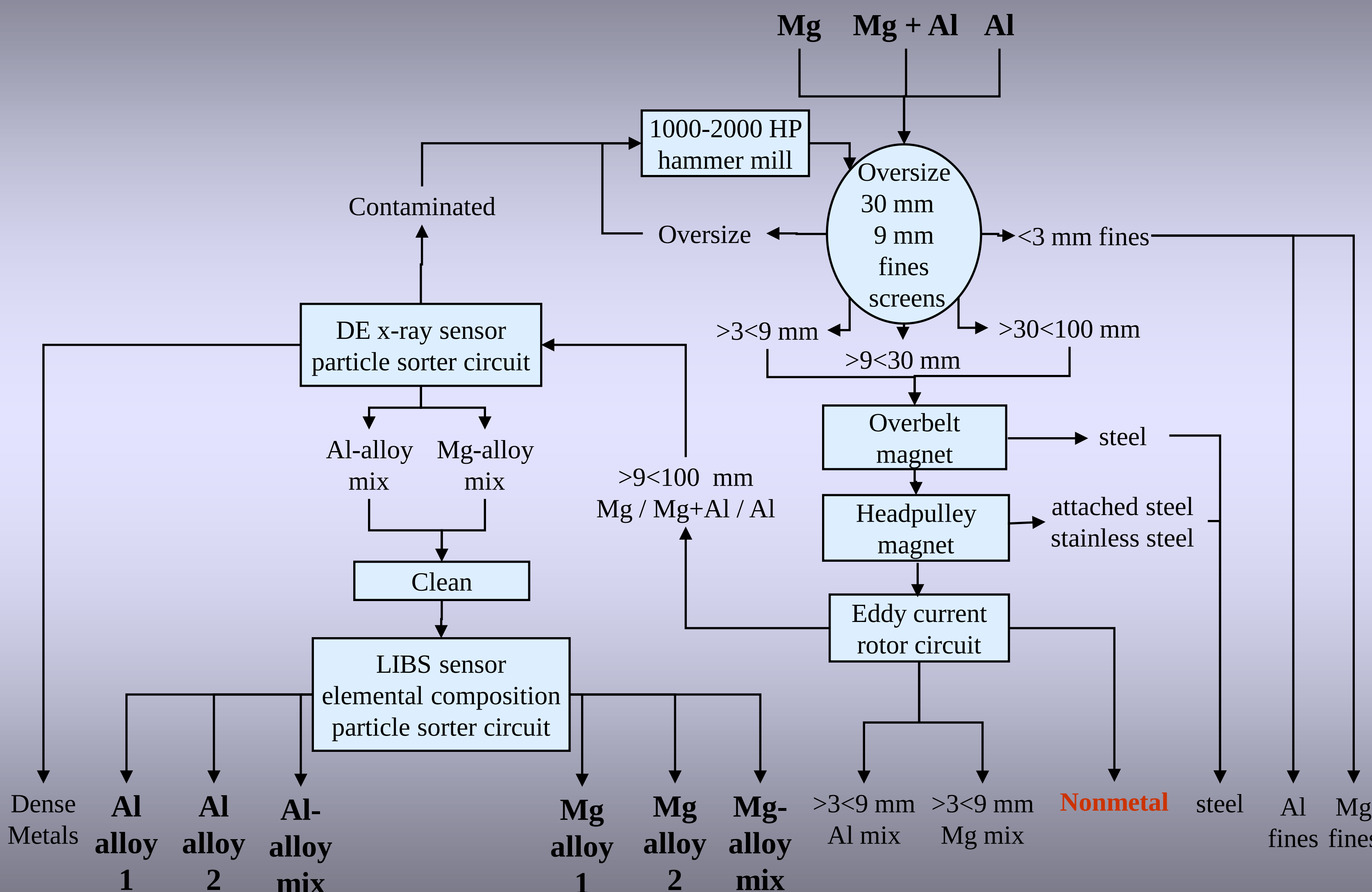
Competition:
Sorting table vs Sorting circuit

Shredder residue dry sorting plant



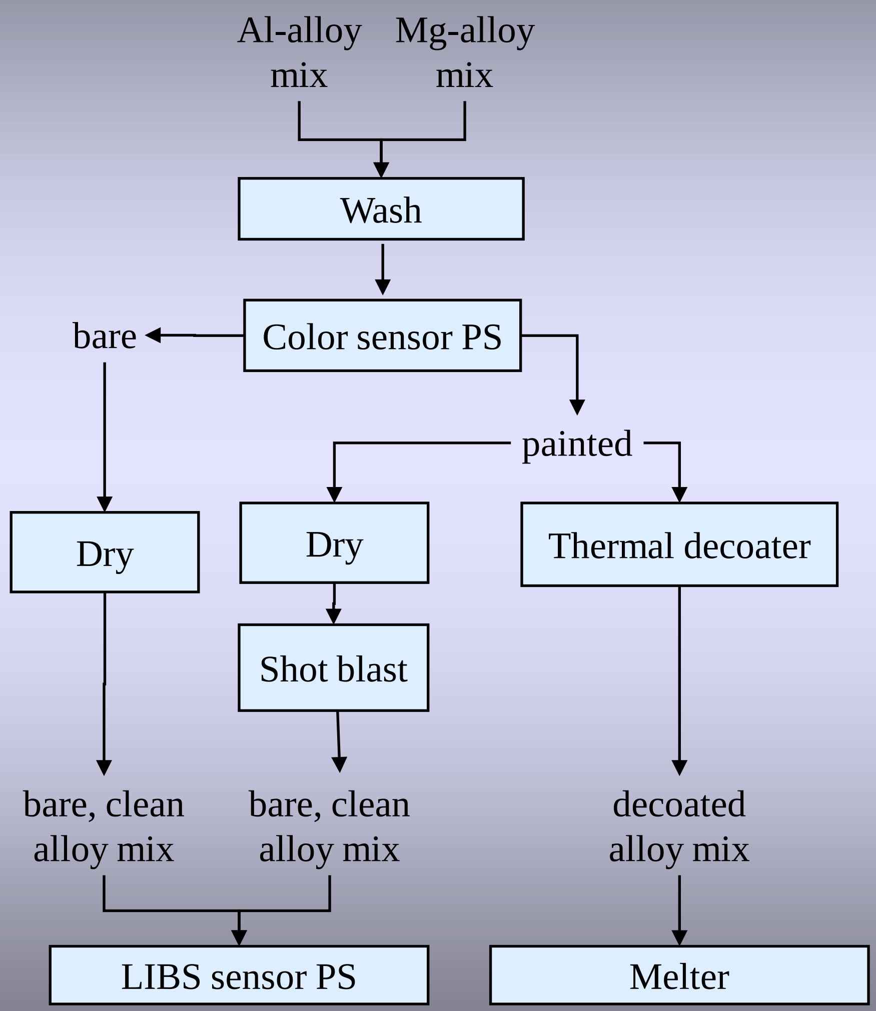
GESING CONSULTANTS INC

LM alloy batching/sorting plant



GESING CONSULTANTS INC

Shredded LM scrap cleaning



Summary

- All new LM scrap is recycled
- Efficiency of new scrap recycling could be improved by improved alloy separation at source or by particle sorting
- Primary steel shredders process ELVs commingled with other metal-containing scrap
- LM can be effectively separated from the shredder residue as NMMC
- Mg is not separated from light metals at the shredder
- Only a portion of the NMMC concentrate is treated by dense-media plants producing Al and Al + Mg alloy mixes
- Remaining Mg scrap stays commingled with Al shred and is chlorinated out of Al foundry alloys
- Al + Mg mix is handsorted in Asia and Mg desulphurizes Chinese steel
- New particle-sorting technologies and processes under development have the ability to complete metal scrap separation by parent metal and by alloy

LM recycling development needs

Development categories

Post-consumer light metal scrap survey

Minimization of manufacturing scrap generation

Maximization of metal recovery

Separation of metal scrap containing Mg alloys

Segregation, sorting and batching of LM scrap

Optimum use for the LM scrap in batching secondary alloys

Secondary light metal alloy development

Difficult to recycle layered multi-alloy and composite materials

Reactive alloying element recovery and recycling

Scope of the optimization of LM recycling

Development projects should fall into the following general areas:

- Scrap recycling system understanding and quantification
- Minimization of scrap generation and maximization of scrap recovery and recycling, both during product manufacturing and post consumer
- Recycling technology and processes development and demonstration
- Development of alloys and products that consume the recycled scrap

Post-consumer light metal scrap survey

Characterization of the current and future post-consumer light metal scrap stream alloy distributions, average compositions and availability.

- ELV
- In shredder products: NMMC and Al concentrate
- In sink-float plant products: light media float and Al "twitch" dense media float
- In WEEE nonmagnetic metal Mg and Al product

Minimization of manufacturing scrap generation

- Design of casting, forming and manufacturing techniques and processes for minimum new scrap generation
  - Diecasting mould design for minimum casting scrap
- Development of techniques and strategies for source alloy segregation and management of manufacturing scrap

Scrap preparation for separation, sorting and remelting

- Design for effective material liberation during shredding
  - Elimination of toxic and hazardous components
  - Part consolidation
  - Dissimilar material joining rationalization
- Size reduction and separation, mono-material particle liberation
- De-lacquering and cleaning of Al and Mg scrap

Maximization of metal recovery during LM scrap remelting and refining

- Melting of LM with minimum dross and sludge generation
- Melting of Mg with minimum of cover gas
- Minimization of melt losses in Mg refining by fractional crystallization
- Control and elimination of oxide and flux inclusions and dissolved gases from LM melts and castings

Segregation, sorting and batching of LM scrap

- Impurity separation from purchased new scrap, nominally alloy-segregated at source (3003, 5754, 5182, 6061, 6082, 6022, 6111, 6016, 7004, 7008)
- Sorting among known alloys of new mixed alloy scrap (e.g. stamping skeletons 6111/5754 or new Mg alloy scrap mix)
- Separation of Mg alloys, non-Al and Al with non-Al attachments from old Al shred
- Separation of Al rich in Mg from the sink-float plant Al product
- Separation of Al rich in Zn or Cu from the sink-float plant Al product
- Inspection and impurity removal from Mg scrap, nominally alloy-segregated at source
- Separation of Mg-AJxy and Mg-AExy alloys from post-consumer Mg-alloy scrap

Optimum use for LM scrap in batching secondary alloys

Batching of the following alloys is of most interest:

- Mg hardener for Al alloys from the sink-float plant light float fraction
- 319 and 38X foundry alloys from old Al scrap with high Cu and Zn
- 3105 and 3X04 sheet alloys from old Al scrap with high Mg
- 6111 closure sheet from alloy segregated new closure sheet stamping skeleton scrap
- Mg-AZ91 and AZC1231 type alloys from the mixed common Mg-alloy scrap and use of these secondary alloys for both interior automotive components and for electrical and electronic equipment housings
- Secondary Mg-AJ and Mg-AE alloys from Mg-AJ or Mg-AE alloy mix separated from old scrap

Secondary LM alloy development

Study of the sensitivity of alloy microstructure, castability, formability, manufacturability and resulting material properties to variation in existing alloy compositions and impurity contents for:

- Secondary Al casting alloys – 319.X
- Secondary Al wrought alloys – 3X04, 3105, 6082, 6111
- Secondary Mg alloys – AZ91, AZC1231

Development of secondary Mg alloys containing Sr, Y, Zr and rare-earth elements (Mg-AJ and Mg-AE types) using metal sorted out of old scrap and use of these alloys for alternative, less critical, elevated temperature applications.

Layered multi-alloy and composite materials

Recycling problem

Recycling process development for difficult-to-separate materials

- Co-cast and roll bonded layered multi-alloy structures
  - Alloy compatibility of layered structures
  - Identification and separation of layered alloy components or particles
- Particulate and fiber reinforced metal-matrix composites
  - Identification and separation of filled components or particles
  - Uses for metal-matrix composite scrap and development of recycling technologies for these uses
  - Metal-matrix recovery from composite scrap

Opportunity to expand markets for secondary alloys

Development of secondary alloy cored, layered structures

- Al core - Al clad
- Mg core - Al clad
- Batching of core alloys from sorted scrap

Reactive alloying element recovery and recycling

Important reactive alloying elements for Al and Mg include:

- Li
- Ca, Sr
- Y, Zr
- Rare earths: La, Ce, Nd…

Alloys using these alloying elements find applications in property-critical high-temperature and aerospace applications.

Closed-loop recycling of old alloy scrap directly back into these property-critical alloys is undesirable.

Most of these elements can be refined out of either Mg or Al melt by electrolysis, chlorination or redox reactions with molten salt fluxes.

There is a need for an efficient process for recovery of these alloying elements from electrolyte, chlorination residue salts and/or spent salt fluxes.

Existing rare-earth separation and reduction processes then result in production of prime quality RE metals.

Such process would enable "recycling" of these very high price alloying elements back into high value, property critical automotive and aerospace applications.

The competition

Automotive Recycling –
Economic and Environmental Imperative

Aluminum Association
Auto & Light Truck Group
Doug Richman, Kaiser Aluminum

Aluminum Recycling Preamble

- Aluminum: one of the most recycled automotive materials
  - Recycling rate > 95%
  - Sound "free market" economic drivers
  - Aluminum Life cycle model: "cradle-to-cradle"

- Current practice
  - Pre consumer (Prompt)

    effective systems
  - Post consumer:

    $1 B in value erosion annually

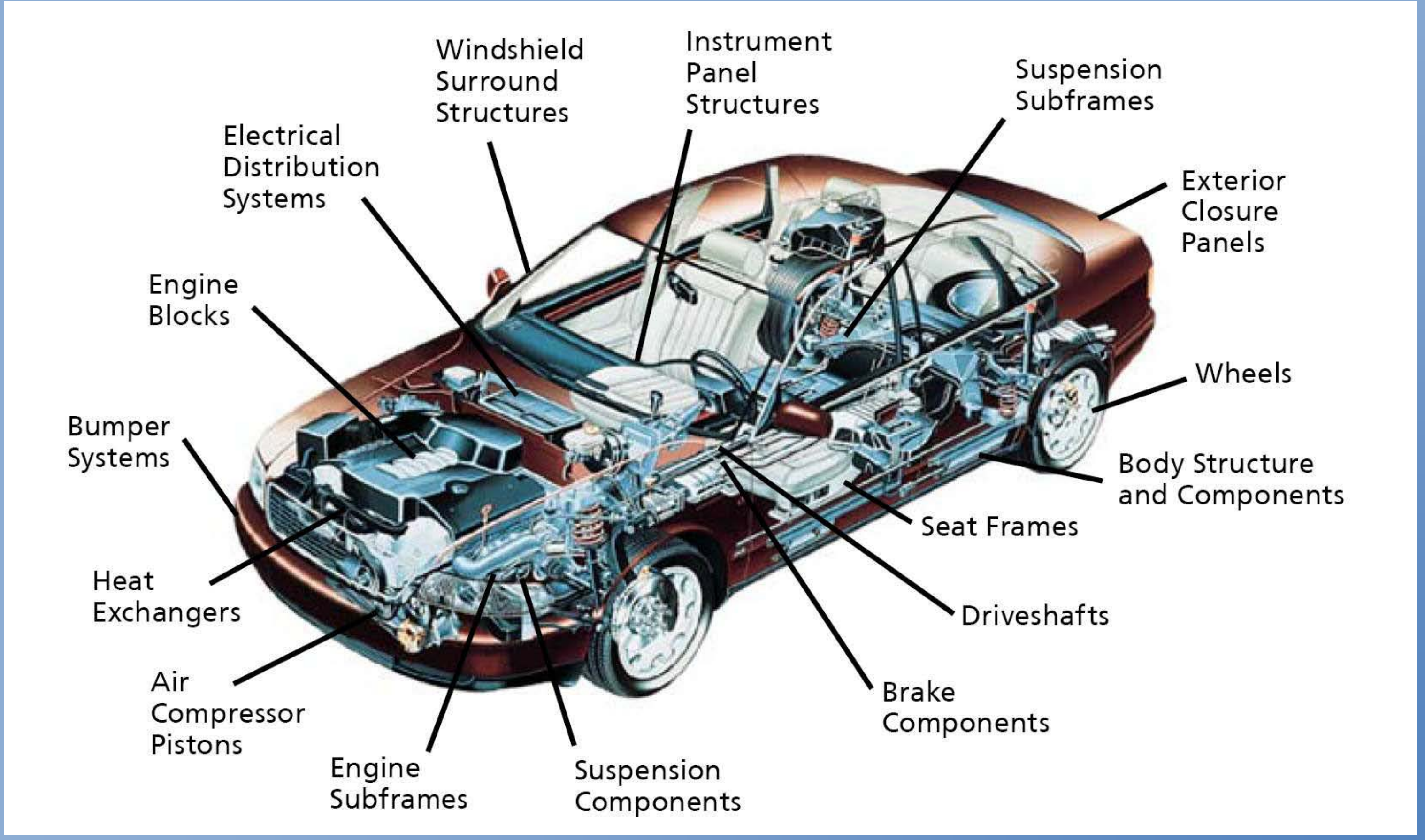
    $8 B annual foreign trade deficit

Greatest opportunity: Post consumer recovery

Recycling Automotive Aluminum

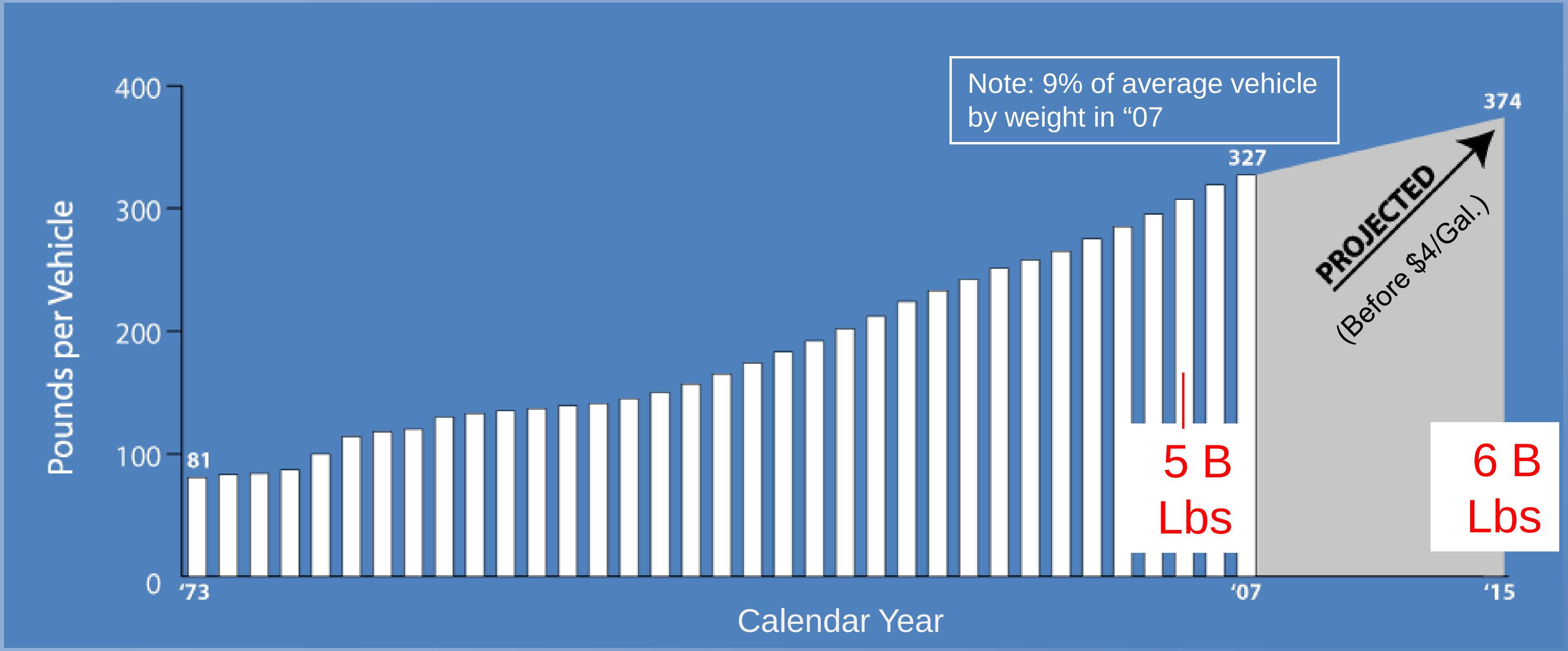
- **Outline:**
  - Automotive Aluminum (Q1)
    - today
    - anticipated growth
  - Current recovery infrastructure (Q2, 3, 4)
  - Potential recovery enhancements (Q5,6, 7,8,9)

Automotive Aluminum Today



Three Decades of Steady Growth

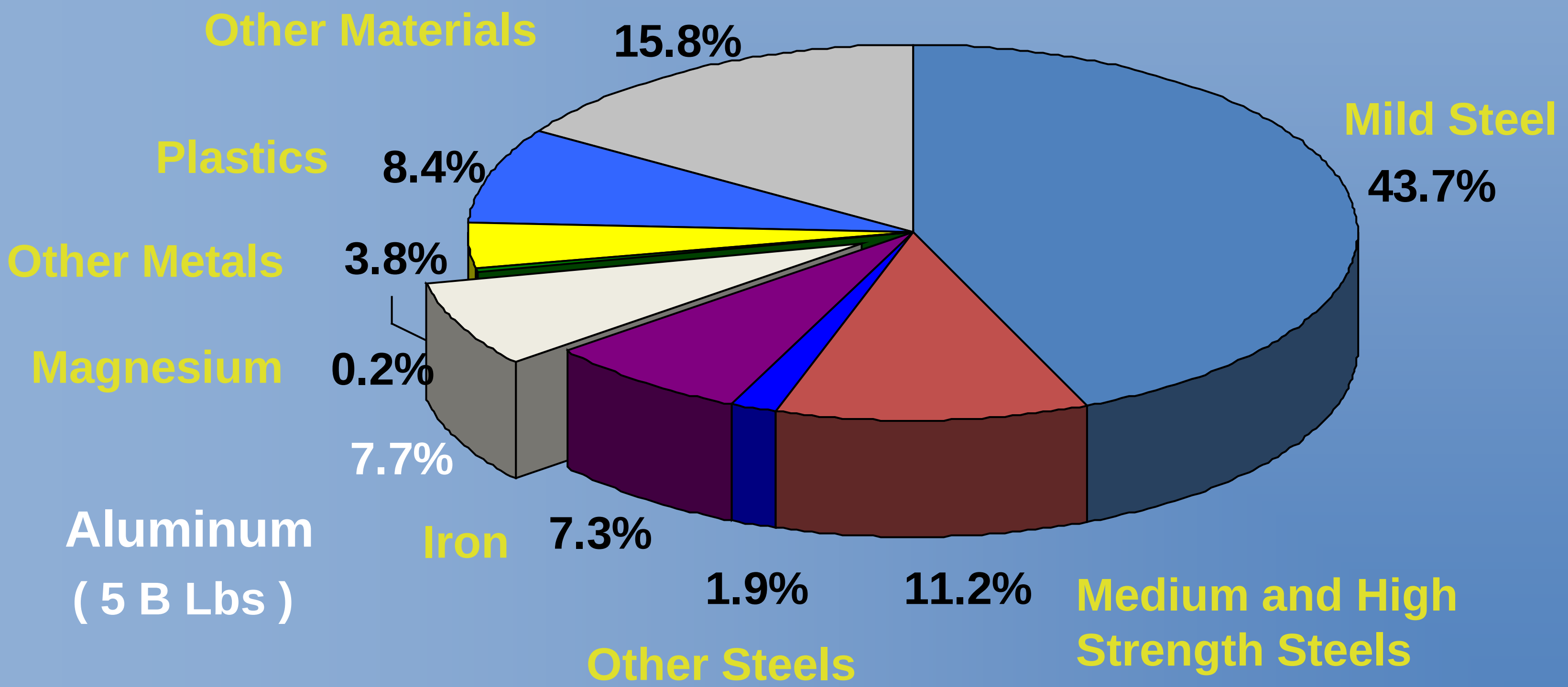
North American Light Vehicle Aluminum Content:



Q1 – Anticipated growth

North American Light Vehicle – Material Content

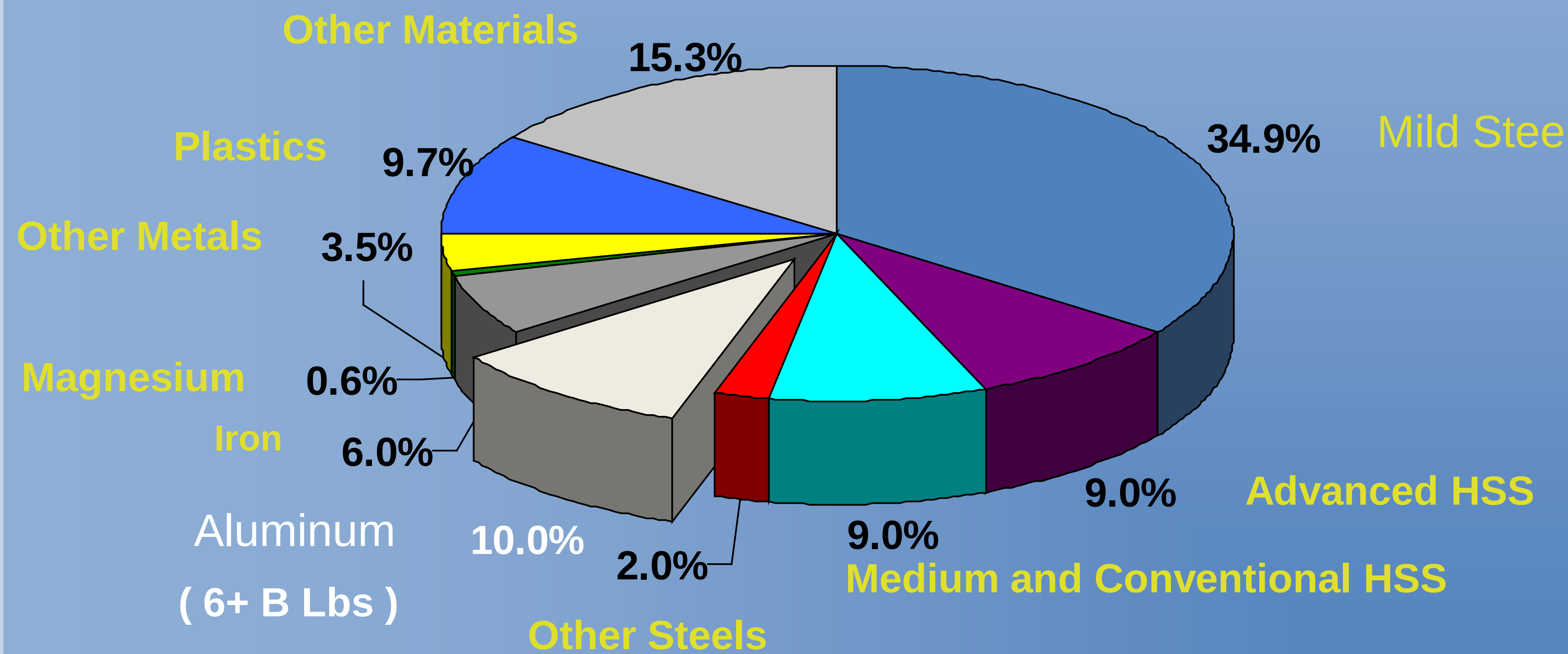
Calendar Year 2005



3,982 Pounds of Material Content

North American Light Vehicle – Material Content

Calendar Year 2015



3,743 Pounds of Material Content

Automotive Aluminum – Share by Vehicle System (2007)

Components	Aluminum Share
» Heat exchangers	100 %
» Pistons	100
» Transmission cases > 98	
» Cylinder heads	> 85
» Engine blocks	> 65
» Control Arms	> 40
» Knuckles	> 40
» Bumper	> 10
» Drive shafts	> 35 (RWD)
» Closure panels	> 10
– Complex Structures	
» Cradles/sub-frames	> 10 %
» BIW	----

Automotive Aluminum Recycling

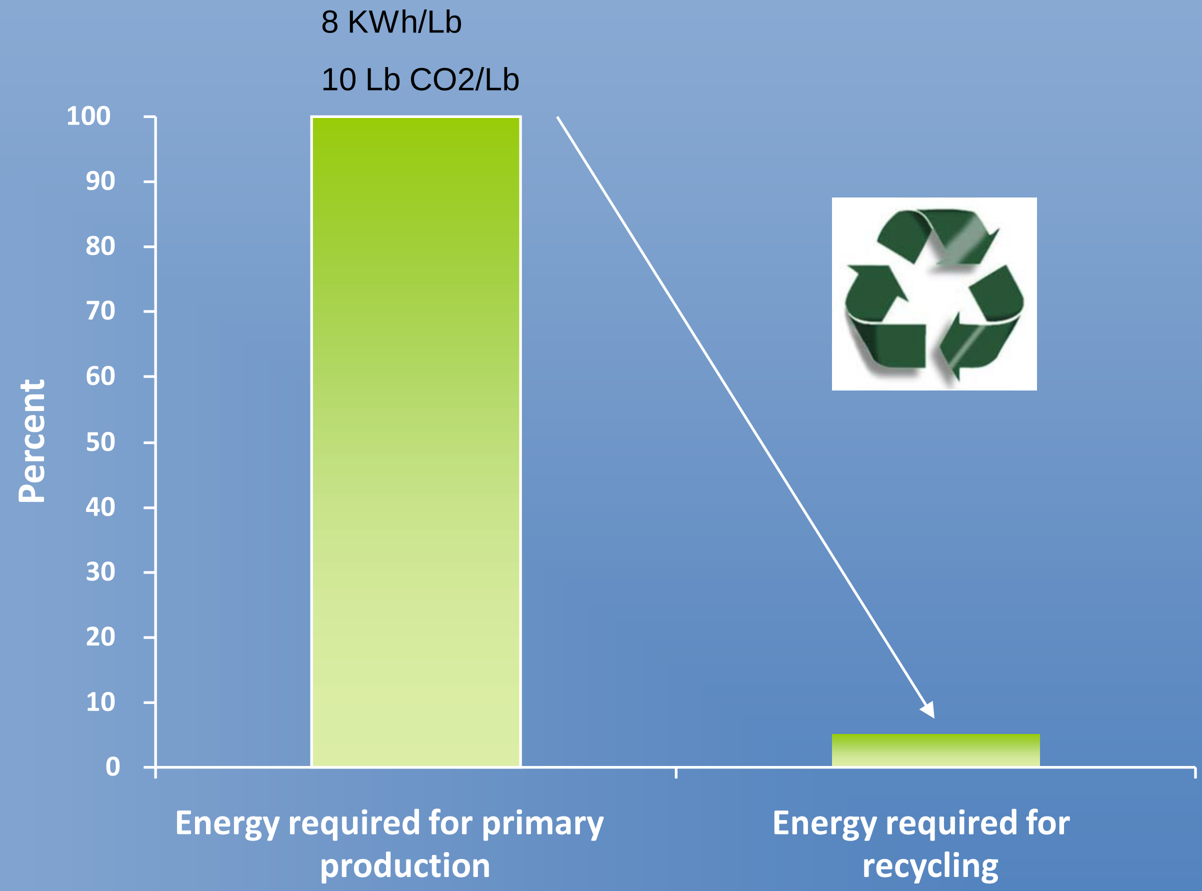
Automotive Aluminum - Infinitely Recyclable

AUTOMOTIVE ALUMINUM
The Performance Advantage™
The Aluminum Association, Inc

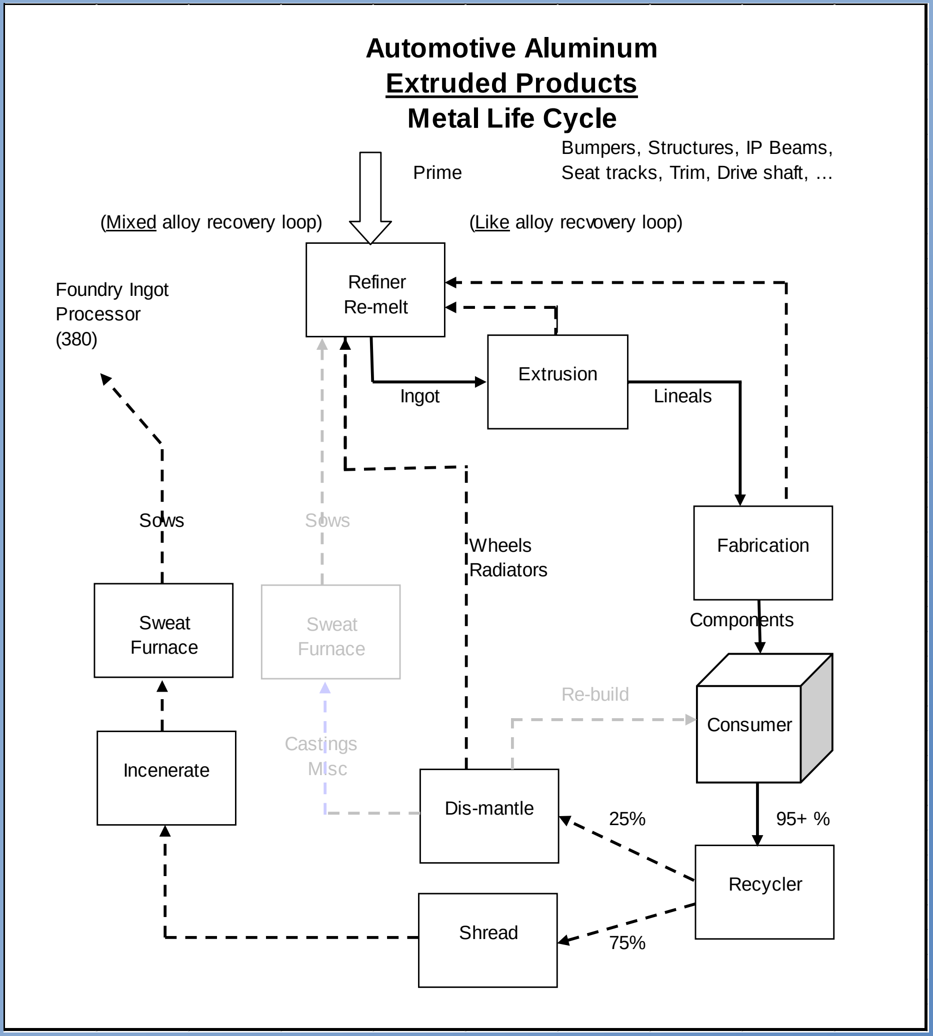
A practical business model:

Recycled aluminum <u>saves</u>

- 95% of CO_2
- 95% energy
- $$$

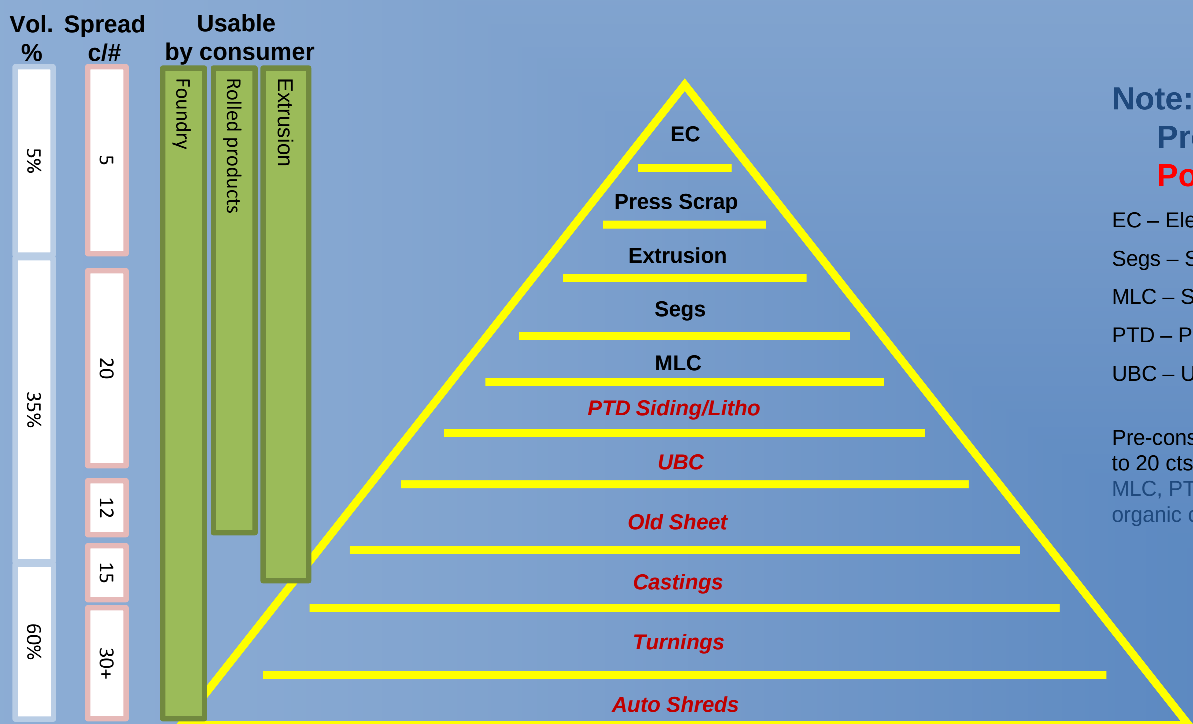


Recycling Automotive Aluminum



North American Aluminum -

Recycled Material Value Pyramid



Note:

Pre Consumer

Post Consumer

EC – Electrical Cable

Segs – Segregated "parts", Pre -consumer, clean

MLC – Segregated "Clips", Pre-consumer, clean

PTD – Painted Siding

UBC – Used Beverage Containers

Pre-consumer material with organic contaminant @ 10 to 20 cts/lb additional discount

MLC, PTD Siding/Litoh and UBC spread assumes some organic coating

* Spread costs are "indicative"

DAR – Sept 08

Pre consumer Automotive Aluminum Recycled Material (Prompt)

Product Form	Cast	Extrude	Flat	
Market "05 (Lbs)	4.0 B	0.5 B	0.5 B	
Prompt (Mill/Fabricator)		20 %	20 %	
Prompt "05 (Lbs)	**0 %**	**0.2 B**	**0.2 B**	**0.4 B Lbs**
Market "15 (Lbs)		1.0 B	1.0 B	
Prompt "15 (Lbs)	**0 %**	**0.4 B**	**0.4 B**	**0.8 B Lbs**

Note: Strong Prompt recycling systems are in-place

Q2 – Anticipated Prompt growth

Post consumer Automotive Aluminum Recycled Material

AUTOMOTIVE ALUMINUM The Performance Advantage™ The Aluminum Association, Inc

- **<u>Post consumer</u> material cycle**

(It's all Economics)

- 12 year half life
  - 2.5+ B Lbs recycled in "05 (50% of market demand)
- >60% of recovery is <u>shredder</u> product
  - Heavily devalued ($1.0 B)
  - > 60% exported (China)
    - Trade imbalance ($1.0 B)

Post consumer Automotive Aluminum Recycled Material

- Existing recycle infrastructure - Limitations and constraints
  - Prompt (high velocity)
    - Generally works well – segregated, clean, practical handling
    - Efficiencies good, subject to continuous improvement (energy)
  - Post consumer
    - Dismantling largely cost prohibitive
    - Shredder product (60 to 240 cars per hour)
      - Mixed alloys, materials
      - Iron pick-up
      - "Fluff" contamination
    - Shredder product metal recovery
      - High recovery cost - Export market

Q3-4 – Existing collection systems

Post consumer Automotive Aluminum Recycled Material

- **Sorting Technology (Shredder the tool of choice) –**
  - Opportunities:
    - Complete segregation of light metals – current 1% to 10 % Zn, Mg
    - Ability to segregate by specific alloy
    - Elimination of Iron contamination – current 0.02 to 0.10 %
    - Elimination of "fluff" contamination

Q5/Q6 – Existing collection systems opportunities

Post consumer Automotive Aluminum Recycled Material

- **Re-melt practice enhancements**
  - Energy efficiency
  - Technology to remove dissolved iron (break-through required)
  - Technology to remove dissolved zinc (break through required)

Q7 – Re-melt technologies

Post consumer Automotive Aluminum Recycled Material

- **Market trends (2010 – 2020)**
  - **No availability constraint on automotive**
    - **Aluminum industry can meet demand**
    - **Sufficient global primary capacity**

      (No new primary capacity in North America)
  - **Aluminum recycled material balance**
    - **Recycle supply lags consumption (12 year half-life)**
    - **primary production (imports)**

      Support market growth

      Replace shredder product export

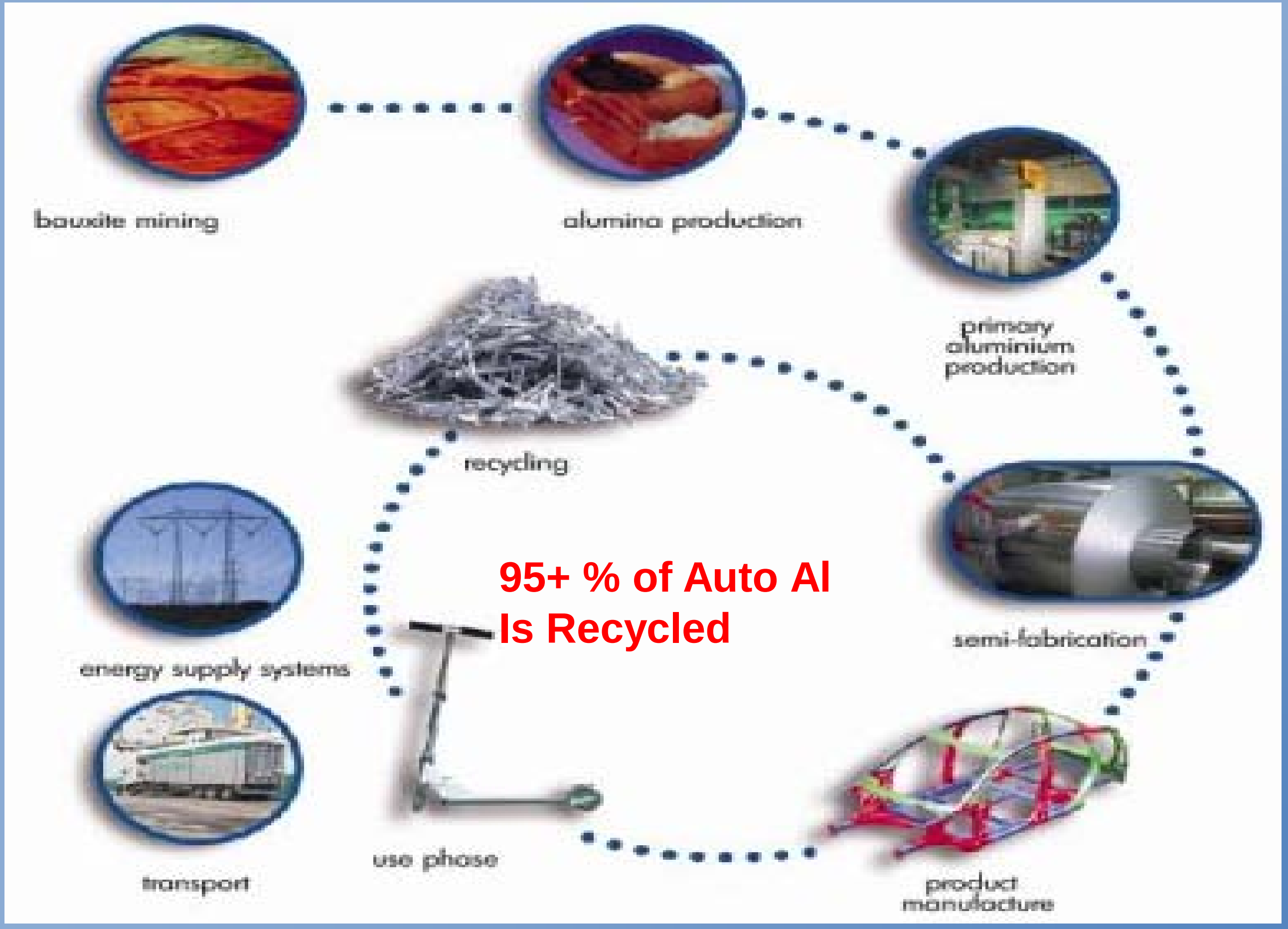
Q8 – Availability of post consumer material

Post consumer Automotive Aluminum Recycled Material

- **Opportunities / Priorities**
  - Preserve value in post consumer recycling
    - Shredder
      - Complete elimination of iron contamination
      - Segregation by alloy
    - Re-melt
      - Technology to remove dissolved iron
    - Product design
      - Design for recycling (shredder)
      - Alloys, eliminate paint, coatings, adhesives
  - Avoid contamination from aluminum MMC particles

Q9 – Opportunities

Thank you



Life Cycle of Automotive Aluminum

Automakers Lighten Up

AUTOMOTIVE ALUMINUM
The Performance Advantage™
The Aluminum Association, Inc

Daimler AG
"Every new Mercedes-Benz model will be 5 percent lighter than its predecessor."

Ford
"Each Ford Motor Co. model will lose 250 to 750 pounds depending on its market segment."

Nissan
"Nissan will cut the weight of its vehicles by an average of 15% over the next seven years as it seeks to improve fuel efficiency."

GM
"The company will use different materials, such as more magnesium and aluminum, to make its vehicles lighter and more fuel-efficient."

Land Rover
"The LRX was engineered to make it one of the cleanest vehicles in its class -- its lower weight and reduced aerodynamic drag aid fuel efficiency and reduce C02 emissions."

Volkswagen
"Automakers are substituting aluminum or plastics for steel wherever possible to reduce vehicles' weight."

Post consumer Automotive Aluminum Recycled Material

- **Dismantling – difficult to make cost effective**

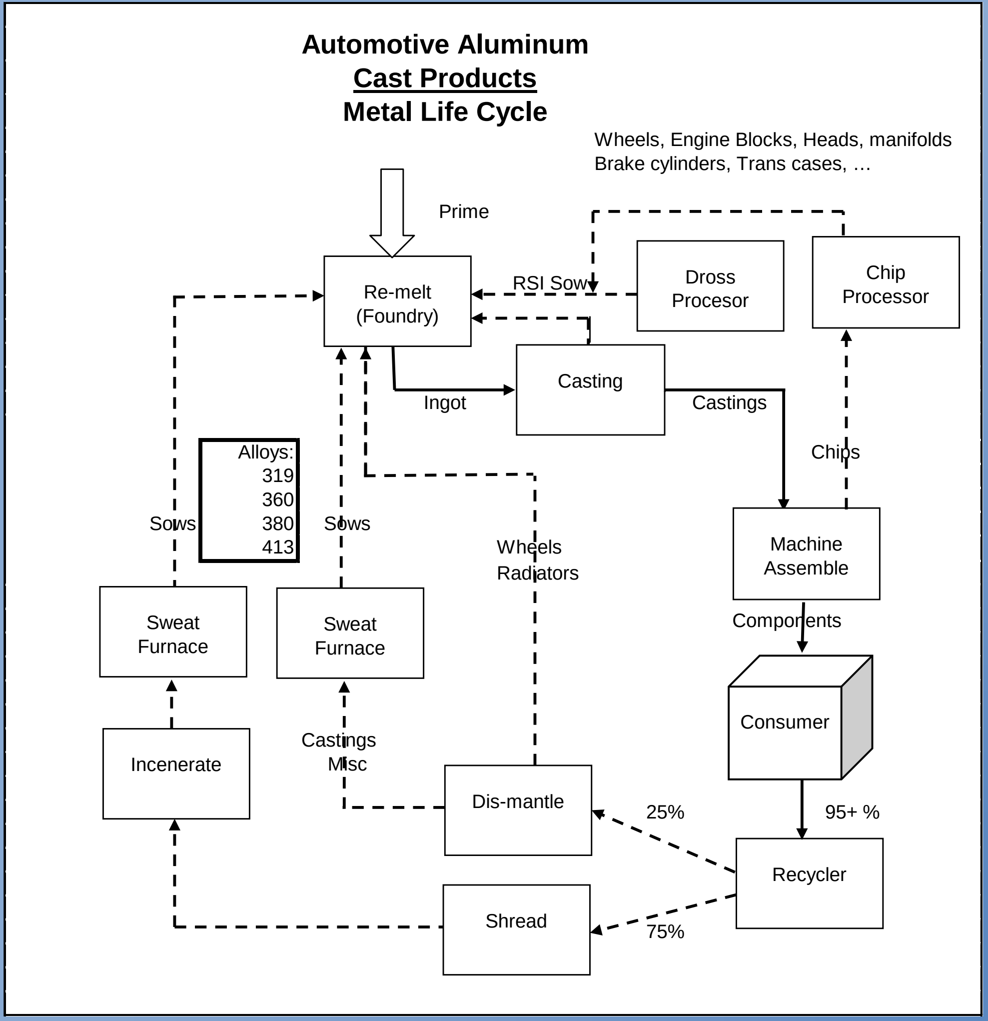
  (It's <u>all</u> Economics)

  – Predominantly easy to remove <u>masses</u>
    - Wheels, radiators, rebuild components
    - "Limited" recovery of large castings (market driven)
      – Requires "sweat " segregation

  – Recovery enhancements
    - <u>Removal labor cost</u> – Design for Recycling
      – Minimal fasteners
      – Monolithic structures
      – Eliminate: paint, coatings, adhesives

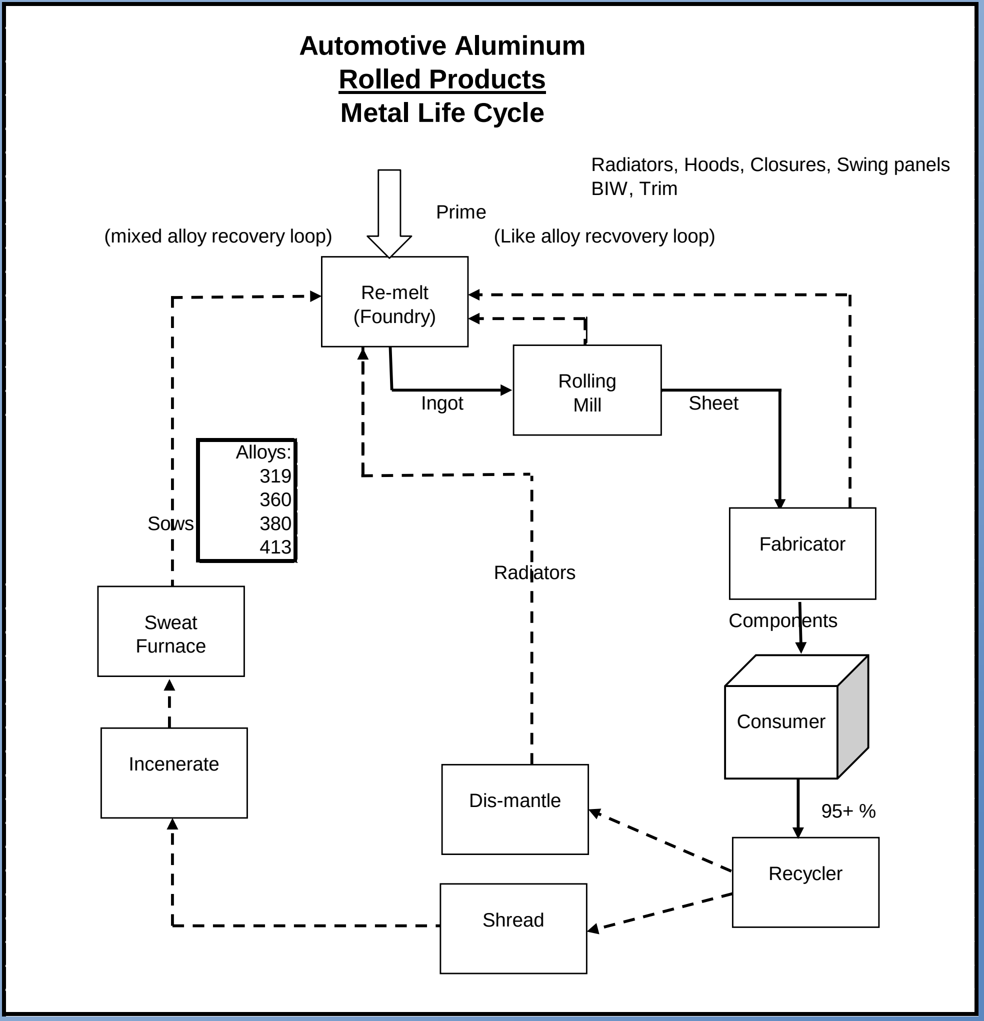
Q3/Q4 – Existing collection systems

Recycling Automotive Aluminum



AUTOMOTIVE ALUMINUM
The Performance Advantage™
The Aluminum Association, Inc

Recycling Automotive Aluminum



MAGNESIUM TRENDS AND AUTOMOTIVE APPLICATIONS

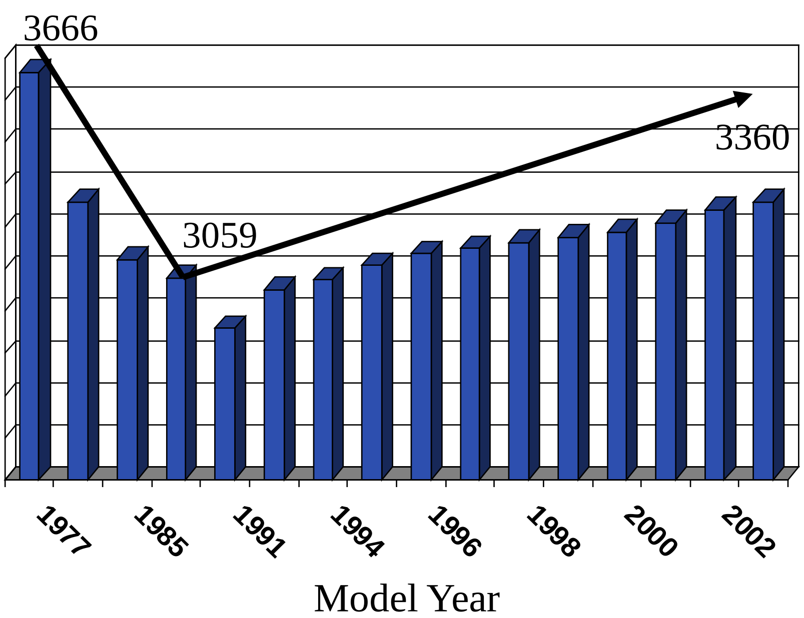
Bob R. Powell
Materials & Processes Lab
General Motors R&D Center

Automotive Lightweight Materials Recycling Workshop
United States Council for Automotive Research (USCAR)
Southfield, Michigan
September 24, 2008

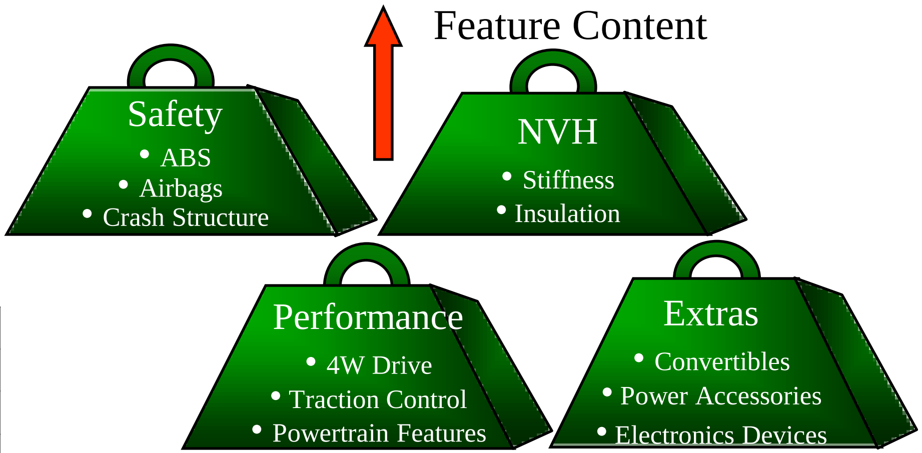
Outline

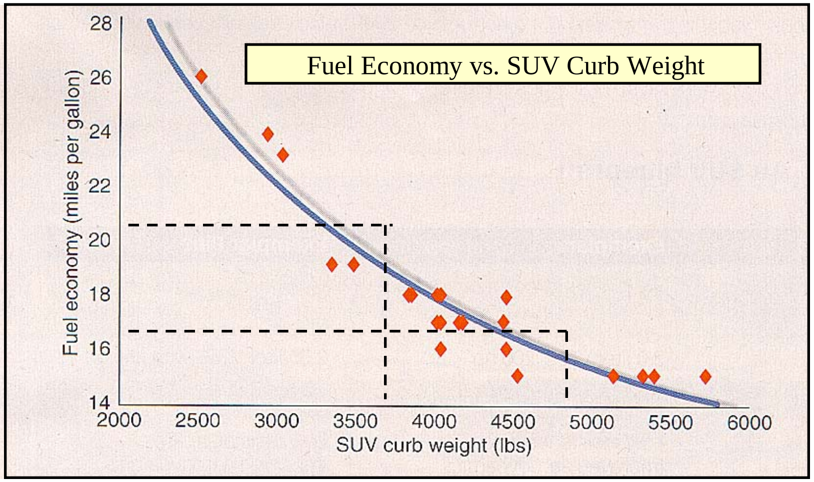
- Introduction
  - Need for and Value of Lightweighting
  - Motivation for Use of Magnesium
  - Historical and Current Automotive Use of Magnesium
- Challenges for Use of Mg in Automobiles
  - Cost
  - Casting and Forming
  - Joining
  - Recyling
- Industrial Survey on Recycling of Mg Alloys

Need for Light Weighting



Source: American Metal Market



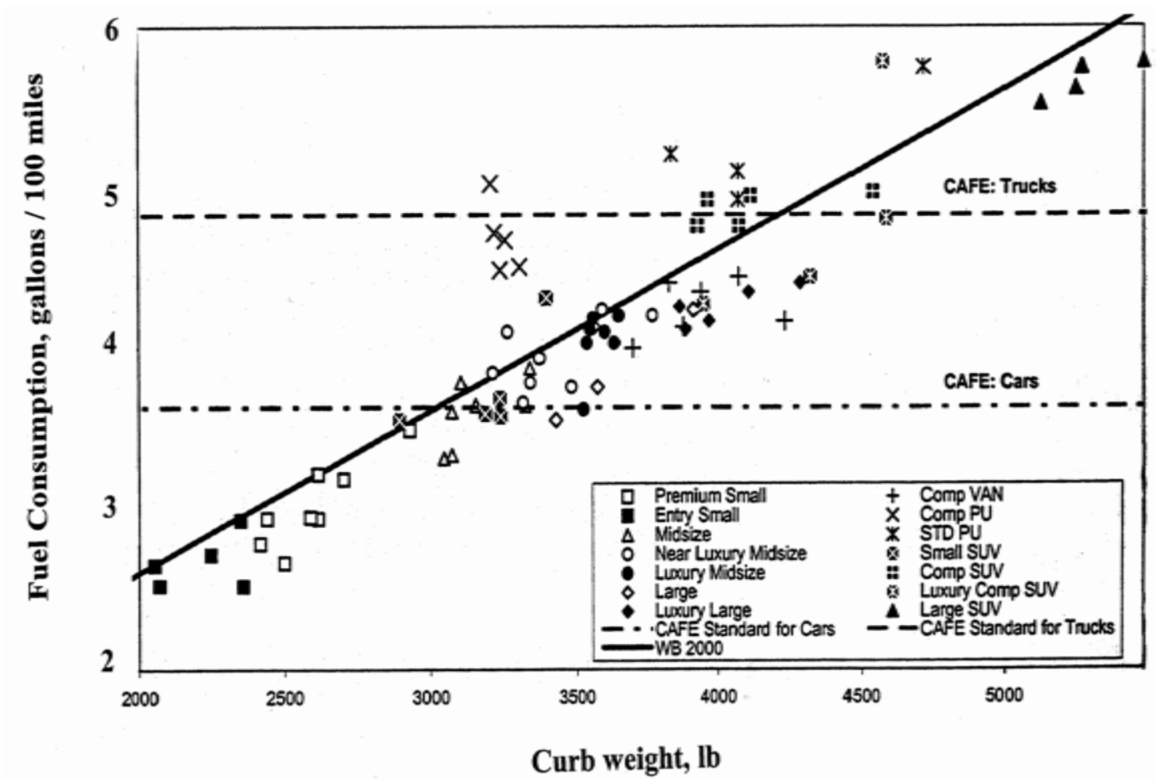


Source: Design News 10/2/00

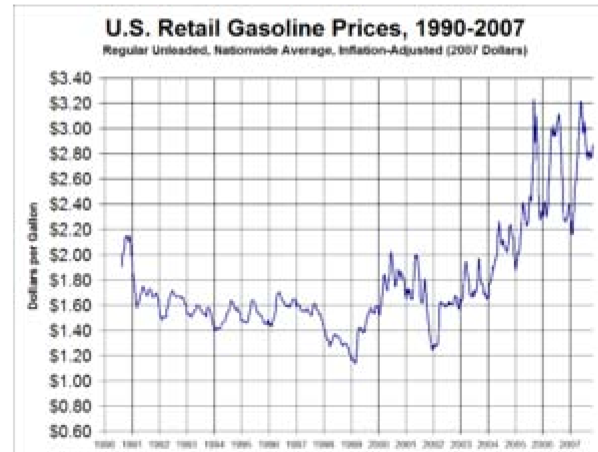
- Vehicle weight reduction is an enabler for improved vehicle performance and fuel economy

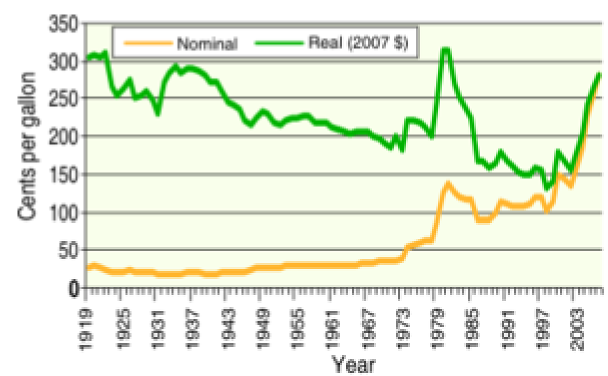
Need and Value of Light Weighting – fuel prices impact

- cost of driving
- amount of driving
- vehicle sales mix



Source: NRC – "Effectiveness and Impact of CAFE Standards", 2001, p5A-4 (courtesy A. Luo)

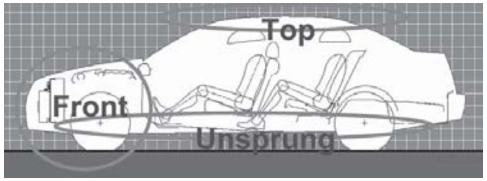




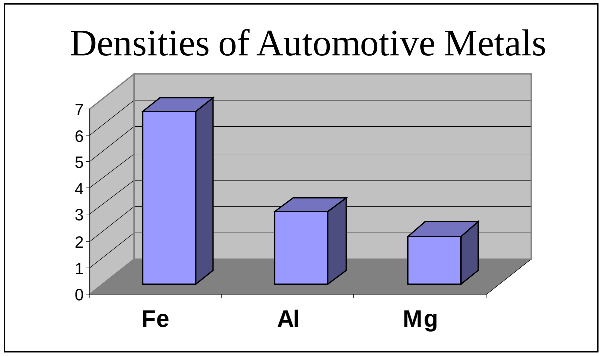
Source: Energy Information Administration, *Short Term Energy Outlook*, *January 2007*

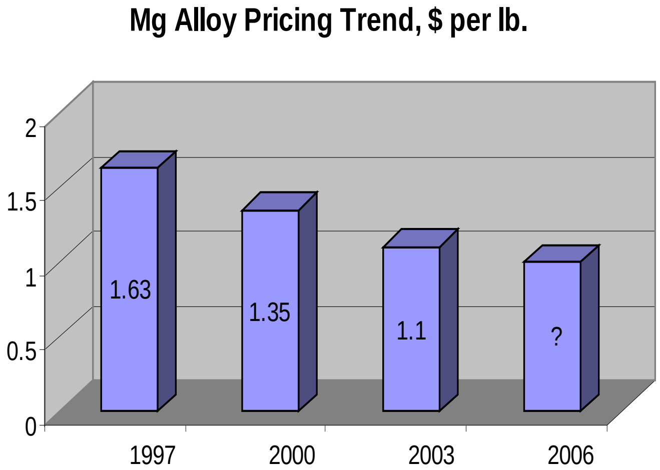
Motivation for Using Magnesium

- Need to reduce weight of vehicle to aid fuel economy and performance.
- Mg is potentially 33% lighter than Al and 80% lighter than Fe for major castings.
- Relative to steel and Al, cast Mg has competitive specific modulus (stiffness, E/ρ) and very good specific yield strength (σ_Y/ρ).
- Manufacturing advantages associated with cast Mg
  - Thinner walls
  - Parts consolidation
  - Short part-to-part cycle time
- Magnesium prices have been decreasing and new low creep alloys are available.
- Magnesium has demonstrated ability to replace aluminum and steel for instrument panels, suspensions, transfer case, valve covers, etc.

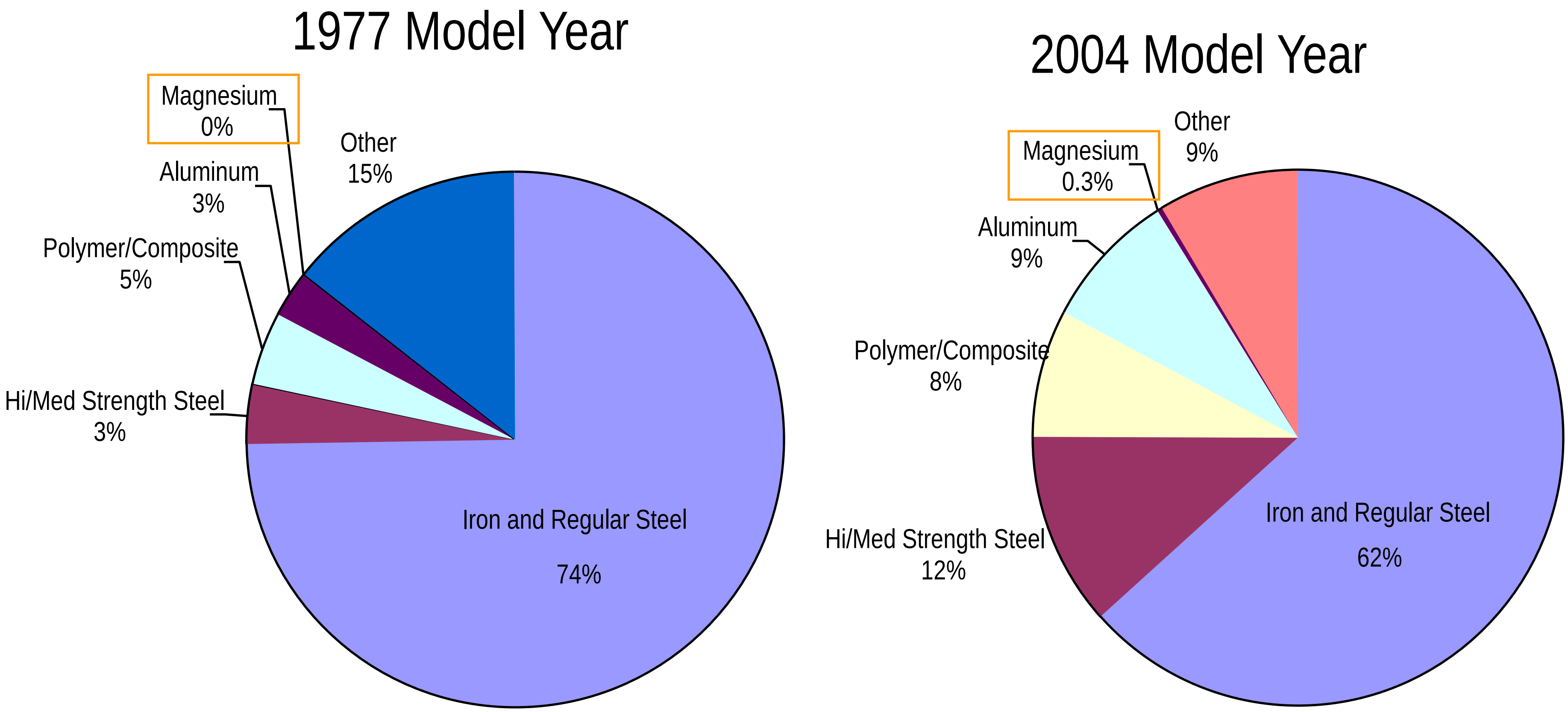


Mass reduction value depends on location in the vehicle.



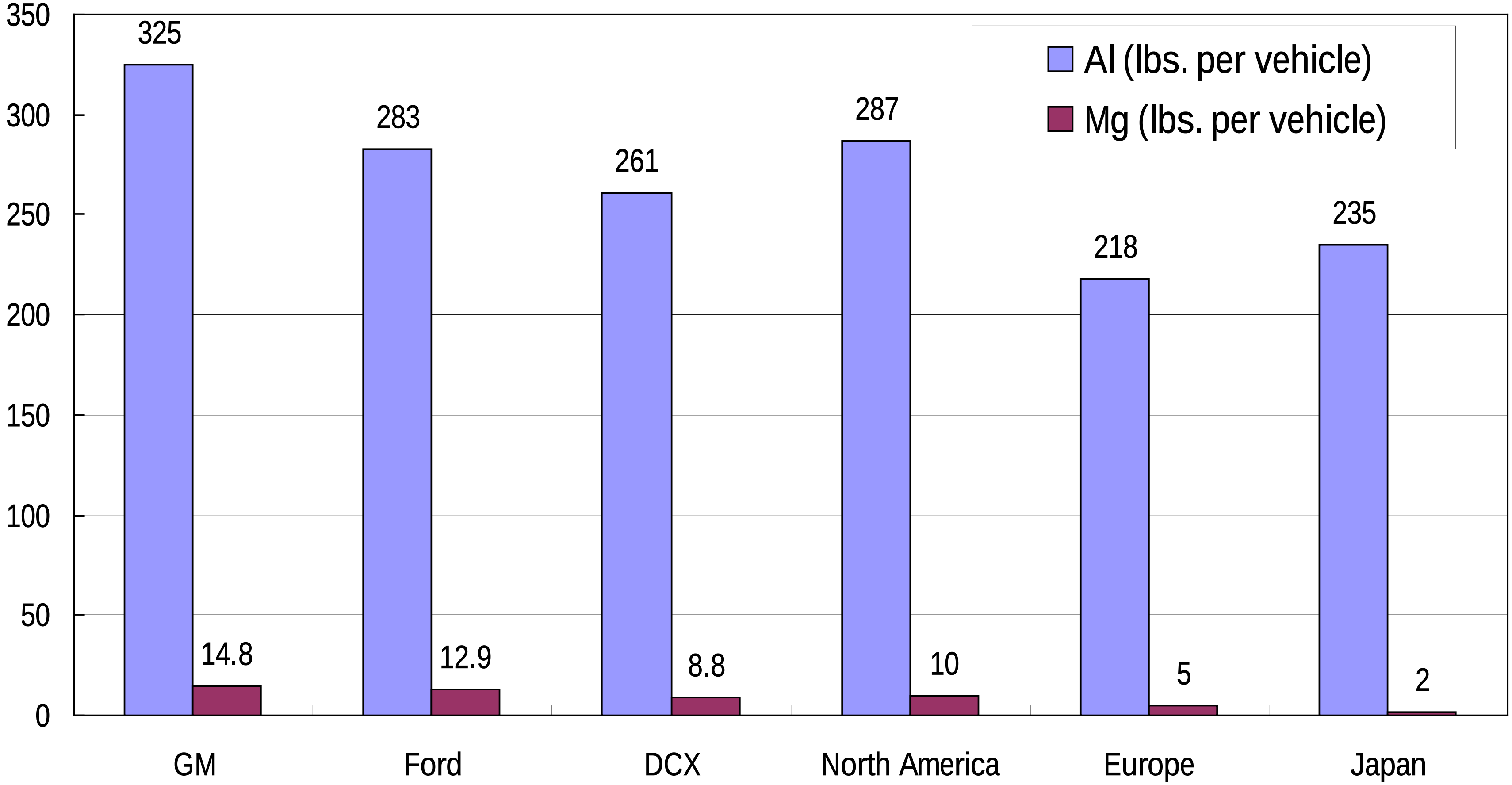


Materials in a Typical NA Family Vehicle



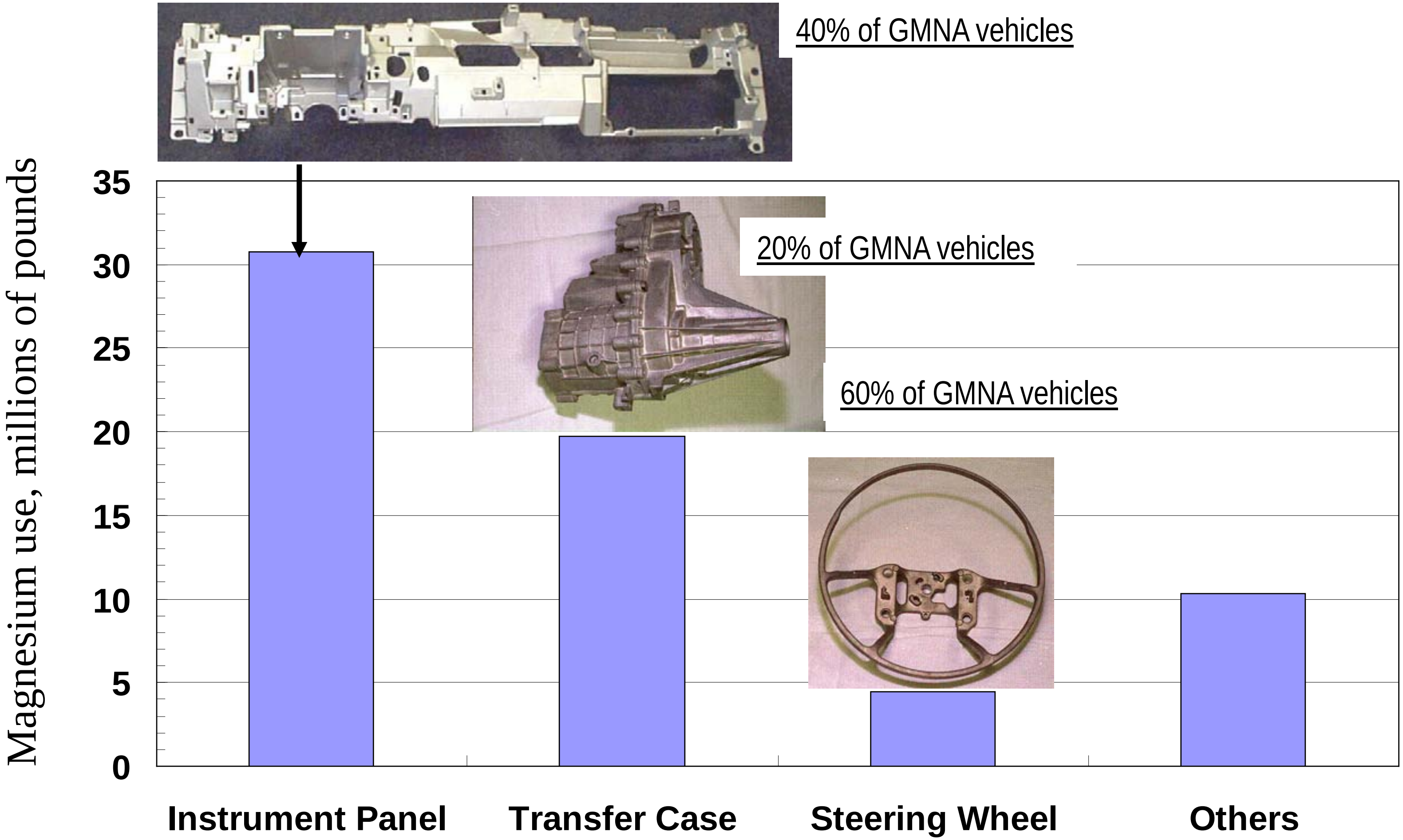
(Source: American Metal Market)

Al and Mg Content per Vehicle (2004)



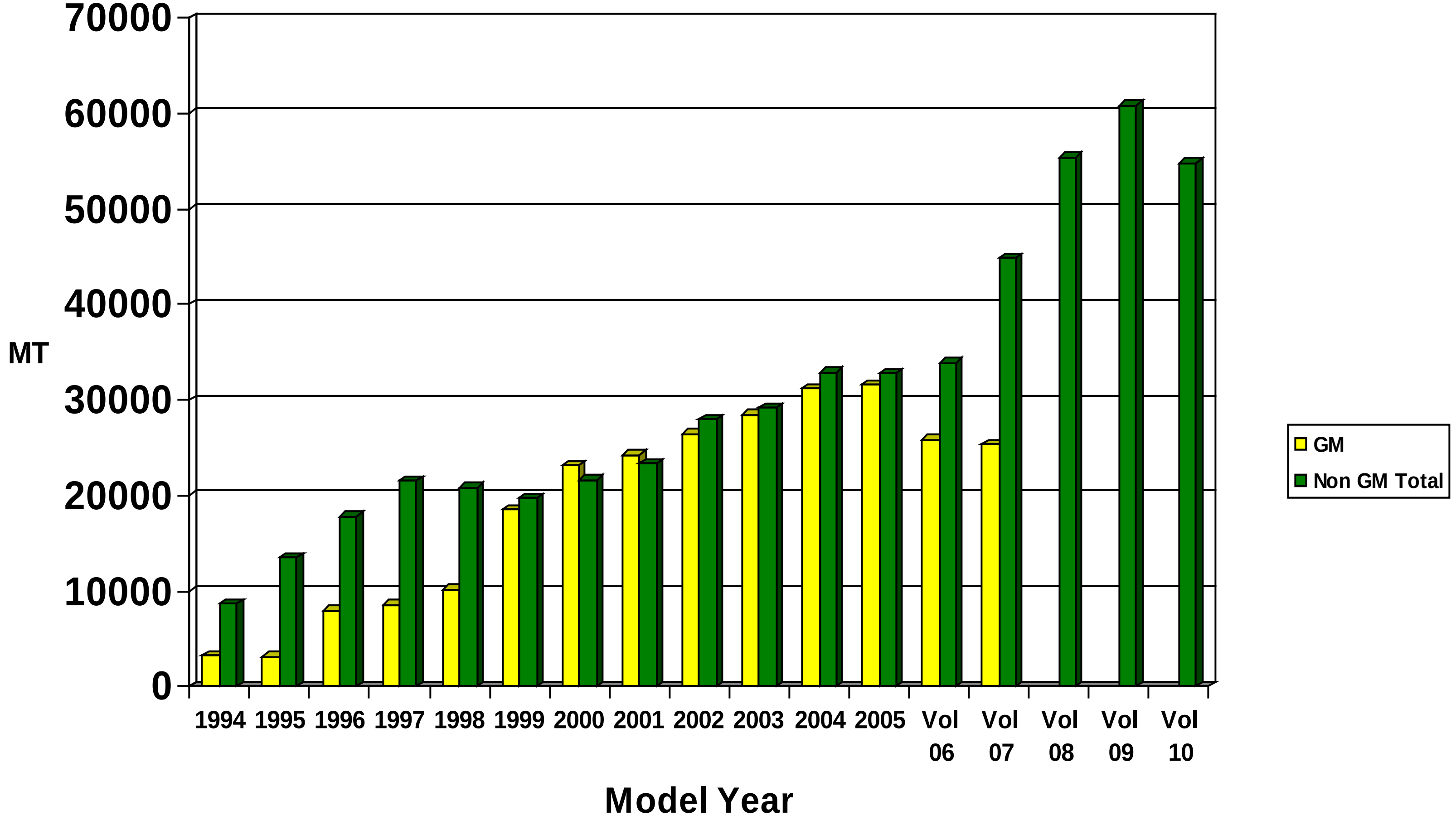
(Source: Ducker Research and Hydro Magnesium)

2005 GMNA Mg Usage: 65 million lbs



(Source: GM Worldwide Purchasing)

GM and Total Non-GM Use Potential



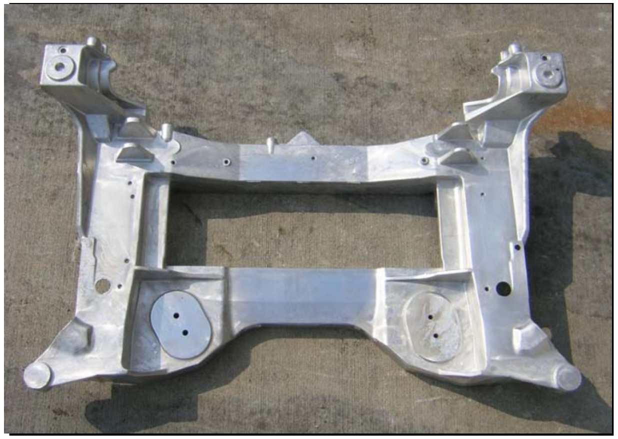
2005 Model Year and prior volumes are based on the forecast volume at that time.
2006 and beyond are maximum potential assuming all forecast applications occur.

(Source: GM Worldwide Purchasing)

Corvette Z06 Mg Cradle

Benefits:

- Mass Reduction: Mass savings of 5.6 kg (34%)
    - Mass Delta: 16.4 kg (Al) to 10.8 kg (Mg)
- Improved vehicle performance
- Avoidance of $1000/car gas guzzler tax
- Very high visibility



Chrysler - Viper Magnesium Front of Dash

<u>Feature Integration</u>

•Steering column attachment

•HVAC opening

•Brake booster attachments

•Pedal attachments

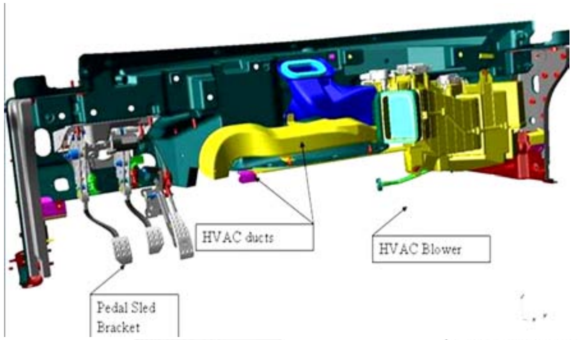
•Wire harness attachments

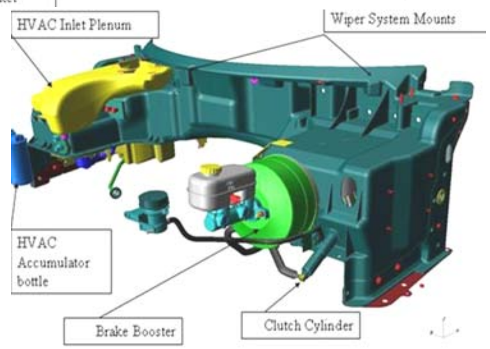
•IP structure attachments

•Door hinge attachments

•Hood hinge attachments

•“A” pillar mounting attachments





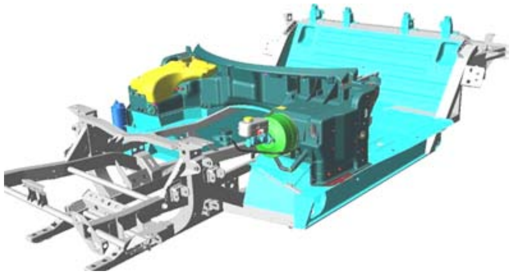
•Weight Reduction – 15.4 Kg (51%)

•Cost Reduction – ~30%

•Part Integration – Went from 51 parts to 10 parts

•Low volume application <5,000/yr

•Parts supplied by Meridian Magnesium North America

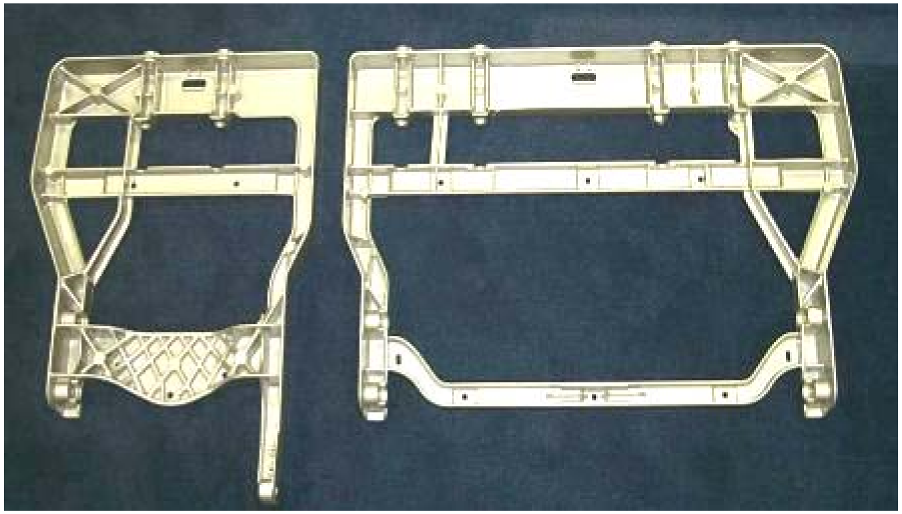


Chrysler - Magnesium Seat Structures

Feature/Component Integration :

- Side Rails
- Upper, Lower, and Center Cross Rails
- Head Restraint Tubes
- Recliner Attachments
- Bezel / Pull Strap Feature
- Back Panel / Trim Cover Attachment Holes
- Torsion Bar Attachment Slots
- Tube Attachment Holes

RS Minivan Stow & Go Seatback Frames



- Part Integration – Went from 24 parts to 2 parts
- Weight Reduction – 2.27 Kg (49%)
- High Volume Application (~430,000/yr)
- Parts supplied by Meridian Magnesium North America

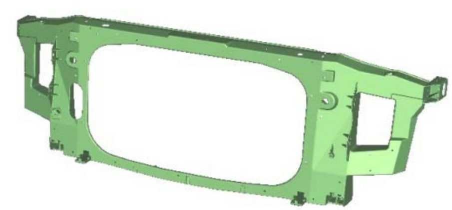
Ford – F150 Radiator Support

The Ford F-150 Cast Magnesium Radiator Support is Primary Structure because it is Totally Integrated into the Body-In-White

Multiple Steel Stampings…

27 Lbs.

Replaced By…



A One-Piece Casting.

10.5 Lbs.

Powertrain Mg Application Development

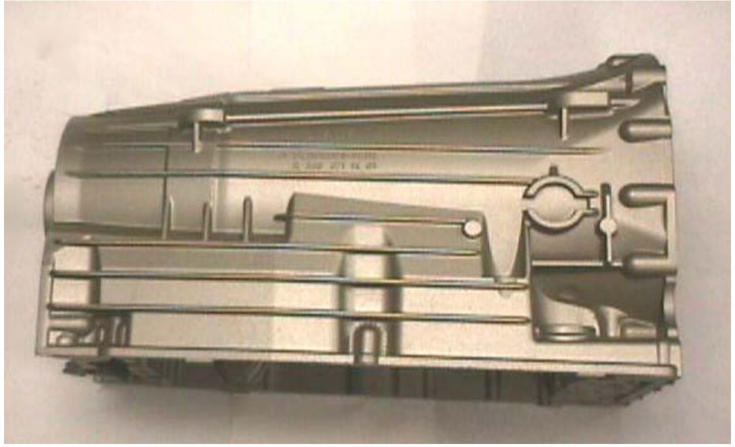
- Advanced Development
  - Honda oil pan, manifold – SOP 2007
  - Audi I4 hybrid engine aka BMW
  - VW I3 Lupo – AVL concept engine
    - Al-Si bore liners
    - Ferrous inserts in bulkhead

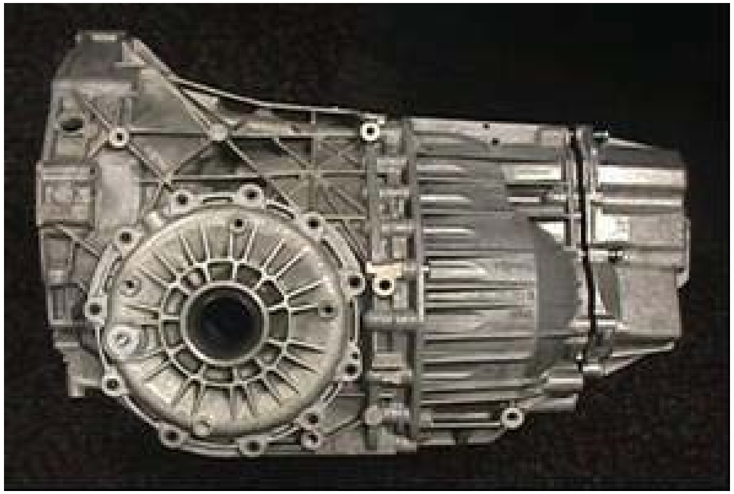
(Source: CSIRO)

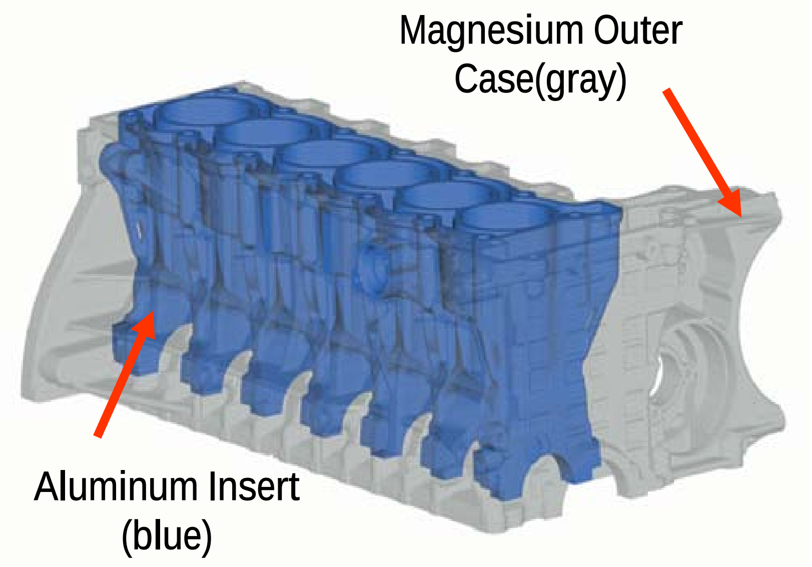
Engine block investigations by GM		
1958	VE-253 (V-8)	AZ91C
1970	Mark IV	AZ92A
1987	Chevy 5.7L (V-8)	ZE41A
1987	Pontiac 3.0L (L-4)	ZE41A
1988	Olds Quad 4	ZC63
1989	L-98	ZC63
1991	Corvette (V-8)	ZC63
1996	Northstar (V-8)	ZC63
1996	Quad 4	ZC63

Powertrain Mg Production Components

- Production
  - Mercedes 7-speed transmission housing
  - BMW composite engine
    - (Al engine in Mg shell)
  - Audi 6-speed CVT
  - 2006 Acura TSX 6-speed transmission
  - Ford and GM cam covers







Magnesium Powertrain Cast Components Project

Task 1

Alloy evaluation and selection for each engine component

1.1 Test matrix and test program
1.2 Castability trials
1.3 Electronic database
1.4 Alloy selection for prototype components – pair-wise analysis

Task 2

Engine component design and cost modeling

2.1 Engine block, bore and journal strategies
2.2 Fasteners, gaskets, sealing
2.3 Coolant and corrosion
2.4 FEA design, integration and analysis
2.5 Component casting and casting analysis
2.6 Technical cost modeling

Task 3

Building Mg scientific infrastructure: 5 Research Projects

Task 4

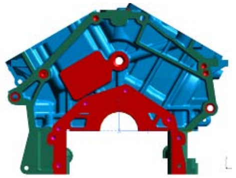
Task 5

Task 6

Significant challenges
- Overcoming higher thermal expansion of Mg for engine
- Robust corrosion protection – coolant and galvanic
- Casting sound components: eliminate casting defects

Prototype casting – HPDC and LPPS

Alloy selection for prototypes



Excised specimen Testing

Engine testing

Decision Gate

Patent Application

Final Report

2001	2002	2003	2004	2005	2006	2007

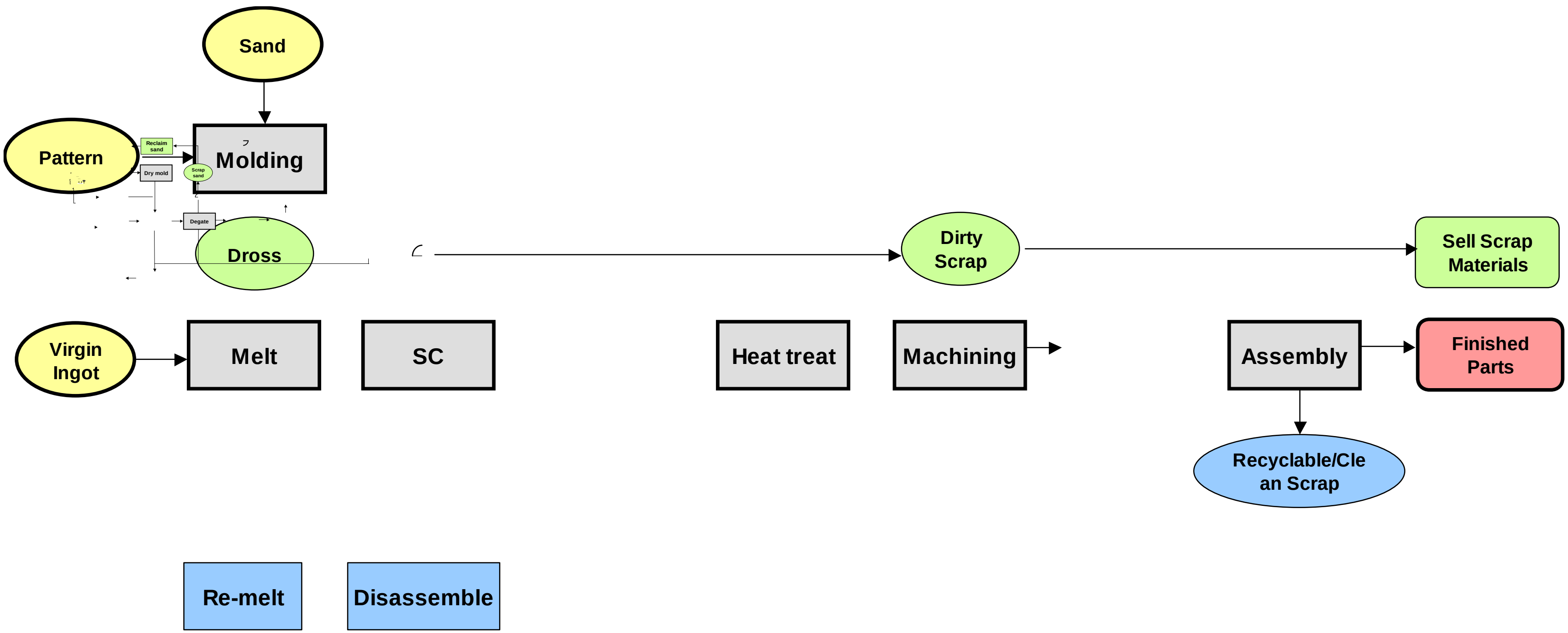
bob.r.powell@gm.com

Challenges for Use of Mg in Automobiles

- Cost
  - AM and AZ alloys for body and chassis; but premium alloys for creep resistance in powertrain applications
  - Chemistries of creep-resistant alloys may require new recycling processes
  - Corrosion mitigation
  - Cover gas for melting and casting – sulfur hexafluoride
- Casting and forming manufacturing processes
  - High quality casting for demanding applications
  - Increased technical understanding and experience for wrought Mg applications
- Joining
  - Similar and dissimilar metals
  - Galvanic corrosion

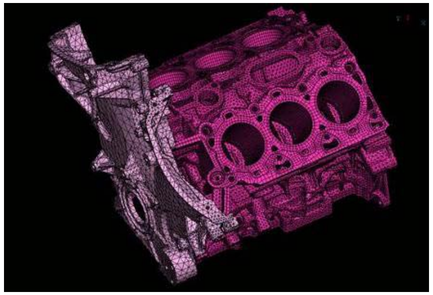
Magnesium Powertrain Cast Components Project – Cost Model

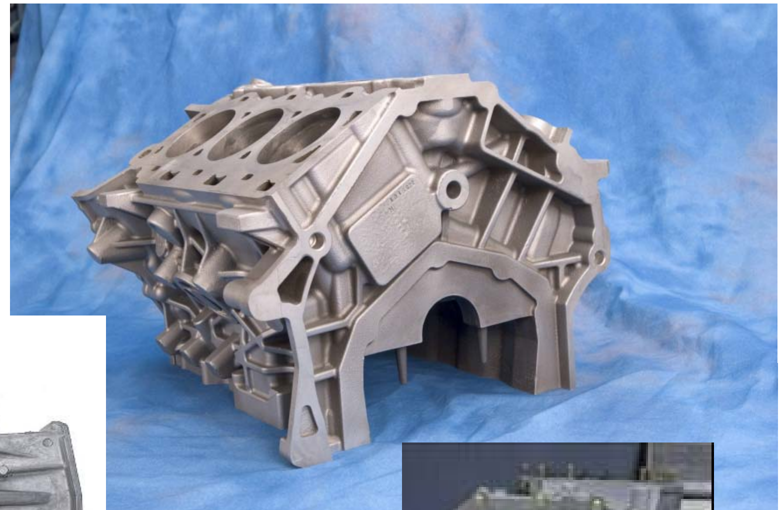
(IBIS Associates)



Recycling Challenges for Use of Mg in Automobiles

- Alloy Chemistry
  - Flux recycling methods well established for AM and AZ alloys
  - Creep-resistant alloys use rare earth and alkaline earth alloying – these precipitate with flux used in AM and AZ alloy recycling
  - Note: Calcium reduces tendency of melt to oxidize.
  - Chemistries of creep-resistant alloys may require fluxless recycling processes or re-alloying
  - Sand casting alloys have little or no recycling experience
  - New alloys may have different sensitivities to trace elements – possible impact on corrosion behavior/mitigation
- Scrap Classes
  - Low grade scrap from casting and machining – how to process or dispose of
  - Separation of dissimilar metals – depends on joining methods
  - Identification of alloys – impact of misidentified alloy on recycling process
- MPCC Industrial Survey on Recycling of Mg Alloys
  - Four page survey in support of MPCC Task 3





This material is based upon work supported by the Department of Energy National Energy Technology Laboratory under Award Number Nos.DE-FC05-95OR22363, DE-FC05-02OR22910, and DE-FC26-02OR22910.

Titanium Recycling

Presented by Curt Lavender
Pacific Northwest National Laboratory

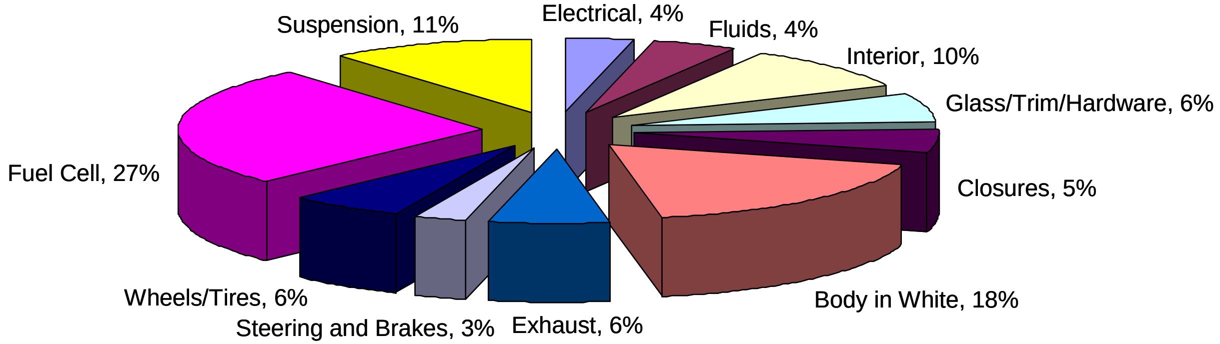
USCAR September 24th, 2008

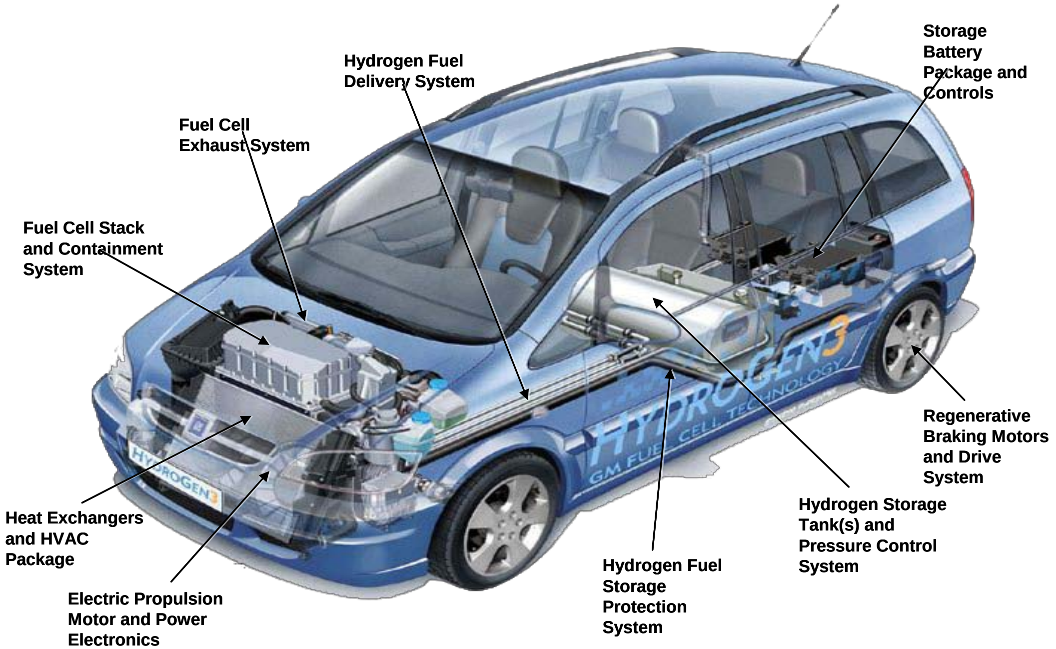
Pacific Northwest
NATIONAL LABORATORY

Outline

- Titanium in Automobiles
- Current Titanium Processing and Recycle
  - Where recycling occurs in today's processing
- The potential effect of the High Volume Automobile Industry
  - Emerging technologies needed
- Conclusions
- Gaps

Overview of Fuel Cell Materials Needs





PEM Fuel Cell Weight Savings

- Fuel Cell
  - Bi-polar plates
  - Tie Rods – 55% mass reduction
  - Manifolds – 45% mass reduction
  - Porous Ti may also work in the gas diffusion layer to provide structural support
    - May eliminate need for flow-field plates – simplifies design
    - Allows for higher torque of fuel cell to promote longer life and less leakage

Total Vehicle Savings
With Ti Intensive Materials Substitution
Neglecting Body-in-White

	Steel or Stainless Steel, kg	Titanium, kg	% Savings with Ti
Fuel Cell Power Unit	300	197	34%
Vehicle Structure	818	647	21%
Total Fuel Cell Vehicle	1118	844	**25%**

- A 10% mass savings in an automobile can result in fuel economy improvements from 1 to 3% - model dependent.
  - Titanium impact on US fuel usage is potentially very high
- A similar study by GM suggested that 60% of the mass of the chassis alone could be saved. (Kim et al. 2006)
  - *Technical feasibility demonstrated for many of the applications considered*

Current Titanium Processing

- Titanium has high value as scrap and there is a very mature recycle industry
  - Many material contracts require all scrap generated during secondary processing to be returned for re-melt
- Ingots can be produced with 100% recycle content of Ti
  - Alloying addition make-up can be required
  - Most melt methods are in fact consolidation of loose materials
    - Chemically; primary sponge is preferred as a feed material however from an ingot yield scrap is preferred

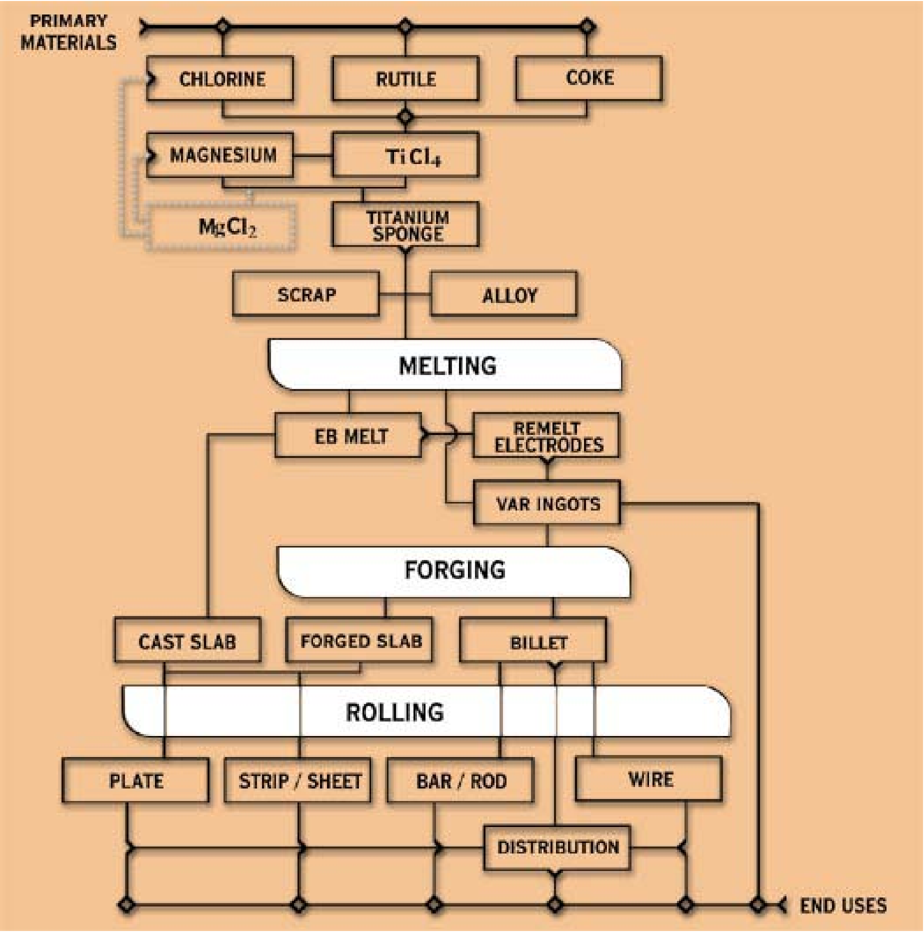
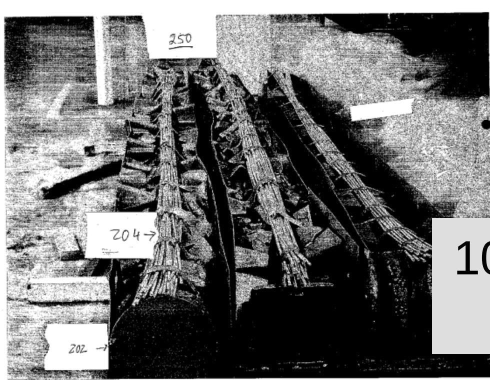


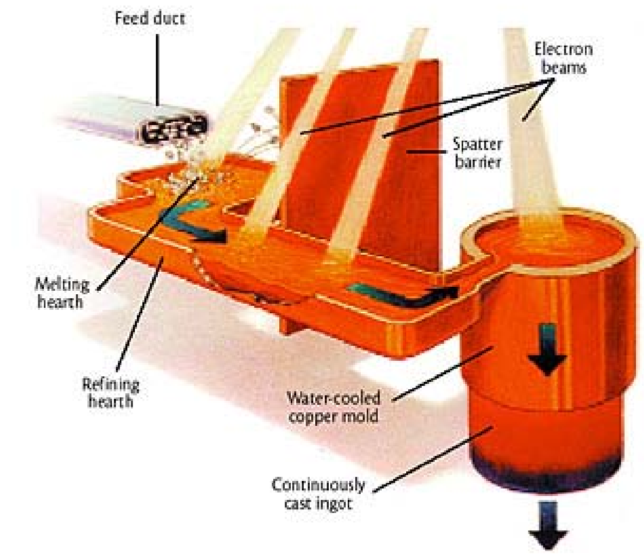
Chart by Timet

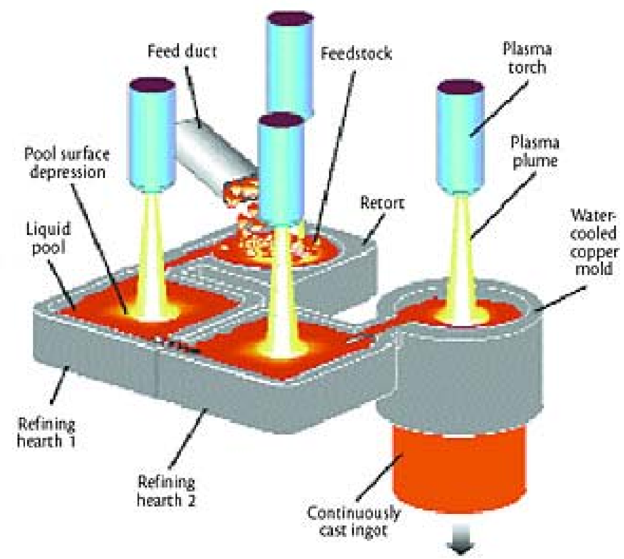
Current Recycle of Titanium

- Cold Hearth Melt Methods have improved recycle and greatly reduced cost
  - Purification for HDI, LDI and volatiles
- Currently being qualified for single melt use in aerospace
  - Already in use as single melt for chemical, medical and "CP" grades



100% Recycle Feedstock

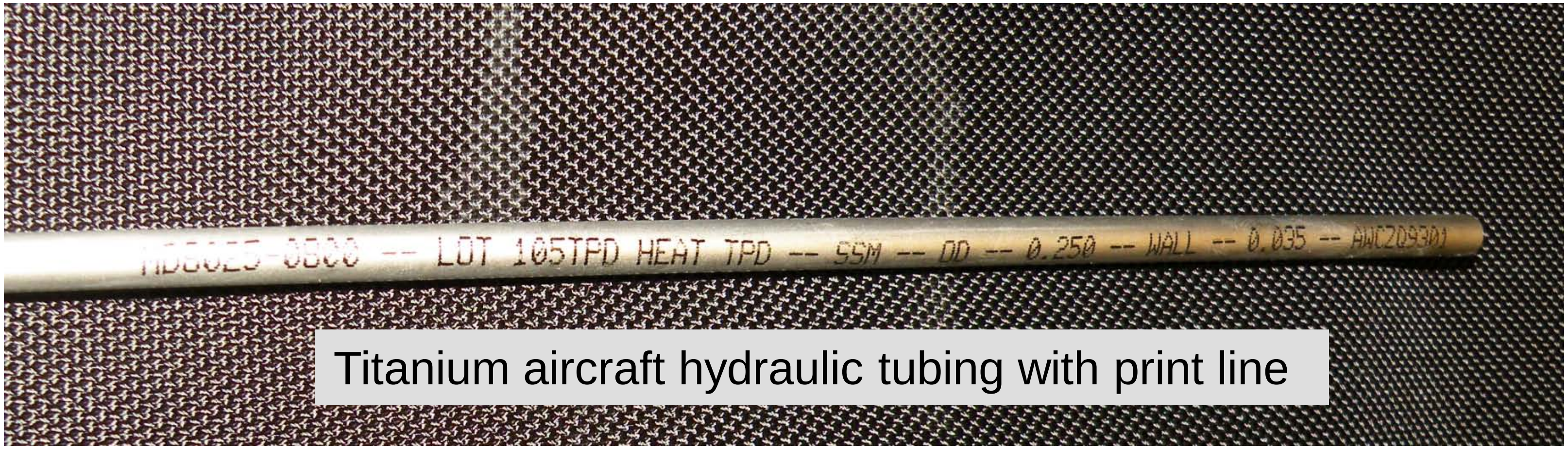




Schematics by Timet

Scrap Sorting

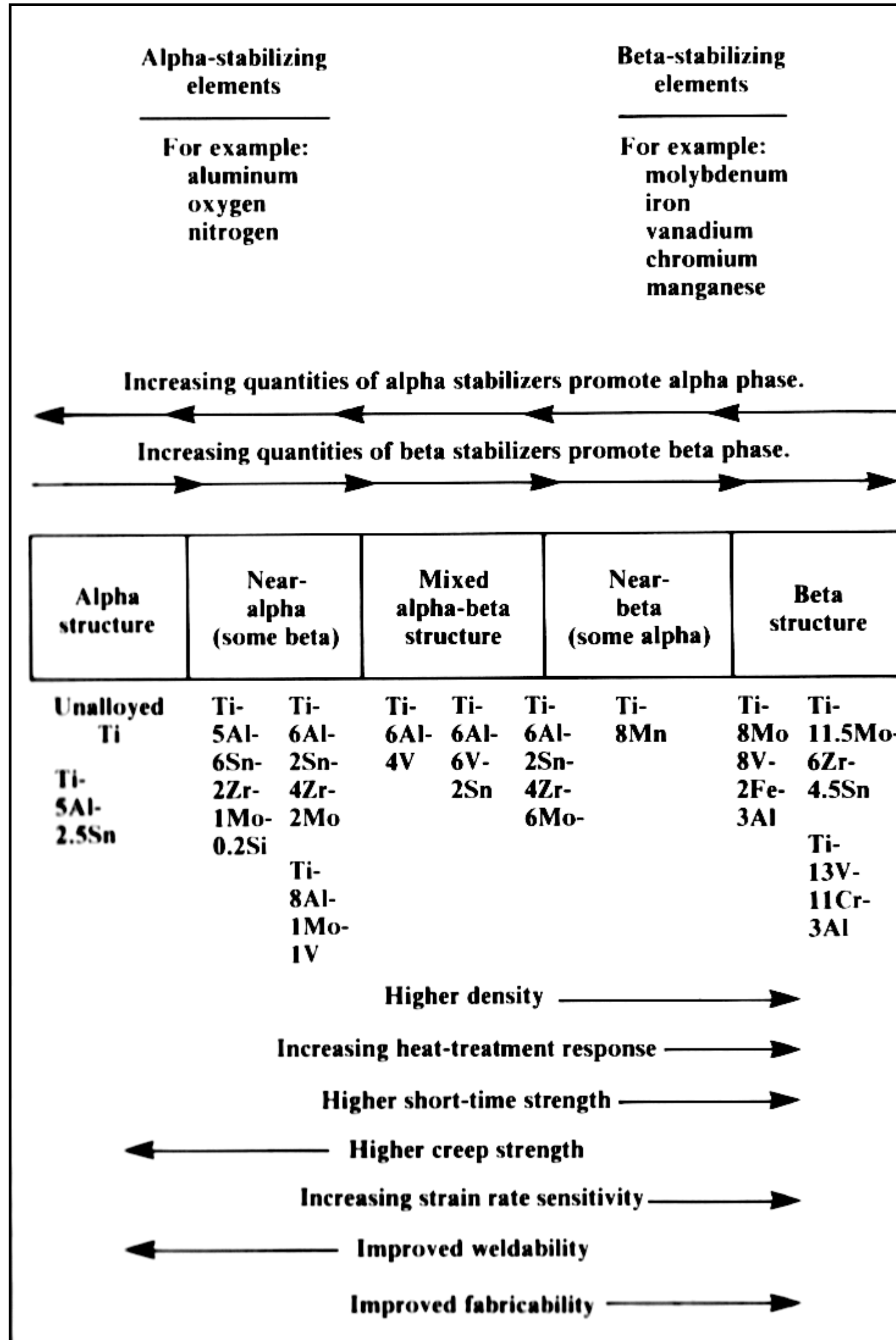
- Because Ti is used in the aero, medical, and chemical industries tight controls are held over parts and lots
  - Secondary processors maintain heat traceability and return scrap to raw material supplier for credit. Secondary suppliers are liable for ingot chemistry mixes.
  - Aero and chemical industries commonly serialize 100% of parts and are traceable to the heat chemistry
  - A large percentage of scrap recycle is performed without analysis
- If traceability is lost typical chemical analysis methods are used
  - Spark, XRF, wet chemical
  - This can be particularly costly for intersticial elements which are vital to titanium alloy properties; C, O, N
    - ELI grades are particularly valuable scrap



Titanium aircraft hydraulic tubing with print line

Titanium Alloys

- Titanium has multiple phases
  - Both alpha and beta phase can be stable at room temperature based on alloying and TMP
- Alloys
  - The "workhorse" alloys are Ti6Al4V and Grade II CP
  - All can be envisioned for automotive industry
    - Beta – Springs
    - Alpha – Valve train
    - Alpha + Beta – Fasteners
  - The most challenging alloys for scrap sort are CP grades I to III which vary C, O and N
- The automotive industry will likely move away from high cost alloying elements



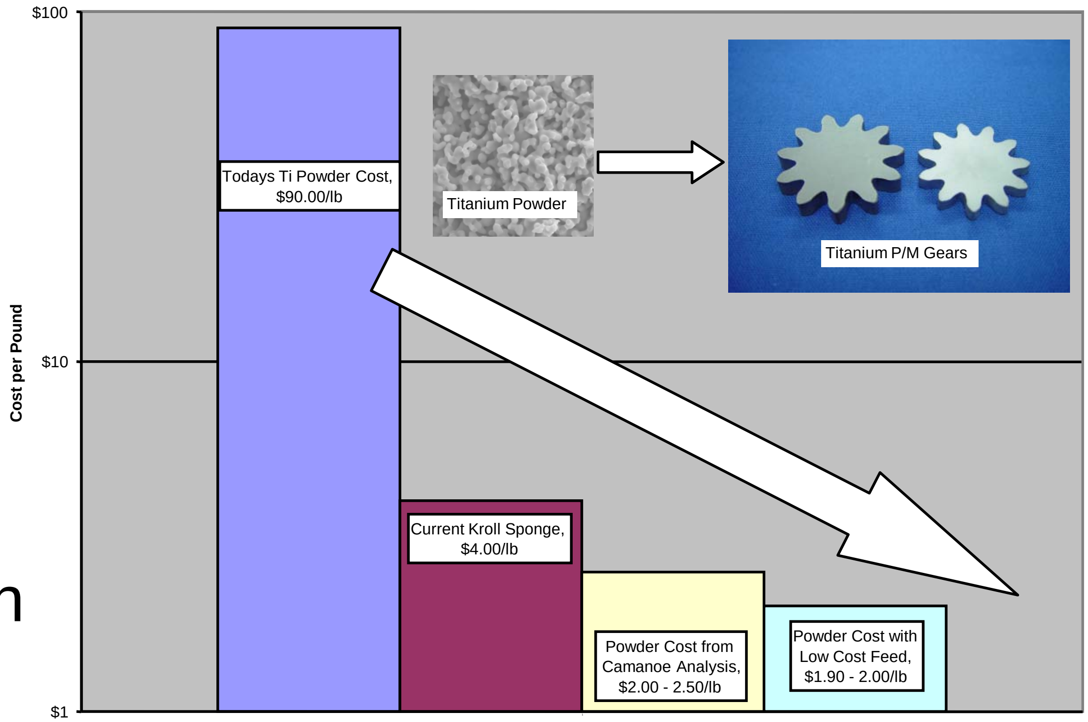
From Titanium; A Technical Guide

Titanium Recycling and the Automotive Industry

- The primary reason that Ti is recycled today is the high scrap value and raw material cost
- The current cost of titanium is prohibitive for automotive use
  - New technologies are being developed that will lower the cost and may allow widespread use in automobiles
- If there is widespread use of Ti the recycle industry may need to change
  - Heat traceability is difficult and costly and unlikely to happen in the automotive industry
  - Chemical analysis methods are costly and time consuming

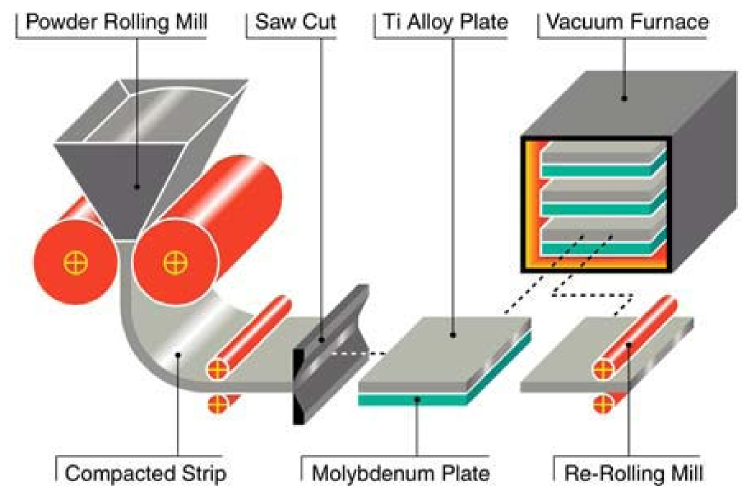
The Effect of Emerging Titanium Technologies

- Several new technologies are under development that may meet the cost needs of the automobile industry
- The new technologies lend themselves to even lower cost solid state consolidation



Solid State Consolidation

- Solid state consolidation from powdered feedstock is new technology being invested in heavily
  - Emerging titanium technologies produce powders amenable to powder consolidation at very low cost.
  - However, powder production from chunky scrap is very costly and if the automotive industry uses large amounts of titanium the aerospace and chemical industries may not be able to consume all scrap.

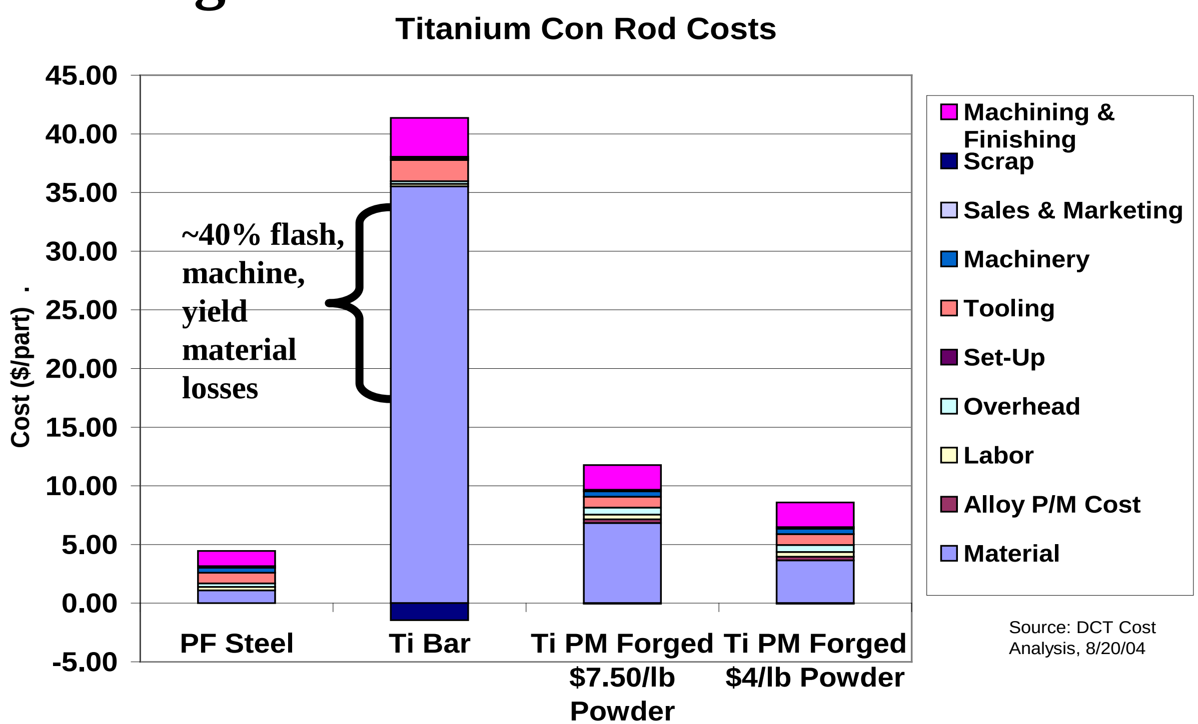


ADMA Products Inc.

Powder Forged Connecting Rod

Powder Forged

Forged from Bar



Source: DCT Cost Analysis, 8/20/04

Conclusions

- Titanium can impact the mass of automobiles and reduce US oil consumption
- Titanium is easily recyclable with today's technology and a mature recycle industry exists
  - Given today's titanium cost structure
- Today's titanium cost is prohibitive for the automotive industry; new technologies are needed and are under development
  - Automotive goals are approachable
- The automotive industry may choose type and quantity of alloying elements not in balance with the current Ti users.
- The new titanium technologies work easily into low cost solid-state processing
  - Current recycle industry not applicable

Pacific Northwest
NATIONAL LABORATORY

Gaps

- Recycle technology gaps required for automotive titanium could be broken down into 2 categories:
  1. Enhancements to the current industry for cost and throughput that cross-cut the anticipated new Ti processing
     - Identify opportunities to more rapidly and accurately sort scrap and consolidate for re-melt; control methods used today by the aerospace, chemical and medical industry may not be practical
  2. Developments in support of the anticipated emerging industry
     - Develop scrap processing strategies to support an industry that uses solid-state consolidation

Automotive Applications and Recycling Trends of Metal Matrix Composites

Presented by Curt Lavender

Originally part of a presentation by
Darrell Herling, PNNL and
Dr. Warren H. Hunt, Jr., Aluminum Consultants Group, Inc.

Applications of Aluminum Metal Matrix Composites: Past, Present, and Future
ASM Materials Solutions 2003

Pacific Northwest
NATIONAL LABORATORY

Outline

- Types of Metal Matrix Composites
  - Similar to polymer matrix composite in variety
  - Will impact recyclability
- MMCs in automobiles
  - Can impact fuel economy
  - Diversity in type of MMC used
- Current recycle
- Recycle if adopted by automotive industry
- Conclusions
- Gaps

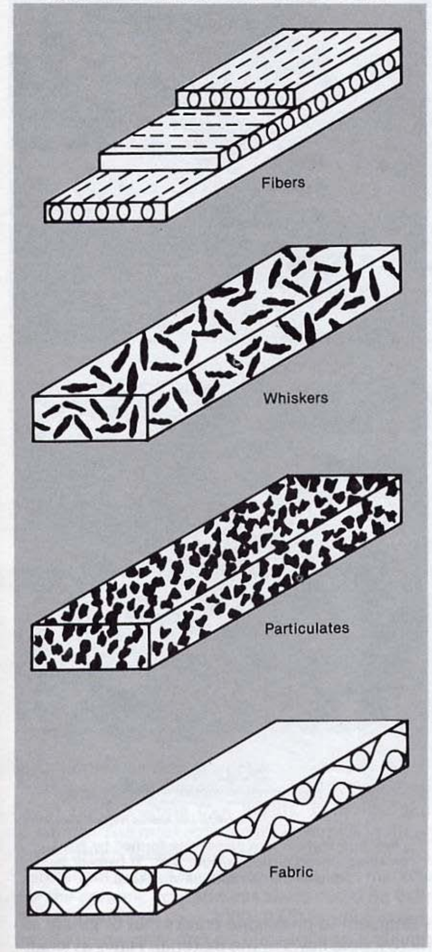
Historical Background

- 1960-70’s: Initial interest in continuous fiber composites
- Late 1970’s: Renewed interest in whisker reinforced MMC
- 1980’s: Major development era
  - 1982: Al-SiC composites via powder metallurgy routes for aerospace and defense applications, mechanical property driven
  - 1985: Patenting of stir casting for Al-SiC, leading to low cost materials for automotive applications, stiffness and wear resistance driven
  - 1987: Initial Zweben articles on use of Al-SiC for electronic packaging, physical property driven
- Late 1980’s-early 1990’s: Air Force involvement
  - Title III Program for DRA
  - Monofilament Ti MMC development
- Today: Established commercial materials with selected applications as well as emerging second generation opportunities

MMCs are Defined by Reinforcement Phase and Matrix Alloy

- Continuous fiber
  - Unidirectional
  - Cross-plied
  - **Woven/fabric**
- Discontinuous reinforcements
  - **Chopped or short fiber**
    - Whisker
  - **Particle/particulate**
    - **Grinding media**
- Typically reinforcing phase is ceramic to take advantage of CTE, hardness and elastic modulus
  - Steel has been used in Al
- Alloys
  - **Al**, Mg, Ti, Ni…

Figure 2.—Composite Reinforcement Types



SOURCE: Carl Zweben, General Electric Co.

Pacific Northwest NATIONAL LABORATORY

ANSI H35.5 System for Aluminum MMC

6091/SiC/20p-T6

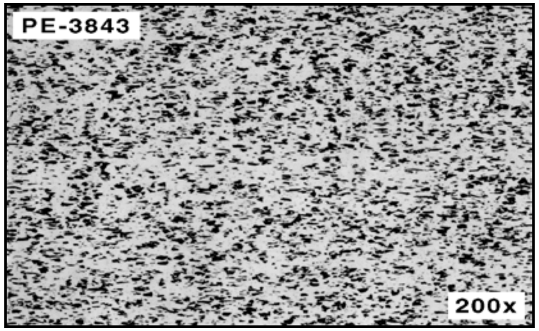
AA alloy designation

Reinforcement composition

Reinforcement content, volume %

Reinforcement type,
p=particle
p=whisker
f=fiber

Temper



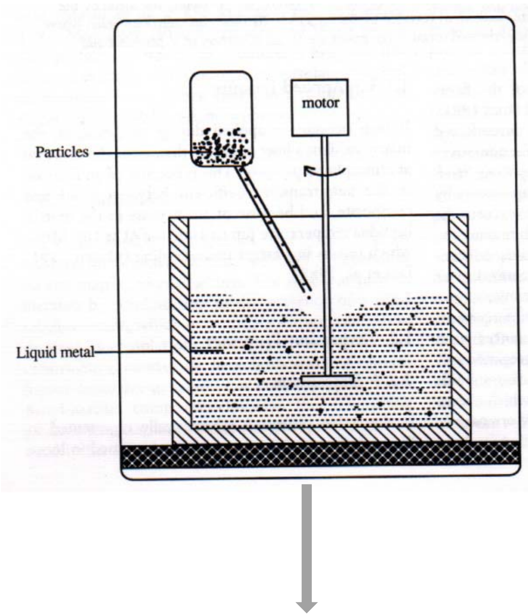
Pacific Northwest
NATIONAL LABORATORY

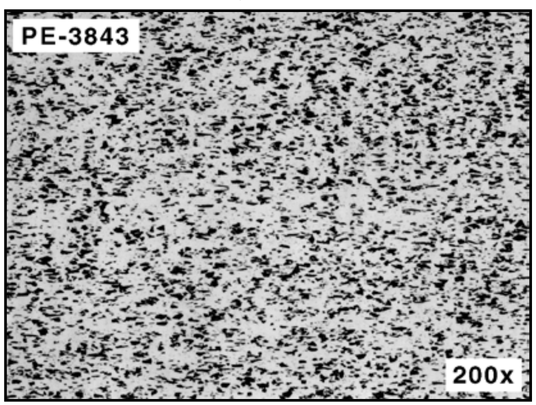
Primary Composite Processing

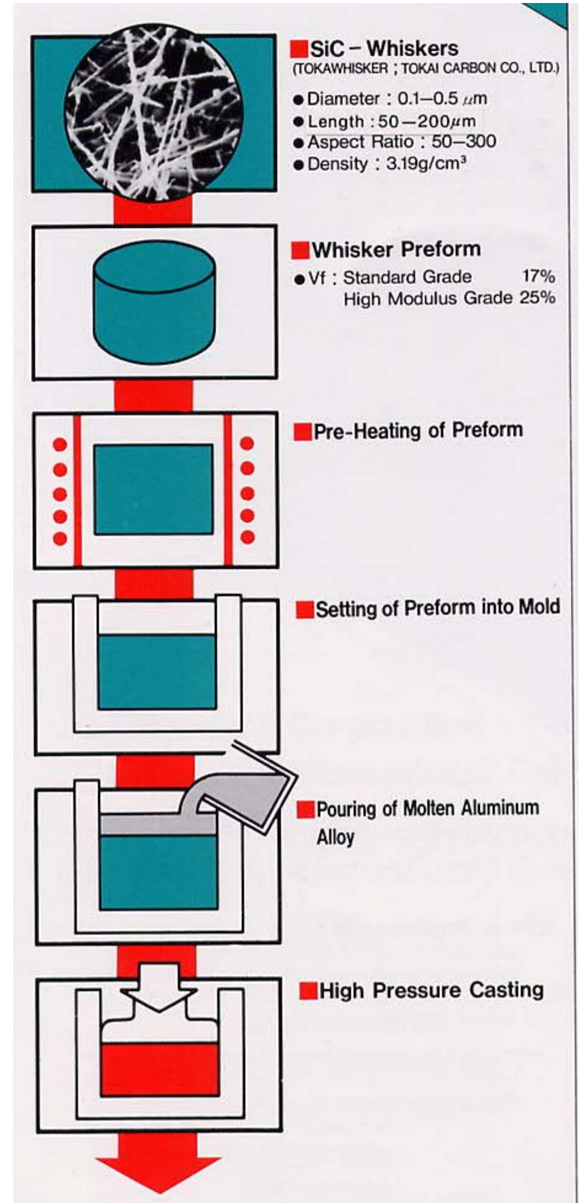
- Liquid State Processes
  - **Liquid metal mixing processes**
  - **Liquid metal infiltration processes**
    - **Preform process used by the auto industry**
  - Spray deposition processes
  - In situ formation processes
- Solid State Processes
  - Powder metallurgy
  - Diffusion bonding
- Vapor State Processes

Pacific Northwest
NATIONAL LABORATORY

Liquid Processing







Conventional Foundry Processes

Secondary Processing

- Thermomechanical processing
  - **Extrusion**
  - Forging
  - Rolling
- Shape casting
  - **Uniformly reinforced products**
  - **Selectively reinforced products**
    - **Preform**
    - **Centrifugal segregation of particles**
- Net shape powder metallurgy processes

MMCs in Automobiles

- To date, for a variety of reasons, the automotive industry has primarily worked with aluminum and liquid phase processing

- There have been auto applications of particle reinforced aluminum and pre-form infiltration

- The following are slides of production and prototypic auto applications of MMC
  - Illustration of what the future of MMC may be.

Piston

- Typically selectively reinforced with discontinuous alumina-silica fibers in the ring groove area for improved wear resistance
- Initial application in Toyota diesel engine piston in Japan in the 1980's

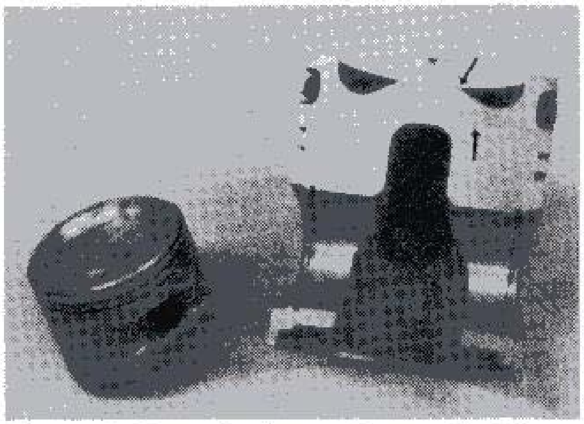
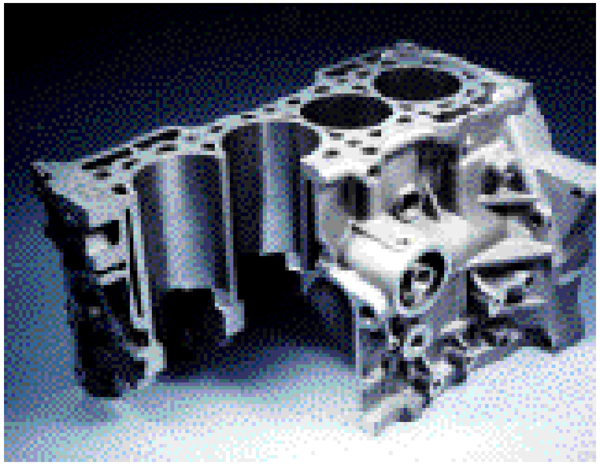


Figure 9. Cast aluminum pistons. At right, a selectively reinforced (note arrows) piston for heavy-duty diesel engines. At left, a fully reinforced piston for a low-emission passenger car engine.

Cylinder Liner

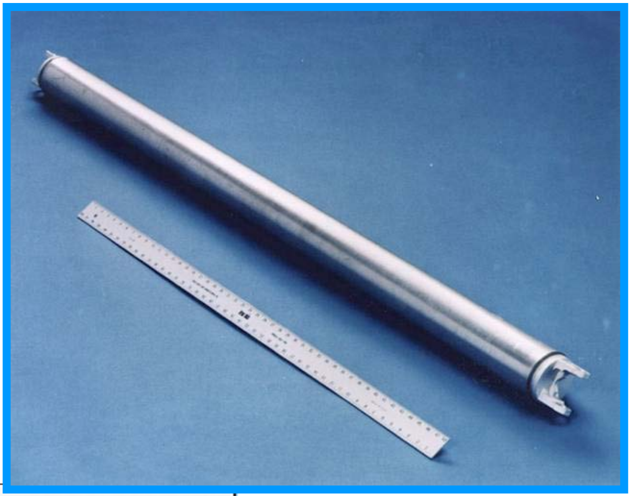
- Alumina-graphite hybrid preform integrally cast with aluminum engine block
- Utilized in Honda Prelude 2.3L engine along with other applications
- Replacing conventional cast iron liner, the benefits include reduced weight and improved cooling efficiency



Courtesy Duralcan USA

Drive Shaft

- 6061/Al2O3/15p extruded tube replaced two piece aluminum shafts
- Application on Corvette, GM S/T truck, and Ford Crown Victoria
- Benefits include increased critical speed to allow reduction in diameter or increased length of drive shaft



DURALCAN® **ALUMINUM COMPOSITE DRIVESHAFT TUBING / MINIMUM PROPERTIES**

YIELD STRENGTH	37 Ksi
ELONGATION	3.0%
MODULUS	14.1 Msi
SPECIFIC STIFFNESS	30% GREATER THAN STEEL OR ALUMINUM

POTENTIAL FOR:
13% - 14% INCREASE IN CRITICAL SPEED
OR
12% REDUCTION IN DIAMETER
OR
6% INCREASE IN LENGTH VERSUS ALUMINUM OR STEEL

Courtesy Duralcan USA

Brake Rotor

- Semi-permanent mold cast 359/SiC/20p replaces gray cast iron
- Application in Plymouth Prowler, Lotus Elise, and other specialty vehicles
- Benefits include reduced mass, reduced noise, and improved corrosion performance

PROPERTIES VS. CAST IRON IN BRAKE APPLICATIONS

	F3S.20S-T61	F3D.20S-T5	GRAY CAST IRON Grade 30/35
Elastic Modulus (Msi)	14.3	16.5	13.0 – 17.2
Yield Strength (Ksi)	49	57	31 – 39
Density (lbs/in³)	0.0999	0.1019	0.257
Thermal Conductivity (BTU/ft•hr•°F)	107	85.5	27.3
Specific Heat (BTU/lb•°F)	0.200	0.198	0.096
Thermal Expansion Coefficient (10⁶/°F)	9.7	9.4	6.8

Courtesy Duralcan USA

Brake Caliper Prototype

- Prototype utilizes cast aluminum rotor with selective reinforcement by alumina fibers, replacing cast iron
- Benefits include up to 50% weight savings while fitting in existing design envelope

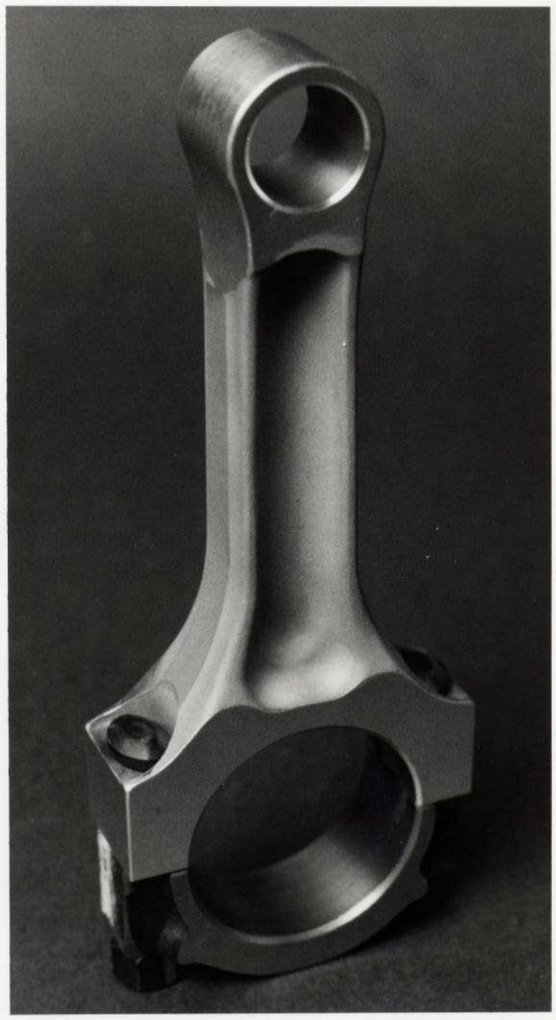
A traditional cast iron brake caliper and an Aluminum Matrix Composite (AMC) caliper. The AMC is the same size as cast iron, but half the weight!

Pacific Northwest
NATIONAL LABORATORY

Courtesy 3M

Connecting Rod Prototype

- A variety of MMC prototype parts have been produced and demonstrated
- No commercial applications due to cost issues
- Benefits from replacement of steel rods include reduced shaking forces and increased fuel efficiency due to lighter weight powertrain



Courtesy Ford Motor Co.

Pacific Northwest
NATIONAL LABORATORY

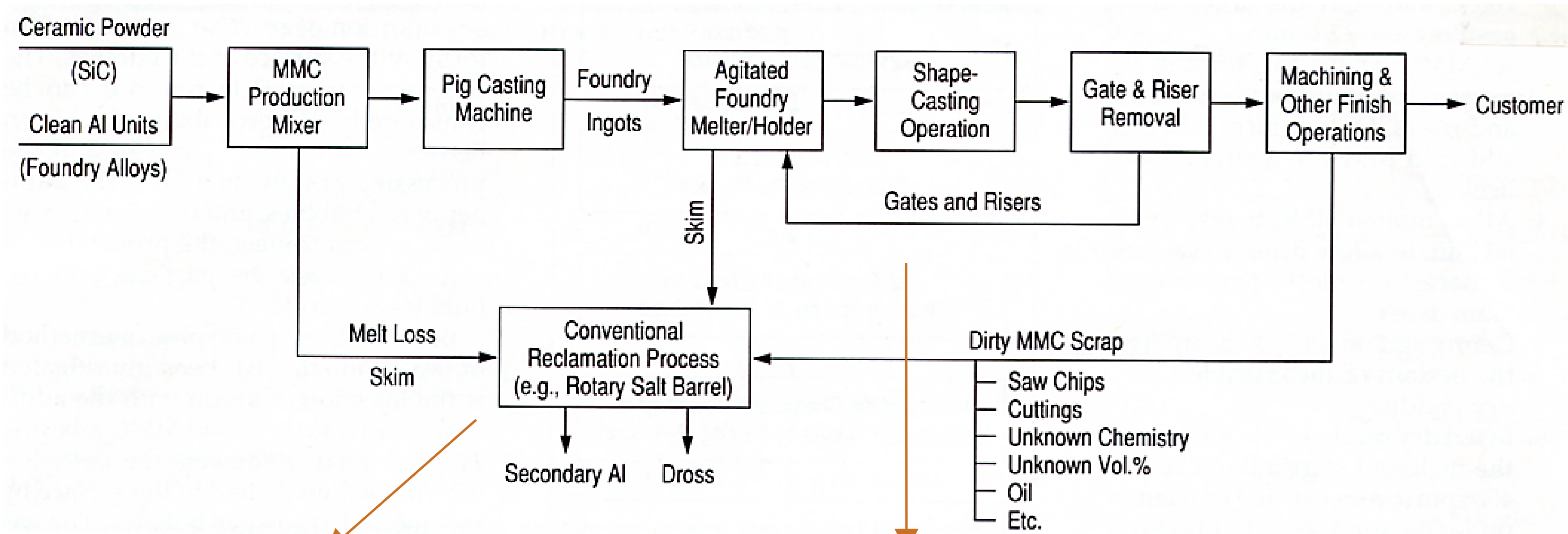
MMCs in the Automotive Industry

- There were several varieties of MMCs used
  - SiCp
  - Graphite fiber
  - Al_2O_3 particle
  - Al_2O_3 fiber
  - Al_2O_3 and Graphite Fiber
- To date all have liquid phase processed
  - As-Cast or extruded for particle MMC
  - Typically pre-form processed for fibers
  - One exception is the con-rod

Current Recycle

- Many parts have been made what happened to MMC?
  - No value proposition to reclaim MMC based on low volume
    - No scrap sorting established
  - No risk to aluminum supply it is has been lost in the noise of the current recycle industry
- Al/MMC have been recycled as aluminum and matrix recovered
  - Unlike most polymer matrix composite the aluminum matrix can be reclaimed

Current Extent of MMC Recycling and Reclamation



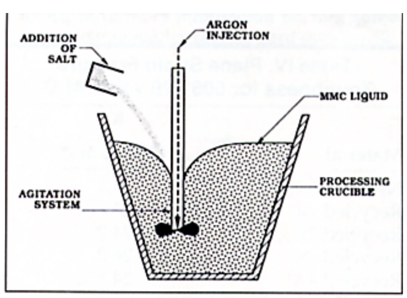


Figure 8. A schematic of the gas injection and salt addition reclamation process.

Unknowns in Long Term MMC Recycling

- Performance degradation
  - Impact of remelting
  - Matrix-reinforcement interface degradation
- Materials Yield
  - Loss due to dross formation
  - Loss of matrix (if reinforcement is to be stripped from composite)

- *Need controlled studies to investigate*

Conclusions

- MMCs are a class of materials that can impact the use of oil in the US and may see more widespread application
- MMCs have not seen continuous widespread use in automotive applications
  - Primarily driven by cost
- No appreciable recycle industry due to the low volume of production of MMC
  - No scrap segregation is occurring due to low value and MMCs are being tossed in with aluminum and reinforcing phase is lost in dross.
- MMCs are recyclable
  - Matrix can be “100%” recycled
  - Reinforcement phase more challenging

Gaps

- Given that the current recycle process for aluminum can be used a study could be made to predict at what volume/percentage of production does it makes sense to segregate MMC.
  - It is possibly a non-issue
- Need to develop a strategy around each likely class of MMC
  - It seems clear that matrix reclamation is technically feasible
  - It is less clear what can and should be done with dross containing reinforcement phase
- It is possible that a cost benefit analysis including recycle could drive future MMC design
  - For example SiC although a better reinforcement will have a lower ROI than Al_2O_3 due to recycle challenges and contamination.

Aluminum Recycling and the Automotive Industry

Ray D. Peterson
Director, Technology
Aleris, International

Aleris International, Inc.

Outline

- Aluminum Recycling
  - General Trends
  - Automotive Specific
- Issues
  - Cost – Energy, Recovery, Throughput & Labor
  - Scrap:
    - Availability – Manufacturing scrap vs Post-consumer
    - Identity
    - Impurities
    - Magnesium Removal
  - Molten Metal Deliveries
  - By-products
- Example of a Roadmap Leading to a DOE Project
- Conclusions

Aluminum Recycling

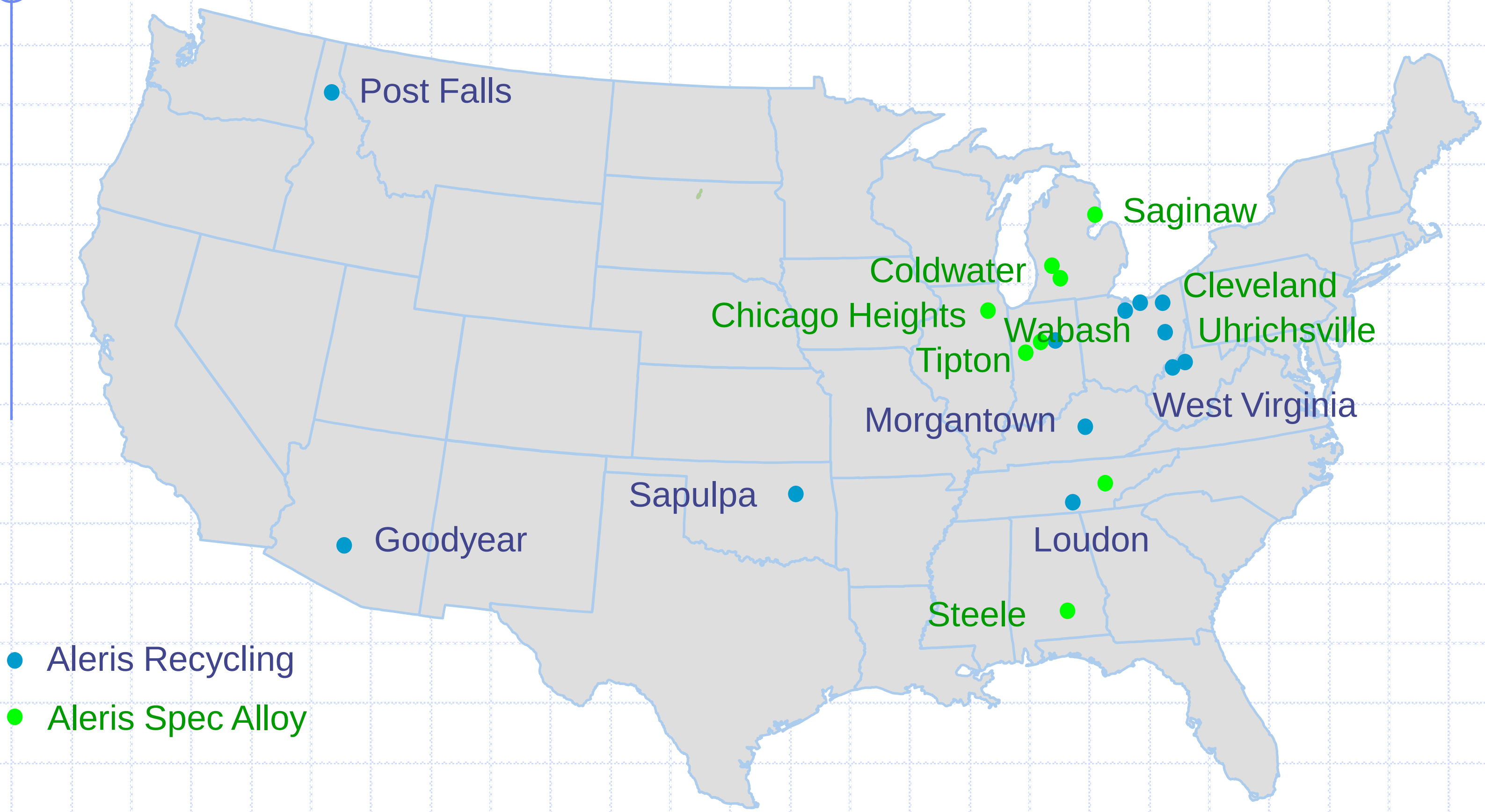
- Aluminum Recycling is successfully practiced today with the Automotive Industry.
  - Manufacturing scrap is effectively recycled back into the system.
  - Post consumer scrap is often more problematic, but is the largest source of input for some automotive cast alloys

Historical Trends for the US Al Supply

- The US domestic production drop has required more importation of primary metal and increased the need for recycling of domestic and imported scrap and by-products.
- Recycling now accounts for approximately 30% of the US domestic metal supply.

- Aleris has followed or led this same trend.

US Aleris Recycling Locations



Aleris also has recycling plants in Europe, Mexico, Canada, & Brazil

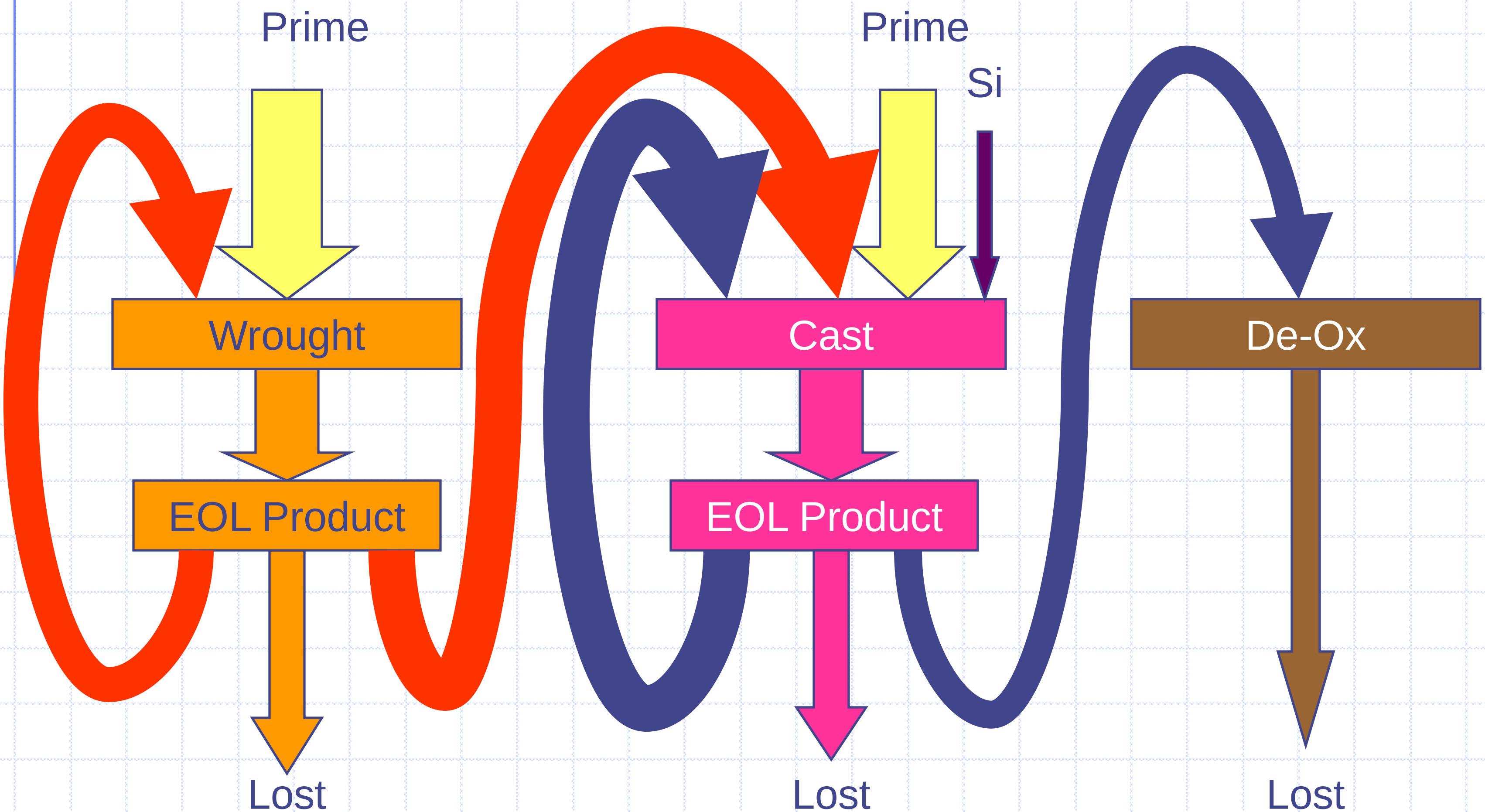
Common Automotive Alloys

- Wrought
  - 5754 6111 3004 6061
    - Most are “Primary” based due to low Fe limits
- Cast

  Primary Based:
  - 356 357 ** Low Fe and Cu limits

  Secondary Based:
  - 380 383 319 ** More open limits

Automotive Aluminum Recycling Path



Secondary Aluminum Market-I

1. Wrought Products
   - Items Cast and then mechanically transformed:

Sheet	Plate	Forgings
Foil	Extrusions	Wire

   - Wrought alloys can contain the many alloying elements such as Si, Mg, Cu, Zn, and Mn.
   - Can be work hardening or heat treatable.

Wrought Scrap Examples

Class 1

Manufacturing Scrap

UBC

Old Painted Siding

Mixed Low Copper Clip

Post Consumer Scrap

Secondary Aluminum Market - II

2. Cast Products
   - Items made into cast shapes:

alternator housings	brackets	wheels
brake calipers	fittings	pistons
small engine housings	B & T	

   - Primarily Al - Si alloys
     - May also contain zinc, copper or magnesium

Cast Scrap Examples

Borings & Turnings

Runners

Manufacturing Scrap

Castings

Wheels

Radiators

Post Consumer Scrap

Twitch

Issues in Automotive Recycling

- Cost of Delivered Material to Our Customers is Impacted by:
  - Scrap cost
  - Recovery rate
  - Processing costs
    - Energy Efficiency
    - Labor
    - Throughout

Making Secondary Alloys

- In the "Ideal" situation, we return "like alloys" to their same system.
  - Must know their source or be able to identify them to be able to do this.
  - Contamination is always an issue.
- To effectively make secondary alloys today, we need multiple alloys or scrap types so we can properly blend them to make a final chemistry.

Two Ways to Achieve this Goal:	Limited Alloy Use in Automobiles versus Alloy or Part Sorting after Dismantling

Cost of Scrap – An Economic Lesson

- Scrap follows a typical supply-demand curve, but it is also priced with an expectation of a certain recovery.
  - Scrap pricing generally trends with primary aluminum commodity pricing.
- Higher recovery scraps command a higher price.
- Pedigree (knowledge of the scrap composition) also plays a big role the in price.
  - Alloys with lesser amounts of alloying agents usually command higher prices because they can be used for more applications.
- How much cost can we afford to put into our scrap by pre-processing?

Complexity of Recycling Scraps

Different scraps require different processing technologies.

Lower left corner is where its most difficult to process and most expensive.

Source of Scraps

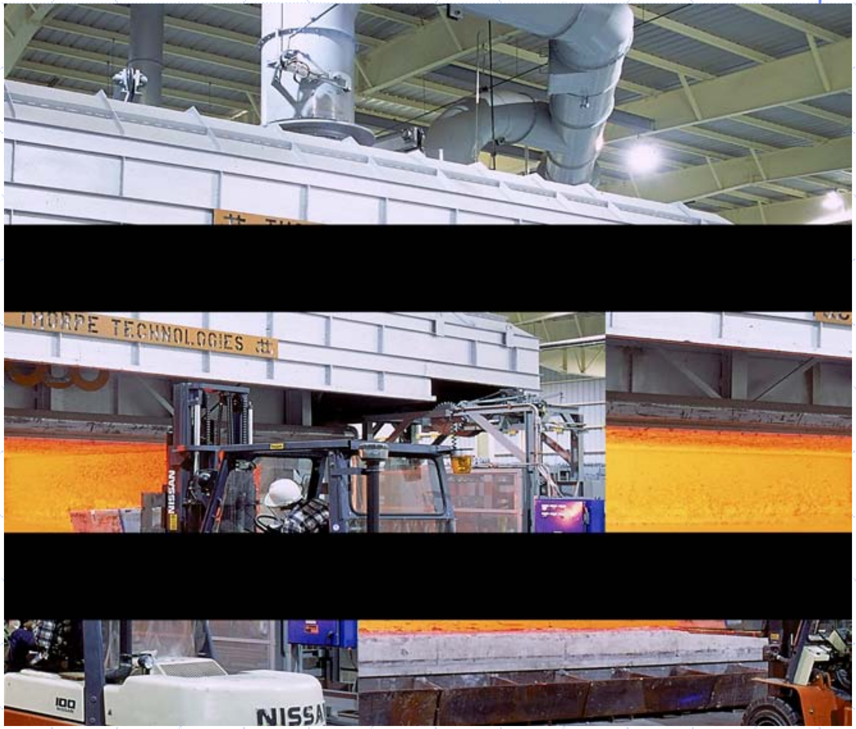
- Industrial Scrap
  - By-product of manufacturing operations.
  - Highly effective return rate
    - High quality scrap & concentrated in single location.
    - Relatively easy processing – upper right corner except for turnings.
- Post-Consumer Scrap
  - Varying quality
    - Commingled or contaminated
    - Tends towards lower left corner
  - Geographically highly dispersed
  - Return rate is dependent on consumer and dismantler, as well as local and National laws.

Technology's Impact on Recycling

- The biggest economic driver in recycling is metal recovery.
  - Changes to processes to improve recovery have the greatest economic impact.
  - Most new innovations developed for Al recycling have been geared towards improved recovery.
  - Virtually all changes strive to minimize oxidation during melting:
    - Improved furnace designs
    - Decoating painted, lacquered and oily scraps
    - Rapid submergence devices
    - Improved fluxing practices
  - A slight advantage in recovery can give you a significant advantage in the marketplace.

Technology's Impact on Recycling

- Following recovery improvements, changes to lower production costs are the next most beneficial.
  - Reduce energy costs
    - Better burners
    - Air preheating
    - Scrap Preheating
  - Increase throughput
    - Larger burners Larger furnaces
  - Decrease labor costs
    - More automation
    - Larger scale of operations



Scrap Issues

- Manufacturing scrap – easily and efficiently returned into the recycling system
  - No help needed
- Post-consumer scrap – automotive scrap recycling is relatively efficient, but the mixed form is not preferred
  - Combination of wrought and cast alloys
  - Low Fe and high Fe alloys – different destinations!
  - Small scrap sizes and organic contamination
  - Cost effective help needed

Processing Issues

- Impurities:
  - Volatiles – oils, cutting fluids, ASR, plastics
  - Compositional Issues:
    - Attached – incompletely separated alloys or other metals
    - Commingled – physically free, but ineffectively separated alloys and other metals
  - Cost effective help needed

Processing Issues

Magnesium Removal:

- For many alloys Mg concentration must be lowered.
- Current technology is removal by Chlorine gas

Desired Reaction:

$$Mg_{(Al)} + Cl_2 \rightarrow MgCl_2$$

Undesired Side Reactions:

$$2H_{(Al)} \rightarrow 2HCl$$

$$MgCl_2 + H_2O \rightarrow MgOHCl + HCl$$

Cost effective alternatives to chlorine use are needed.

Molten Metal Deliveries

- Molten deliveries allow our customers to receive metal in a "ready to cast" condition.
- Issues:
  - Thermal efficiency for the producer is low
  - Limited delivery distance

Improvements in energy efficiency are needed.

By-Products (Closed Loop Recycling)

- All by-products of aluminum recycling could be recycled and re-used:
  - Aluminum: back to aluminum products
  - Flux (NaCl and KCl): reuse in recycling
  - Aluminum Oxide: use as feed component in cement manufacturing, refractories, or other low value materials.

Process improvements needed to lower costs of by-product recovery.

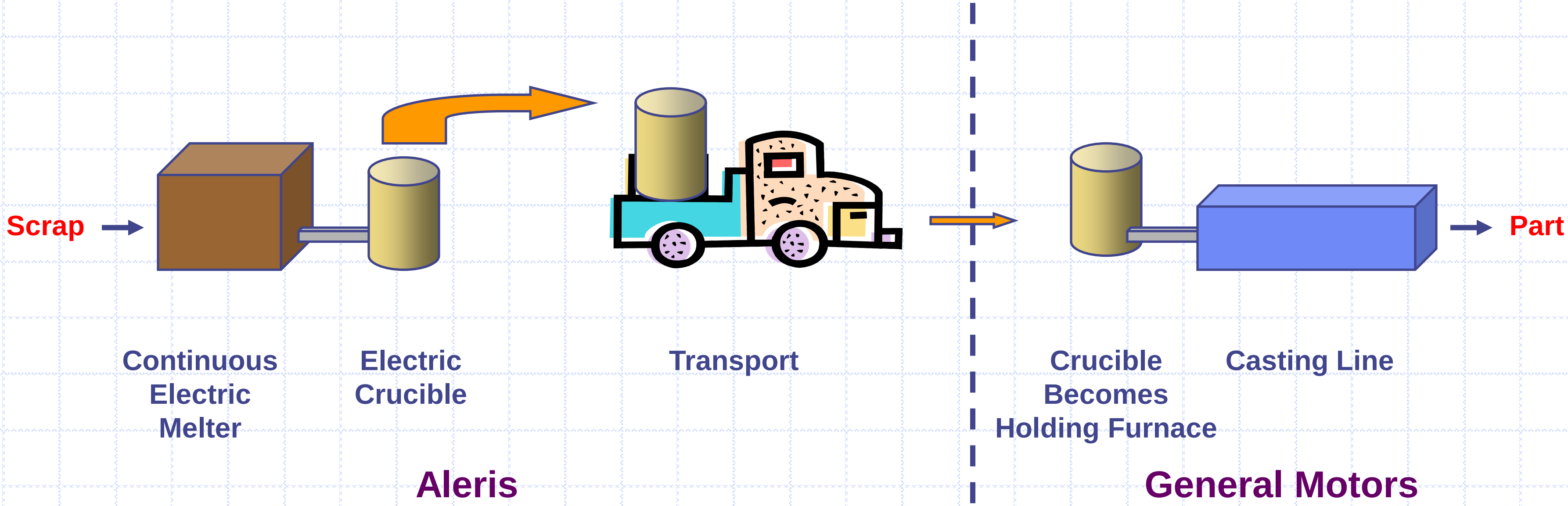
Apogee – GM – Aleris DOE Project

- Goals were determined in earlier Roadmapping exercise.
- Led to a multi-million dollar cost-shared project to revolutionize the way we melt scrap and deliver molten metal.
- Heavy industrial participation:
  - Aleris International – Metal melter and transporter
  - General Motors – Metal receiver and foundry
  - Apogee – Technology developer and supplier
  - Nat’l Labs and Universities – specialized analysis

Apogee – GM – Aleris DOE Project

Project Goals:

- Reduce energy consumption by 75%
- Reduce melt loss (improved recovery)
- Eliminate Holding Furnaces at Customer
- Improve metal quality



DOE/GM/Aleris Project Vision

Overview

- Improve secondary alloy melting efficiency
  - Replace reverberatory furnace with ITM
- Increase holding efficiency
  - Replace external gas heated ladles with electric ladles (TeL)
- Reduce molten inventory
  - Replace gas fired holders with dispensable TeL and CT

=>Replace ~ 7,000 BTU/lb (gas) with 1,100 BTU/lb* (electric) for a net cost savings while improving recovery.

* Excludes 100 BTU/lb melt loss

DOE/GM/Aleris Project Vision

Project Energy Goals

Operation	Current	Project Goal	Enabler
Melting	1,800 – 2,100 BTU/lb	552 BTU/lb	Isothermal Melting (ITM)
Holding	35 – 45 BTU/lb-hr	8.5 BTU/lb/hr	BSPP Holders
Transport	> 50 BTU/lb-hr	7 BTU/lb/hr	Electric Ladles (TeL)
Melting to Solidification	~ 7,000 BTU/lb	1200 BTU/lb Target* * Includes all melt loss	ITM + TeL + Conductive Trough

Conclusions

- Automotive recycling of aluminum is a strong industrial process.
- Need new technologies to for lower processing costs:
  - Recovery Energy Mg Removal
- Need reliable and consistent scrap sources:
  - Fewer auto alloys?
  - Improved dismantling?
  - Sorting?
- Roadmapping can be an effective tool in selecting worthy and achievable research projects.

Magnesium Recycling and Optimum Melt Processing

Boyd Davis

Kingston Process Metallurgy Inc.

Overview of Mg recycling

- Mg can be considered in 3 different forms
  - Pure Mg
  - Mg alloy
  - As an alloying agent in Al
- Mg in Al accounts for much of the Mg recycled
- Focus here is on pure Mg and Mg alloy
  - Mainly in die-casting operations

Overview of Mg recycling

- Recycling of Mg (other than clean scrap) is not wide spread in North American industry
  - Highly reactive with oxygen (and nitrogen)
    - High dross while handling
    - Potential for fires
    - Elaborate capital equipment
    - Training
  - Impurities and alloying agents
    - Makes recycling to pure Mg difficult
    - Cu and Ni cannot be removed
  - Mg has other commercial uses
    - e.g. Iron desulphurization, aluminum alloying

Overview of Mg recycling

- Typically, new scrap (Class 1) is often internally recycled or sent for additions to aluminum
  - Most economical way as it avoids all transportation costs
  - However, requires some investment at start for quality control and to qualify the ingots by optical emission.
  - Meridian has implemented Class I recycling in their facilities
- Other magnesium, such as high surface area or oxidic (dross, sludge) material is often discarded or provided to "recyclers" at a cost
- Typical 50% yield in diecasting
  - 41% of the Mg lost is Type 1 scrap
  - 5% is dross, 5% is returns
  - 36% is gates, runners, and trim scrap. [1]

[1]R. Brown, "Magnesium Recycling Yesterday, Today, and Tomorrow," *The Minerals, Metals and Materials Society* Proceedings (2000), pp. 1317-1329

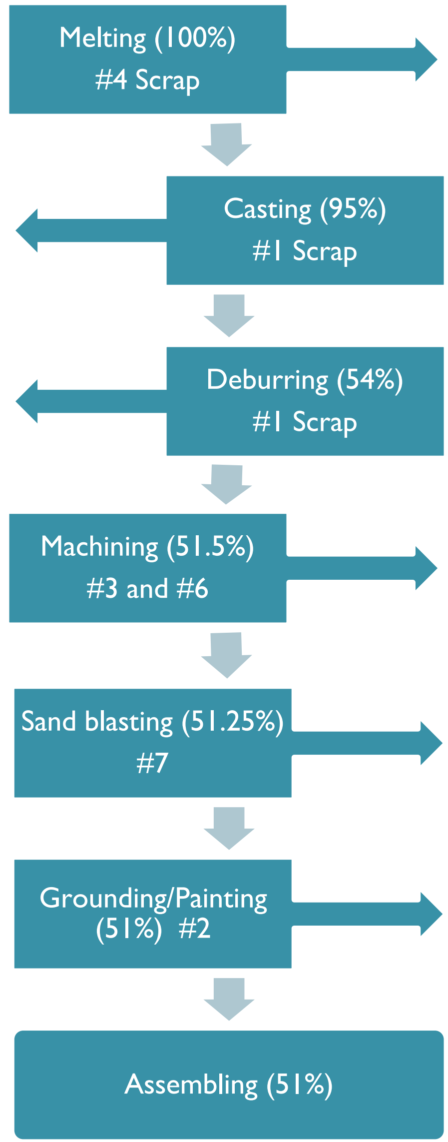
Mg Scrap Class Characterization

Class 1	-	High grade clean scrap without impurities (e.g. scrap castings)
Class 2	-	Clean scrap with aluminum or steel inserts - No copper or brass
Class 3	-	Dirty, oily, wet and/or contains sand, Cu, Ni
Class 4	-	Chips, metal-rich dross
Class 5	-	Low metal dross, sludge
Class 6	-	Scrap containing salt

Mg scrap generation in diecasting*

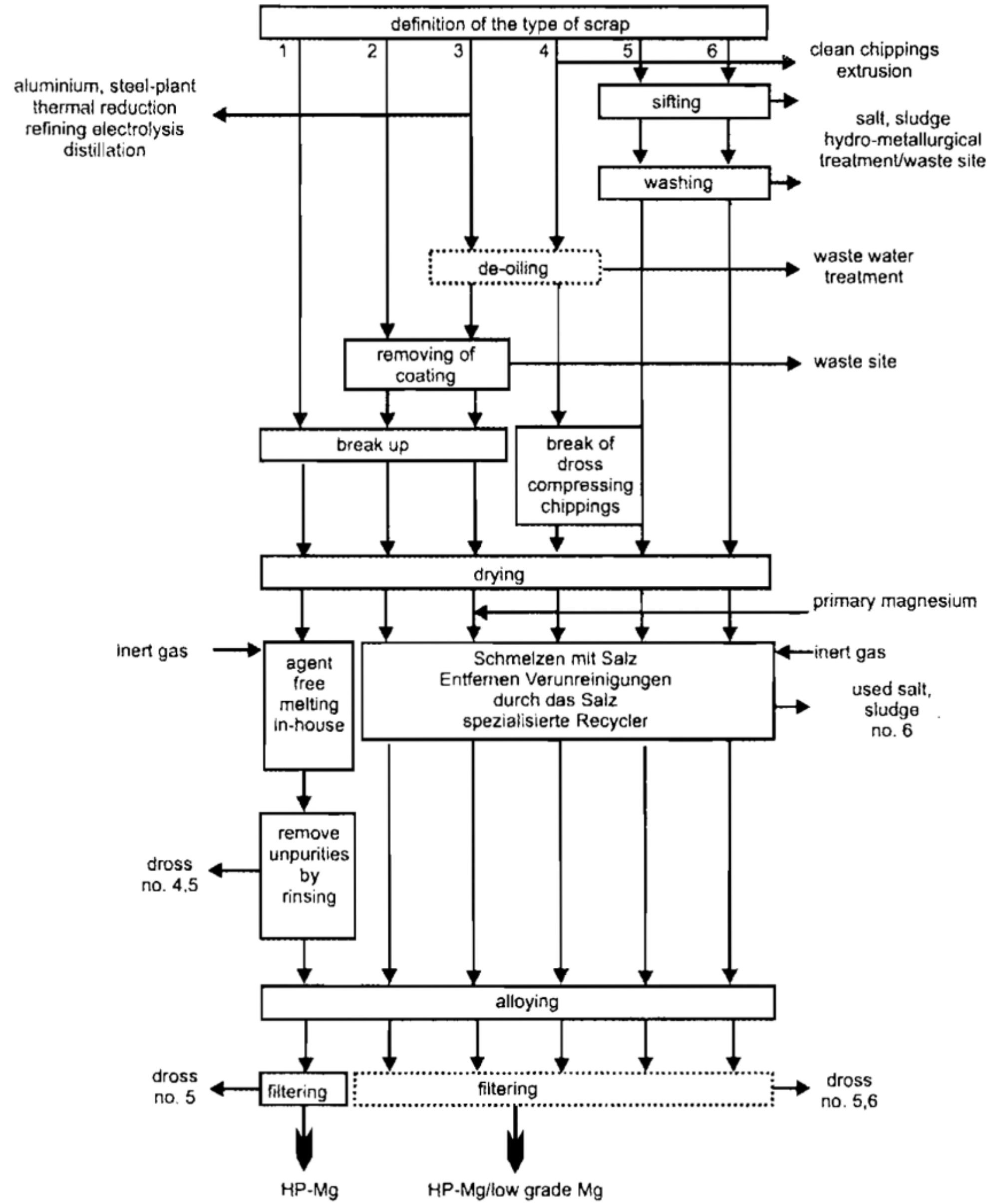
Internal processing

External Processing



*D.C. Scharf, Tech. Univ. Clausthal
% is % recovered from previous operation

Schematic of Magnesium Recycling



C. Scharf and A. Ditze, "Present State of Recycling of Magnesium and its Alloys and their Applications", in: B. Mordike and K. Kainer (Ed.) Magnesium Alloys and their Applications, Wolfsburg April 28-30 (1998) pp. 685-690

Issues around recycling magnesium

There are a number of difficulties/issues to overcome when processing magnesium:

1. Magnesium reactivity
2. Particulate removal
3. Purity
    1. Cleaning of tramp elements
    2. Alloying methods
    3. Beryllium
4. Sludge

Magnesium reactivity

The highly reactive nature of magnesium is a barrier to effective recycling. Magnesium will burn in air producing run away reactions/fire. Salt, cover gases, and Be are used to protect magnesium for different applications.

Cover Gas

- SF_6 has been used as a cover gas since it is non-toxicity and is highly effective
- SF_6 has been cited by the Montreal Protocol on GHGs to be eliminated in most applications
- Europe moving to eliminate SF_6

Cover Gases

<u>Replacements</u>

- SO_2 has been used with success
  - Hygiene issues
  - Slightly more variable protection
  - Potential danger – sulphur-dome effect
- Other gases proposed
  - HFCs (variant of Freon)
  - Fluoroethylketone
  - Ar, Xe blends
- Issues are mainly in proper use of the gas

Particles

There are a number of particle sources in recycled Mg:

- Oxides
  - Includes Mg based and refractory materials
  - Of primary importance (10-150 mm long)
  - Dross and other highly oxidic material cannot be filtered since the filters will clog too often
  - Oxide particles can occur at any point during the processing of molten Mg
- Intermetallics (Fe and Mn compounds)
- Sulphides / Carbides / Nitrides
- Salts

Purity

- Key metals to remove are Fe, Cu, Ni
  - Specs for high purity quality Mg are:
    - 10ppm Fe, 150ppm Cu, and 10ppm Ni
    - Fe typically removed with Mn additions to make FeMn intermetallics
    - Si removed by $ZnCl_2$ or $CoCl_2$
    - Ca, Na removed through $MgCl_2$ additions
      - Must be anhydrous $MgCl_2$!
- Also Zn, Si, Ca, Na, Al
- Hydrogen is removed through chlorine which can also help to remove light metals
- Nitrogen removed through inert gas purging
- Cu and Ni lowered through dilution

Alloying methods

- Typical alloying sequence:
  - Increase magnesium temperature (~710°C)
  - Add and dissolve $MnCl_2$ for Fe control
  - Add other alloying elements (RE, Al, Zn)
  - Decrease the temperature to casting temperature
  - Sample
  - Add Be at the very end just before casting
- Scrap from die casting is called "Returns“
- Die casters must keep alloys segregated
  - Only a minor alloying correction is needed with Be and Mn to get back in spec. The other elements are very stable - even RE.

Beryllium

- Be is used in die casting alloys to prevent Mg oxidation in the die caster furnace
  - Helps reduce melt loss and the need to clean the furnace often
  - ASTM B93 is 5-15 ppm Be
- Must be considered since it is present in die casting returns in the range of 3-5 ppm.
- Be is a toxic element causing Berylliosis disease
  - Difficult to handle in recycling operation that requires intervention (i.e. low grade scrap) due to health and safety issues

Sludge

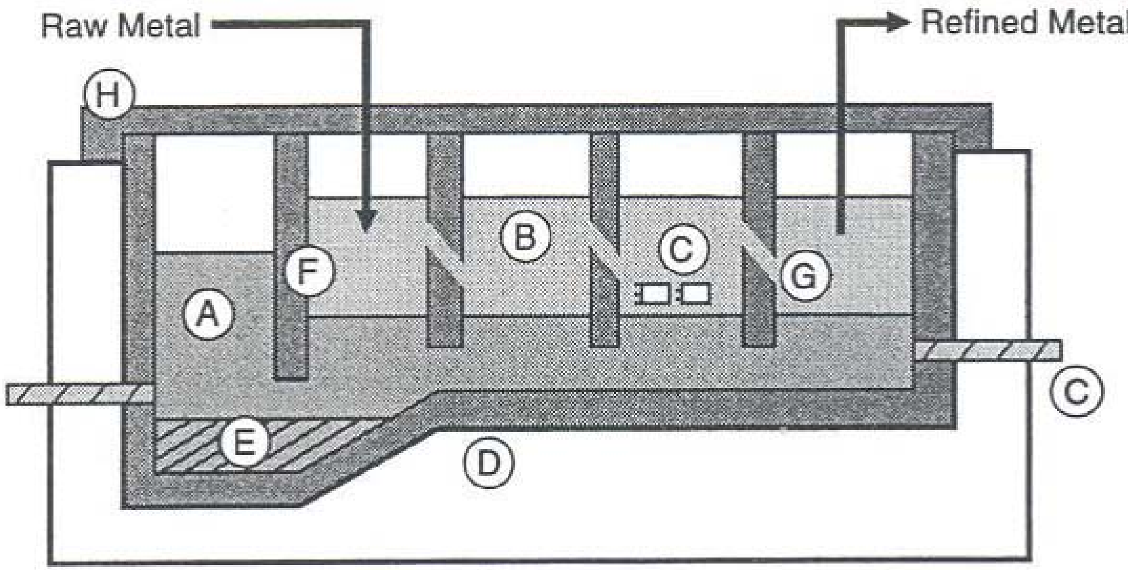
- Melt returns cause a fairly high amount of sludge which is mainly MgO
- Moisture on the surface of returns contributes to increase MgO and this become worse with high surface-volume ratio material.
- Desludging is done by using a grabber or scraper modified to the furnace profile.
- The sludging frequency depends on the room for accumulation and also on the type of alloy.
  - AZ91D generate more dross than AM alloys.

Refining technologies

- Technologies can be split into
  - Flux-based (uses molten salts)
  - Fluxless (uses inert gas and sometimes filters)
- Flux (~1-3% of Mg) helps to remove impurities and protect against fires
  - Increased corrosion and slight HCl produced
- Fluxless has a number of benefits but is only used for new, relatively clean scrap:
  - Dissolved gases removed with inert gas
  - Less dross
  - No rare earth loss
  - Easier removal of particles from surface

Salt Furnace

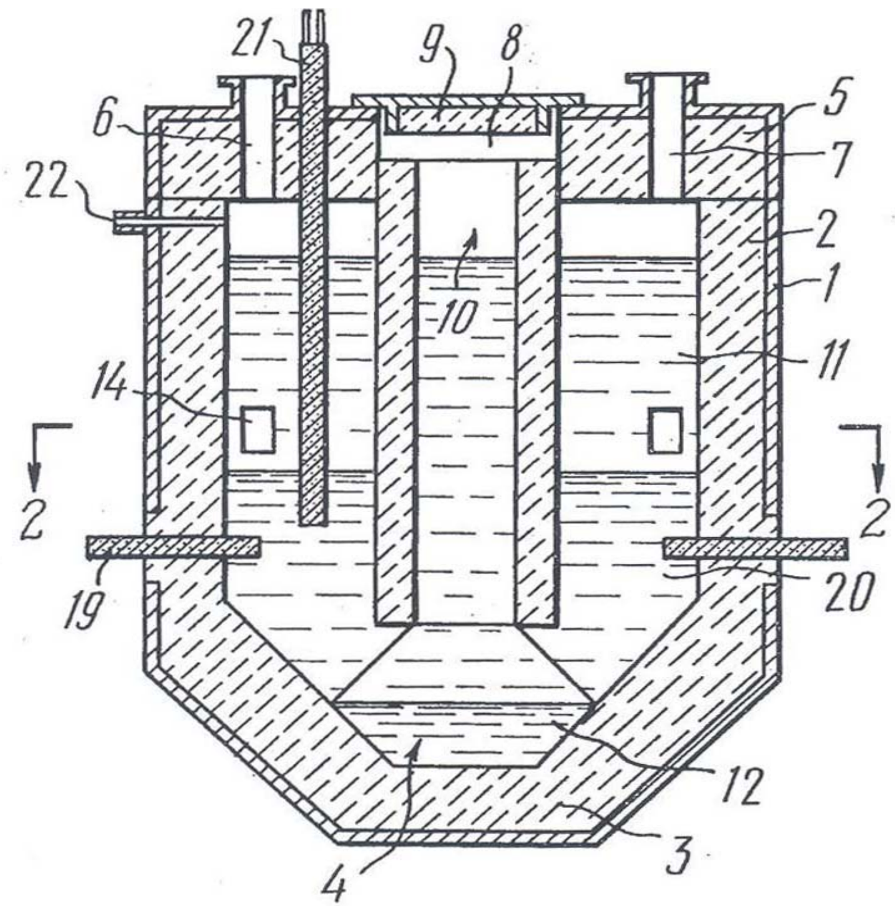
- Developed by Norsk Hydro for melting and refining magnesium
  - Uses particle sedimentation and adhesion due to convection to clean the magnesium metal



A-Salt Melt
B-Magnesium Metal
C-Electrodes
D- Refractory
E- Sludge
F- Partition Wall
G- Metal Port
H- Refractory Cover

Continuous Furnace with Central Sludge Collector

- Minimizes downtime from multiple sludge collection chambers



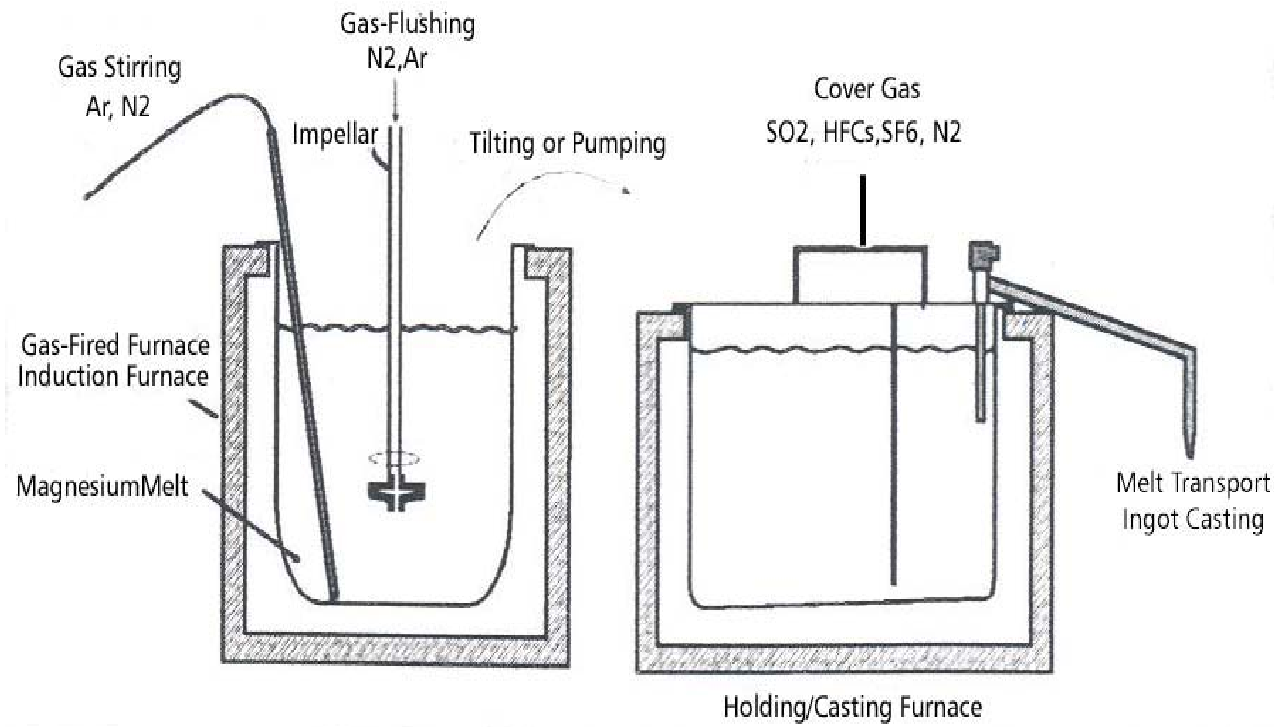
S. Kosarev, et al, "Electric Furnace and Method for the Continuous Refining of Magnesium," *US patent,* No. 3, 882,261, (1975), pp. 1

Flux Refining

- Two fluxes used
  - Cover flux protects metal
    - Simple cover fluxes contain a combination of sulfurous compounds with fluoborate salts or boric acid.
  - Secondary flux
    - Used to agglomerate oxide particles then allowed to settle
    - Typical flux is 49wt% $MgCl_2$, 27wt% KCl, 20wt% $BaCl_2$, 4wt% CaF_2
    - Each salt plays an important role in the refining process.
      - $MgCl_2$ and KCl provide the low melting eutectic
      - The $MgCl_2$ also minimizes surface oxidation by creating a thin-film layer on the metal surface.
      - CaF_2 provides the surface wettability and chemical reactivity with magnesium oxide to cause sufficient removal (dissolution of an oxyfluoride in the flux).
      - $BaCl_2$ increases the density mix with the magnesium and then settle out at the bottom of the crucible.
      - If the magnesium alloy contains rare-earths then $MgCl_2$ is be replaced by $CaCl_2$.

Flux refining

- Salt blended into metal with gas stirring and physical stirring
- Simple but issues of corrosion and sludge among others



Issues around Mg recycling processes

- Recycling of non-class 1 scrap
  - Dross (metallic and oxidic), contaminated material
  - Amounts to about 10% of the magnesium consumed
  - Basel convention may eventually prevent "recycling" of material to China
  - Likely require external processing at central facility
    - Value low, cost high
  - Variability of dross (physical and chemical) are an issue in dealing with a continuous recycling process
- Beryllium
  - Limits interest of recyclers to deal with magnesium

Issues around Mg recycling processes

- Improved alloying methods to reduce energy
  - Non-economical recycling a barrier
- Recycling of RE containing metal to ensure no loss of REs
- Sludge handling / minimization
- Cover gas use
  - Replacement of SF_6
  - Provide industrial standards for gas use
- Salt flux handling (or elimination)
- Design alloys for recycling
  - Balance recycling with properties