Going Electric: Some Materials Aspects for the Thai Automotive Industry

Dr. Paritud Bhandhubanyong and John T. H. Pearce

Department of Automotive Manufacturing Engineering

Panyapiwat Institute of Management, Nonthaburi, Thailand

Abstract

Together with improvements in safety features, fuel economy and ensuring that emissions are less harmful to the environment, light-weighting of vehicles has been and continues to be a major driving force in the design and development of new models. The need for weight reduction has increased the use of new grades of higher strength low C steels (HSS)for body in white applications, encouraged the substitution of steels and cast-irons components by lighter alloys, notably aluminium and to a lesser extent magnesium alloys, and has also seen the introduction of improved polymer based composite materials for body parts especially in sports cars and some commercial vehicles. 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.

The paper outlines some materials aspects of light-weighting for electric vehicles and then considers the impacts that materials trends will eventually have on the automotive sector in Thailand, for example on automotive foundries producing FC and FCD cast iron components, on companies producing steel transmission parts, and not least, on the light alloy producers. In the latter case, both 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.

Introduction

The environmental, ethical and social aspects of changing from Internal Combustion (IC) engines to electric powered vehicles have been covered in a report from the International Centre for Climate Governance [1]. This included information on trends in electric vehicle numbers for the period 2010 to 2016, as shown in Figure 1, which plots data from various countries for both Battery Electric Vehicles (BEVs) and Plug-in Hybrid Electric Vehicles (PHEVs). By the end of 2016 the total number of EVs was just over 2 million, but this was still just 0.2% of the estimated one billion plus passenger carsthen on the road. Figure 1 shows that going electric has so far been driven by China and the United States (US) who together account for around 60% of EV numbers. However, several countries in Europe including Austria, France, Netherlands, Norway and the United Kingdom, have proposed legislation to ban the production of new IC powered vehicles within the next 10-20 years. In order to meet the proposed CO_2 emission targets in the European Union (EU) for the year 2050 a recent assessment [2] of the future market for Al Alloy extrusionshas predictedthat by then most vehicles must not use fossil-fuels, and that over 80% of EU vehicles will need to be electric powered. This would require that some 50% of new sales by 2030 must be EVs. Only Norway appears to be well down that road with 39% of new cars sold in 2017 being BEV models, while in the US, one of the volume drivers in Figure 1, BEVs made up only 1% of new sales in 2017 [3].

As in IC 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. Light-weighting in EVs can build upon the considerable experience gained in reducing the mass of Body-In-White (BIW) for conventional IC and the later hybrid vehicles [4]. In these vehicles it is mainly due reductions in body weight through the use of higher strength steels and light alloys that has enabled the fitting of considerable additional equipment for safety, comfort and emission control without the penalties of excessive weight increase or reduction in fuel efficiency [4].

In looking at the potential for all Al alloy usage in future EV light-weighting, especially as battery enclosures, it has been estimated that 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 where 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 [5].

The Use of High Strength Steels in Auto-bodies.

In 2008, towards overall vehicle weight reduction, members of the World Auto Steel Group set up the FutureSteelVehicle (FSV) programme [6] in order to develop BIW structural designs for selected BEV and PHEV models that made optimal use of advanced/ultra-high strength steel (AHSS/UHSS) grades. FSV followed on from the Ultra-Light Steel Auto Body (ULSAB) Consortium and from later light-weighting projects on closures and suspensions and from the overall ULSAB-AVC (Advanced Vehicle Programme). Under ULSAB, which started in 1994, 35 of the main steel producers from 18 countries joined together to develop a lightweight steel autobody that could meet strict performance and cost criteria. The project was used to demonstrate the capability of AHSS steels in achieving body weight savings through part thickness reduction without the need for downsizing, and also, in improving safety, comfort and overall performance [7]. Conventional Aluminium killed mild steels (AK steels) that were traditionally used for auto-bodies have yield strengths of 150-190 MPa. The ULSAB project defined 2 main groups of higher strength steels as (a) High Strength with Yield Strengths of 210 - 550 MPa, and (b) Ultra-High Strength with Yield Strengths greater than 550 MPa. Higher strength steels that contain significant alloy additions and contain 2 or more phases are often referred to as Advanced High-Strength steels (AHSS) in order to differentiate them from the conventional grades. The sheet thicknesses of the AHSS grades used ranged from 0.65 to 2.00 mm. Comprehensive guidelines to the processing, applications and performance of a wide variety of higher strength sheet steels are provided by the steel industry [8].

Back in 1994 higher strength steel grades only accounted for up to about 50% of the body weight of the latest cars but the ULSAB work showed that there was a potential for their 90% usage in auto-bodies [7]. Weight savings of up to 36% were said to be achievable when compared to the heaviest benchmark vehicle. In particular weight savings were achieved with improved structural integrity by the use of tailored blanks, which matched the strength and gauge of the steel to design requirements. Laser welded tailored blanks made up 50% of the structure, the rest being mainly conventional pressings with some sheet & tube hydroformed parts. The later FSV project showed similar results in that combined use of AHSS, UHSS and other steel grades coupled with production technologies such as multi-thickness blanks, hot stamping, roll forming and hydroforming could enable a 35% reduction (approximately 100kg,) in the base-line mass of a BIW design for the FSV-BEV. Figure 2 outlines the various types of steel used in the FSV-BIW design, only 2.6% of the body is made of mild steel [8-9].

The processing and formability of higher strength steels is different to that of the conventional mild steels used for auto body pressings [5]. 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. Some of the processing routes that can be used for advanced steel body parts are listed in Figure 3. 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. 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 no integrated steel manufacture in Thailand such that most advanced steel grades have to be imported.

The Use and Potential of Light Alloy 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 Department 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 [10]. During the same period the Aluminium Industry, seeing future market opportunities, increased their efforts for the development of Aluminium Intensive Vehicles (AIVs) and in particular the use of Al alloys in hybrid and electric vehicles [3,11,12]. Since then 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.

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 [12]. TheRange Rover example shows that Al has greater potential for use in larger vehicles such as pick-up trucks and SUVs [13] than in smaller cars, except for electric vehicles. 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 [14]. 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.

Lighter than Al, Magnesium base alloys could also be considered as autobody sheet materials. However, in a critical assessment, it has been suggested that the use of Mg alloys is unlikely without research to improve mechanical properties, formability, joining methods and corrosion resistance and to reduce cost [15]. 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 [16]. 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. [17]. Mg alloy die-castings have also been used for some time as inner panels for doors and liftgates and for roof frames for convertibles [18]. The use of die cast thin section structural parts is more promising than the use of wrought alloys, the latter being said to require further developments to achieve suitable and properties [19]. 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 [20].

GFRP and CFRP reinforced polymers must also 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 specialized sports cars and cab, panels and roof parts for commercial vehicles. Mixed Al alloy/CFRP designs have been used for chassis construction [12]. 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 specialized sports cars. However, even for low volumes, for example at 30 cars/day, Ferrari have used Al rather than CFRP [21].

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 [22,23].

To date current mass-market EVs still make considerable use of steel rather than Al alloys, examples include 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 IC 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 or on the other hand keep it warm in very cold weather conditions.

Producing Vehicles Using Light Alloys: 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 and, for when in service, ease of damage repair in the body shop. The castings are used as nodes to join extruded sections in the body frame.

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 [24]. Traditionally cast components have ranged from Cast Iron and Aluminium engine blocks and heads to water and fuel pump bodies, transmission housings, sumps, brake drums, discs, and Al wheels, etc. 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 [25]. 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. Figure 5 shows the Al spaceframe construction for an IC car. The need for even greater weight savings has also spurred developments in Magnesium based casting alloys including improvement in both corrosion resistance and mechanical properties in elevated temperature so that they could compete with Aluminium for use as engine blocks in IC engines.

The forecast for the future use of cast Al alloy power-train parts [26] is shown in Figure 4. 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. However, 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. An example of battery pack support is shown in Figure 6.

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 and in addition sheet Al materialneeds to be produced for structural purposes (e.g. alloy 5754) and for outer body panels (e.g. alloy 6451). Development work will be necessary to optimize homogenization and extrusion processes and 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.

There are many other areas where material and process changes and development will be needed. For example: transmissions of EVs are less complex than IC vehicles and will require less steel; grey iron brake discs may be replaced by aluminium; there is scope for Ti alloys to be used for suspension springs and linkages and damage tolerant under-panels.

References

1. Schneider M. “The road ahead for electric vehicles”. ICCG Reflection No 54, August, 13pp, (2017).
2. Scamans G. “Electric Vehicles Spike Demand for High Strength Aluminium Extrusions”. Light Metal Age, October pp.6-13 (2018).
3. Djukanovic G. “The Great Comeback of EVs”. Aluminium Insider, 17th August, (2018) https://aluminiuminsider,com.
4. Bhandubanyong P. & Pearce J.T.H. “Materials on Wheels: Moving to Lighter Auto-bodies”. ISJET, Vol.2, No.1, pp.27-36, (2018).
5. Maikaew P. “FOMM Asia first to win BoI perks to make battery EVs” Bangkok Post (Business Section) 10th October (2018).

6. “FutureSteelVehicle – Nature's Way to Mobility: Overview Report”, April, 79pp., (2011). www.worlsautosteel.org/projects/future-steel-vehicle
7. "Ultralight Steel Auto Body – Final Report". American Iron & Steel Institute (AISI), Washington D.C., U.S.A., 50pp., March (1998).
8. Keeler S., Kimchi M.,& Mooney P.J. "Advanced High-Strength Steels Application Guidelines Version 6.0, 314pp, April (2017).
9. Broek C.T. "FutureSteelVehicle: leading edge innovation for steel body structures", Ironmaking & Steelmaking Vol.39(7), pp.477-482, (2012).
10. United States Automotive Materials Partnership LLC (USAMP) & Dept. of Energy (DOE) Final Report Compilation OR22910, USAMP, Southfield, U.S.A. 281 pp., April (2011)
11. Stanford K, “Lightweighting boosts vehicle safety”. Aluminium International Today Vol.30 Nov/Dec., pp.10-12, (2017).
12. "The Aluminium Automotive Manual", Version 2013, European Aluminium Association, 84 pp., (2013).
13. Henriksson F.,Johansen K. "On Material Substitution in Automotive BIWs – From Steel to Aluminium Body Sides", Procedia CIRP, vol.50, pp.683-688, (2016).
14. J. Sanderson. “Progress through partnership: Creating sustainable value through customer collaboration”. Aluminium International Today: Sustainability Supplement, pp.38-39, January/February (2018).
15. Kim N.J. "Critical Assessment 6: Magnesium sheet alloys: viable alternatives to steels?", Mat. Sc. & Technology, vol.30, no.15, pp.1925-1928, (2014).
16. Coomber A., Loh C. "Magnesium for motoring", Materials World, Vol.16, pp.38-39, November (2008).
17. Taub A.I.,Luo A.A. "Advanced Lightweight Materials and Manufacturing Processes for Automotive Applications" MRS Bulletin, Vol.40, pp.1045-1053, (2015).
18. Luo A.A. "Magnesium casting technology for structural applications", J. Magnesium & Alloys, Vol.1, pp.2-22, (2013).
19. You S.,Huang Y., Kainer K. &, Hort N. "Recent research & development on wrought magnesium alloys", J. Magnesium & Alloys, Vol.5, pp.239-253, (2017).
20. Kiani M., Gandikota J.,Rais-Rohani M. & Motoyama K. "Design of lightweight magnesium car body structure under crash and vibration constraints", J. Magnesium & Alloys, Vol.2, pp.99-108, (2014).
21. Carney D. "Ferrari prefers aluminium over carbon fiber", SAE Automotive Engineering, 10thNovember (2011), http://articles.sae.org/10391/
22. Chastel Y. & Passemard L. "Joining technologies for future automobile multi-materials modules", Procedia Engineering, vol.81, pp.2104-2110, 2014.
23. Meschut G., Janzen V. & Olferman T. "Innovative and Highly Productive Joining Technologies for Multi-Material Lightweight Car Body Structures", JMEPEG, vol.23, pp.1515-1523, 2014.
24. J. Mitchell. “Thailand - a new player on the world scene”. Foundry International, Vol.20, No.4, December, pp15-25, (1997).
25. Pearce J.T.H. and Bhandubanyong P. “From Ban Chiang to the 21st Century”. Proceedings of the 65th World Foundry Congress, 20-24 October, Gyeongju, Korea, pp.1105 – 1114, (2002).

26. Gaertner J. “Electric Vehicles and the Prospects for Aluminium Castings”. Foundry Management & Technology June (2018).

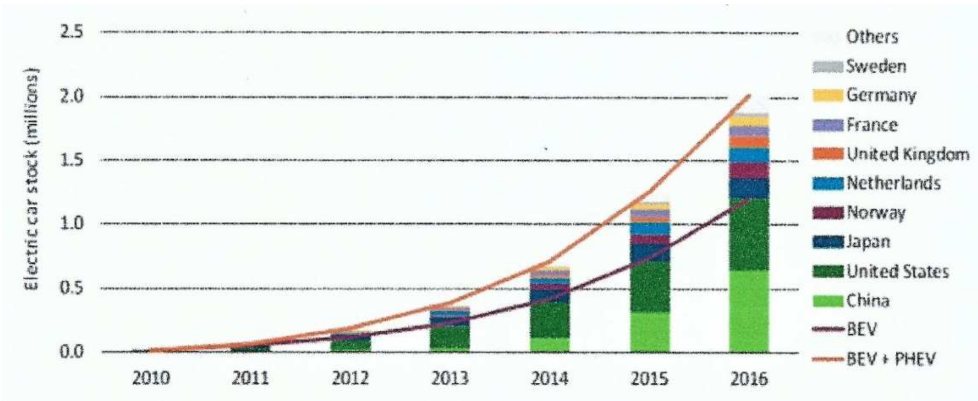

Figure 1

Trends in the global number of electric vehicles during 2010 to 2016. Data from IEA 2017.

After Schneider [1].

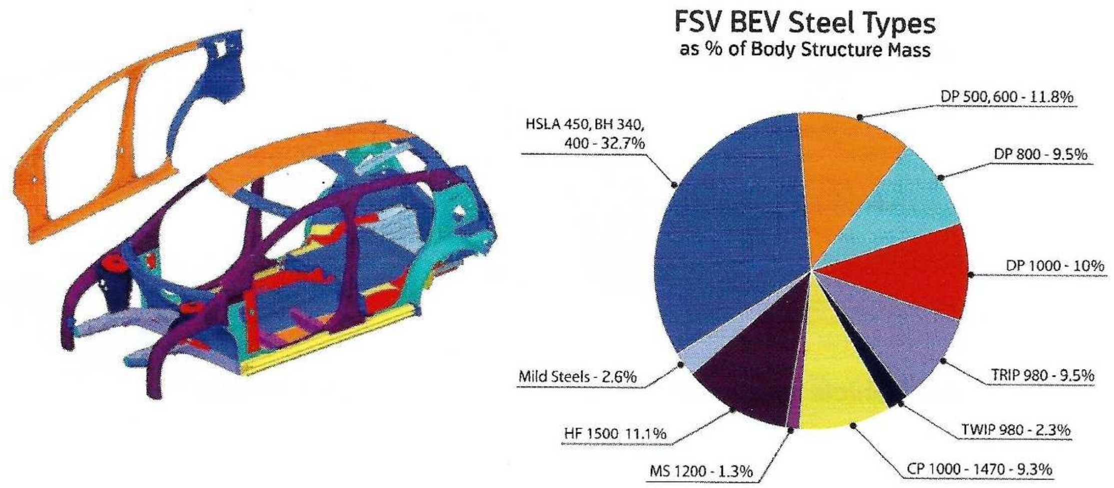

Figure 2

The "FutureSteelVehicle BEV". Steel grades and their distribution for body-in -white (BIW).

After Broek [9].

Key to Grades: HSLA – High Strength Low Alloy, BH – Bake Hardening, HF – Hot Formed,

MS – Martensitic Steel, DP – Duplex Phase, CP – Complex Phase, TRIP – Transformation Induced Plasticity Steel, TWIP – Twinning Induced Plasticity Steel.

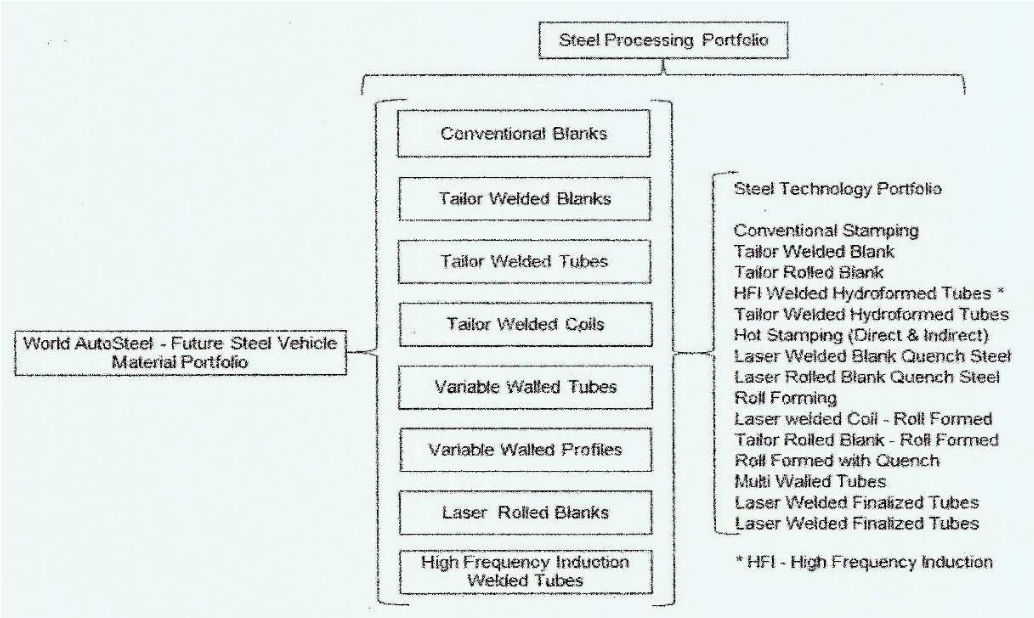

Figure 3 Manufacturing Processes for Steel FSV-BEV body parts [6, 7].

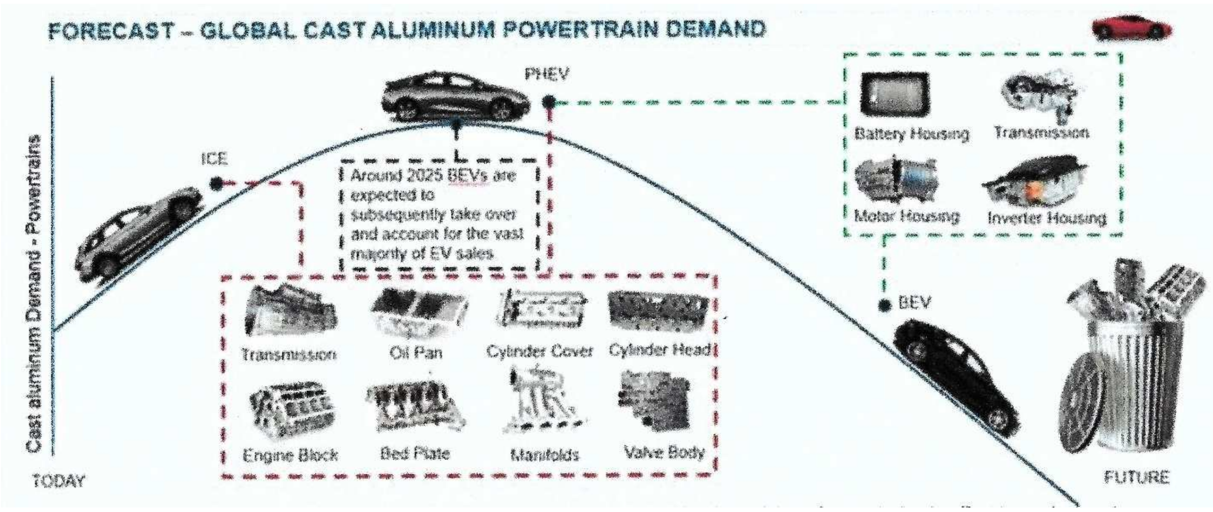

Figure 4

Light metals industry forecast from AluMag Automotive (Germany) for consumption of light alloys showing the effects of moving to electric vehicles. After Gaertner [26].

.

Figure 5

Al alloy spaceframe for IC vehicle constructed from cast and wrought components.

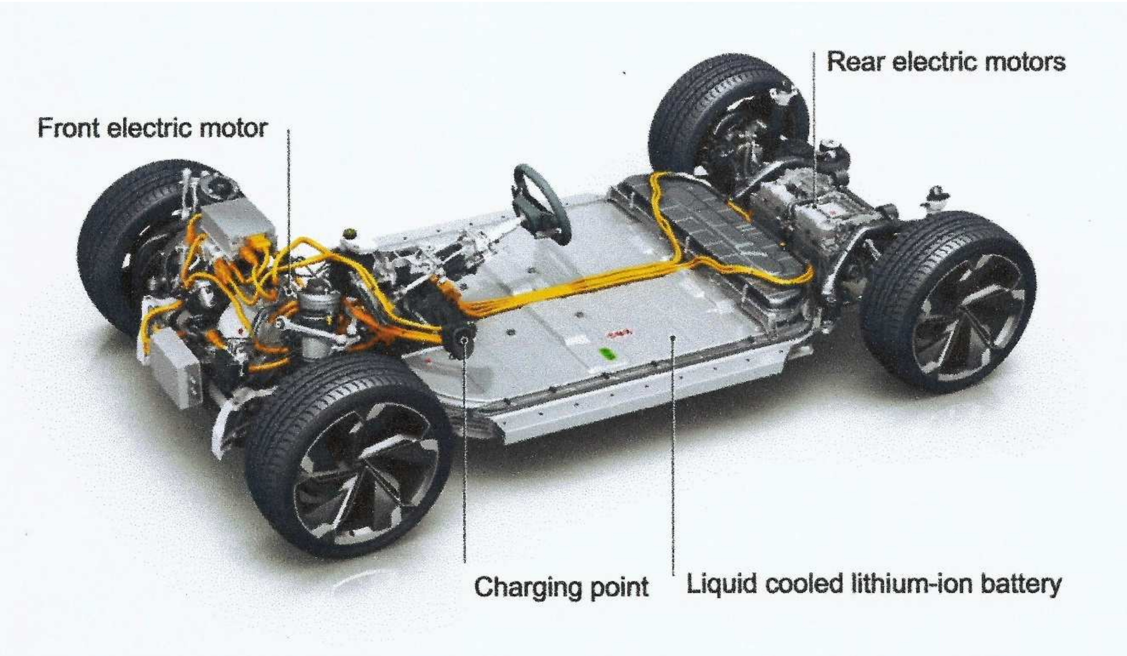

Figure 6

Audi e-tron with skateboard design showing battery pack enclosure constructed from extruded Aluminium parts [2].