Going Electric: Some Materials Aspects for the Thai Automotive Industry

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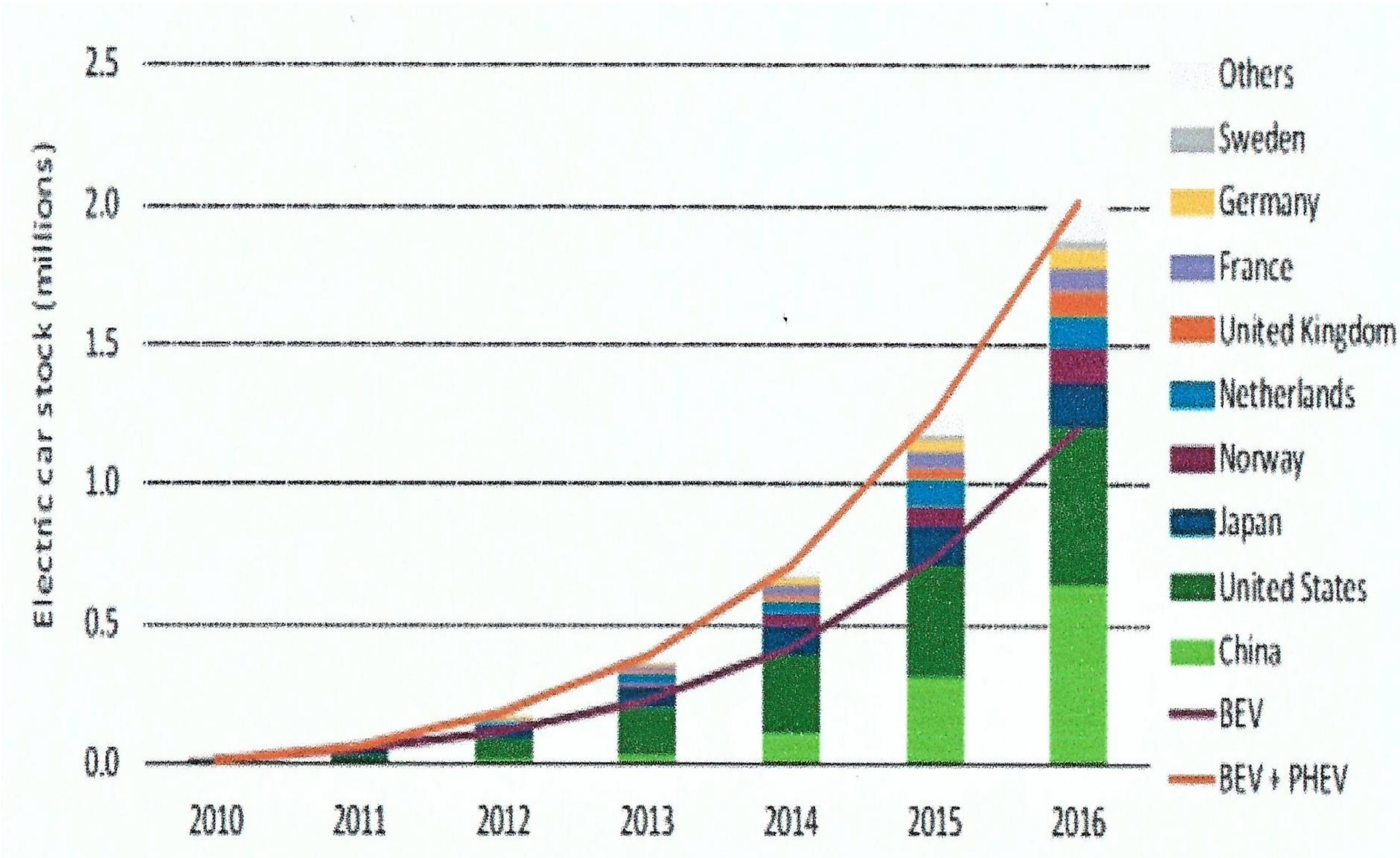
Thai encouragement for EV production

- The Government of Thailand announced in the year 2017 the policy to have 1 million EV running in Thailand by the year 2020
- Currently the Board of Investment (BoI) is offering attractive investment incentives to automakers to set up plants to produce BEVs.
- The first carmaker to benefit from this scheme is FOMM Asia, a Thai-Japan joint venture company, who intend to build 10,000 compact BEVs per year with production due to start in January 2019.

FOMM Asia EV styles

FOMM One :–
Driving range up to 160 km, max. speed 85 km/hr

Growth trends for BEV and PHEV



The automotive future is electric

- It has been estimated that, by 2025, some 35% of new vehicles in the market will be driven by battery power.
- Hence, to compensate for the weight of battery packs, light-weighting in these vehicles gains extra importance.
- Although some first-generation electric vehicles have still used HSS for body and battery enclosure parts the trend is now towards complete replacement of steel by aluminium alloy in the form of sheet, extrusion profiles and die-castings, with some use of magnesium-based die-castings.

40 Years of Light-weighting in conventional IC powered vehicles

- Electric vehicle builders can benefit from the materials developments used to save weight in IC vehicles – notably:
  - Continued progress in Advanced High Strength Steels for body in white
  - Replacement of iron castings and sheet steel welded fabrications by Al alloy castings
  - Use of Al alloys for body in white in place of steels
  - Developments in use of Mg based die castings for body and other parts
  - Use of composite materials for body and other parts

The automotive sector in Thailand

- Automotive foundries producing FC and FCD cast iron components
- Companies producing steel transmission parts
- Light alloy producers mainly Al alloy HPDC and extrusions
- Plastic parts, interior materials, rubbers etc.
- **Going electric will have greatest effect on the metal parts sector since interior and plastic trim etc will remain relatively unchanged.**

General effects on Thai parts industry

- Cast iron engine and transmission parts will be reduced in volume as numbers of ICE vehicles drop
- Capacity and technical capability of the Al-alloy ingot producers and rolling, sheet forming, extrusion and die-casting companies will need considerable improvement and expansion.
- Die-casters will also need to be able to produce magnesium alloy components, e.g. for doors, and electronic control parts.
- Low alloy steel transmission/gear production will have to be cut back.
- Heat treatment specialists will change focus from steel to Al alloys.

Importance of Castings

- Castings have always formed the basis of many key components in all forms of transport, in trains, boats and planes and in all types of motor vehicles.
- The production and application of automotive castings is of paramount importance in Thailand - the Detroit of South East Asia.
- Traditionally ICE cast components include Cast Iron and Aluminium engine blocks and heads

Casting Changes

- Over the last 50 or so years foundries worldwide including Thailand have had to continually change and develop their production in response to significant alloy changes such as the use of Ductile (FCD) Irons in place of Malleable Irons, Grey (FC) Iron and Cast or Forged Steels, and the substitution of Cast Irons by Aluminium Alloy castings, particularly to save weight and improve fuel efficiency in conventionally powered vehicles.
- As mentioned above. In more recent years Aluminium castings have also increasingly replacing welded steel fabrications as chassis and suspension parts, and are being used in combination with wrought forms of Aluminium in body and closures construction.

Light-weighting in EVs

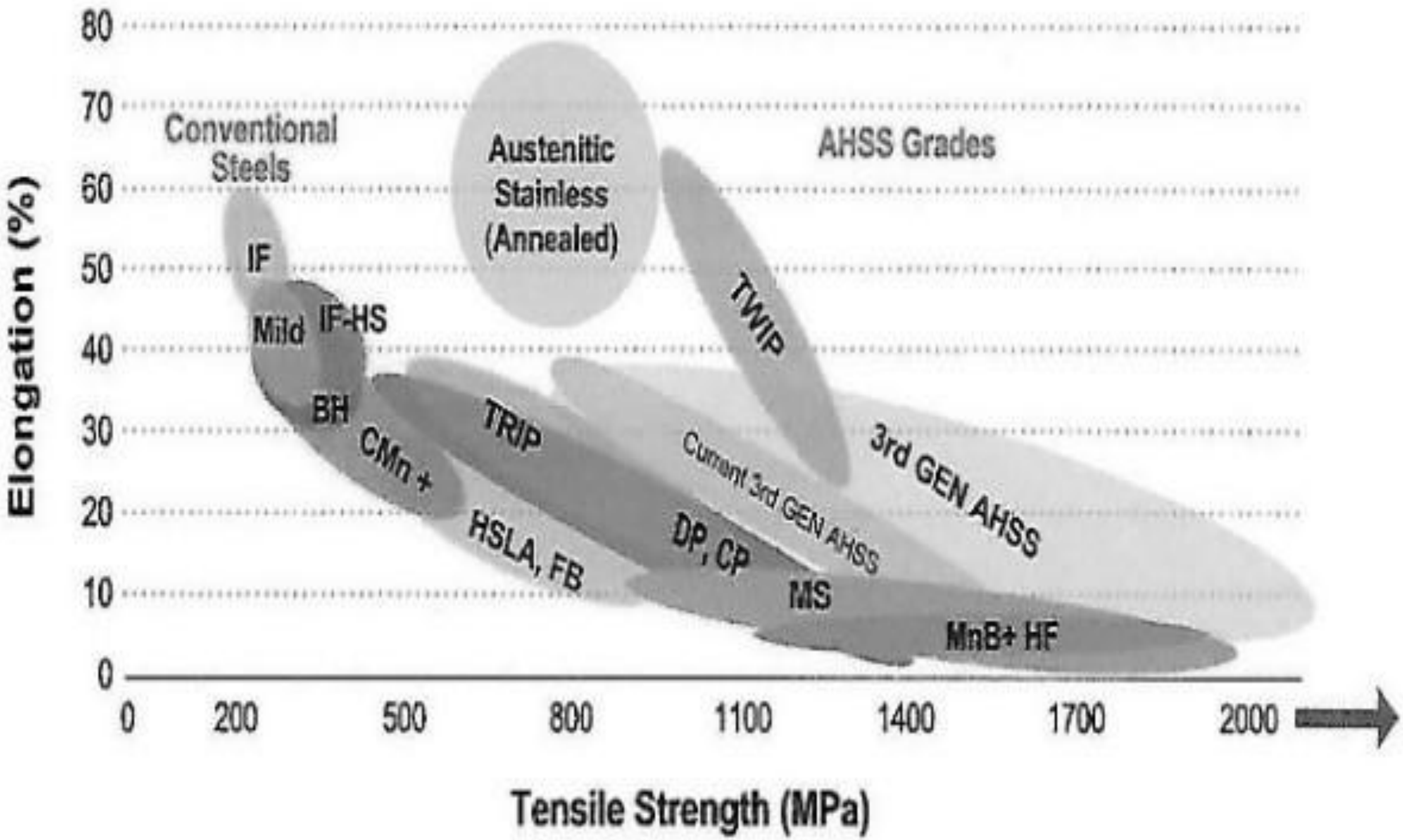
- As in ICE powered vehicles light-weighting of body and other parts is equally if not more important in EVs.
- Light-weighting is needed to offset the weight of heavy batteries and it may also allow smaller battery packs to be used thus reducing costs.
- Alternatively, it may enable increased vehicle range per charge by allowing an increase in the battery pack size.

Some predictions

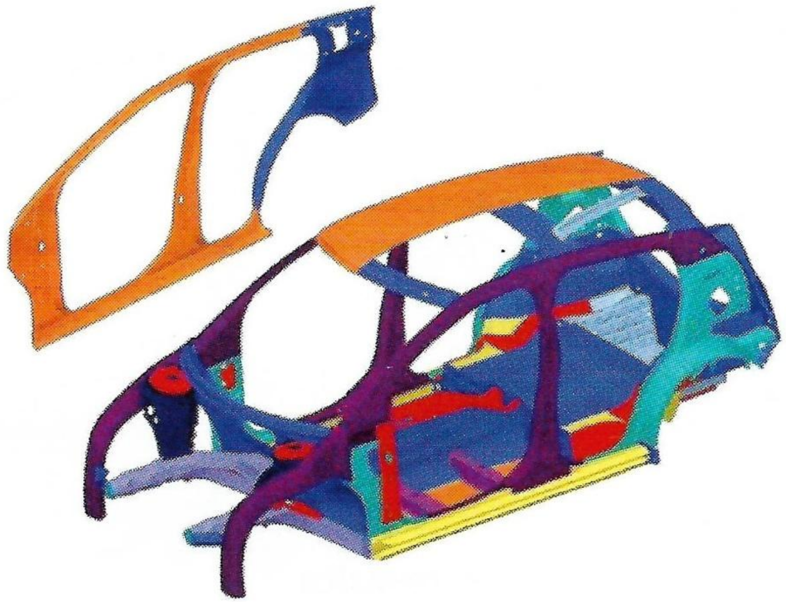
- The annual market for EVS could be as high as 65 million by the year 2040.
- It is predicted that this would increase the annual demand for Al Alloys to over 10 million tonnes with at least some 3 million tonnes per year just in Al alloy extrusions.
- The latter will need considerable expansion in extrusion and associated thermal treatment plus finishing capacities worldwide, especially in Thailand

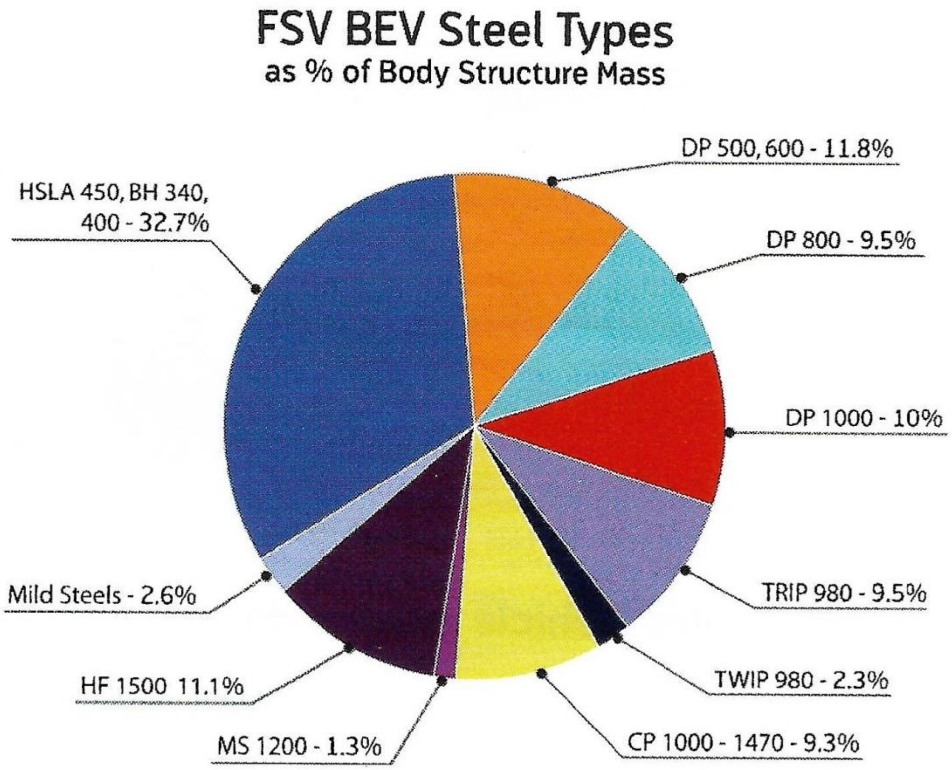
Use of Steels

Variety of auto-body sheet steels



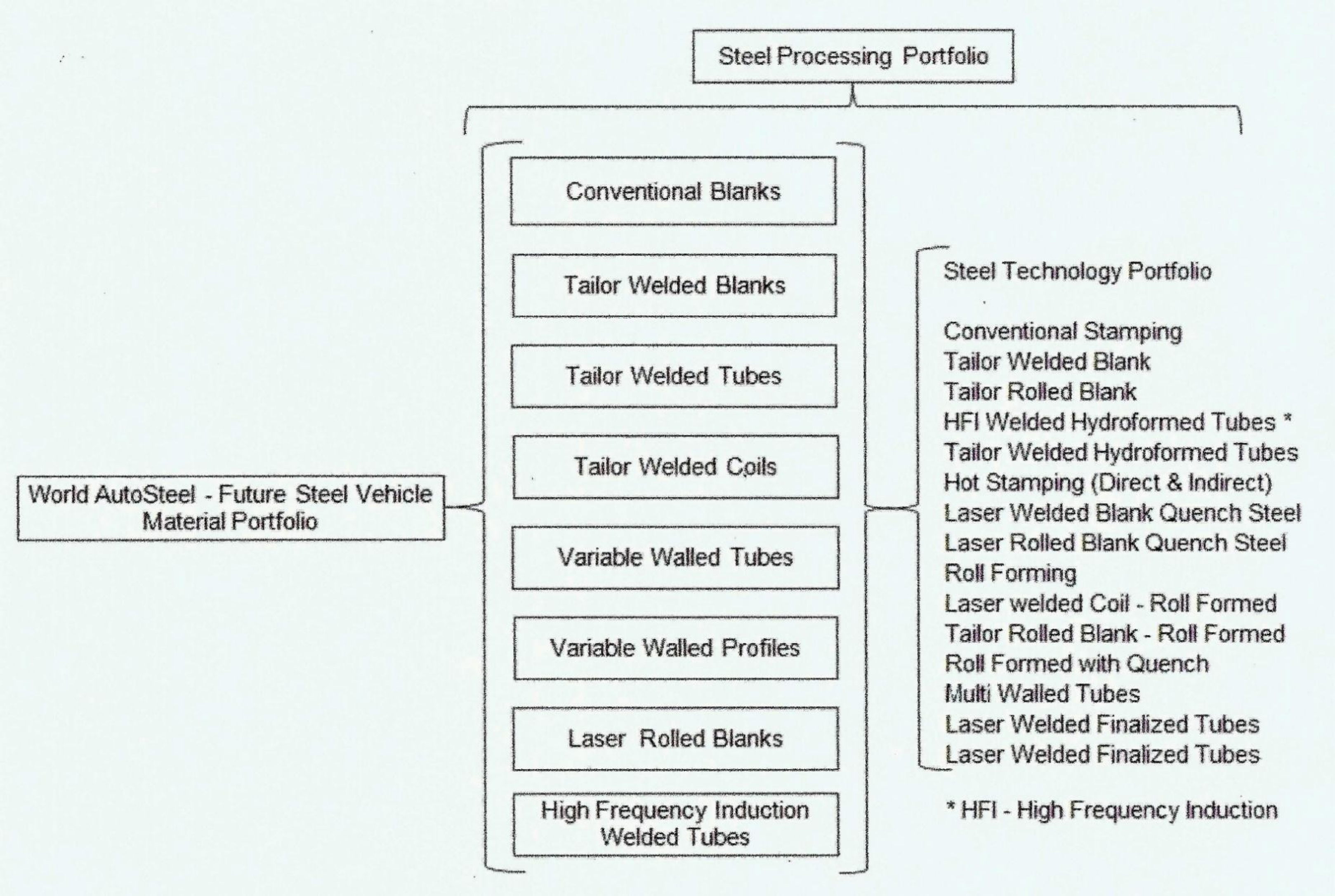
Future Steel Vehicle BEV Steels





HSLA – high strength low alloy. BH – bake hardening. HF- hot formed. MS- martensitic. DP – duplex phase. CP – complex phase. TRIP – transformation induced plasticity steel. TWIP – twinning induced plasticity steel.

FSV – manufacturing processes



Forming AHSS body parts

- The processing and formability of higher strength steels is different to that of the conventional mild steels used for auto body pressings
- Some high strength grades can only be used for relatively shallow pressings and, in order to give consistent performance, all grades required modifications to design of the body part, press tooling, forming conditions, welding and finishing operations.
- Press shops in Thailand need to further develop their capabilities in these processes to meet the greater need for AHSS body parts in electric or hybrid vehicles.

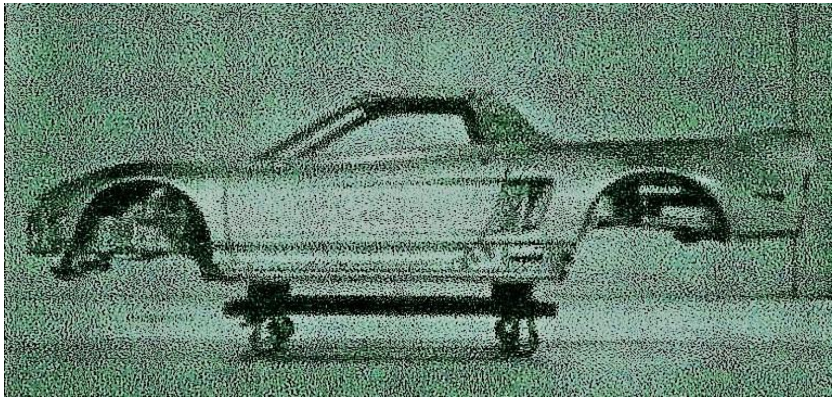
Steel Body pressing in Thailand

- The domestic body parts suppliers in Thailand, who are highly dependent on overseas major car-makers, have to employ the raw materials that are compliant with the specifications of these makers.
- After some 50 years of development, there are now at least three to four medium-to-large domestic companies capable to supply body parts that can satisfy almost all the required steel specifications.
- Some Japanese car makers have developed their own in-house press parts to be produced using special steel sheet forming with as- supplied steel sheet ready to be press forming in the Thai factory.
- Currently there is very limited integrated steel manufacture in Thailand such that most advanced steel grades have to be imported.

Use of Aluminium Alloys

Audi 100 Al-body concept in 1985

Honda Acura NSX – 1st All Al-bodied production car



Year 1989:
Al monocoque body
with weight of 163 kg

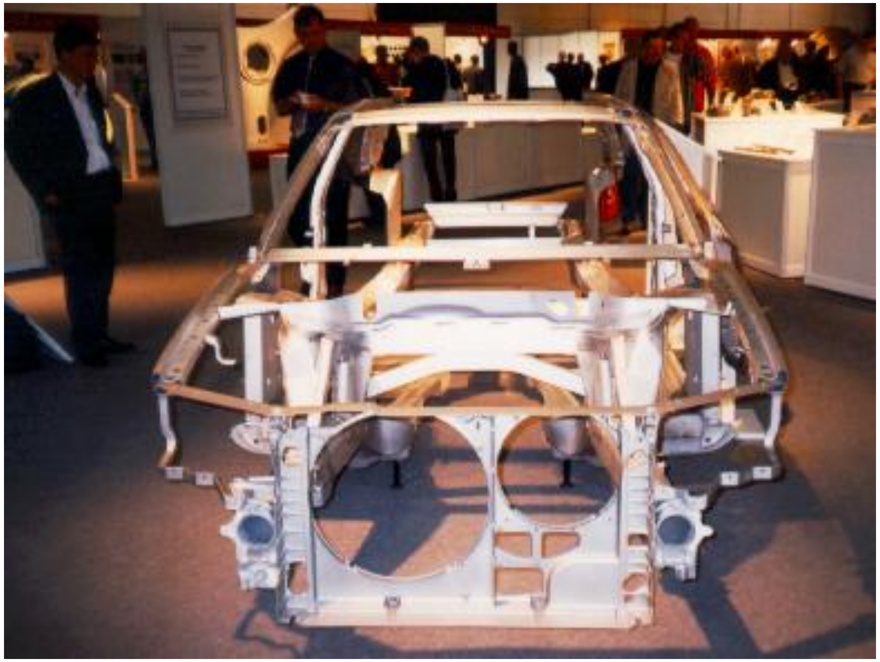
Al auto-bodies

- Progress in the use of aluminium alloys for auto-bodies was accelerated when the United States Automotive Materials Partnership LLC (USAMP) was set up in 1993.
- USAMP was part of the Partnership for a New Generation of Vehicles (PNGV) initiative between the US Dept. of Energy and Chrysler, Ford and General Motors.
- It was succeeded in 2003 by the FreedomCAR and Vehicle Technologies Program (FCVT)) under which the materials focus was on light-weighting through use of dissimilar materials and on the problems of non-destructive evaluation of both structures and joints.

In the US the limited production Plymouth Prowler was used as a "test" for Al-alloy intensive cars.

Retro hot-rod with Al space frame, Al brake discs, Al panels, Al v6 engine, Al transmission case.

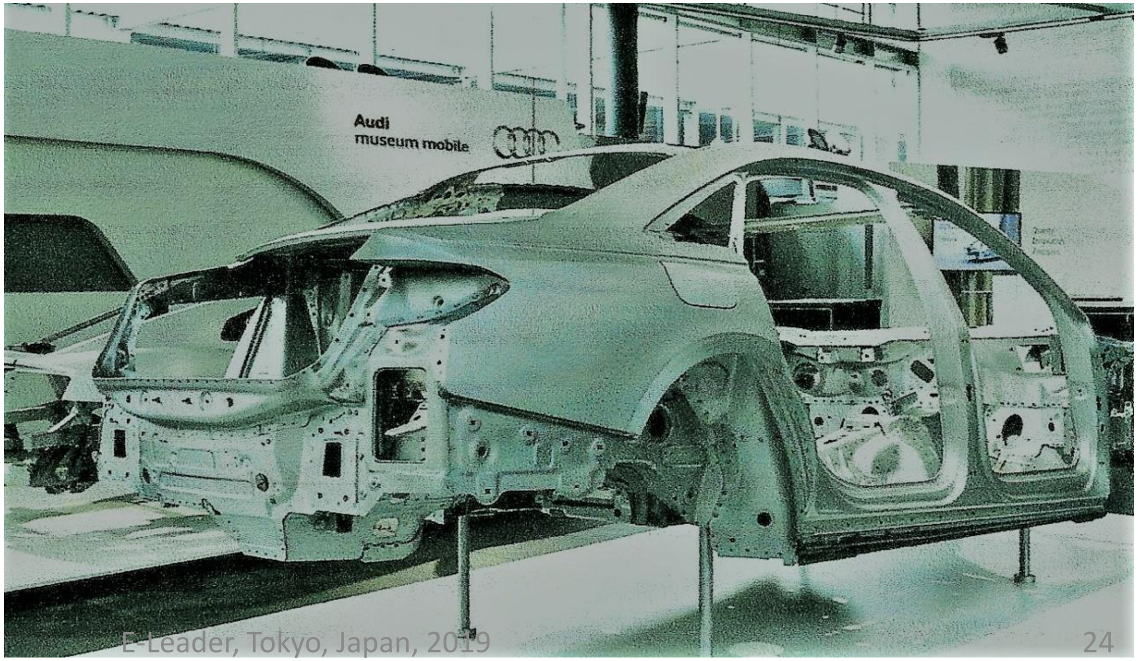
Other "Al cars" introduced were Honda Acura NSX, Audi A8, Lotus Elise



Audi Aluminium Spaceframe

GIFA exhibition 1999
Combined use of cast nodes and wrought sections

Modern ICE vehicle Audi A8 - all Aluminium body on spaceframe



HPDC Al Alloy door frames

Vacuum HPDC in AlMg5Si2Mn alloy The first die cast one piece inner door frame – eliminates complex welding [Diecasting World Spring 2007]

Fig. 1. Interior equipment of the new S-Class with modular doors (picture DaimlerChrysler)

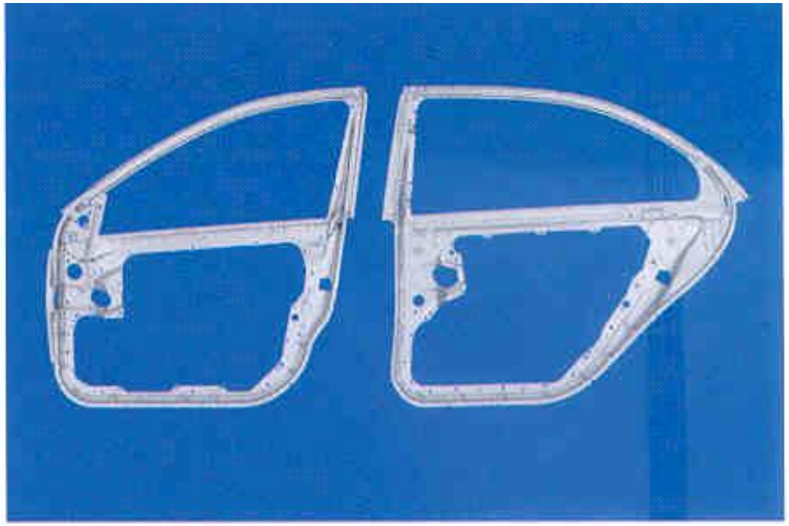
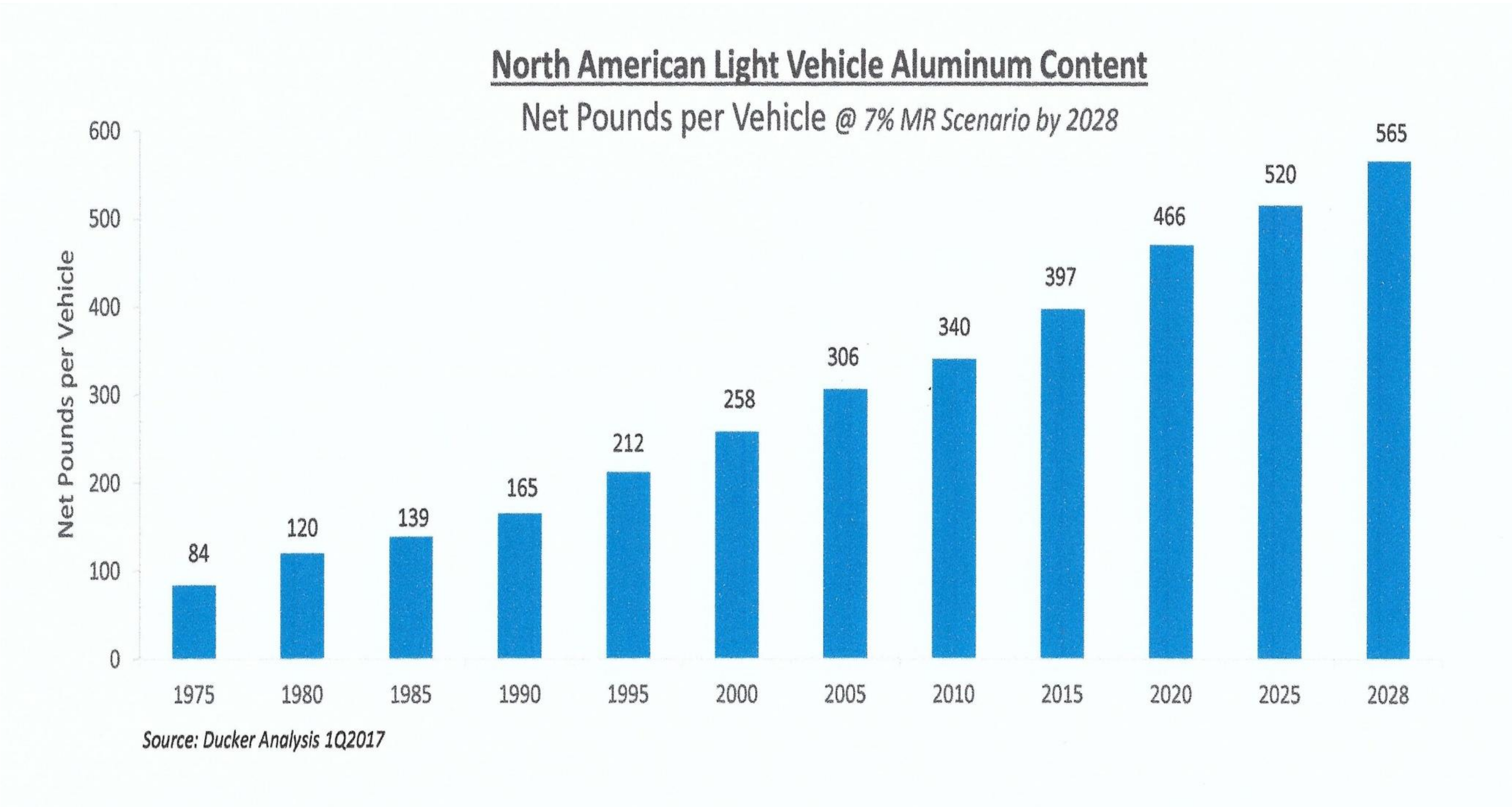


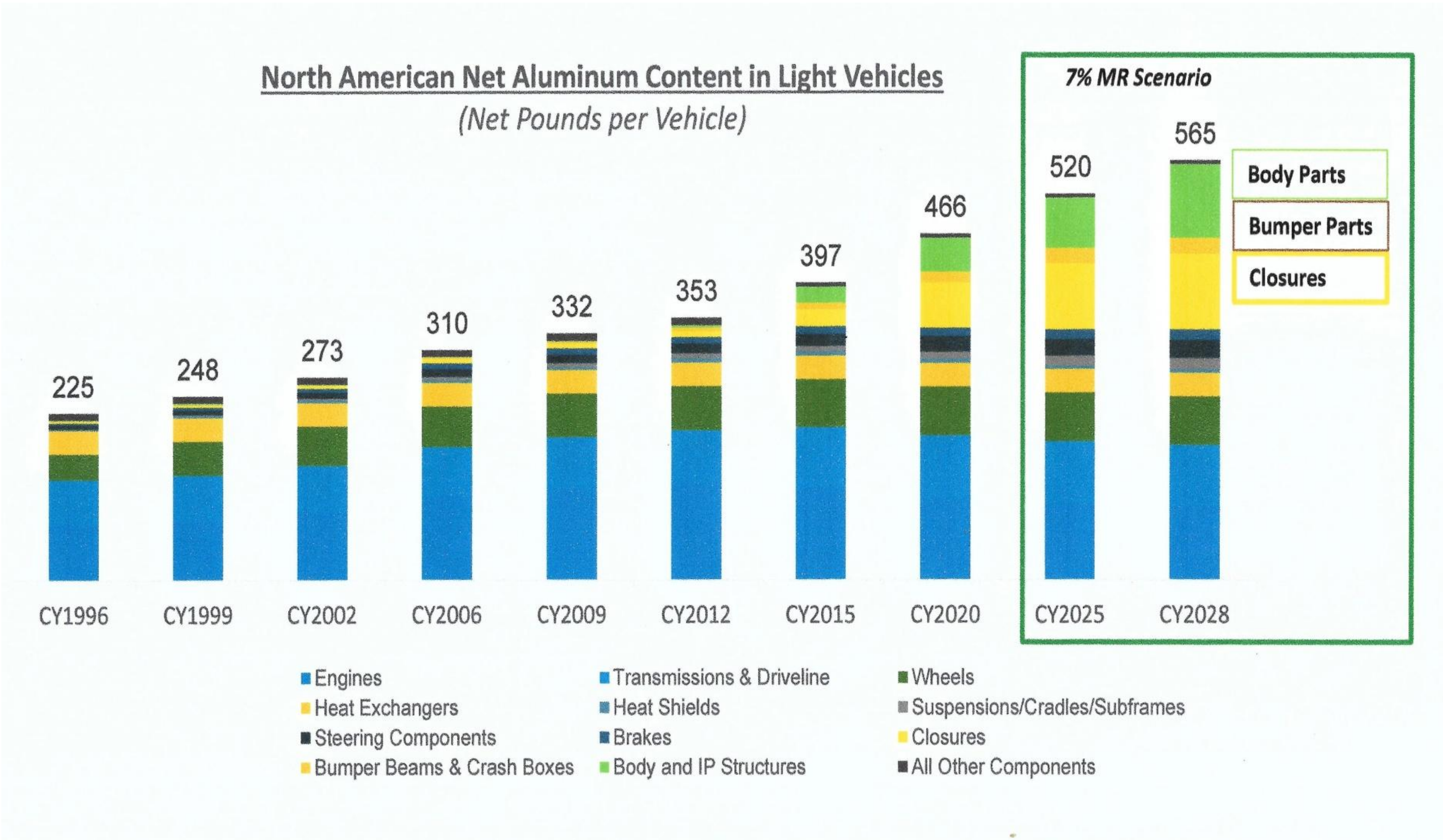
Fig. 2. Door inner-frame using aluminium pressure diecasting (picture GF Automotive)

USA Data & Prediction for Al content (for 7% mass reduction)



USA Use & Predictions for 7% mass reduction re applications.

(Drucker Analysis Report 10/2017)



PM Metal Matrix Composites

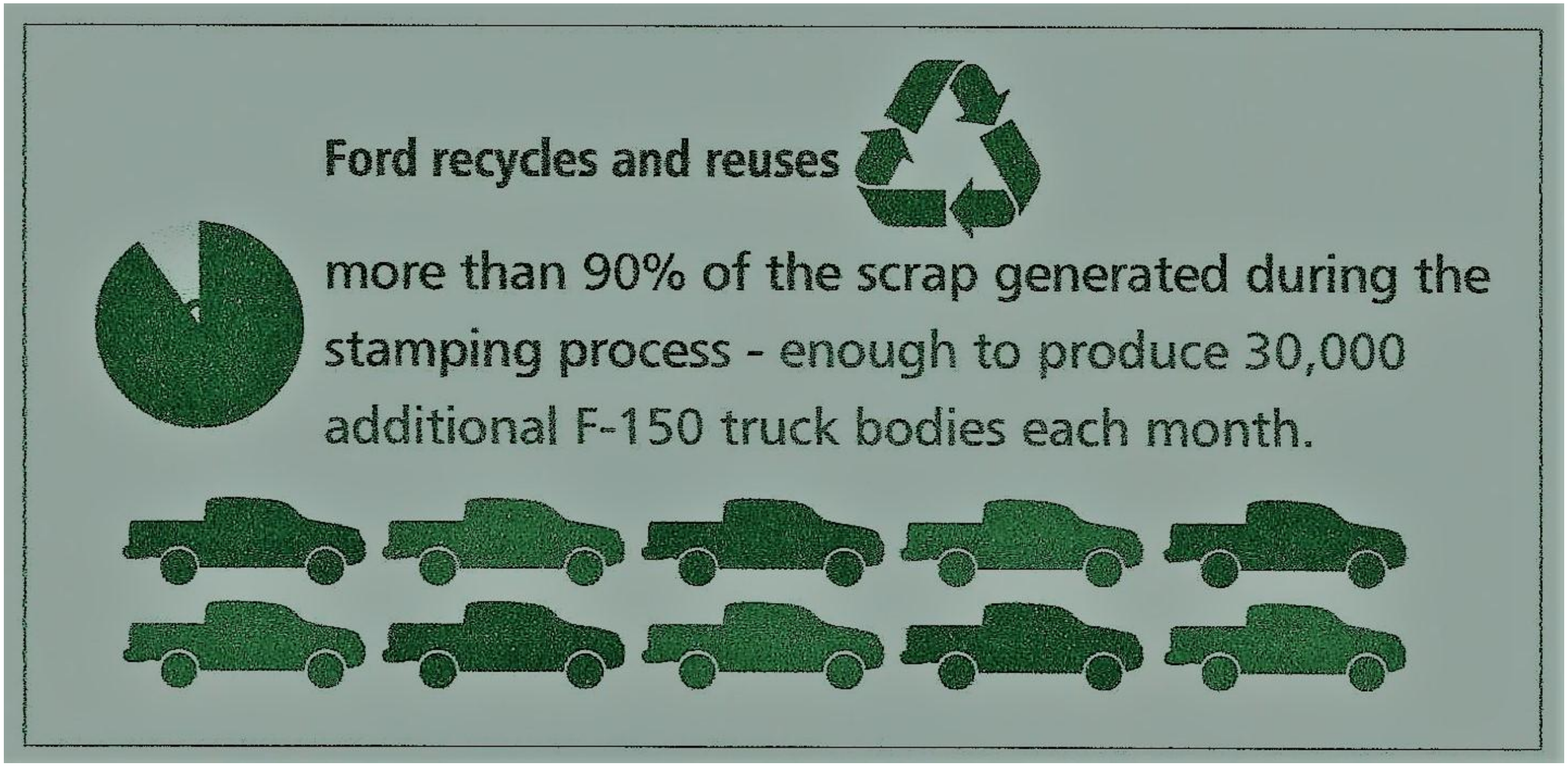
Lotus Elise 1995

All 4 wheels have particulate reinforced aluminium MMC brake discs replacing grey iron cast discs.

Change from Steel to Aluminium

- The change from steel to Al Alloys was highlighted by the use of Al for the body of the 2012 Series 4 Range Rover which is made up of, in mass %: 37% 5xxx Al alloy sheet, 37% 6xxx Al alloy sheet, 15%Al base cast parts, 6%Al extrusion and only 5% of steel.
- The increased use of Al gave a 39% saving in weight over the previous steel bodied model.
- **The Range Rover example shows that Al has greater potential for use in larger vehicles such as pick-up trucks and SUVs than in smaller cars, <u>except for electric vehicles.</u>**

Closed loop Al body system



Production scrap and clippings goes back to Al producer Novelis Inc. in closed loop to recycle to produce new sheet material

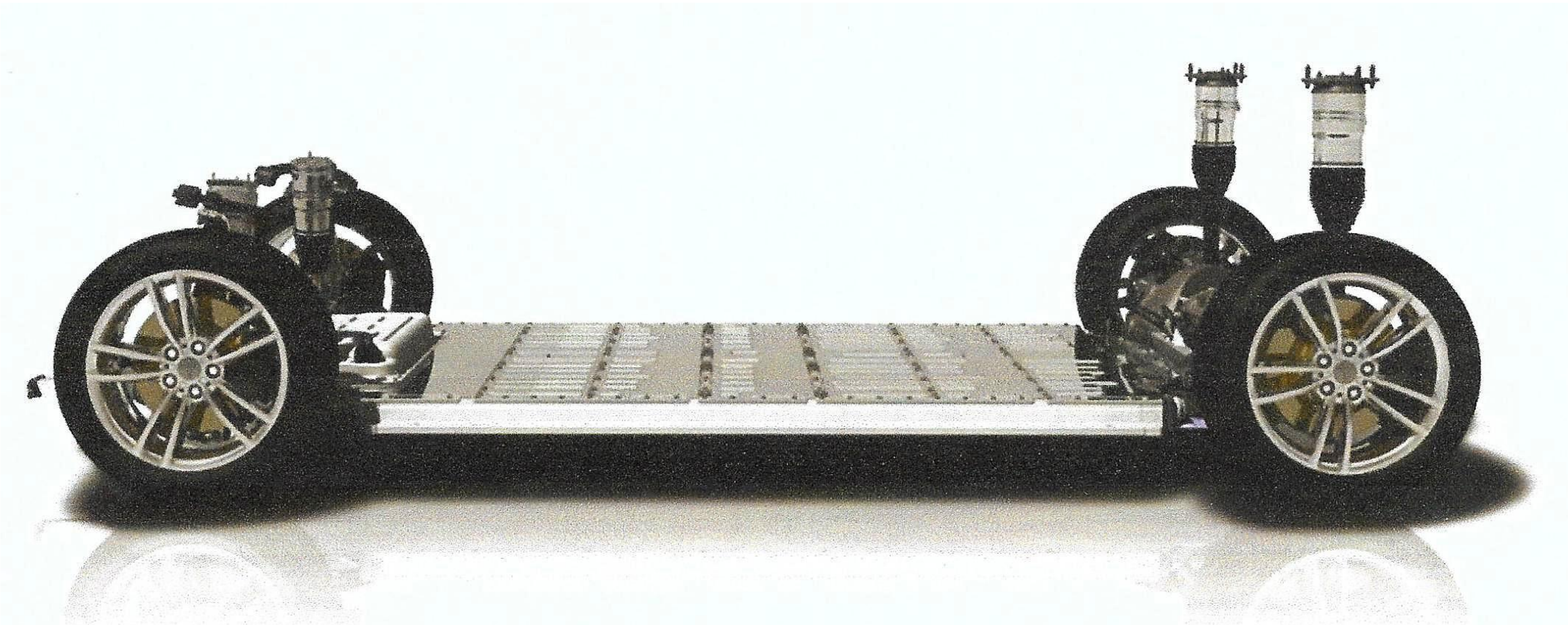
Closed loop Al production

- In the U.S. the Ford F-150 pick-up has an Al body, saving some 300kg in weight compared to steel.
- For both Ford and Jaguar Land Rover over 90% of the scrap generated during pressing of body parts is recycled through a closed loop system with the Al sheet producers.
- Al alloy has long been used for bodies in large commercial vehicles such as trucks and buses, e.g. from 1954 in the London Transport "Routemaster" double-deck bus.

Automotive Castings and Wrought Alloy Combination.

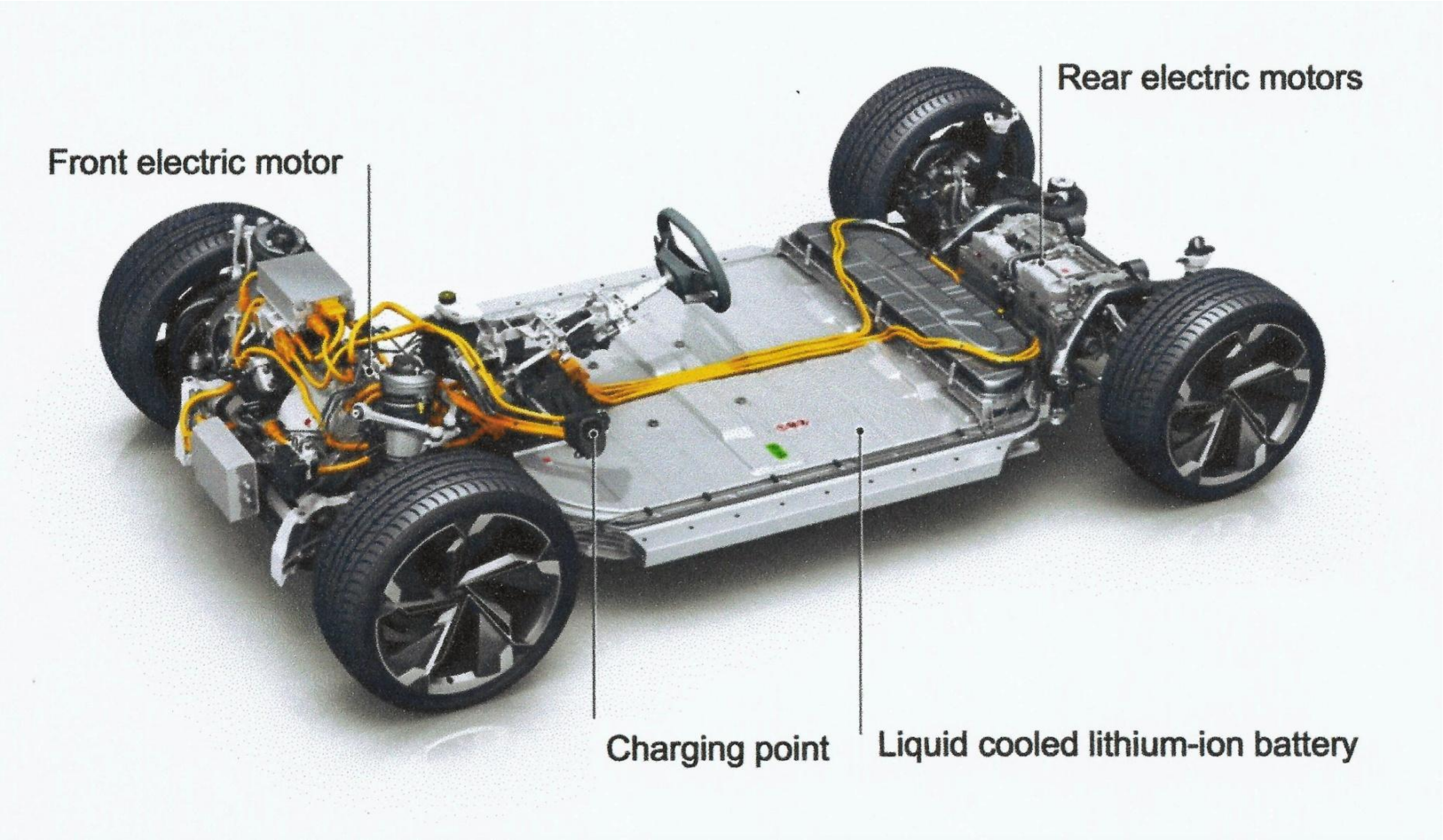
- To compete with steel-based body systems light alloy space from construction requires cast parts capable of
  - **high energy absorption**
  - **stronger and lower cost extruded hollow sections**
  - **reliable low-cost joining techniques**
  - **ease of damage repair in the body shop.**
- The castings are used as nodes to join extruded sections in the body frame.
- **Battery packs and supports will consist of cast Al + Al extruded sections.**

Tesla skateboard design

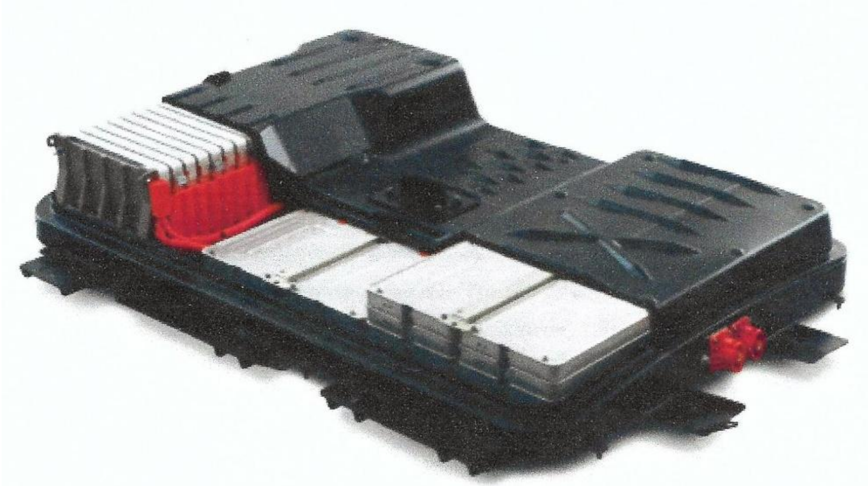


Extruded Al alloy used for frame of battery pack in "skateboard" design

Extruded Al alloy battery enclosure for Audi e-tron

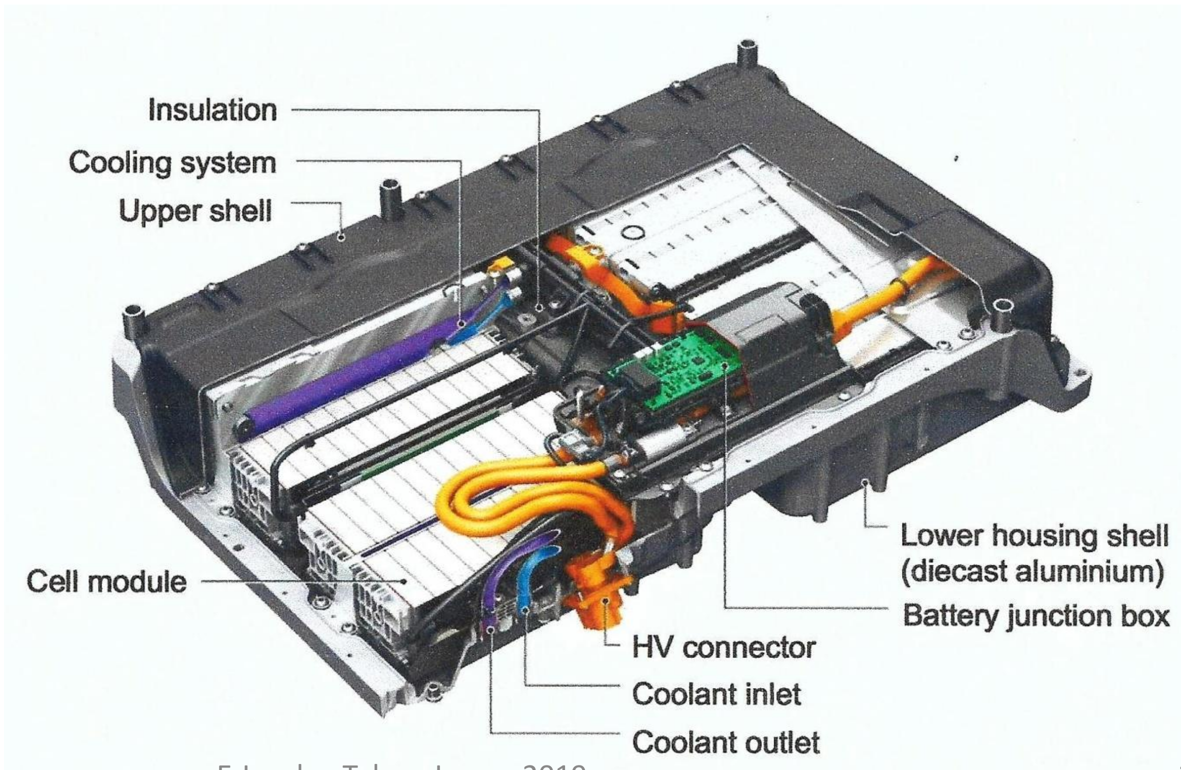


Battery enclosures



Steel pressing battery enclosure for Mark 1 Nissan Leaf

Al- alloy HPDC battery enclosure for Audi e-tron

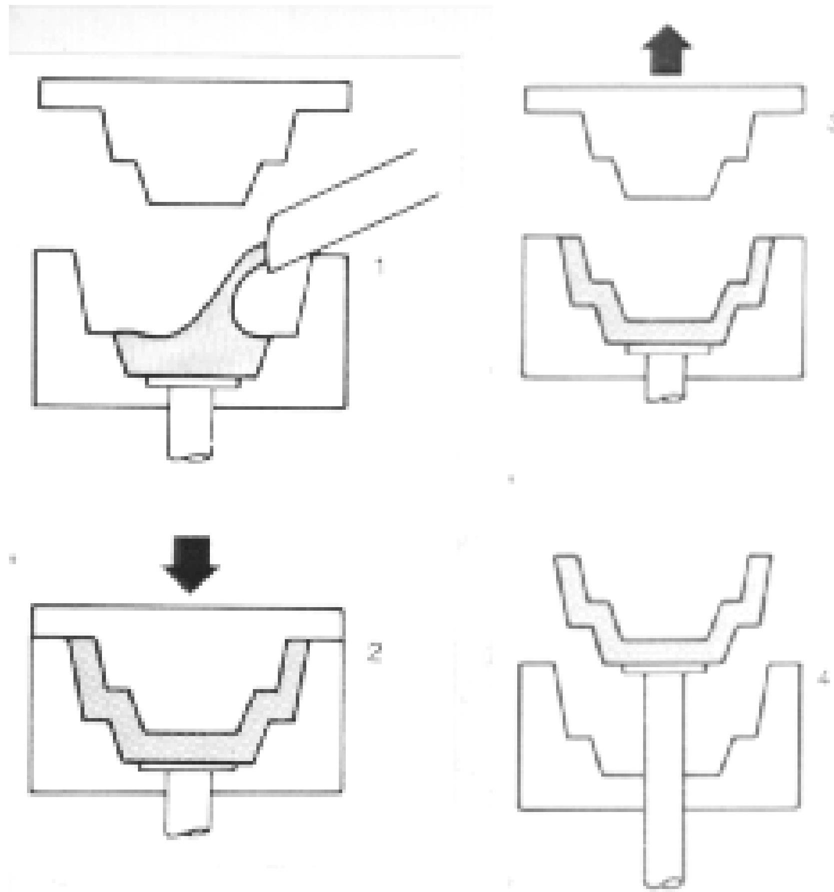


Changes needed in Al castings

- As more BEVs are produced then the automakers will not longer need IC parts such as engine blocks & heads, oil pans, bed plates, cylinder covers and manifolds, etc.
- Instead the castings industry must gradually change their production to supply battery pack housings, electric motor, inverter and power electronics housings and transmission parts.
- In Thailand there is considerable experience in the production of high pressure die-cast Al parts.
- To be capable of producing high strength and higher integrity castings with thin wall thicknesses for body and chassis parts this sector needs to further develop via use of vacuum die-casting technology, and by overall improvements in metal cleanliness, in die filling and in process control.
- The low-pressure die-casters also need to develop capability in the use of sand cores or tube inserts for cooling systems in battery pack support castings.

Squeeze Casting.

- Greatest potential to produce sound castings.
- High cooling rate due to closure of air gap between casting and die gives refined structures.
- No running system required.
- Research needed (as in HPDC) to understand “shear” defects caused by segregation of eutectic liquid and to develop thixo - squeeze casting of semi-solid.



Real Time Shot Control in Die-casting.

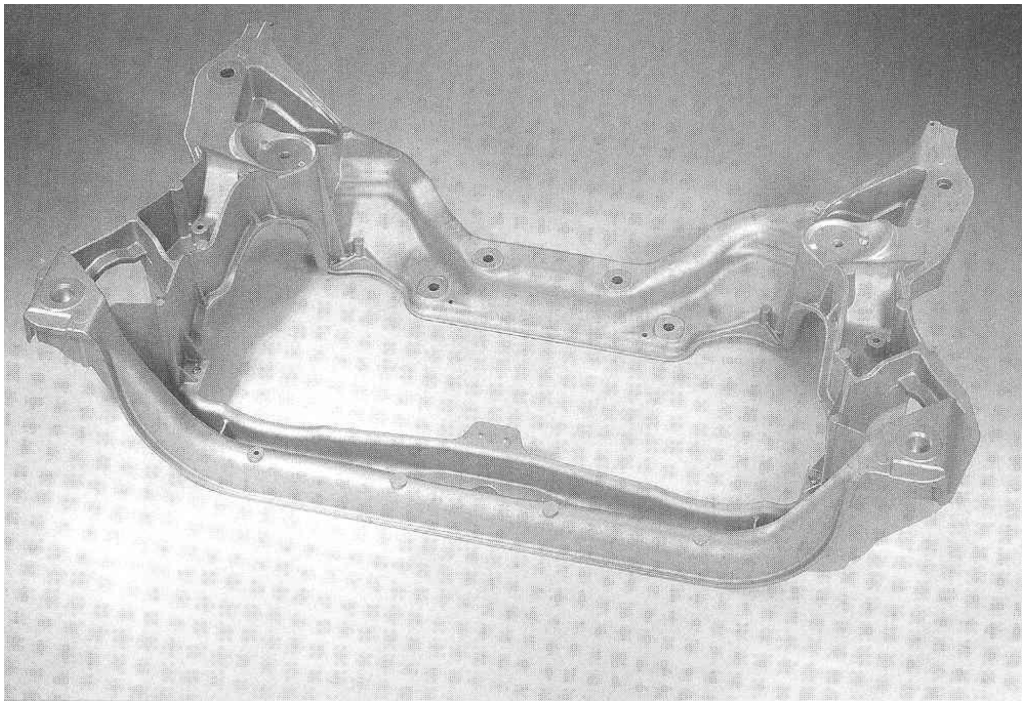
Controlled filling of the die:

- allows production of thinner sections
- enables component weight reduction
- minimises reject rates
- reduced die wear
- 30% energy savings from improved machine hydraulics

Vacuum pressure diecasting

- Allows fully heat treatable high pressure diecastings to be produced
- Very useful for large surface area thin walled components such as an engine cradle frame and is also used to produce nodes for Al based space frames for the car body.

Vacuum pressure diecasting: Engine Cradle



DaimlerChrysler S class

- Casting is 890 x 736 x 170 mm and weighs 10.2 Kg in Al-Si-Mg Alloy
- Used in T6 condition it replaces a multi-part welded sheet steel fabrication giving a 35% reduction in weight.

Use of Magnesium Alloys

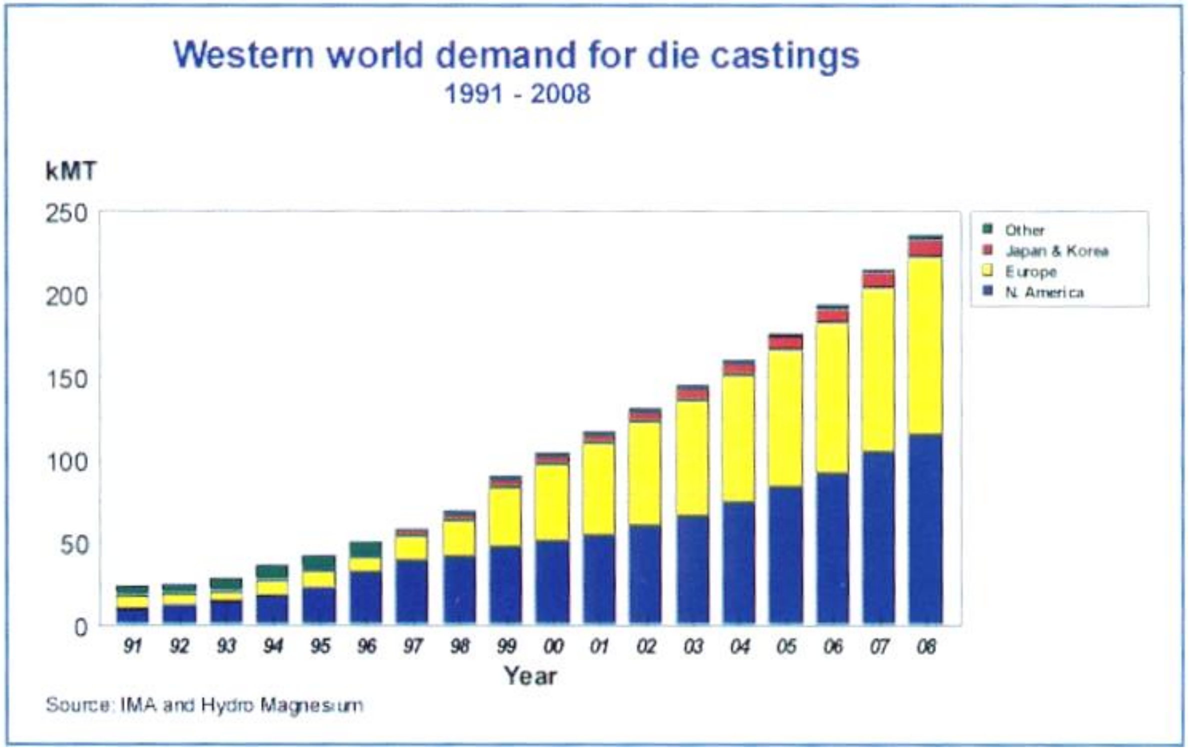
Why is Magnesium competitive?

- At just over half the density of Aluminium Mg is the lightest of all commonly used metals.

- **It offers the potential to reduce weight of vehicles.**

Growth in Magnesium Die castings.

Seat frame in AM60 for Alfa Romeo



Mg Alloy Castings in Bodies.

VW Lupo - the first production car to meet target of 100 km on 3 litres of fuel .

Inner rear door panel of cast AM50 alloy + outer panel of Al sheet gives a 45% wt saving over steel.

Magnesium HPDC boot lid at GIFA 1999

Shows capability of Mg alloy high pressure diecasting in weight reduction

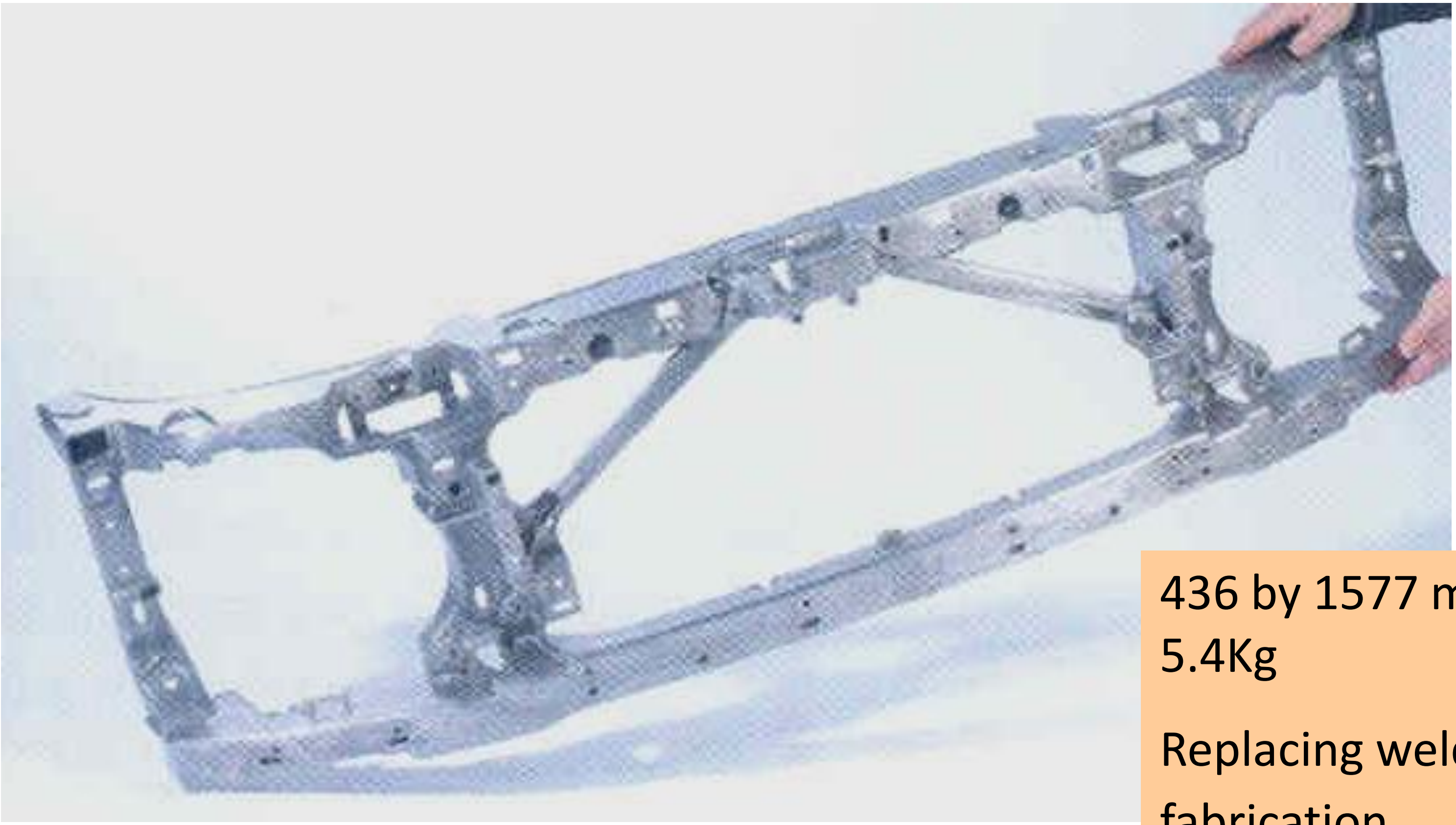
In Diecasting Mg Alloys give lower die wear than Al Alloys because:

- Heat content of Mg is less giving reduced thermal shock
- Mg dissolves iron much less than Al giving reduced "soldering" to the die.

Mg Alloy (AM60) Cross Beam

5kg in weight – carries all dashboard equipment of Land Rover Discovery – UK Casting of 2004 by Meridian Technologies

HPDC Mg Front End for Land Rover



436 by 1577 mm weighing 5.4Kg

Replacing welded steel fabrication

Cast in locators for headlights ,etc.

UK Casting of 2005 in AM60B by Meridian Technologies for Land Rover T5.

Concerns about corrosion

- The Mg alloys that were available up to around 30 years ago were “impure” and as a result had limited corrosion resistance especially in chloride containing environments - **they corroded about 10X faster than Al alloys.**
- The introduction of the “high purity” alloys that have much better corrosion resistance is one of the main reasons for the increasing use of Mg alloys

Preventing corrosion

- Corrosion resistance depends on high purity so contamination during melting and casting must be prevented especially when scrap/returns are recycled

- Correct design must be used when Mg castings are joined or in contact with other metals to avoid bimetallic (galvanic) corrosion since Mg will act as a sacrificial anode.

High Purity (HP) Mg-Al alloys.

- High purity alloys with very low levels of copper, iron and nickel have significantly better corrosion resistance than previous standard alloys.

Alloy	%Cu max	%Fe max	%Ni max	%Si max	Corrosion Rate (mm/yr)
AZ91D	0.05	0.05	0.01	0.1	8
AZ91HP	0.015	0.004	0.001	0.05	< 0.5

Corrosion rate from salt spray tests.

Mg base die-cast parts

- Can be used to replace welded steel fabrications (pressings + tubes) e.g. for cock-pit cross beams in the 2008 Range Rover and Jaguar models.
- The first Mg base chassis component was vacuum die cast in Mg-4Al-4Ce alloy which was used for the IC engine cradle in the 2006 Chevrolet Corvette.
- Mg alloy die-castings have also been used for some time as inner panels for doors and liftgates and for roof frames for convertibles.
- The use of die cast thin section structural parts is more promising than the use of wrought alloys
- Wrought alloys require further developments to achieve suitable formability and properties .

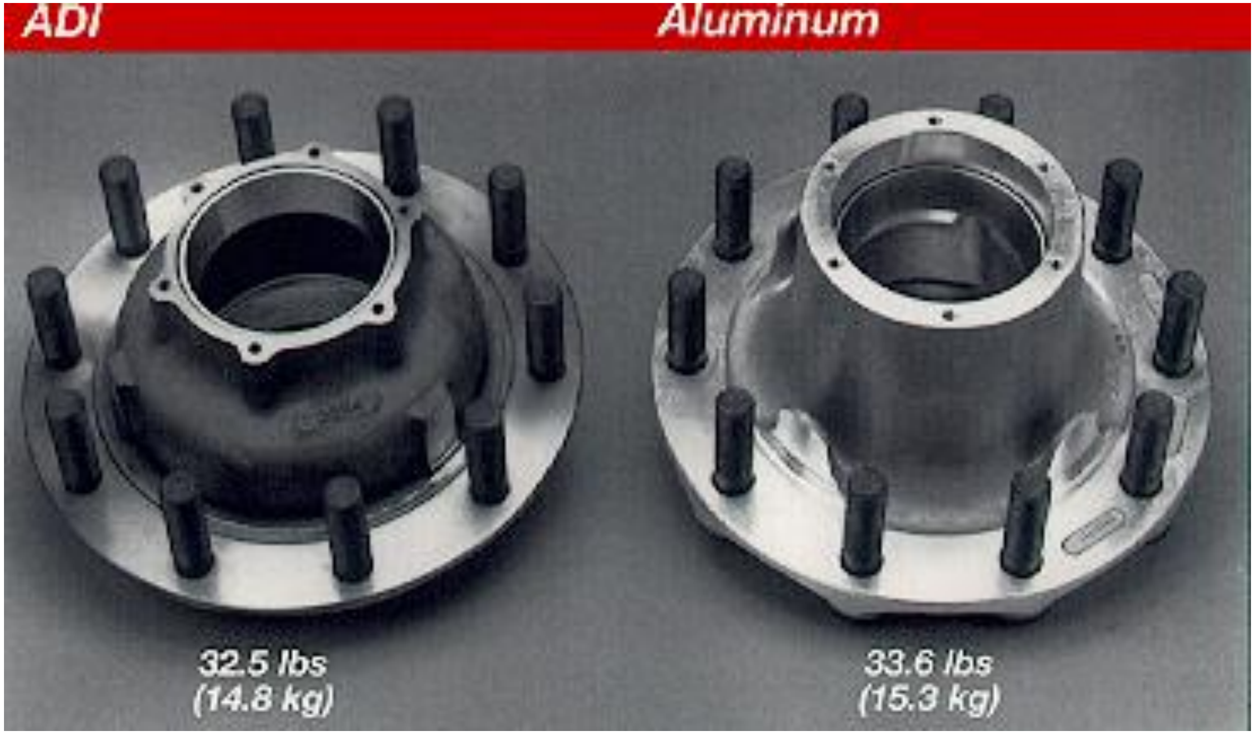
Mg base alloys

- Magnesium base alloys could also be considered as autobody sheet materials.
- Finite element-based study has shown that a Mg autobody structure giving equivalent stiffness to that in steel or Al could be respectively 60% and 20% lighter.

- A critical assessment has suggested that this use of Mg alloys is unlikely without research to improve
  - **mechanical properties**
  - **formability**
  - **joining methods**
  - **corrosion resistance**
  - **And to reduce cost.**

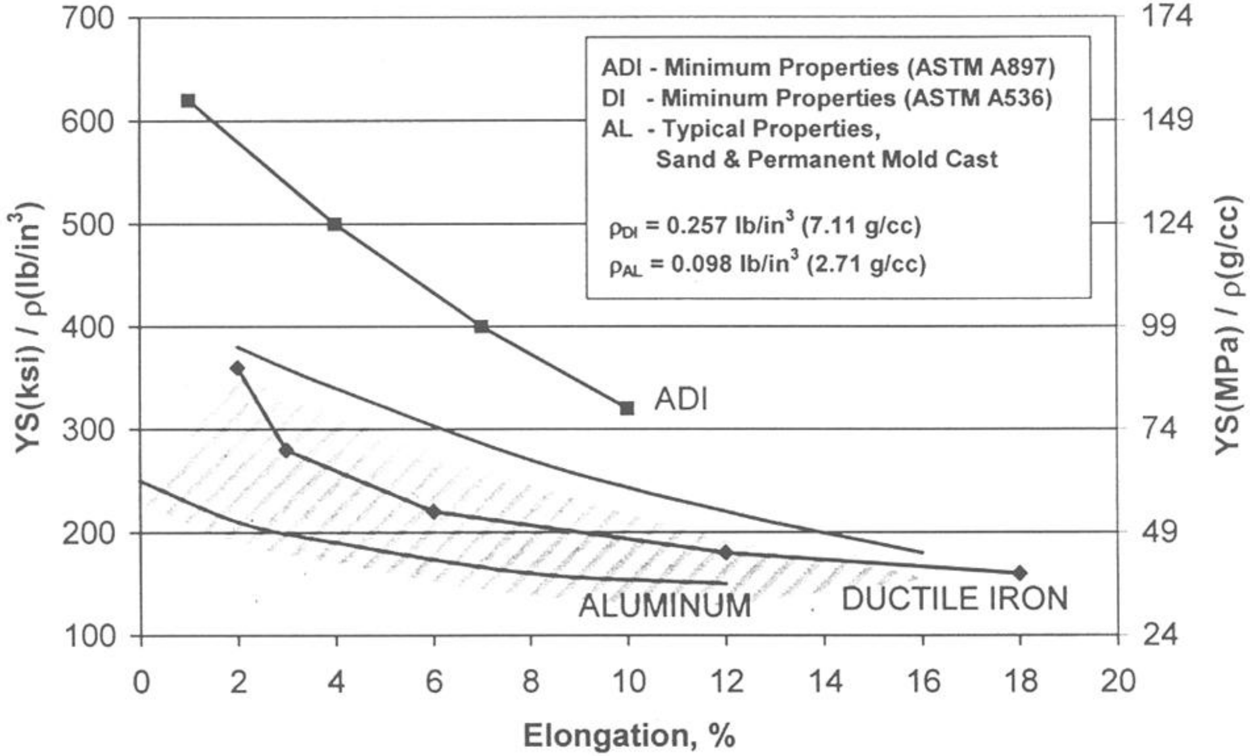
Some other materials

For some components - Cast Iron fights back: ADI is lighter than Al alloy for hubs!



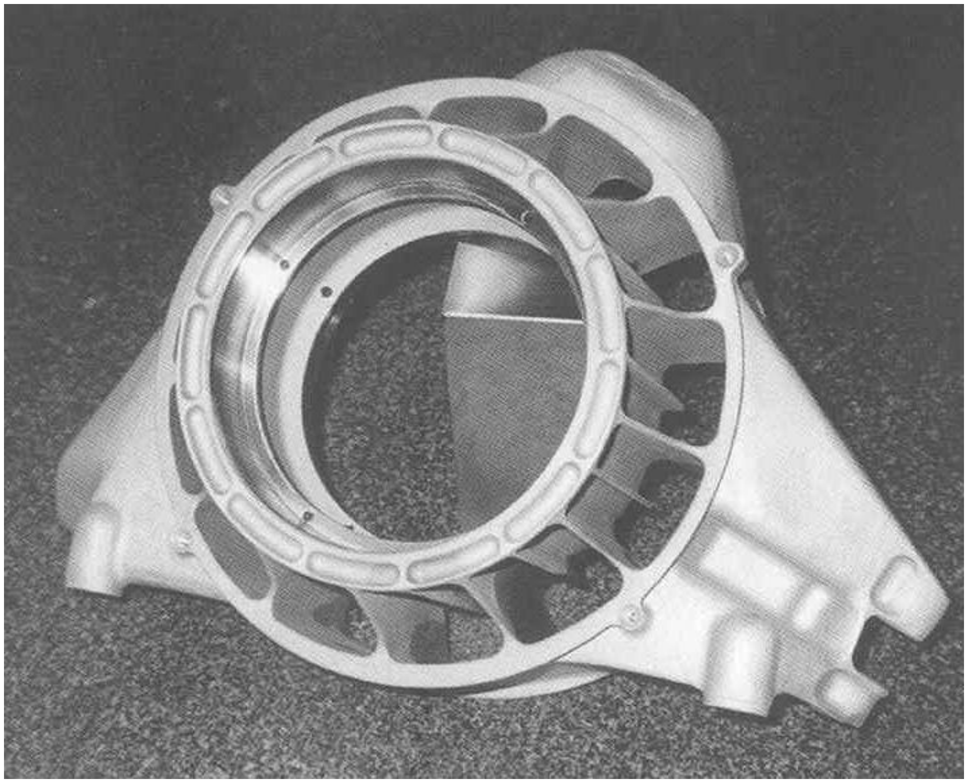
The relatively higher strength of ADI with respect to aluminium allows thinner cross section on this wheel hub, thus bringing the weight down. The ADI wheel hub not only weighs less than its cast Al alloy counterpart, but is also produced at 15% lower cost.

ADI versus Cast Al Alloys:

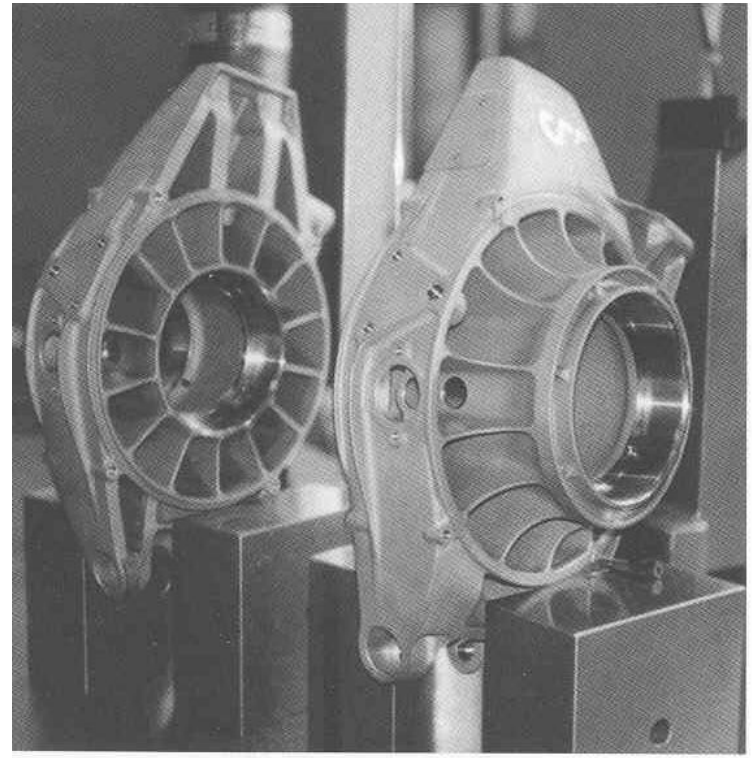


Relationship between Specific Yield Strength and Elongation for typical cast Al Alloys, ASTM A536 grades of Ductile Iron and ASTM A897 grades of ADI. [Loper]. ADI has potential for load bearing suspension parts etc.

Ti Castings may go faster…



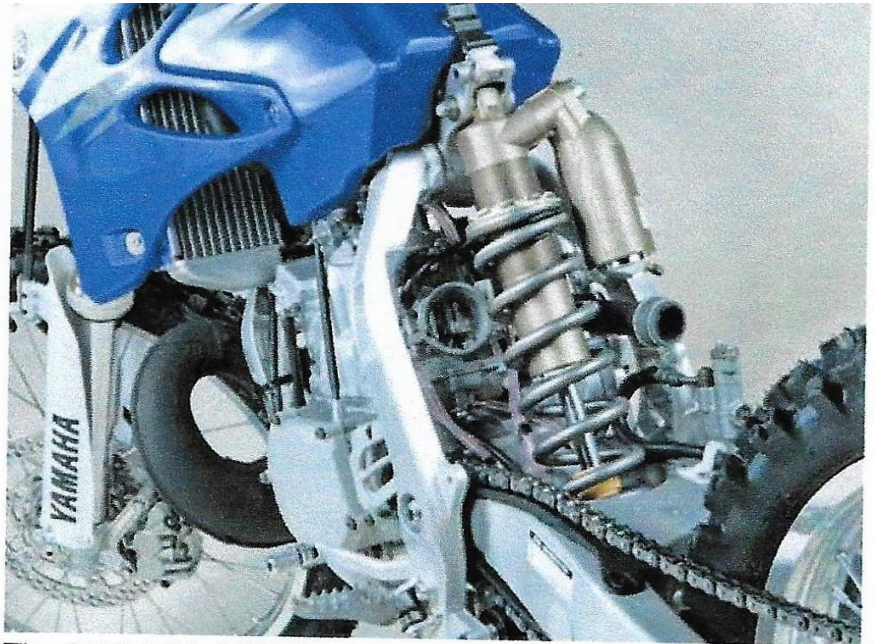
PS patterns from RP sinter-station allowing complex design features difficult to create with conventional tooling and avoiding need for welding [CRP Technology Italy]



Minardi Formula One Car.

The uprights hold and support the wheel hubs and brake parts. Ti Alloy is also for steering box, clutch box and suspension supports

Scope for Ti springs in suspension



The TIMETAL LCB™ monoshock coil spring on the 2006 Yamaha YZ250 MX bike is 30% lighter than an equivalent steel spring

Use ot Ti alloy in place of steel for springs saves space and weight.
Already used in performance motor-cycles.

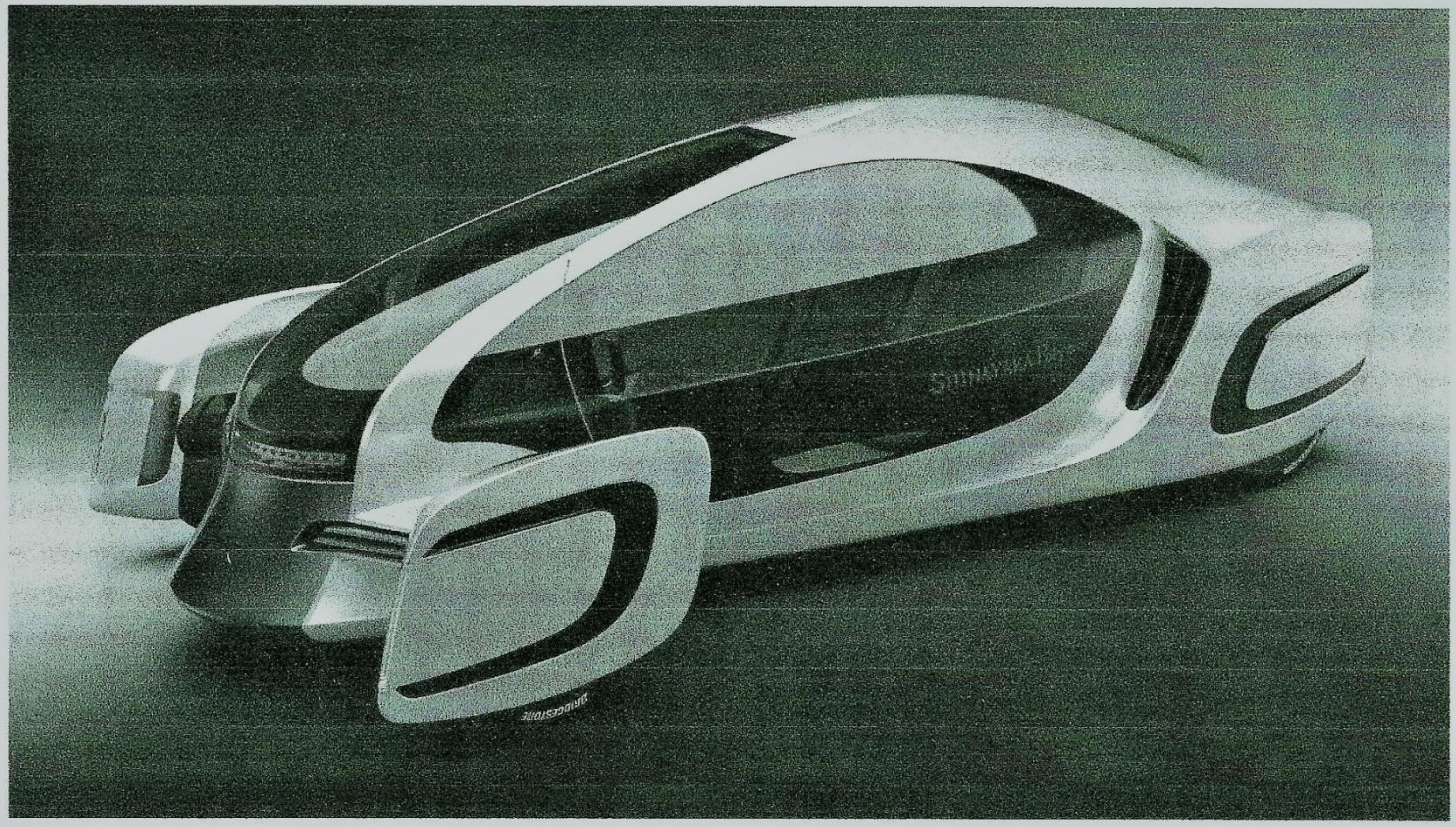
Comparison of specific strength of engineering alloys

Material	Density kg/l	Young's Modulus	Yield Strength	Specific Strength
CP Titanium	4.51	105 GPa	250 - 450 MPa	50 - 100
Ti-6Al-4V	4.43	112 GPa	900 – 1100 MPa	200 - 250
Ti - LCB®	4.79	110 GPa	950 – 1400 MPa	200 - 290
Carbon Steel	7.8	200 GPa	350 - 450 MPa	45 - 60
Aluminium Alloy	2.8	70 GPa	100 - 350 MPa	35 - 125

GFRP and CFRP reinforced polymers

- **Must be considered for use in EVs since they can be rapidly processed into complex shapes and by appropriate design can give equivalent impact resistance to steels.**
- They have been used mainly for specialist sports cars and cab, panels and roof parts for commercial vehicles.
- Mixed Al alloy/CFRP designs have been used for chassis construction
- **CFRP can offer attractive combinations of strength and weight but because it is difficult to use in mass production it has tended to be limited to very low-volume specialist sports cars. However, even for low volumes, for example at 30 cars/day, Ferrari have used Al rather than CFRP.**

Polymer body concept car



An artist's rendering of a prototype car made using high-performance polymer materials. (Courtesy of University of Tokyo professor Kozo Ito)

Using tough polymers and CFRP weight of a prototype car could be reduced to 832 kg compared to 1333 kg for steel body.

Multi-materials

- In achieving an optimized balance between weight saving, performance (safety, longevity, etc.) and cost multi-material bodies need to be built containing combinations from AHSS, cast, extruded or sheet form Al alloys, die-cast Mg alloys and fibre reinforced polymers.
- Hence hybrid-joining technology is equally as important as the base material.
- Materials and process selection has to consider spot and laser welding, riveting, clinching, high speed nailing, friction stir welding, adhesive bonding, etc. with regard to joint integrity and the ease of robot operation.

Some summary points:

Current mass market EVs use steel

- To date current mass-market EVs still make considerable use of steel rather than Al alloys
- E.G. the Tesla Model 3, Nissan Leaf and the VW e-Golf.
- The Tesla S and X models and larger BEV vehicles such as the current Jaguar I-pace are "Aluminium Intensive".
- For smaller ICE and hybrid vehicles it is expected that AHSS steel will continued to be used for body parts, but for BEV Aluminium becomes more competitive, not just **because of its lower density, but because of its heat transfer capabilities which are necessary to keep the battery pack cool of indeed keep it warm in very cold weather conditions.**

Improved Al extrusions needed

- In producing the body frames and battery enclosures extensive use is made of Al alloy extruded sections.
- To date most of the extrusions produced in Thailand are for architectural application, mainly in 6061 and 6063 (Al-Mg-Si) alloys.
- For automotive application extrusions will be needed in higher strength 7xxx series (Al-Zn-Mg-Cu) alloys
- Sheet Al material needs to be produced for structural purposes (e.g. alloy 5754) and for outer body panels (e.g. alloy 6451).

Al wrought development needed

Development work will be necessary to optimize

- **Homogenization and extrusion processes**
- **Subsequent strengthening heat treatments,**

and

- **When a sufficient supply of clippings, off-cuts and scrap is available to recycle this material for extrusion billet production, etc.**

Competition between body materials

- Over the past 20 years the Steel and Aluminium producers have continued to promote their various alloys for use in light-weighting of all types of vehicles.
- Likewise, the polymer sector remains focused on increasing the applications of glass and carbon fibre reinforced polymeric (GFRP and CFRP) materials, especially for doors and bonnet and boot covers.

Other changes

There are many other areas where material and process changes and development will be needed. For example:

- **Transmissions of EVs are less complex than ICE vehicles and will require less steel;**
- **Grey iron brake discs may be replaced by aluminium**
- **Scope for Ti alloys to be used for suspension springs and linkages and damage tolerant under-panels.**