Aluminum
Battery Enclosure Design

Andreas Afseth

Technical Director, Automotive Body Sheet, North America
CONSTELLIUM

Constellium

Agenda

1. Constellium
2. Aluminum usage in Battery Electric Vehicles and Battery Enclosures
3. Drivers for material choice in Battery Electric Vehicles
4. Specific requirements for Battery Enclosures
5. Summary and conclusions

Constellium At A Glance

Key Figures

100+
years of experience

~13k
employees

+28
production facilities

3
R&D Centers

€5.9 Bn
2019 revenue

Products And Solutions

- ROLLED PRODUCTS
- EXTRUDED PRODUCTS
- AUTOMOTIVE COMPONENTS
- RECYCLING

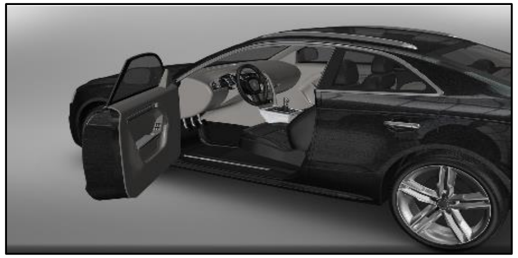
Where We Operate

> An extensive footprint for design, development and production in Europe, North America and China

Constellium activity in global Automotive

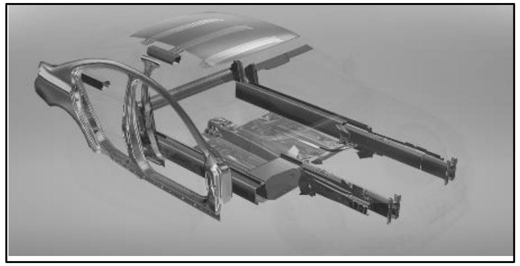
Car Body Closures

Decorative Parts



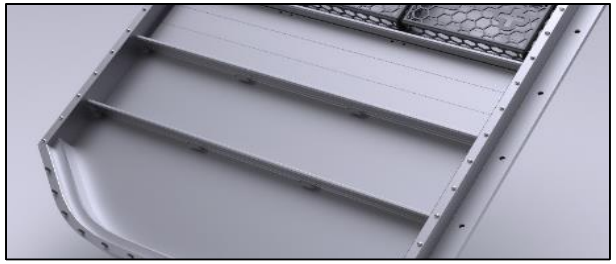
Heat Exchangers

Body Structures



Crash Management Systems

Battery Enclosures & Cooling Plates



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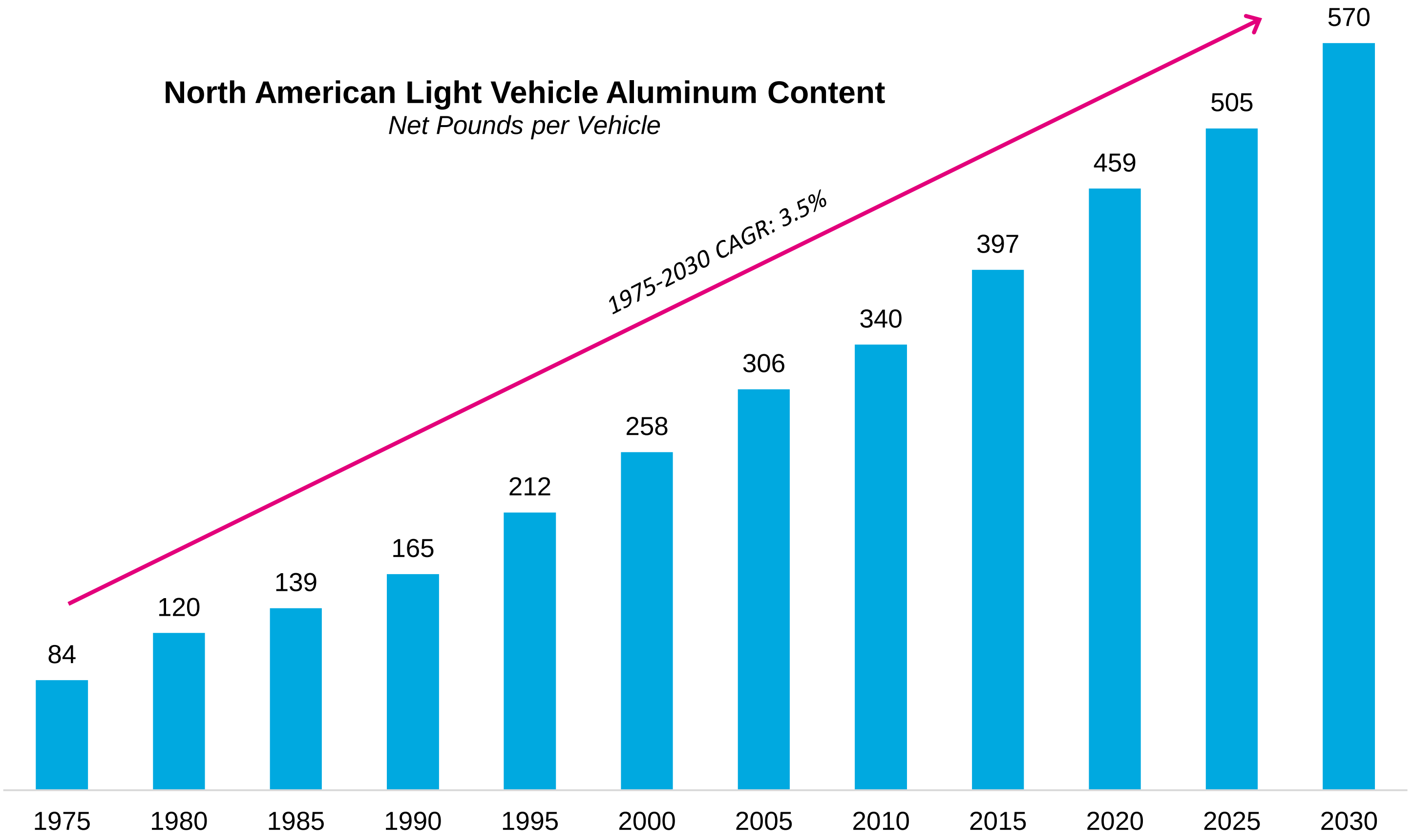
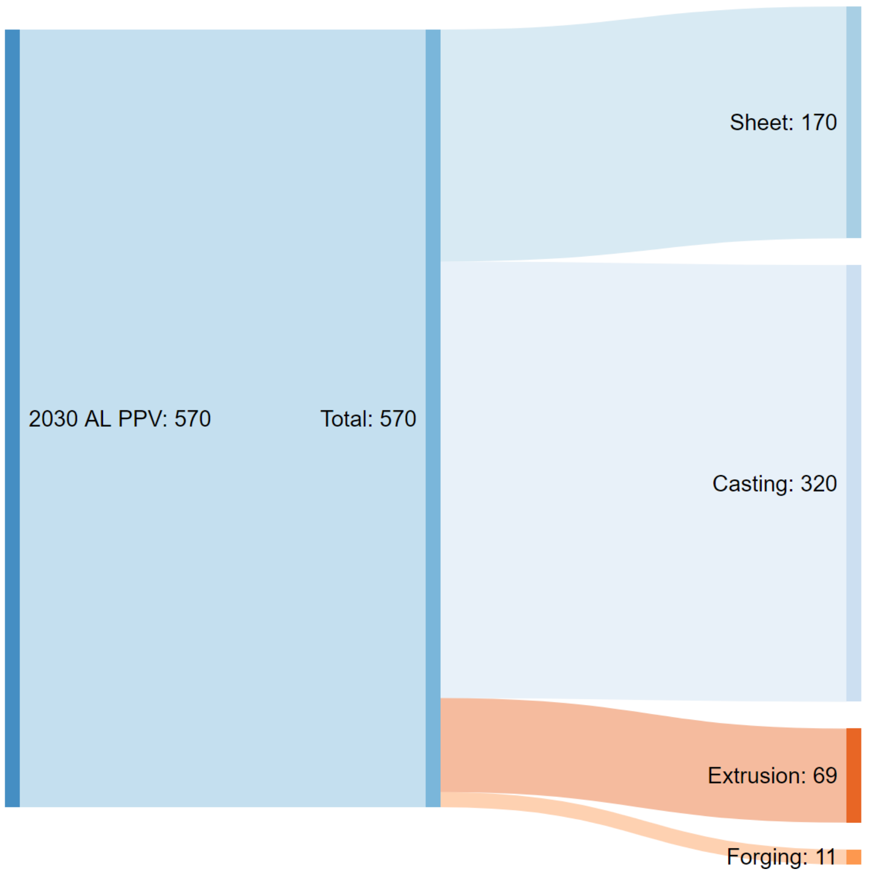
Aluminum content in North American Light Vehicles

Aluminum continues to be the fastest growing material in automotive applications. Growth from 2020 onwards is driven by substitution of steel in platform parts as well as through significantly higher aluminum content of battery electric vehicles,



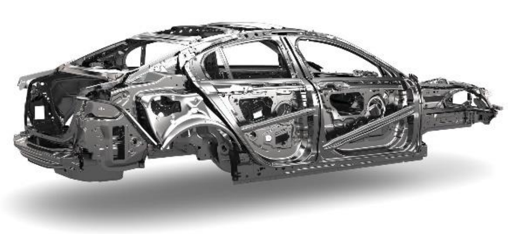


Source: DuckerFrontier

Automotive Aluminum Applications by Parts

Platform parts (structural)

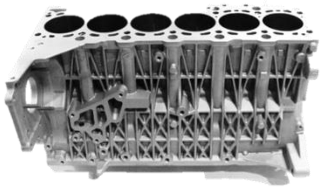
Body-in-white
Body closures
Chassis
Suspension and frame parts
BEV: Battery Enclosure



Only in Electric vehicles

Component parts (non-structural)

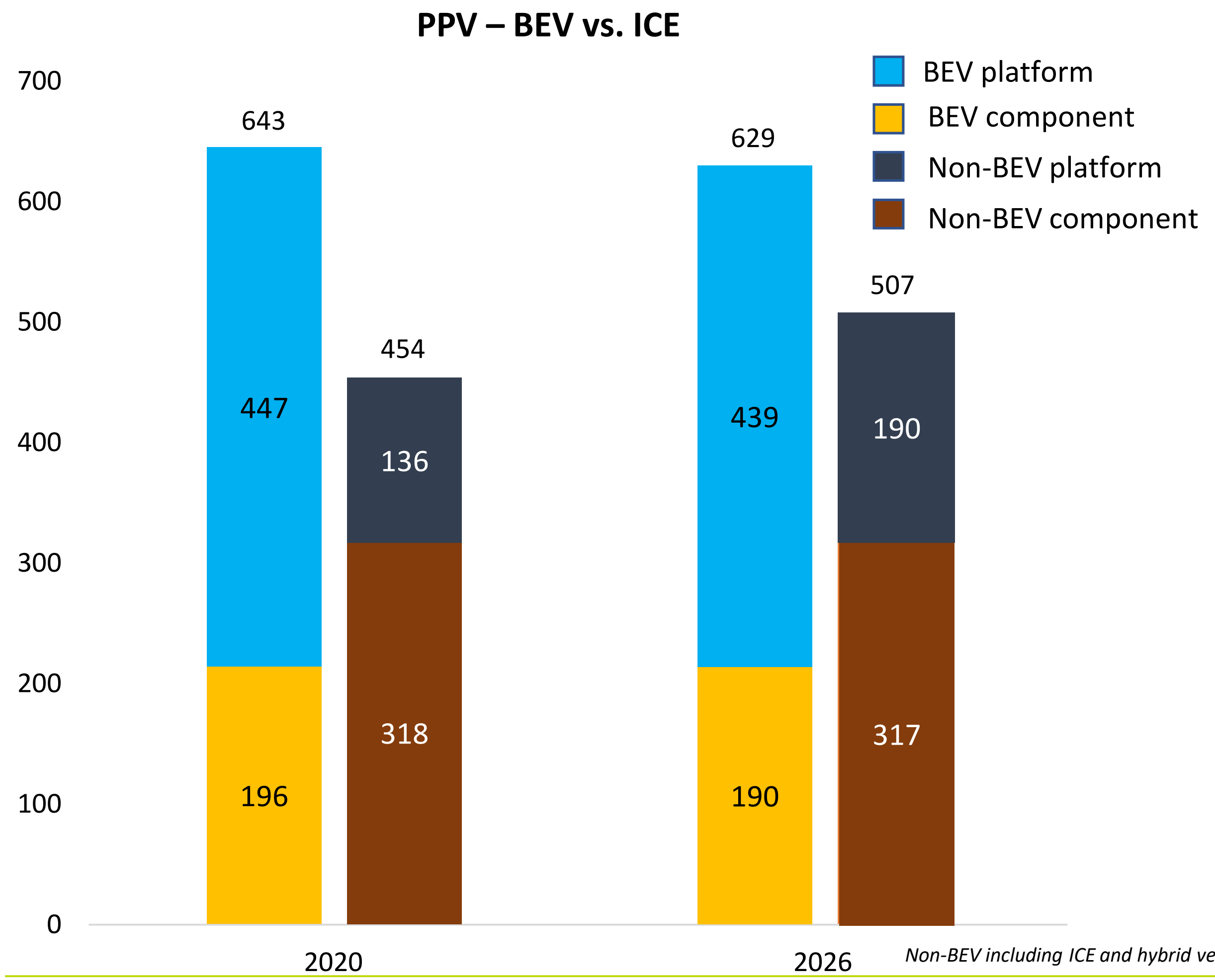
Powertrain
Driveline
Transmission,
Trim
Brake
Steering
Wheels
Heat exchangers
BEV: Electric Motor housing
BEV: Converter housing
BEV: Gearbox housing
BEV: Battery Cables



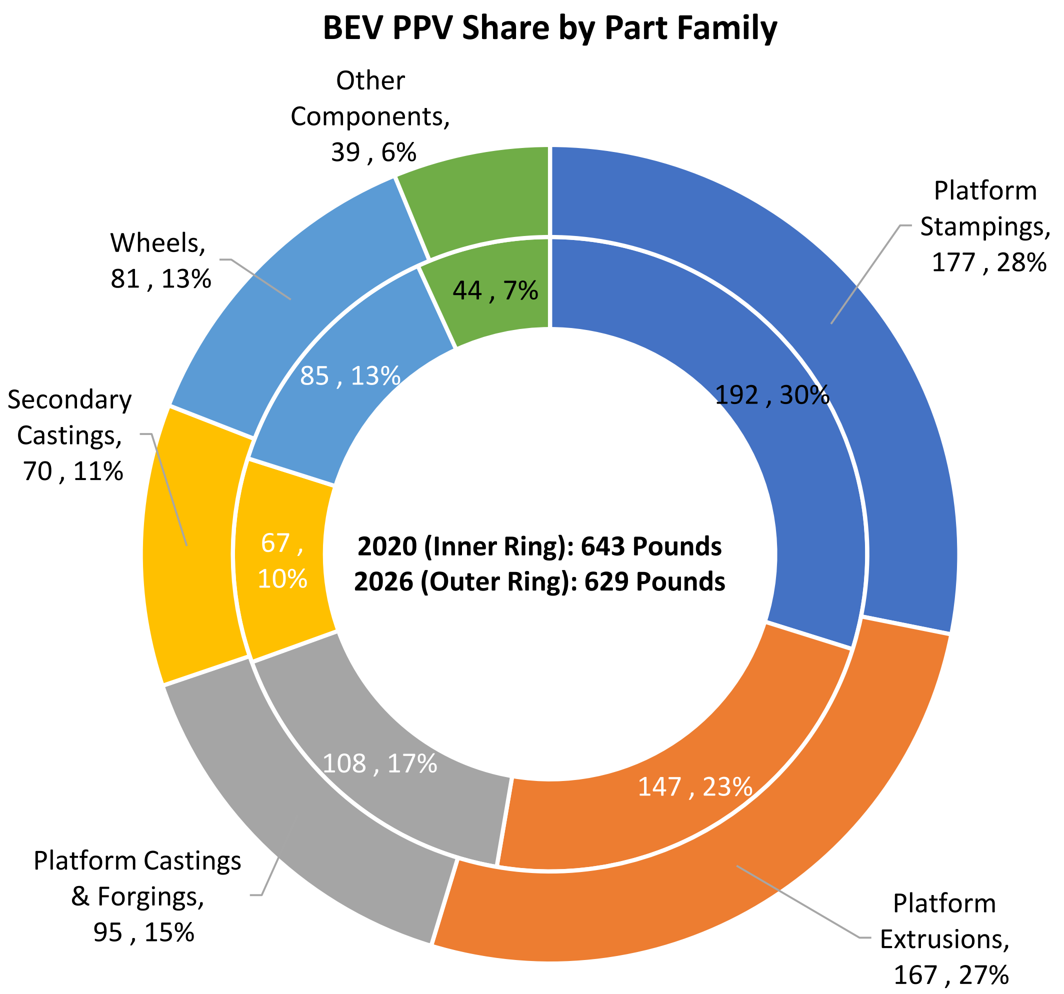
Only in non-BEV vehicles

Aluminum Content BEV vs non-BEV

BEVs use more than three times as much aluminum than non-BEVs in platform parts today. This difference will be reduced to a factor of ~2 by 2026 as aluminum platform use is increased in non-BEVs and several smaller BEV models are launched.



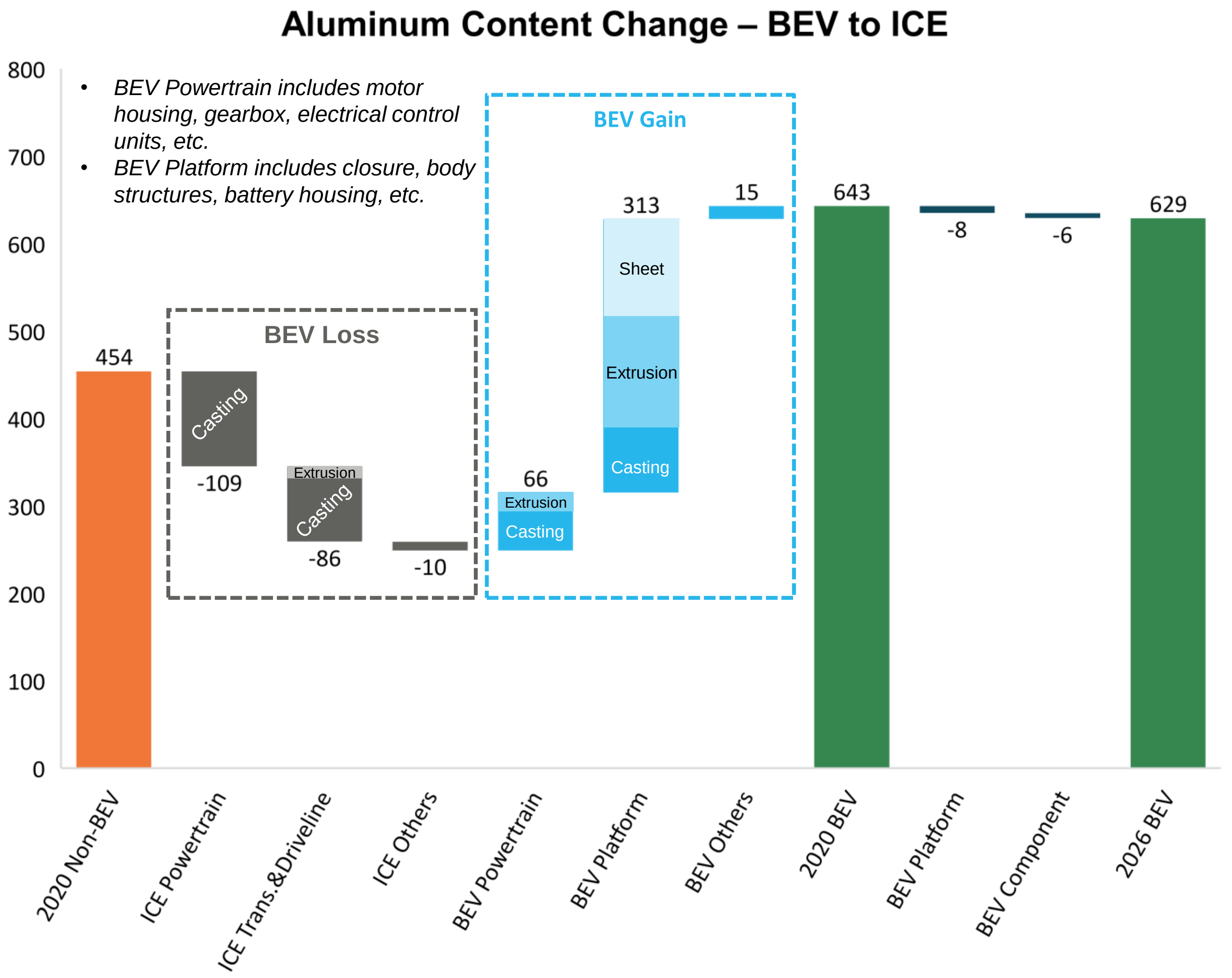
Non-BEV including ICE and hybrid vehicles



Source: DuckerFrontier

Aluminum Content tradeoff

Eliminated ICE Parts	
Powertrain	• Internal combustion engine related components, such as block, cylinder head, cam cover, oil pan, piston, etc., are eliminated on BEVs
Transmission and Driveline	• Transmission case, valve body, clutch housing, etc. are the major aluminum components removed from ICE models • For AWD and RWD models, components such as transfer case, drive shaft, differential carriers are also not necessary on BEVs
Added BEV Parts	
BEV Powertrain	• Aluminum casting or extruded traction motor housing will compensate the loss from engine parts; dual motor models will need two housings • Some BEV powertrain may need reduction gearbox, of which case is normally aluminum casting • Electrical units such as inverter/converter/BMS are also packed in aluminum casting housings
BEV Platform	• BEVs have stronger needs for lightweighting than ICE models to improve range. • Aluminum penetration of platform parts, including closure and body platform components, is higher on BEVs • With more lower-segment BEVs entering the market, the average content of aluminum platform parts is likely to decrease after 2022



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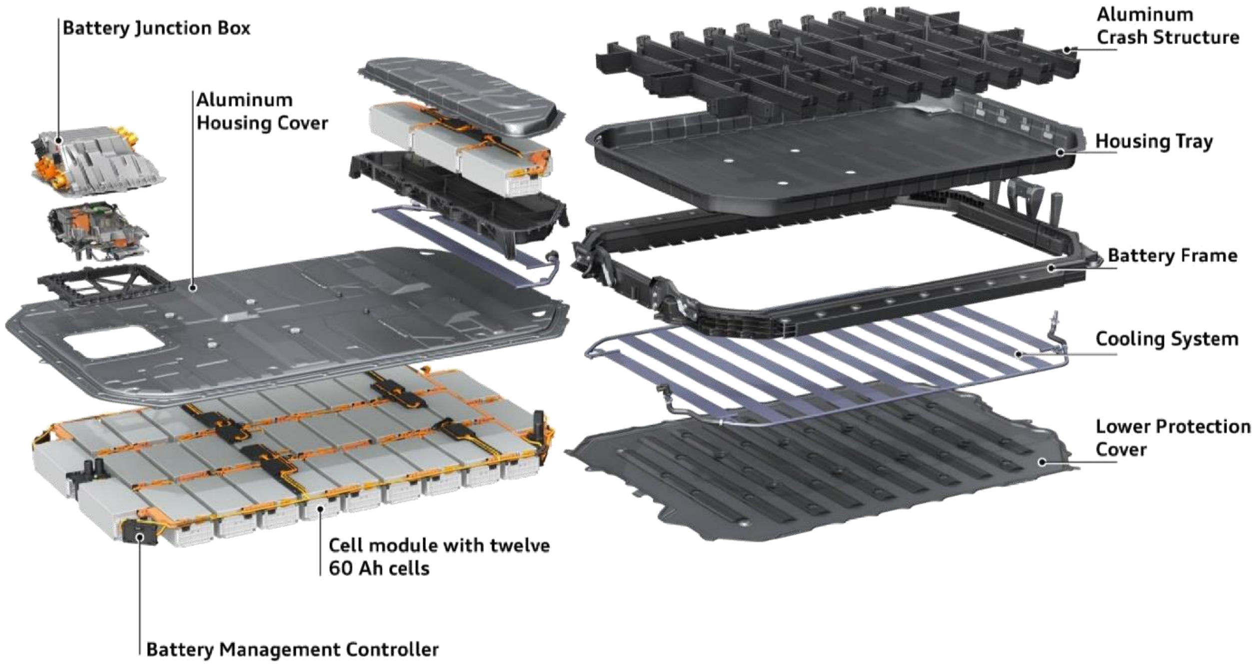
Source: DuckerFrontier

Major Aluminum Parts in BEV

Battery Pack Structure

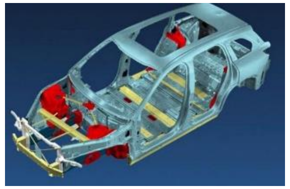


Component	Typical Product Type	Typical Weight
Frame & structure	Extrusion	75 Lbs.
Cooling System	Extrusion/Sheet	10 Lbs.
Top Cover	Sheet	15 Lbs.
Tray / Lower cover	Sheet / Extrusion / Casting	45 Lbs.

Traction & Electrical System

Component	Typical Product Type	Typical Weight
Traction Motor Housing	Casting, Extrusion	30 lbs.
Reduction Gearbox	Casting	25 Lbs.
Inverter/Converter Housing	Casting	6 Lbs.
BMS Housing	Casting	5 Lbs.
Wiring Tube/Connecter	Extrusion, Casting	4 Lbs.

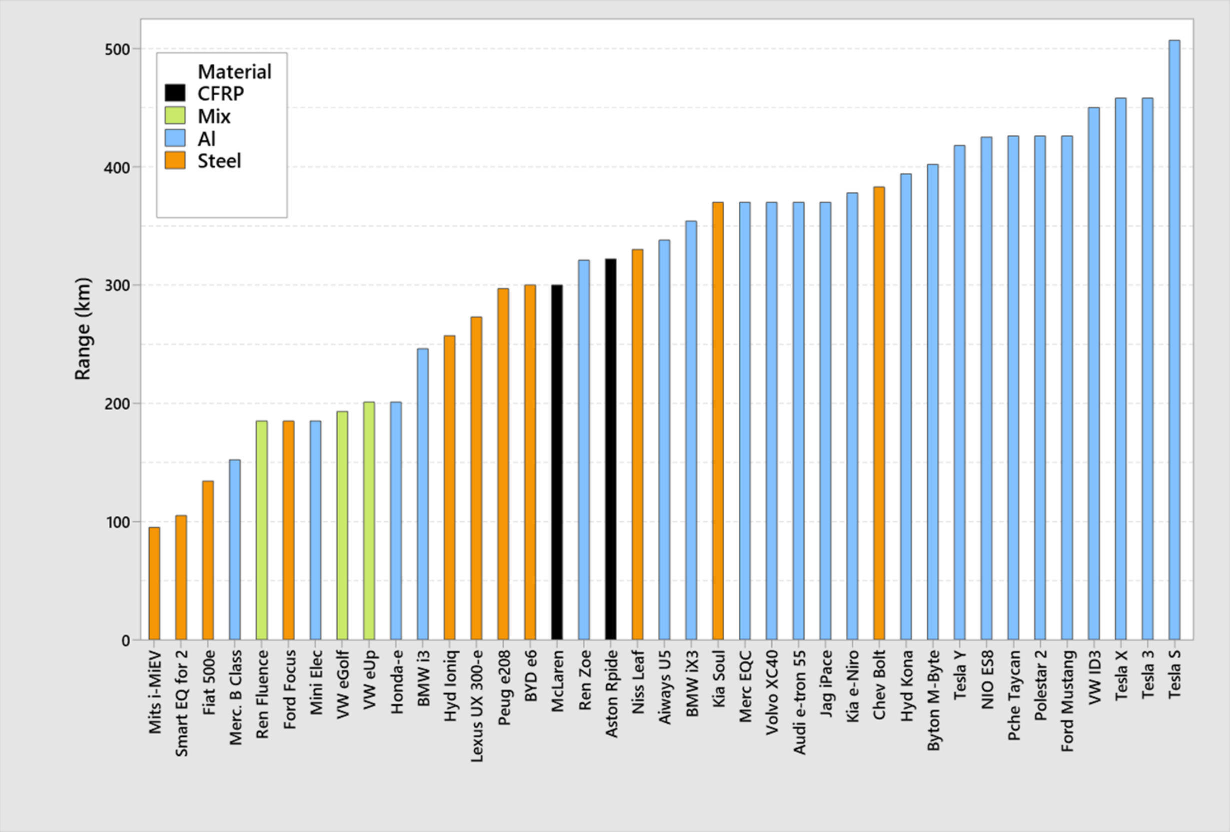
Body and Closure

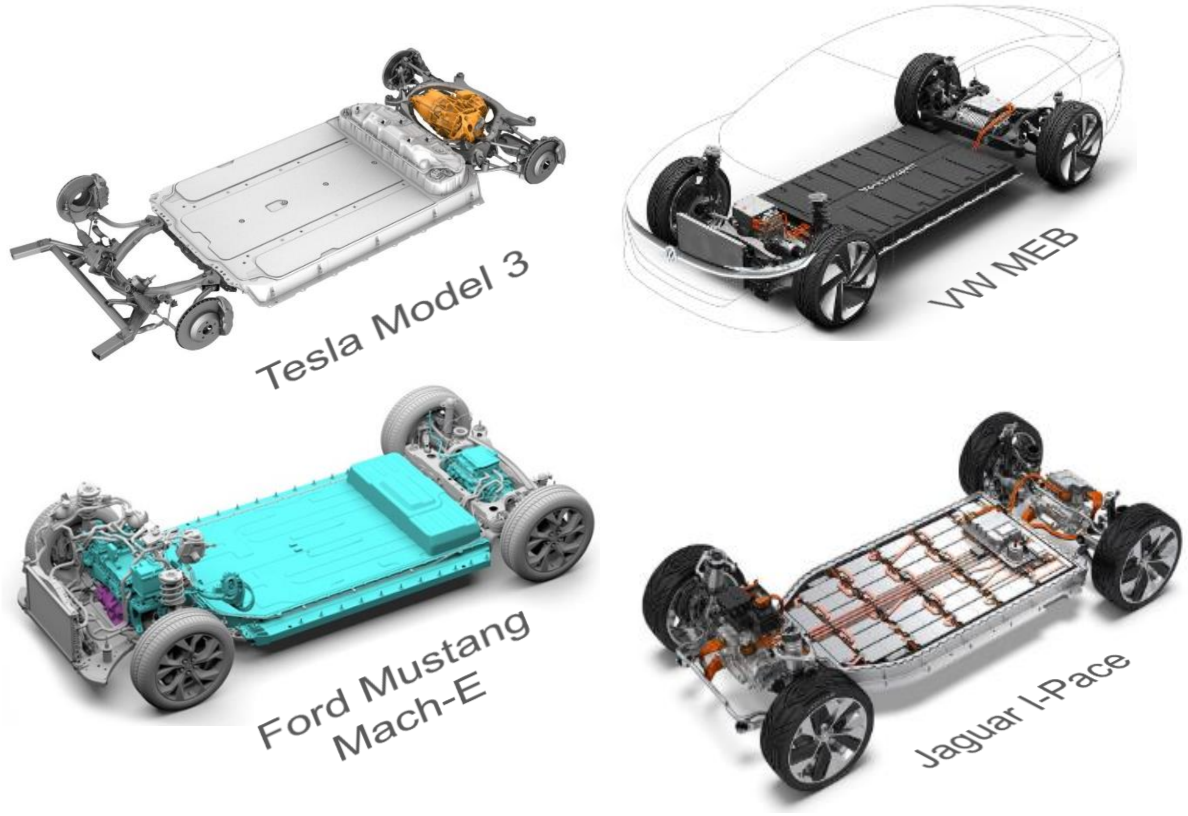


Component	Typical Product Type	Typical Weight
Body Structure	Casting, Extrusion, Sheet	200 Lbs.
Closures	Sheet	100 Lbs.

Battery Enclosure – Material choice current vehicles

The majority of long range BEVs in current production worldwide use aluminum as the main material for the battery enclosure.





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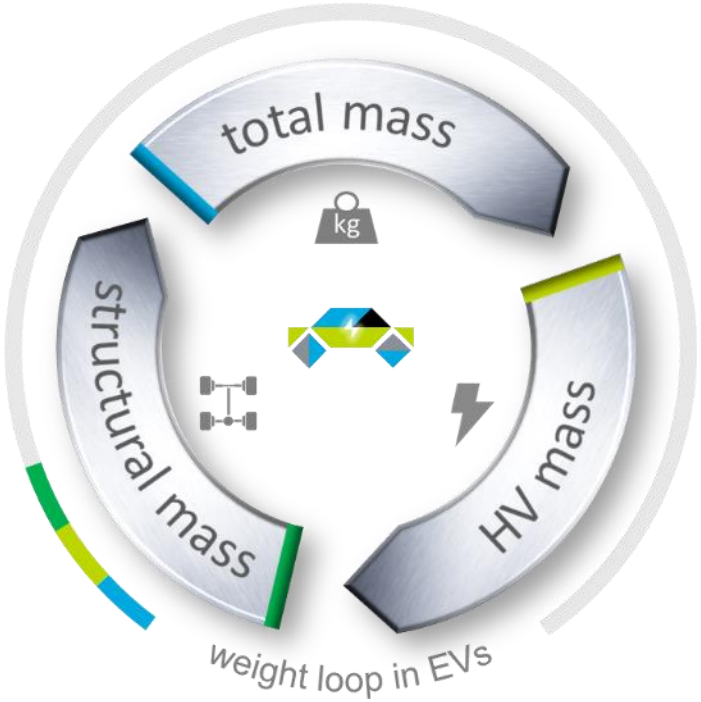
- **3. Drivers for material choice in Battery Electric Vehicles**
- 4. Specific requirements for Battery Enclosures
- 5. Constellium development and prototyping capabilities

Drivers for Material Choice and Lightweight design

Performance

Range
Acceleration / driving dynamics
Towing capability / payload
Energy consumption
Charging time
Safety / crash / fire resistance
Durability for lifetime of vehicle



Cost

- Component material cost
- Component manufacturing cost
- Cost impact of re-sized structure/powertrain
- Total solution cost

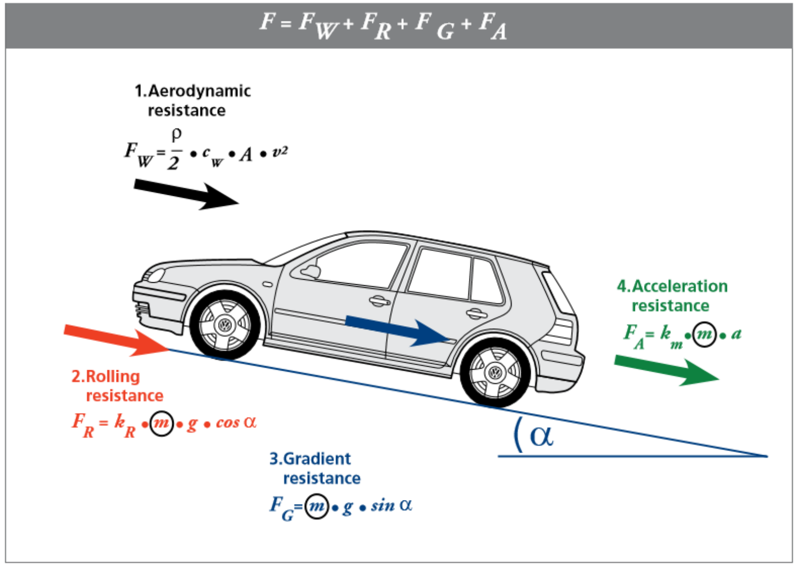
Sustainability

Life Cycle Analysis
CO_2 impact of manufacturing phase
CO_2 impact of use-phase
End-of-life recycling / re-use

Drivers for material choice: Performance

Range ◄► Driving dynamics ◄► Energy consumption ◄► Towing capacity / payload

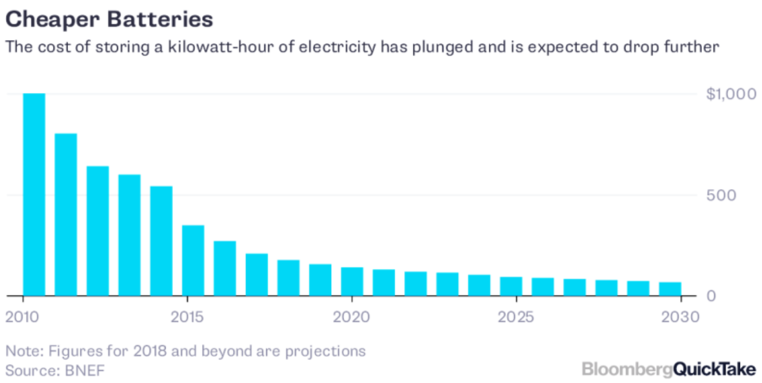
- A lighter vehicle body will always have a better overall balance of key BEV performance criteria.
- An optimized aluminum design for individual components or complete vehicle body structure is ~ 40 % lighter than an equally optimized steel design.
- A cheaper but heavier steel body can achieve the same range and even acceleration as a light aluminum body by adding more batteries and using more powerful electric motors → secondary weight gain
- 100 kg primary increase in body structure weight of a long-range electric SUV require around 3.5% larger battery and 6% more powerful motor to achieve same range and acceleration. (*)

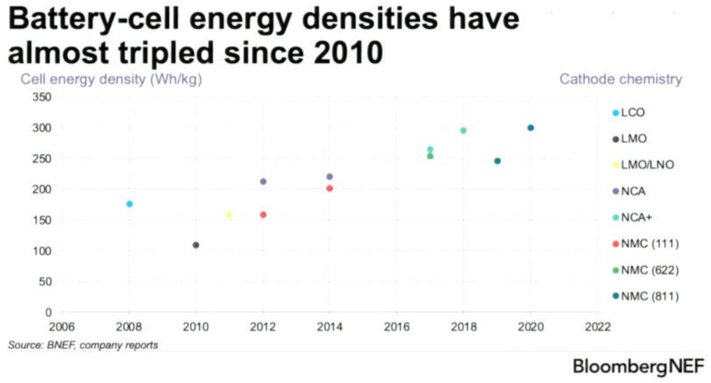


* https://ee.hydro.com/automotivewebinar

Drivers for material choice : Cost

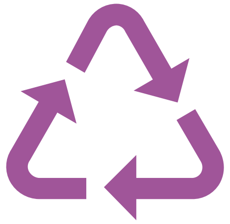
- Raw material cost comparison ≠ value of light-weight design.
- Cost of weight saving by design or material substitution must be considered in relation to the secondary weight and cost saving of body structure, battery and component re-sizing.
- Historically high battery cost ($/kWh) and low storage density (Wh/kg) made value of light weight construction obvious = savings just from downsized battery packs easily paid for increased material cost when choosing aluminum over steel.
- As battery costs and energy density continue to improve, the $-value of light–weighting will be reduced, and we expect to see increased material competition.
- The value proposition of light-weight aluminum design is more compelling for large and/or performance-oriented vehicles and we expect to see aluminum remain dominant in these segments.





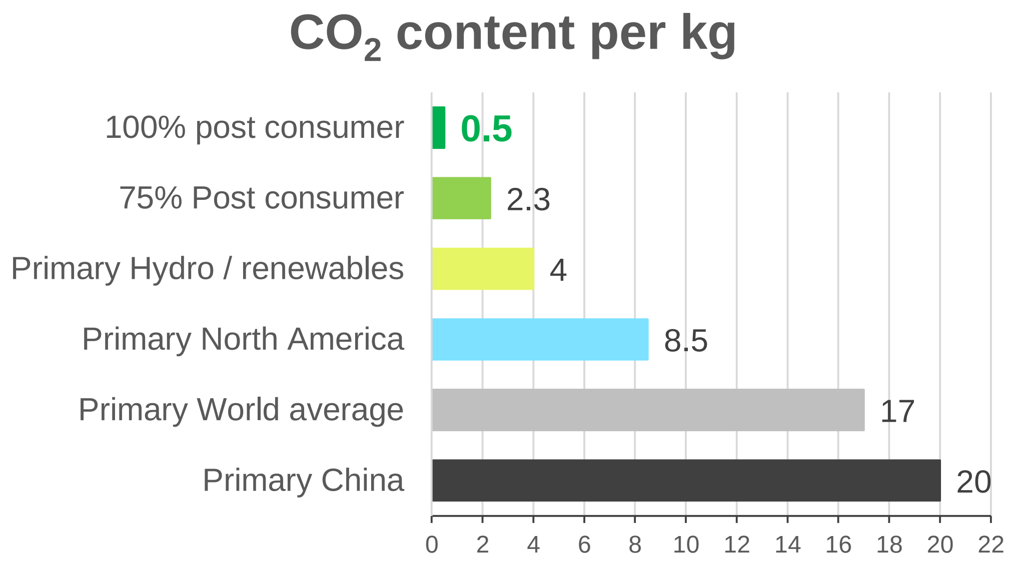
Drivers for material choice: Sustainability

- Green House Gas (GHG) impact of design and material choice is best assessed on specific cases by Life Cycle Analysis respecting ISO 14040/44 guidelines.
- There are limited unbiased studies on the GHG impact of light-weight design with aluminum compared to other materials specific for all-electric vehicles.
- Results can be very misleading if using assumptions that do not reflect reality for CO_2 emissions during primary manufacturing of aluminum or how much aluminum is recycled.
- Key facts to explain the potential net positive carbon footprint of light-weighting BEVs with aluminum are:



At the end of a vehicle's life, automotive aluminum is 96% recycled and reused for automotive parts.

(Source: WPI 2016, 2018)



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Poll #1

Which criteria is most important for you personally to choose a battery electric vehicle over an ICE or hybrid car ?

A = Longer range

B = Reduced charging time

C = Minimal lifecycle CO_2 footprint

D = Cost, will only buy a BEV if it is cheaper than the alternatives

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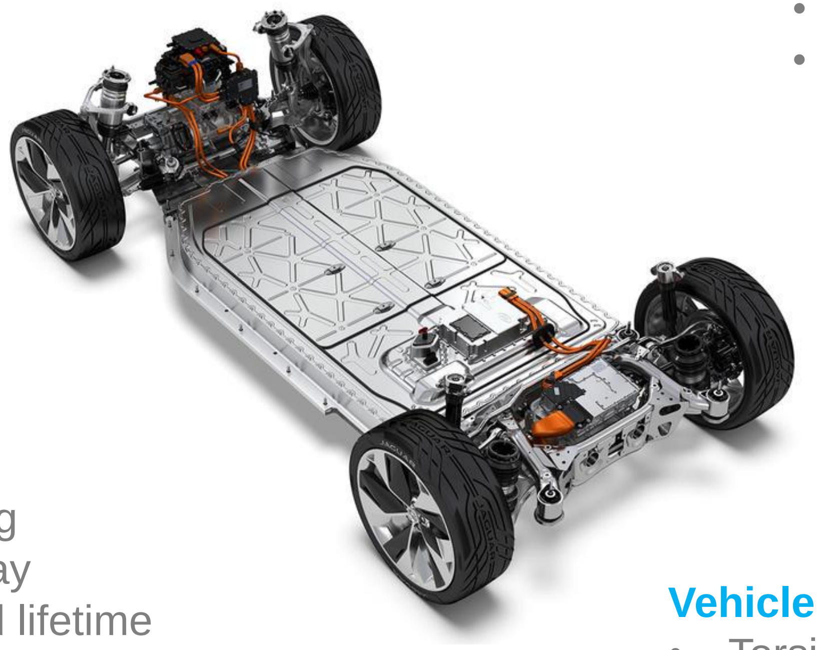
Battery Enclosures Design Criteria

Safety: Crash, impact and fire resistance:
- Vehicle crash / side impact resistance
- Bottom impact resistance
- Firewall protection of passenger compartment

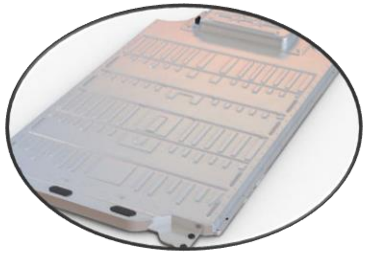
Sealing, shielding and durability
- Waterproof seal of battery modules
- Electromagnetic shielding
- Corrosion resistance and bond durability for life-time of vehicle.



Thermal management:
- Integrated heating and cooling
- Guarantee no thermal runaway
- Optimize battery capacity and lifetime

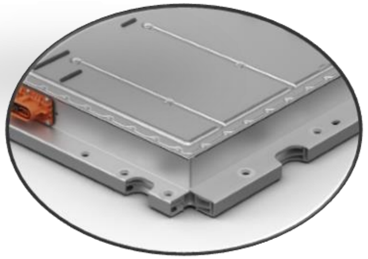
Vehicle integration, space and weight optimization:
- Torsional stiffness
- Modularity to accommodate different battery sizes
- Respect volume & allowable dimensions
- Minimize weight at cost target

Battery Enclosures Main Aluminum Parts



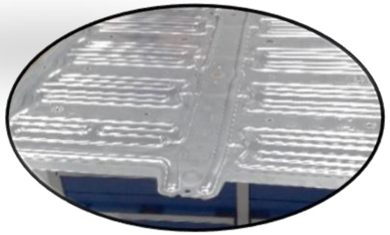
Top protection cover

- Seals the enclosure and protects passenger compartment from heat / fire
- Stamped aluminum sheet with high formability



Structural frame and cross members

- Protects the cells from intrusion in crash
- Most commonly in extruded profiles
- Requires very high strength alloys combined with high ductility



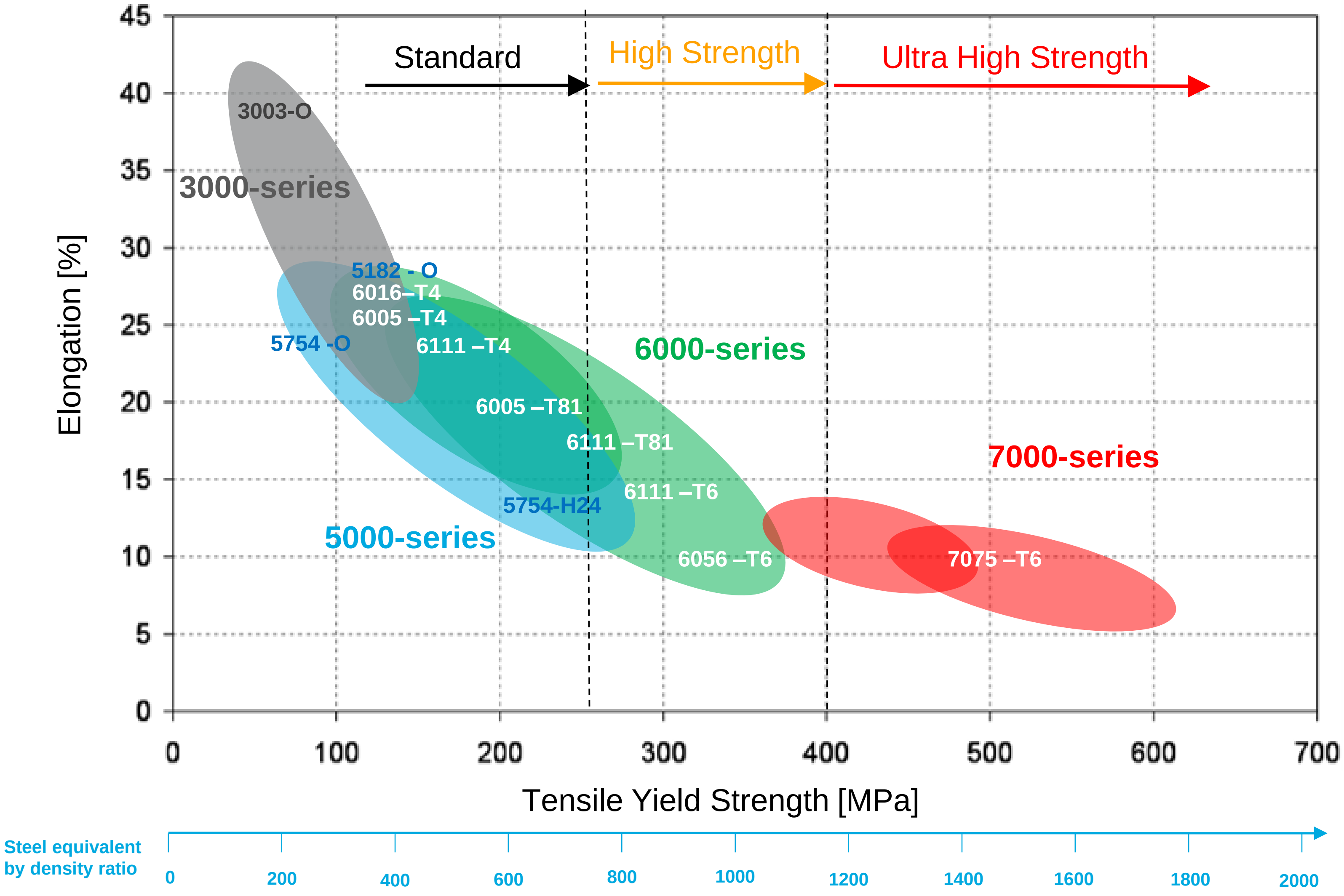
Cooling plate / thermal management system

- Ensures stable operating temperature for the cells
- Can be either brazed sheet or extruded profiles. May also be integrated in bottom cover

Bottom plate / lower protection cover

- Protects the cells from undercarriage impact, road debris etc.
- Welded extrusion and sheet solutions are both used
- Sheet can be flat or stamped to also act as tray
- Requires high strength / high ductility alloys

Constellium Automotive Body Sheet Alloys



6000-series = Al-Mg-Si-(Cu)

- Heat treatable
- Major automotive alloy family
- Very good cold formability in T4 temper
- Gains strength through paint-bake or PFHT
- Excellent corrosion resistance

5000-series = Al-Mg

- Non-heat treatable
- Very good cold formabilty in O-temper
- Can be strengthened by cold work in H-tempers
- Excellent corrosion resistance

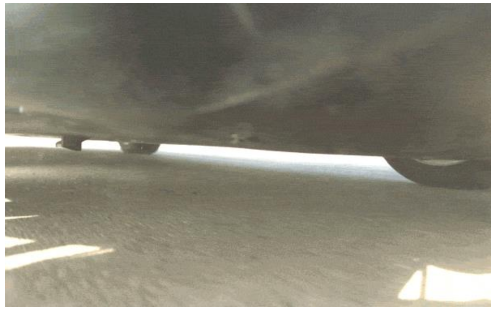
3000-series = Al-Mn

- Non-heat treatable
- Low strength – excellent formability
- Heat exchangers / heat shields

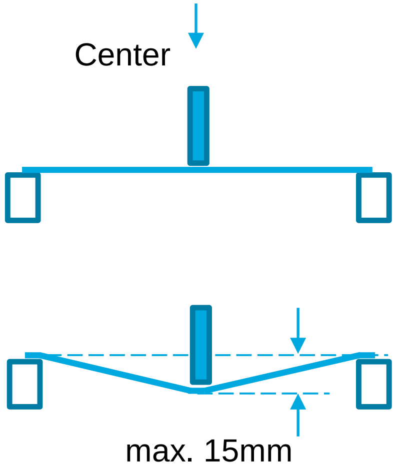
7000-series = Al-Zn-Mg-(Cu)

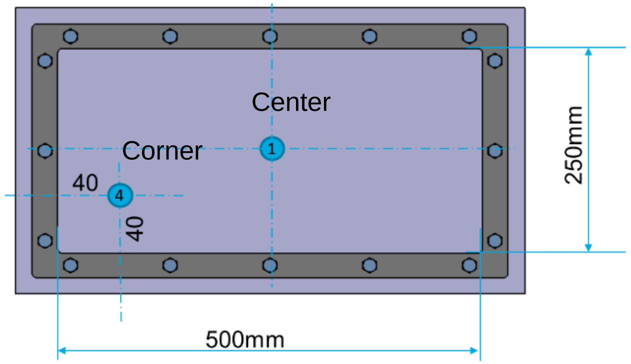
- Heat treatable – highest strength alloy family
- Currently not in volume automotive use
- Limited cold formability
- Hot stamp + press quenchable
- Can be susceptible to stress corrosion cracking

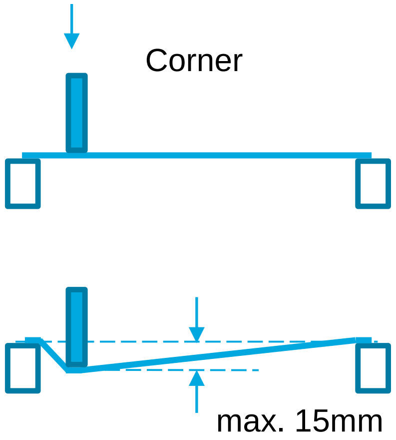
Bottom Plate Impact resistance



- To evaluate different material, alloy and temper solutions we use an in-house numerical simulation tool backed up by a physical testing protocol
- We record the force vs displacement for up to 15 mm intrusion in different positions of a test sheet firmly fixed in a frame.
- This allows to determine the equivalent gauge based on absorbed energy and therefore weight saving potential of new grades and solutions.



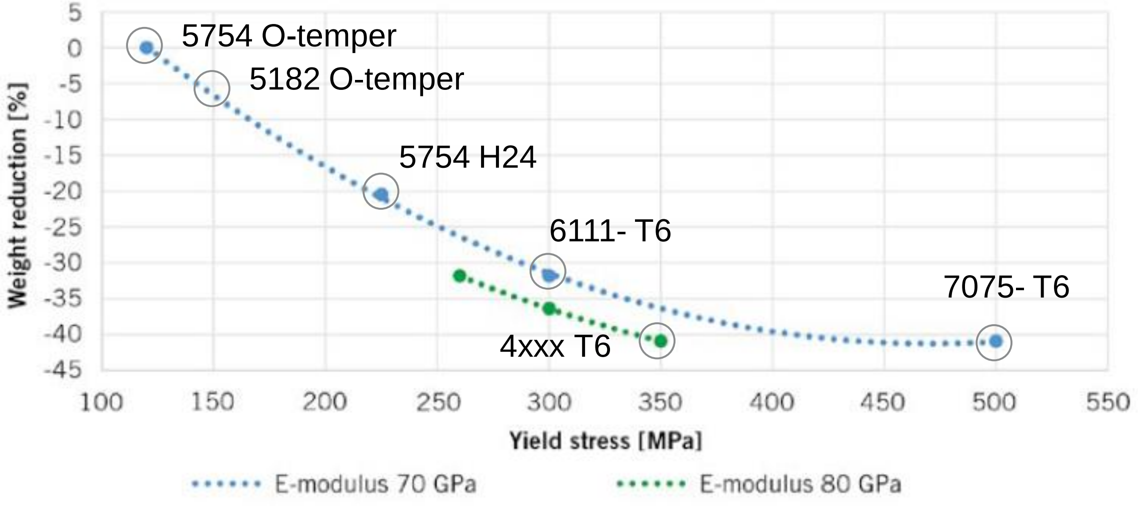




Bottom Plate Alloy selection

Higher strength alloys allow for significant weight and cost reduction.

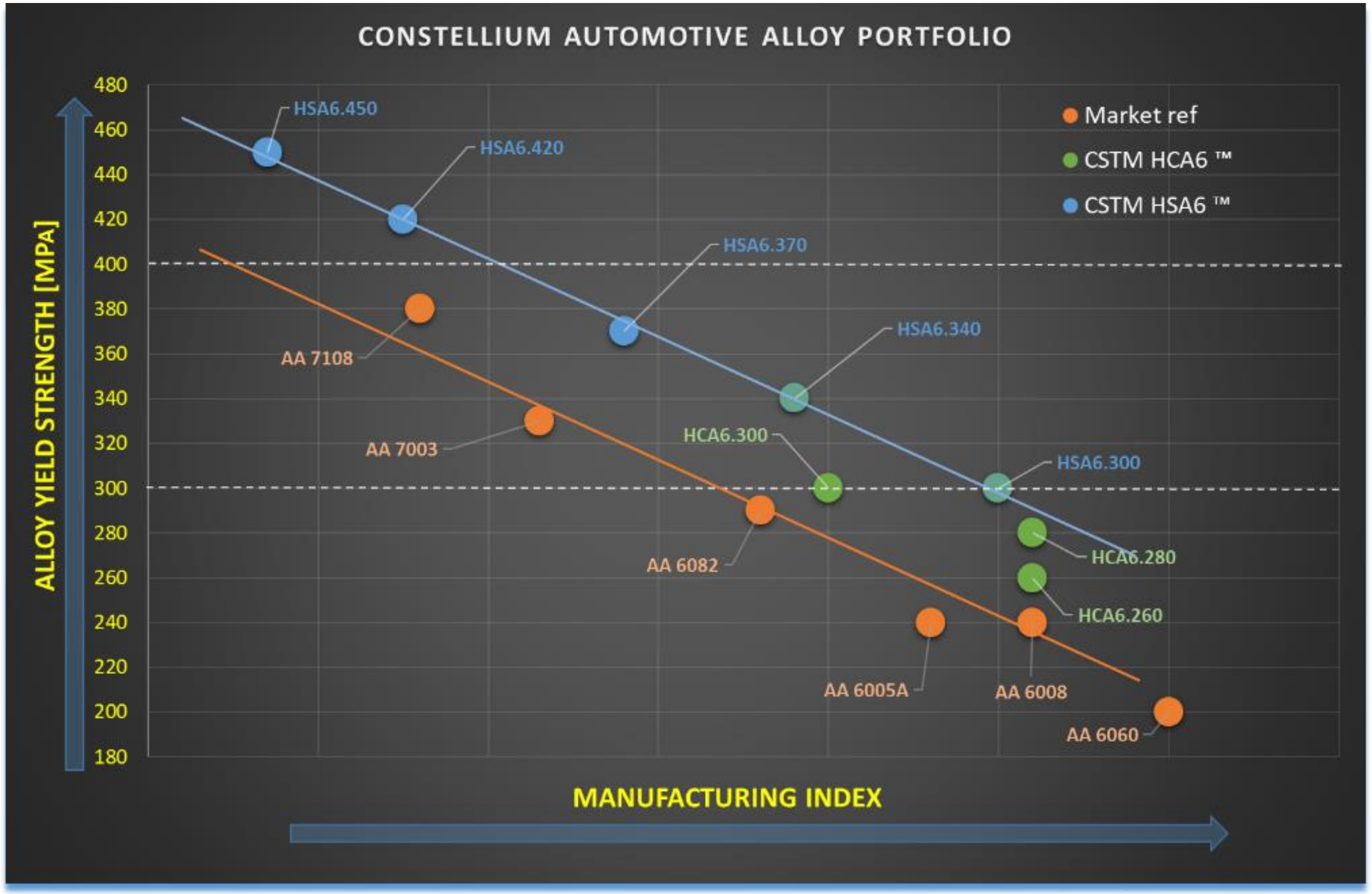
Alloy	Temper	TYS [MPa]	UTS [MPa]	E-Mod [GPa]	Status
5754	O-temper	120	250	70	Available
5182	O-temper	150	290	70	Available
5754	H24	225	290	70	Available
6111	T4 + PB	280	340	70	Available
6111	T6 / PFHT	300	360	70	Available
7075	T6	500	530	70	Development
4xxx	T6/PFHT	350	390	80	Development



- Current state-of-the-art solution is high strength 6111 in peak aged temper – saves 30% weight vs benchmark 5754 O-temper
- 40% weight reduction is technically feasible with 7075 T6 or with developmental 80 GPa E-modulus / 350 MPa YS 4xxx alloy

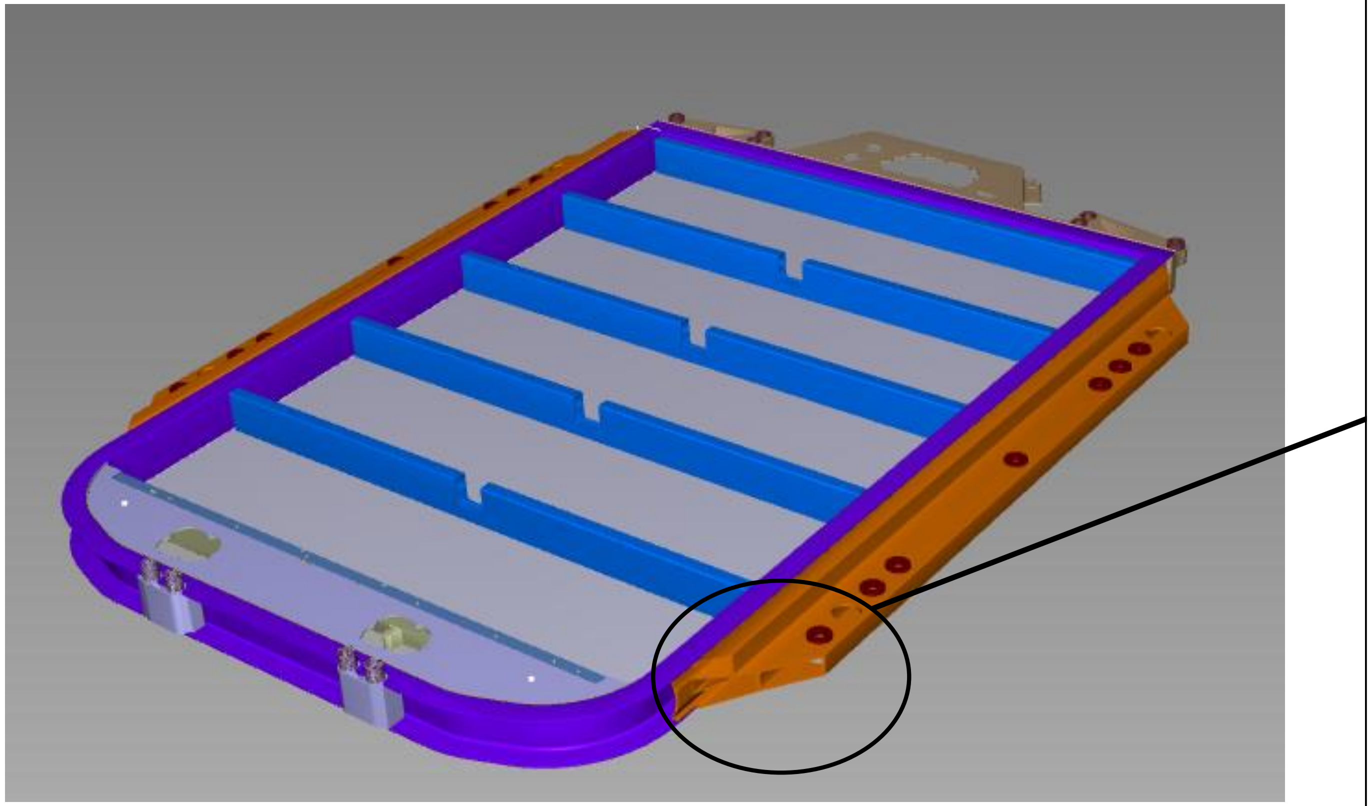
Constellium Extruded Automotive Aluminum alloys

Strength and ductility requirements can be met with advanced 6xxx alloys with excellent corrosion resistance, joinability and ease of recycling.

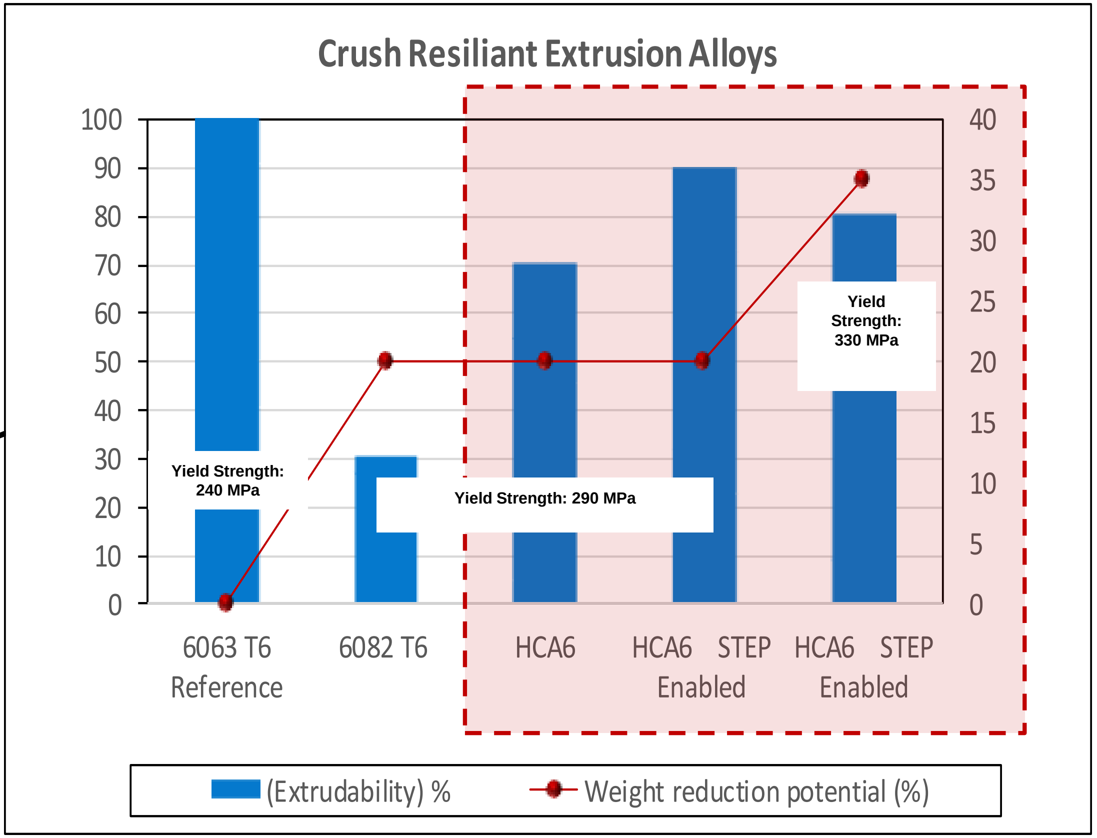


- HSA6™ family are proprietary 6xxx alloys achieving higher strength and better manufacturability than 7xxx series alloys
- HCA6™ family are proprietary high strength 6xxx with high ductility for energy absorption in crash
- Constellium HSA6/HCA6 Aluminium alloys provide Weight Savings of > 20% Versus Conventional Al Alloys

Dual Material Battery Enclosure Protection System



Example Battery Enclosure



Advanced Extrusion Alloy & Design To Provide Cost Effective Light Weight Solutions

Summary and conclusions

- Aluminum as sheet and extruded profiles is the preferred material for BEV body structure, closures and battery enclosures.

- Aluminum battery enclosures or other platform parts typically gives a weight saving of 40% compared to an equivalent steel design.

- Light-weight design allows:
  - Better overall performance = range, acceleration, payload, energy consumption and/or
  - Cost savings at iso-performance by downsizing of battery, motors, structure

- Aluminum is infinitely recyclable with zero loss of properties. At end of life 96% of automotive aluminum content is recycled. Recycling aluminum only requires 5% of the energy needed for primary production.

- North American automotive aluminum contains recycled metal and primary metal manufactured mainly with renewable, hydroelectric power.

Poll #2

What do you think the share of BEV battery enclosures made with aluminum as the main material will be in 2030:

A = 100%

B = 75%

C = 25%

D = 0 %