Introduction to Aluminum Use in Automotive

The Aluminum Transportation Group

Presenter

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Constellium
Technical Director

Day 1 Agenda – Introduction

- Overview of workshop content
- Aluminum use in North American Light Vehicles
- Aluminum use in ICE vs Battery Electric Vehicles
- Sustainability and Recycling
- Historic and recent BIW and closure applications
- Alloy and temper designations

Day 1 Agenda –

10:00 AM:	Automotive Aluminum Sheet: Production Flow Path and General Metallurgy, Debdutta Roy
11:00 AM	Aluminum Stamping and Forming Part I, Zhi Deng
12:00AM	Networking lunch
12:45AM	Aluminum Stamping and Forming Part II, Zhi Deng
1:00PM:	Joining Aluminum and other Materials, Tamer Girgis
2:00PM:	Introduction to Aluminum Extrusion, Jeff Victor
3:00PM:	Guided Tour of Munro
5:00PM	Happy hour networking 5 p.m.

Day 2 Agenda –

8:45 AM:	Post-Extrusion Processing, Jeff Victor
9:30 AM	Casting processes and metallurgy, Francis Breton & Ray Peterson
12:00AM	Networking lunch
12:30AM	Casting alloys, Francis Breton & Ray Peterson
1:00PM:	Joining Aluminum and other Materials, Tamer Girgis
2:00PM:	Corrosion and Repair, Tamer Girgis
2:45PM:	Closing remarks
3:00PM	Guided Tour of Munro

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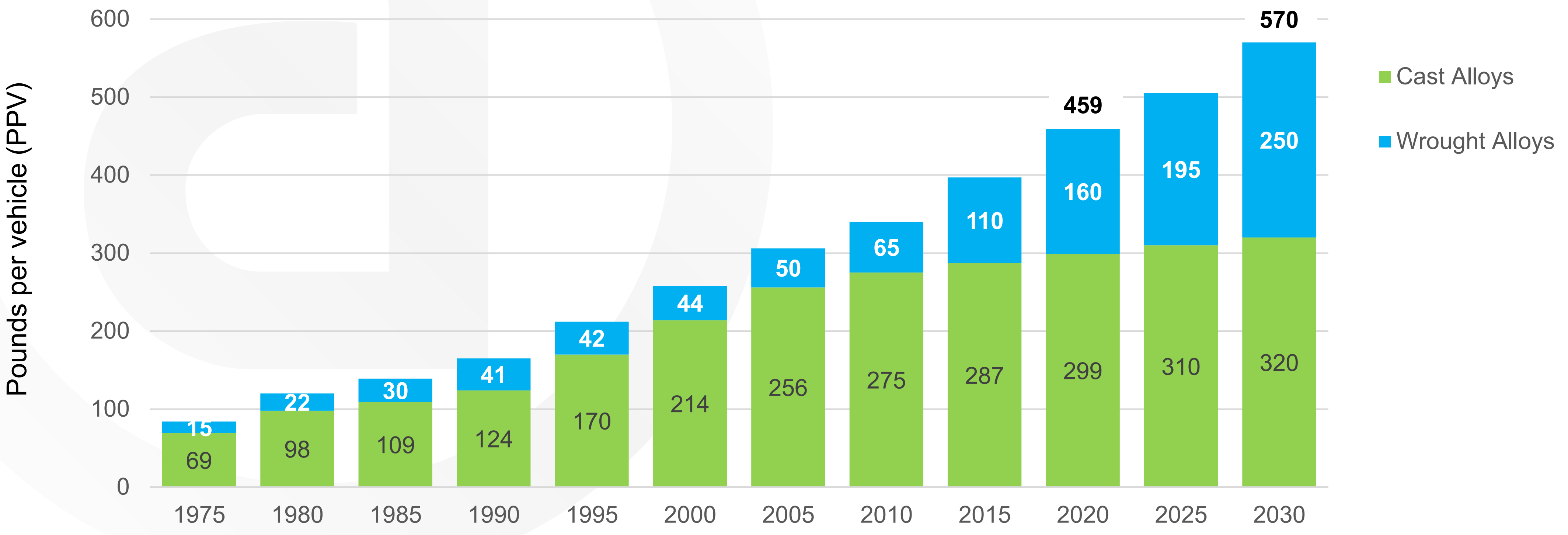
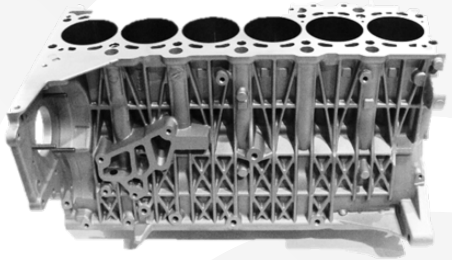
Aluminum Use in Light Vehicles

Aluminum has been the fastest growing material in light vehicles now for more than 50 years. The first wave of aluminum growth was mainly for castings in powertrain and wheels. Since 2015 growth has been mainly in wrought alloys – sheet and extrusions in body structure and closures.

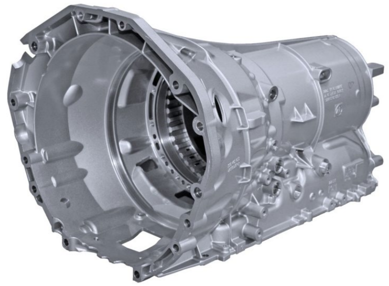


Source Ducker

Common Uses of Aluminum - Components



Engine Blocks



Transmissions

Wheels

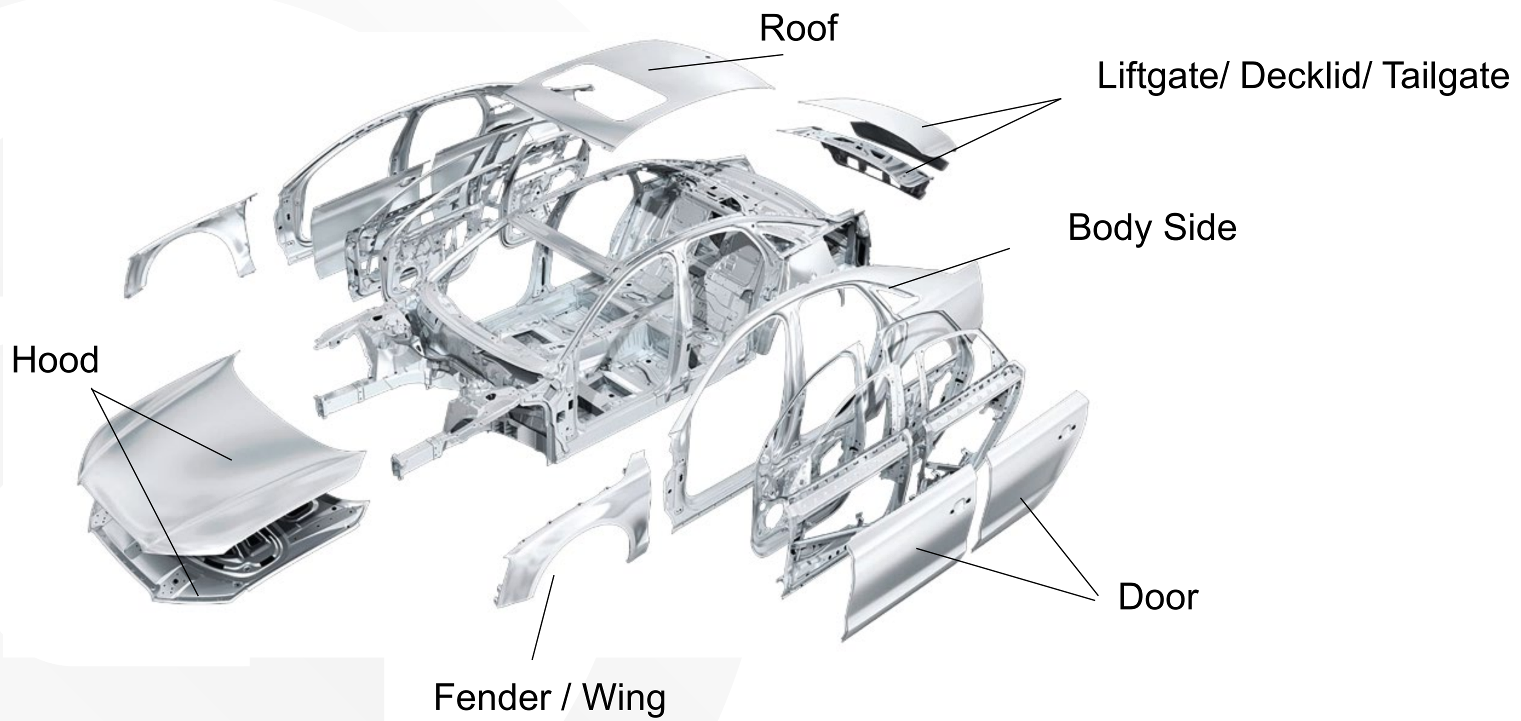
Cylinder Heads

Pistons

Heat Exchangers

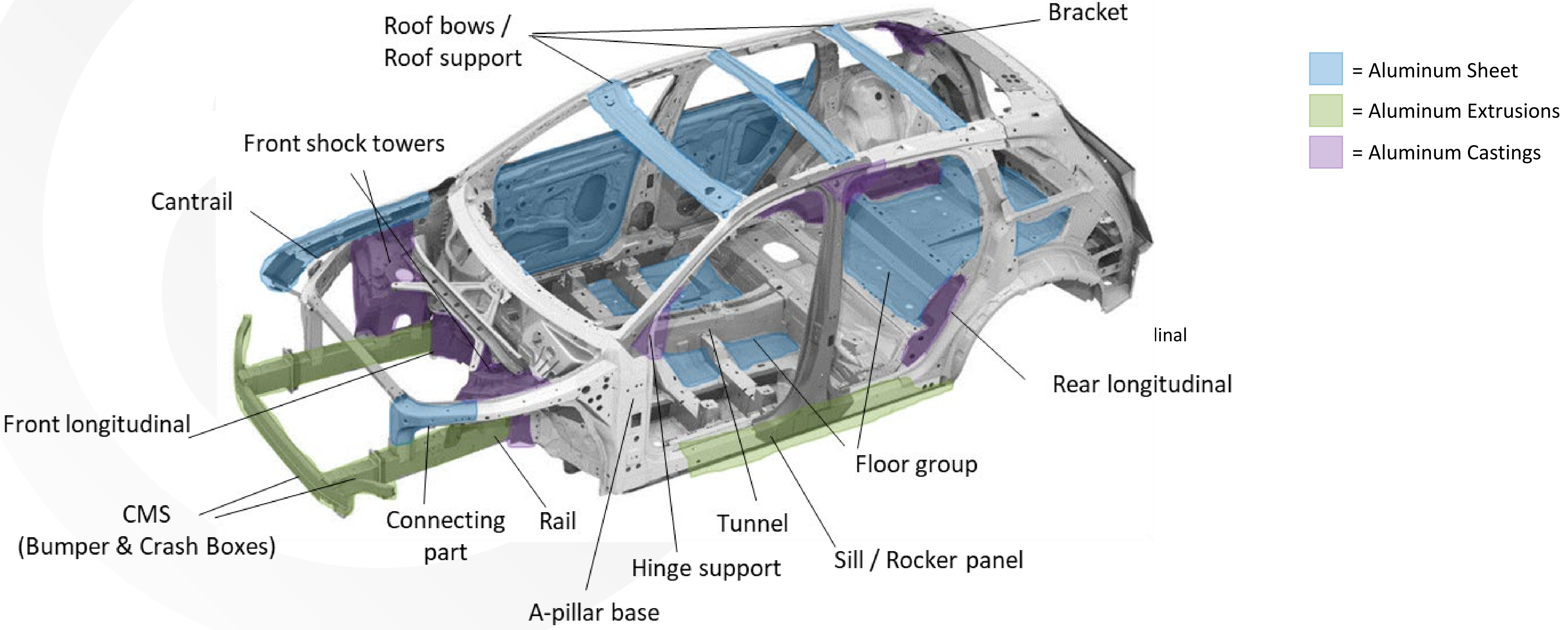
Suspension components

Common Uses of Aluminum - Closures

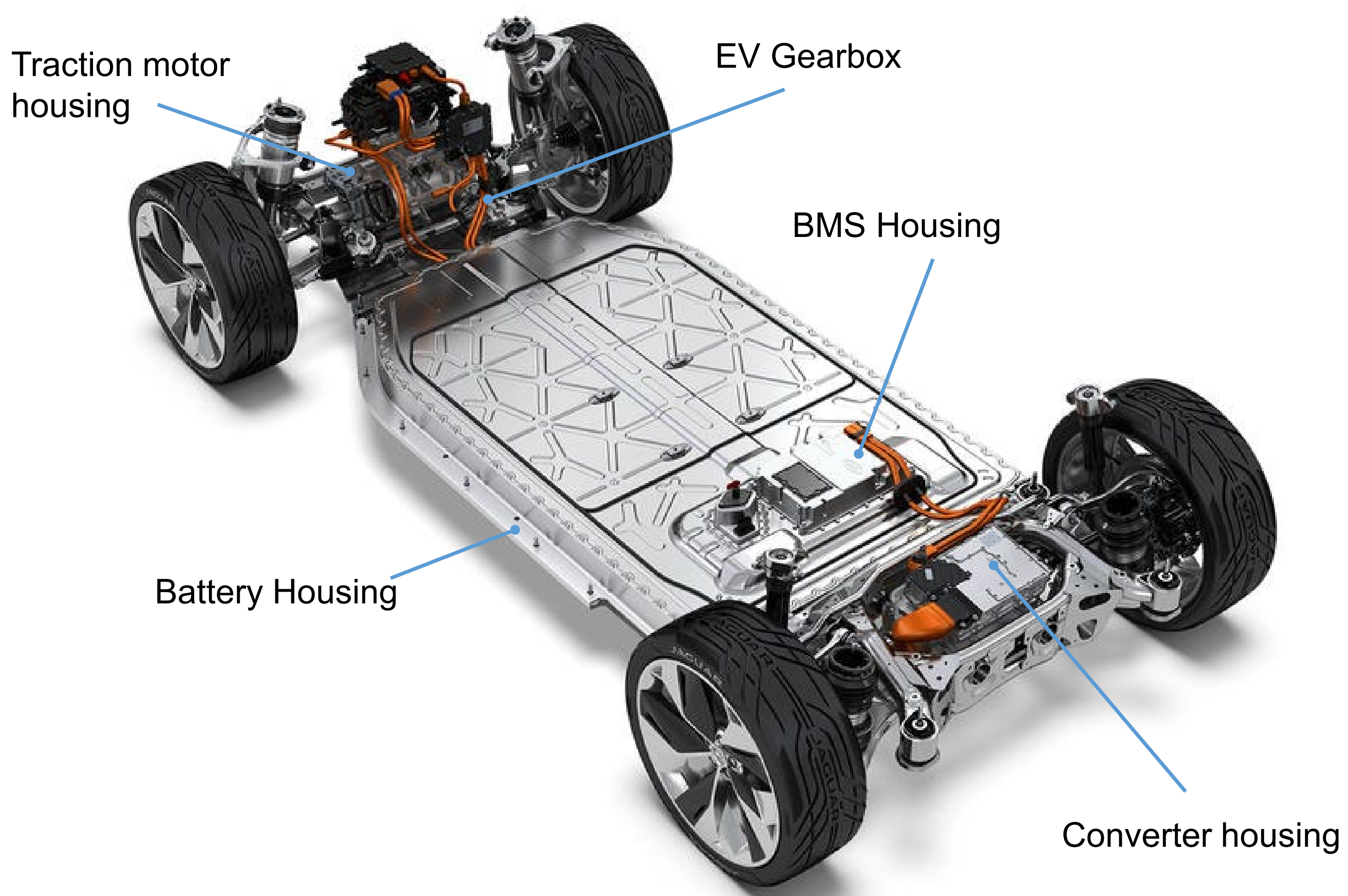


Part	Hood	Liftgate / decklid	Fenders	Doors	Roof	Body side
2010 Penetration	<10%	<1%	<5%	~0	~0	~0
2020 Penetration	**63%**	**28%**	**19%**	**21%**	**~7%**	**~7%**
2026 Forecast	**81%**	**46%**	**36%**	**30%**	**~7%**	**~7%**
Typical weight save	4-7 kg	4-9 kg	4-8 kg (x2)	20-35 kg (x4)	4-8 kg	5-8 kg

Common Uses of Aluminum – Body Structure

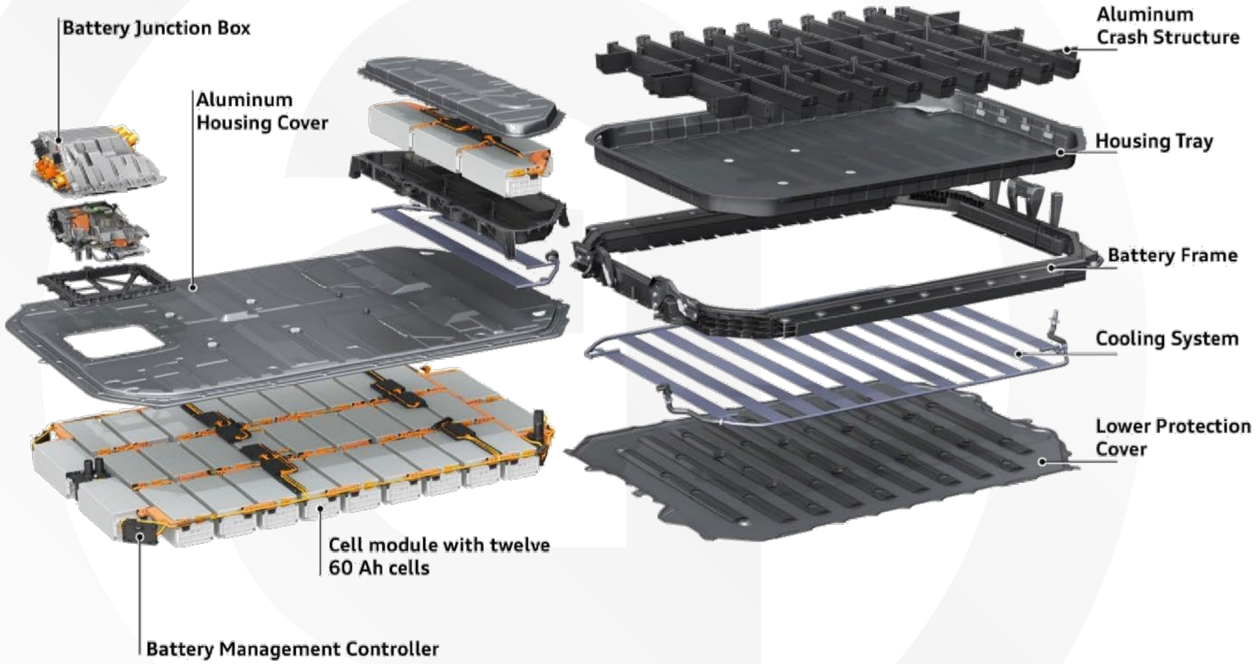


Common Uses of Aluminum – BEV specific



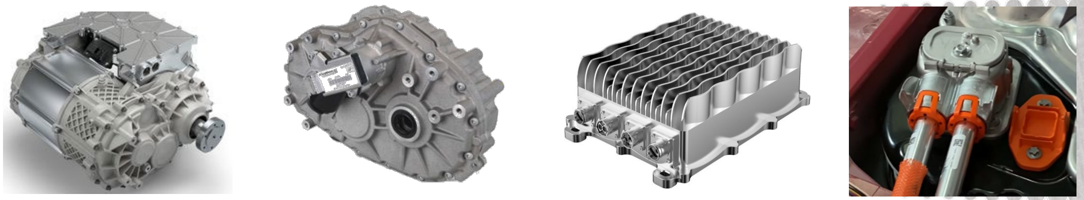
Common Uses of Aluminum – BEV specific

Battery Pack Structure



Component	Typical Product Type	Typical Weight
Frame	Extrusion	100 Lbs. - 250 Lbs.
Cooling System	Extrusion	5 Lbs. - 20 Lbs.
Cover	Sheet	10 Lbs. - 20 Lbs.
Tray	Sheet, Casting	10 Lbs. - 30 Lbs.
Reinforcement	Extrusion, Casting	5 Lbs. - 10 Lbs.

Traction & Electrical System



Component	Typical Product Type	Typical Weight
Traction Motor Housing	Casting, Extrusion	30 Lbs. - 50 Lbs.
Reduction Gearbox	Casting	20 Lbs. - 40 Lbs.
Inverter/Converter Housing	Casting	5 Lbs. - 7 Lbs.
BMS Housing	Casting	3 Lbs. - 6 Lbs.
Wiring Tube/Connecter	Extrusion, Casting	3 Lbs. - 5 Lbs.

Body and Closure

Component	Typical Product Type	Typical Weight
Longitudinal	Casting, Extrusion, Sheet	40 Lbs. - 80 Lbs.
Closures (hood, doors, etc.)	Sheet	100 Lbs. - 200 Lbs.
Reinforcement Beams	Extrusion, Casting	20 Lbs. - 60 Lbs.

Source: DuckerFrontier, Volkswagen Group, GM

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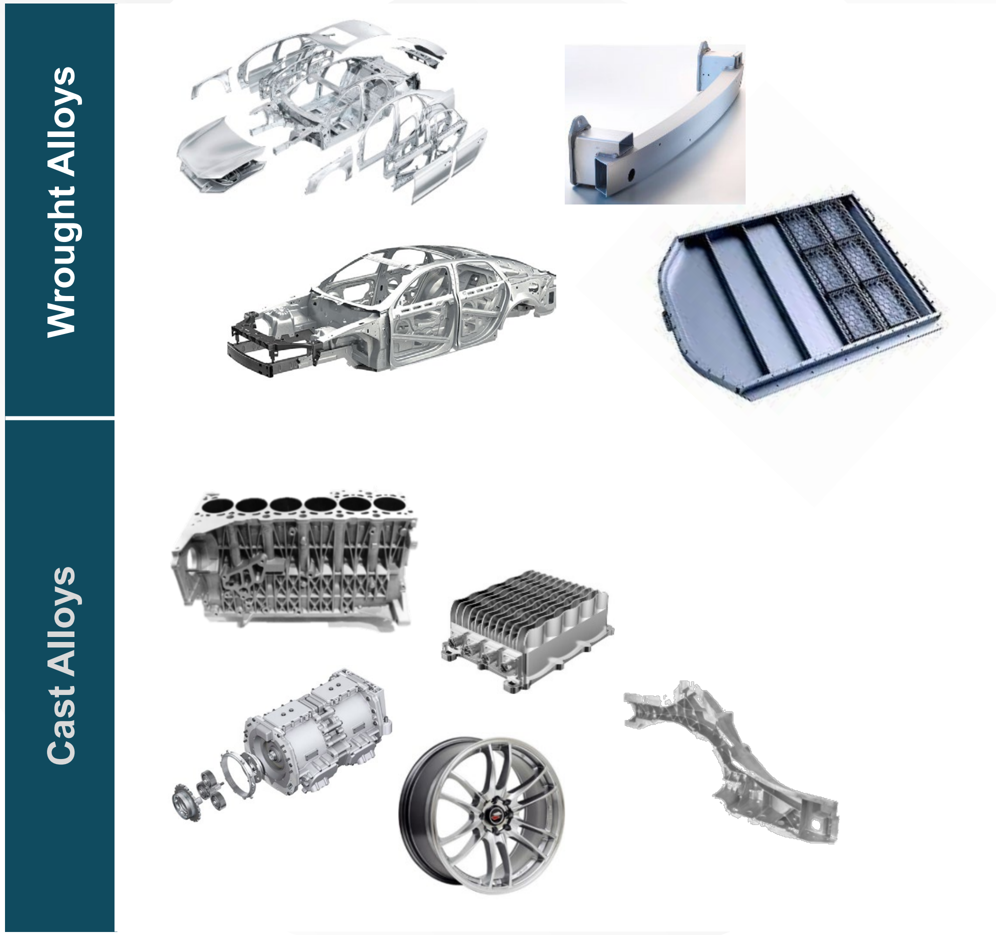
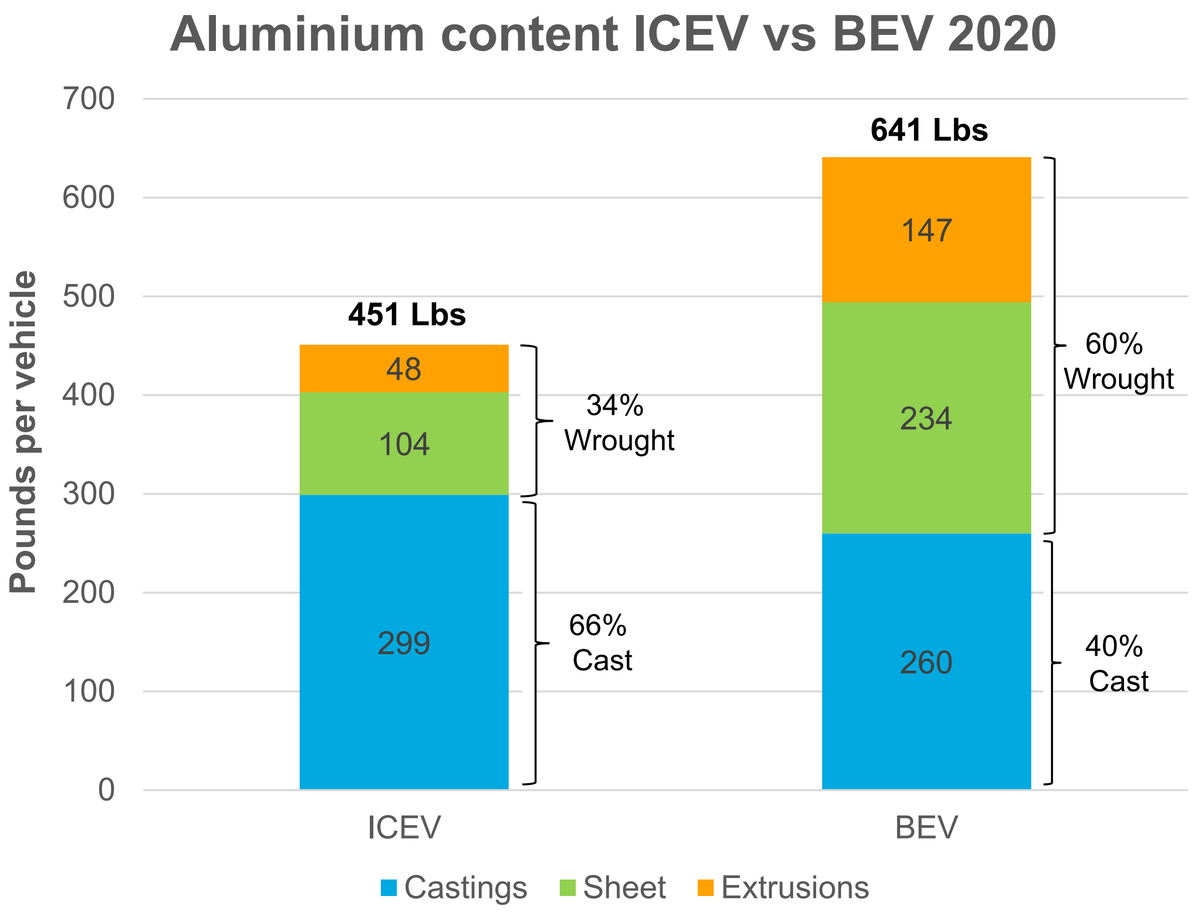
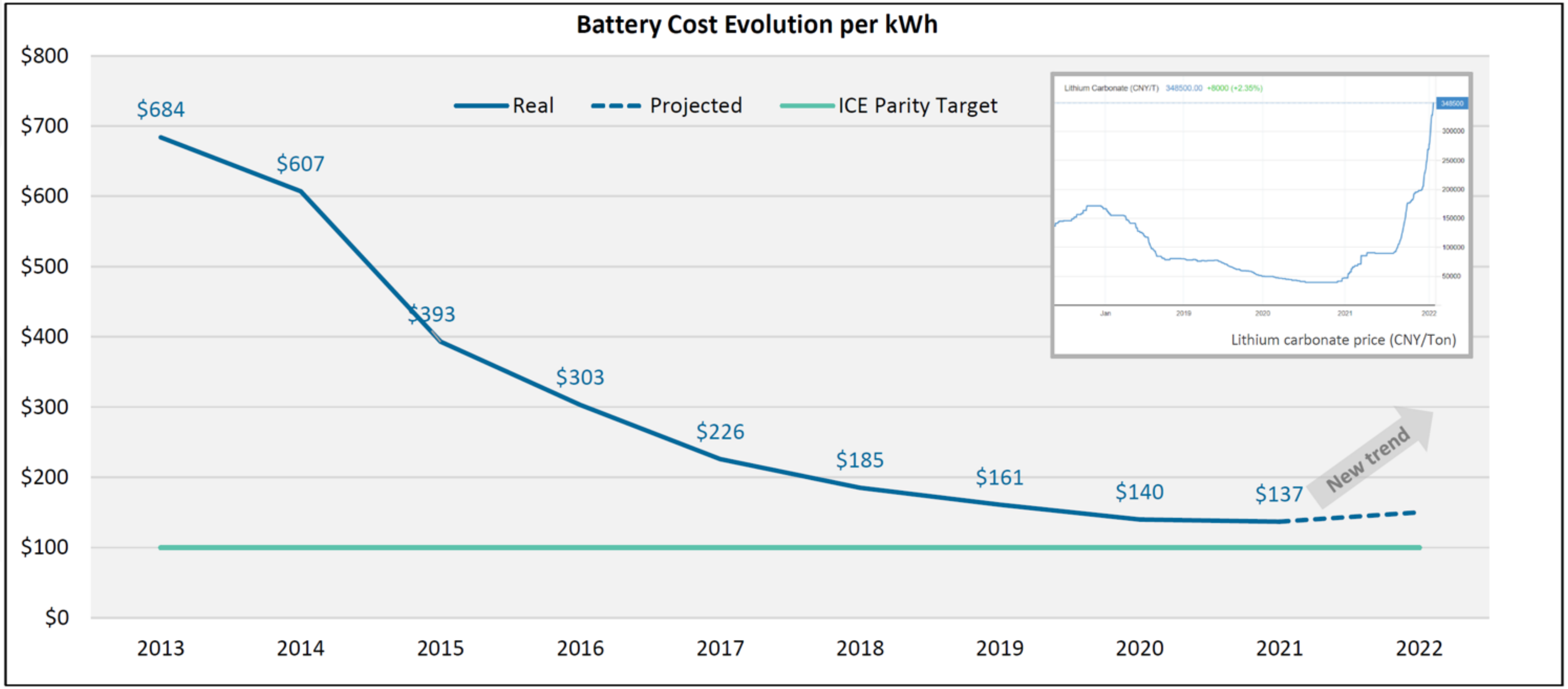
Battery Electric Vehicle Aluminum Content





Source: Ducker

Battery Electric Vehicle Aluminum Content



Source: Ducker + BNEF

Battery Electric Vehicle Aluminum Content

	City vehicle		Family crossover		Pickup truck	
Range	**300 miles / 480 km**		**400 miles / 640 km**		**500 miles / 800 km**	
Scenario	**Status Quo**	**Optimized**	**Status Quo**	**Optimized**	**Status Quo**	**Optimized**
Battery / Motor	67 kWh / 121 kW	63 kWh / 110 kW	105 kWh / 200 kW	96 kWh / 180 kW	186 kWh / 287 kW	172 kWh / 256 kW
Curb Weight	1,394 kg	1,265 kg	1,656 kg	1,480 kg	2,214 kg	1,982 kg
Al. Content	**167 kg = 12%**	**348 kg = 20%**	**331 kg = 20%**	**618 kg = 42%**	**598 kg = 27%**	**1,038 kg = 52%**
Savings	- 310 kg steel + 181 kg Al **+$383**	Resize battery & electric motor **-$459**	- 445 kg steel +273 kg Al **+$849**	Resize battery & electric motor **-$948**	704 kg steel +440 kg Al **+$1,402**	Resize battery & electric motor **-$1,478**
	Net: **$76 / BEV**		Net: **$99 / BEV**		Net: **$76 / BEV**	

ATG / FEV study concludes that there is and will remain a strong business case for light-weighting BEVs by using aluminum in place of steel. In addition, larger / heavier vehicles with long range will continue to use more aluminum

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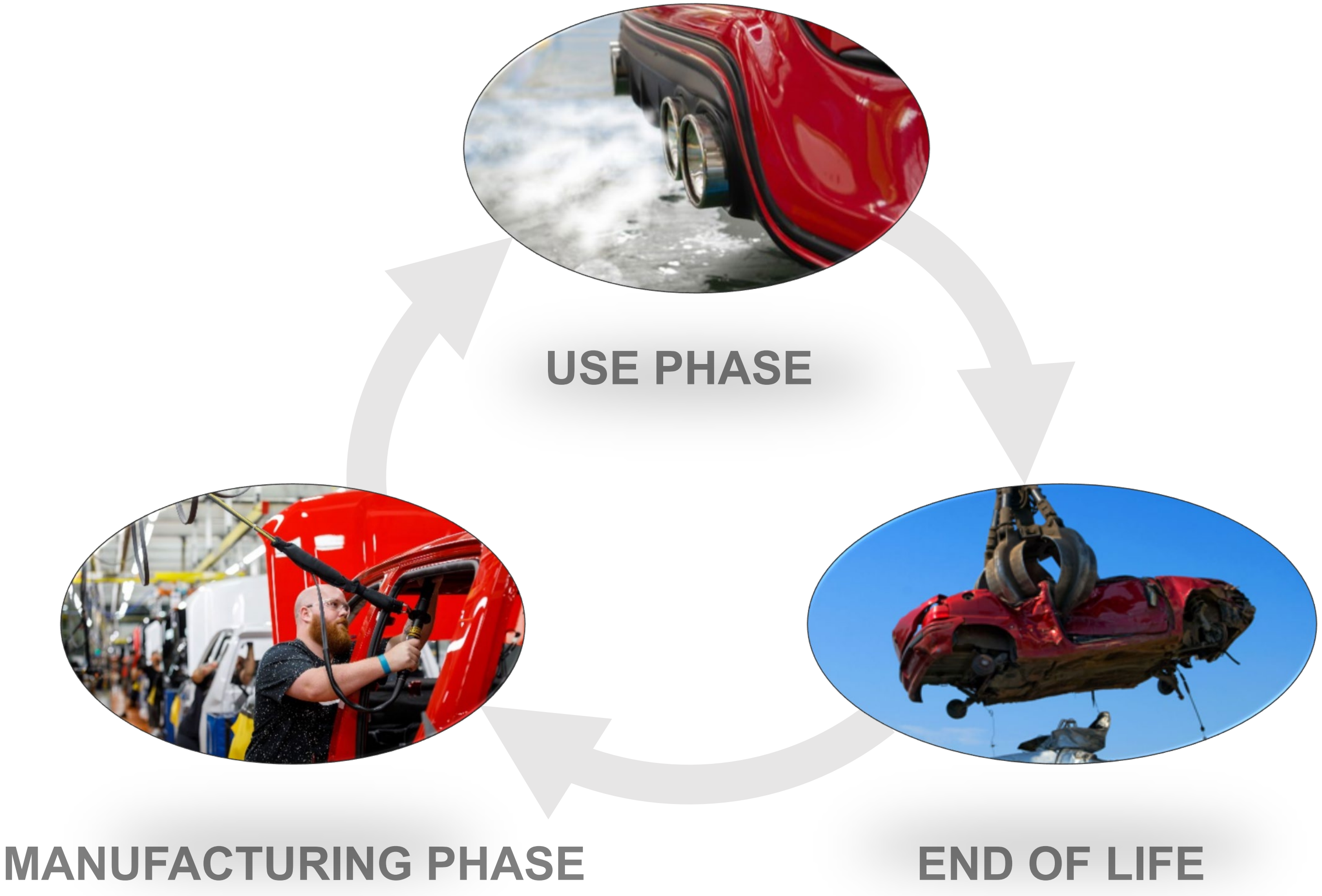
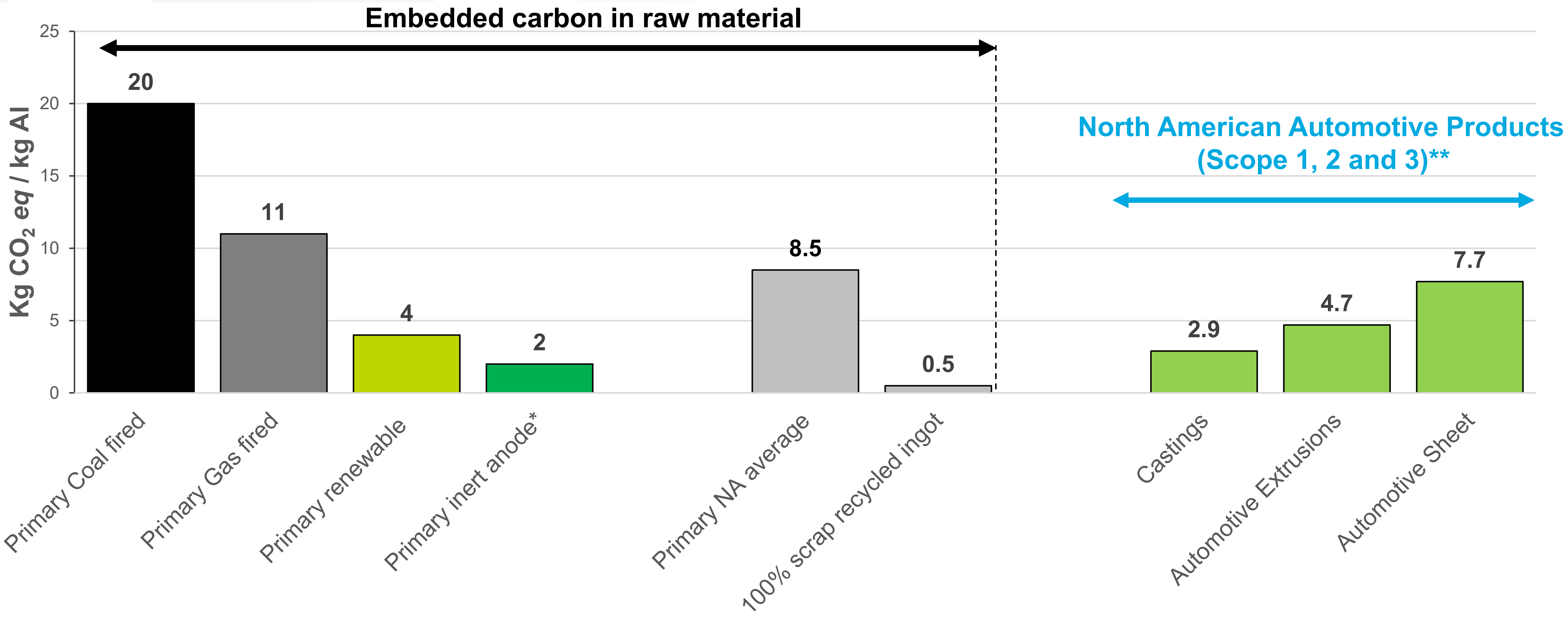
Life Cycle Analysis vs Tailpipe emissions



- Until now fuel economy legislation and public focus has been on **use-phase tailpipe** emissions.
- Increasing share of zero emission vehicles – shift towards full **LCA impact on greenhouse gas emissions = CO_2 *eq***
- Emissions in **manufacturing phase, fuel cycle** and **end-of-life recycling** becomes increasingly important.

Sustainability – Carbon footprint

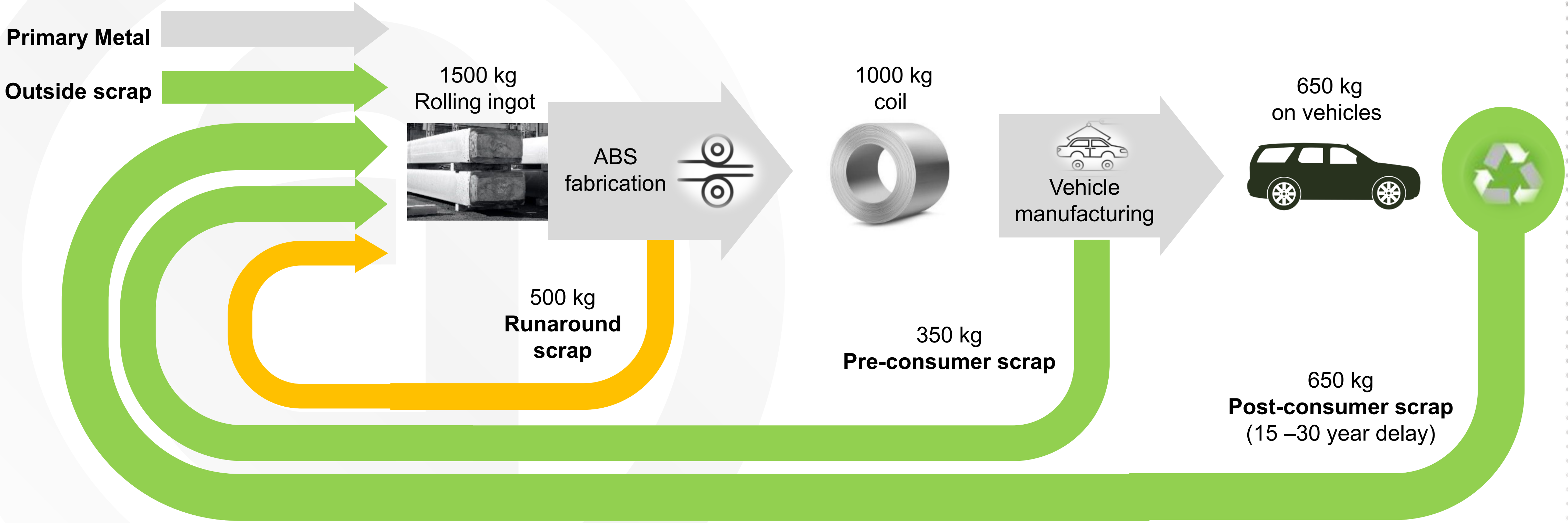
Due to the high energy need (electricity) for producing primary aluminum – the carbon footprint of aluminum vary hugely depending on the source. Recycling aluminum requires only a fraction of this energy.



* Estimated as products are under development

** AA LCA report 2022

Recycling of Aluminum ABS - Material flow

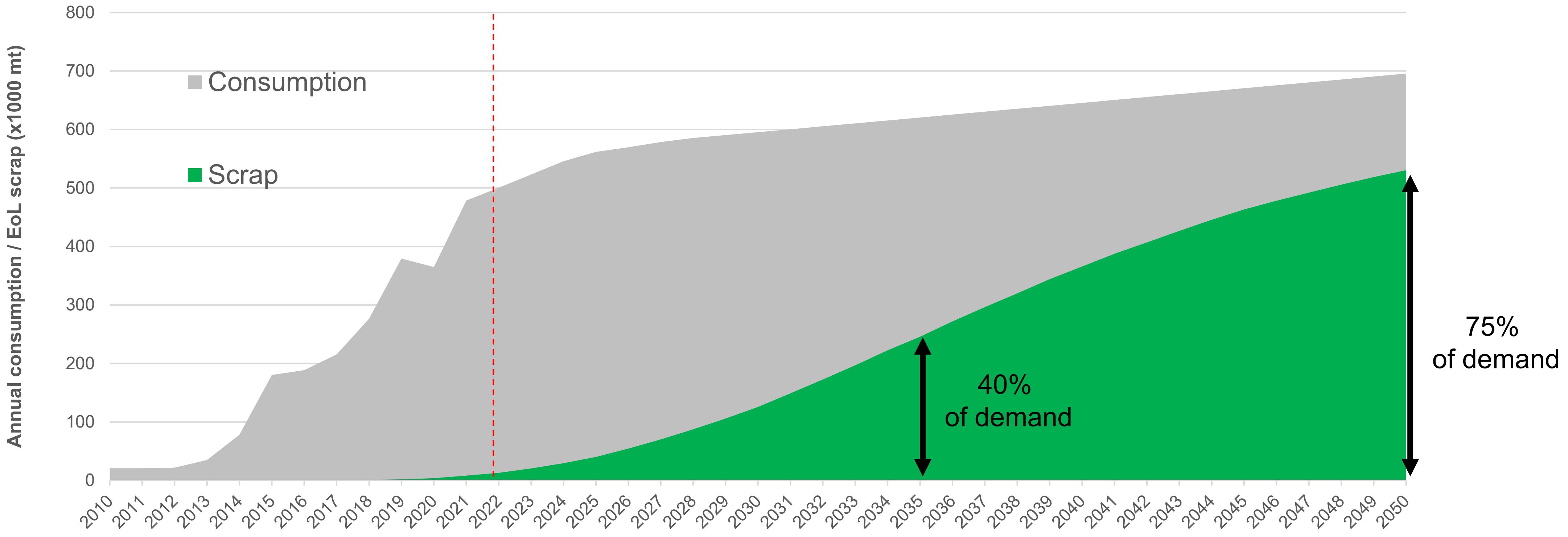


Pre-consumer = Blanking and stamping scrap. Current recycling rate very close to 100%, but used in a mix of "closed loop" where alloys are sorted and returned to mill to be recycled into same product and "open loop" where scrap is mixed with other scrap sources and used mainly in casting alloys.

Post-consumer = End-of-Life vehicle scrap. Current recycling rate also >95%, but low share of wrought alloy content due to vehicle life. Scrap is almost exclusively used in secondary castings for ICE powertrain.

The coming Wave of Aluminum Sheet Scrap

Aluminum ABS from the 1st gen vehicles are just starting coming back as scrap.
By 2035 the EoL scrap will meet **40%** of the NA auto industry demand and this share will rise to **75%** by 2050.



Adapted from UoM, Ford, LMC study: "The coming wave of aluminum sheet scrap from vehicle recycling in the United States" Resources, Conservation & Recycling 164 (2021)

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Aluminum BIW are Not New

1922 Ford Model T

Grumman LLV

US Postal delivery trucks began production in 1987

Vehicle design life was 24 years and was extended to 30 years in 2009

Next generation is also AIV design

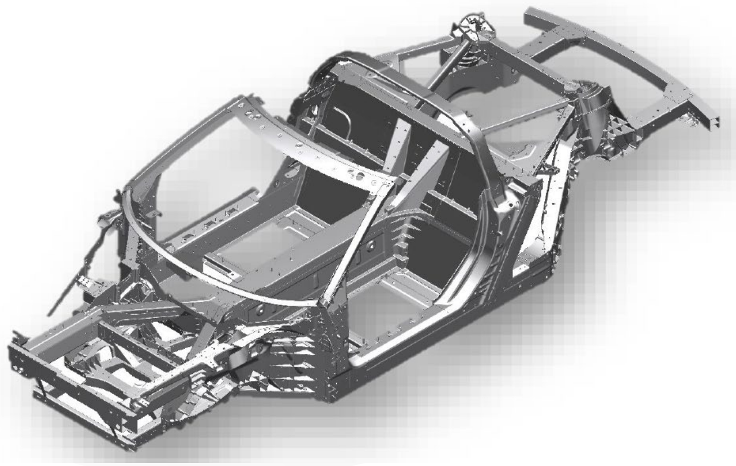
Acura NSX

All aluminum – 1990-2005

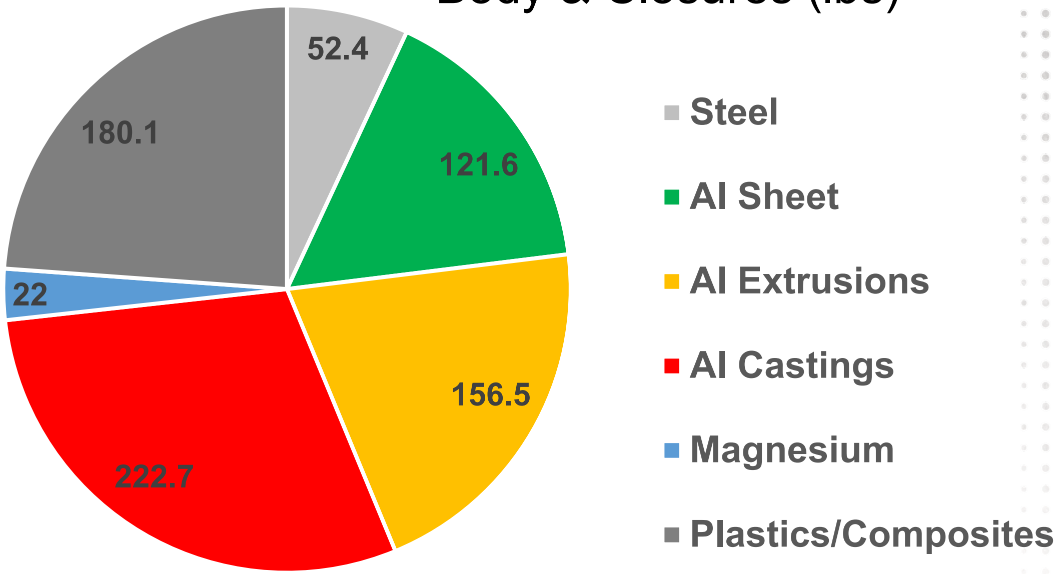
2016 – present
Multi-Material Space frame

Corvette

Aluminum / Multi Material Body Structure since 2006

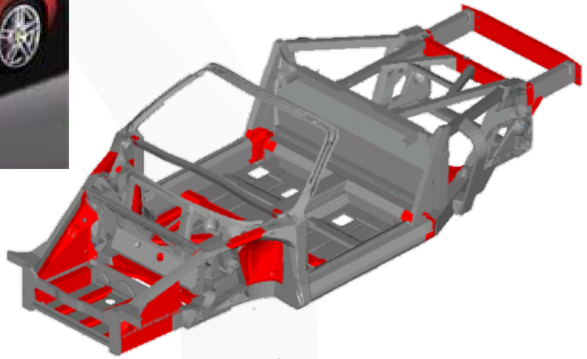


C8 Materials Composition
Body & Closures (lbs)



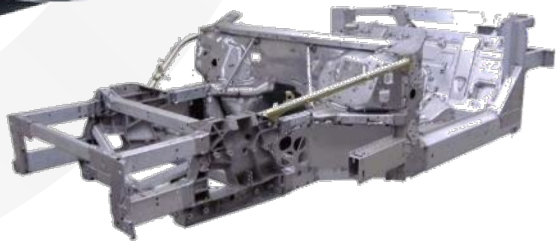
Ferrari/Lamborghini Aluminum Vehicles

Ferrari 430
Aluminum since 1998



Lamborghini Gallardo
Aluminum since 2003

Ferrari 599
Aluminum since 2003



Audi Mixed-Material Vehicles

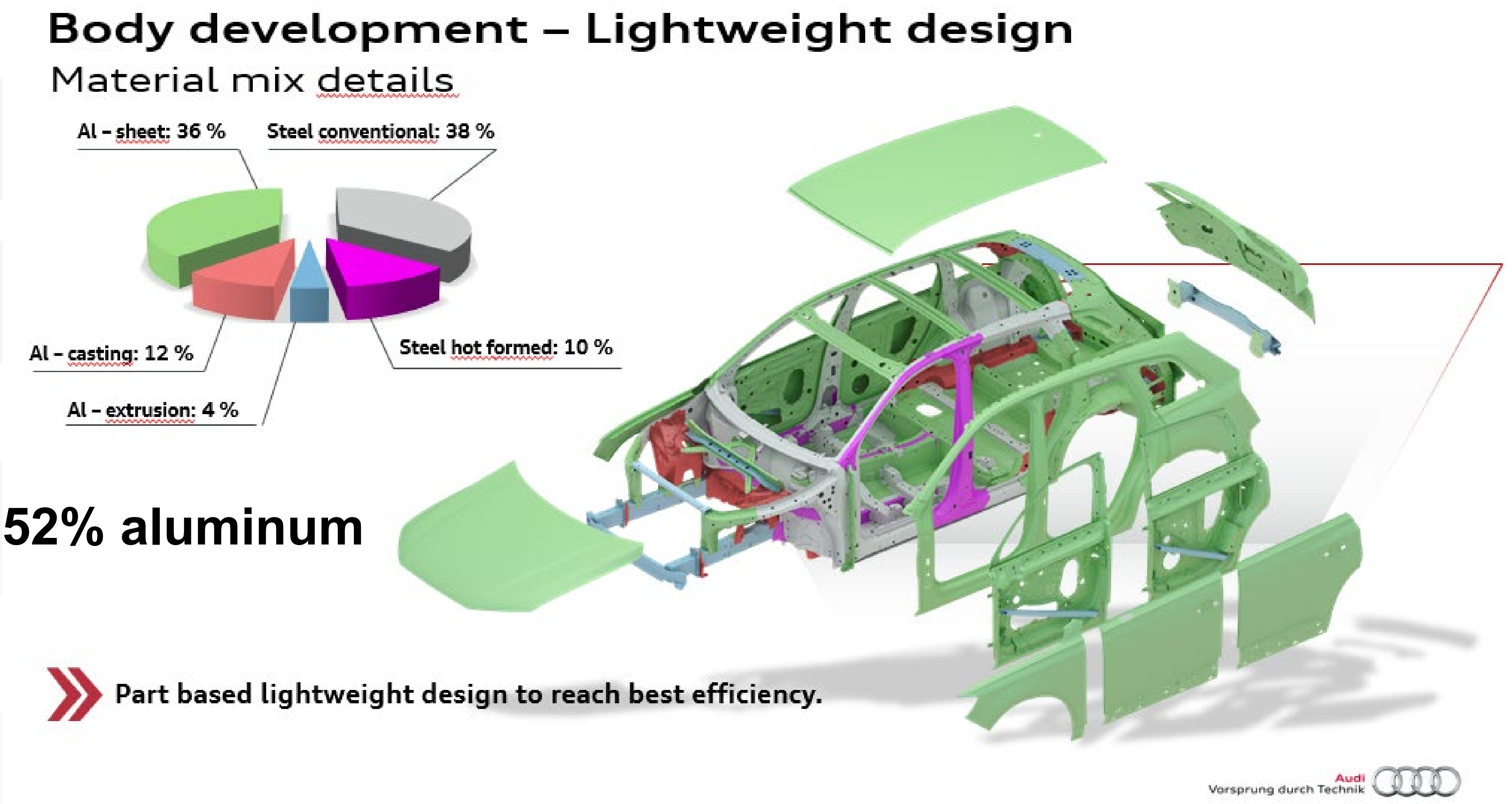
Audi A8
Aluminum since 1994

Audi A2
Aluminum 2000 - 2005

Audi TT
Aluminum since 2008 (hybrid steel/alum)

Audi R8
Aluminum since 2006

Audi Q7 – Hybrid Steel/Aluminum



48% steel / 52% aluminum

Jaguar/Land Rover Aluminum Vehicles

All Jaguar vehicles have aluminum BIW

Jaguar XJ
Aluminum since 2003

Jaguar XF
Aluminum since 2008

Jaguar F-Pace
Hybrid steel/aluminum

Jaguar XE
Aluminum since 2015

Jaguar F-Type
Aluminum since 2013

Jaguar I-Pace – Aluminum
2019 European Car of the Year

Range Rover


DRIVEALUMINUM
RANGE ROVER
The aluminum-bodied Range Rover has a reduced weight that is equivalent to the weight of five average adults.

2014 Steel F-150 and 2015 Aluminum F-150 Comparison

- **Ford F-Series is the best-selling vehicle in America**
- **Super Duty trucks (F-250, F-350, F-450) also in aluminum**

Supercrew with 5.5 ft box
Length = 5890 mm
Wheelbase = 3670 mm

	Steel 2014 F150 (kg)	Aluminum 2015 F150 (kg)	Wt. Savings (kg)	% Savings
Hood	10.9 (Alum)	10.6	0.3	3
Fenders	20	7.5	12.5	60
Tailgate	20	9.8	10.2	51
Doors (4)	85	47.6	37.4	44
Cab	283	158	125	43
Cargo Box	105	60	45	43
Total	524	294	231	44

Reference: EuroCarBody 2015, October 21-22, 2015, Bad Nauheim, Germany.

Aluminum Intensive Ford F-150 since 2015

2019 fuel economy (20/26 mpg) – 2WD 2.7 L Ecoboost (10 speed)
2019 fuel economy (22/30 mpg) – 2WD 3.0 L Diesel (10 speed)

Best in class cargo performance

700-890lbs lighter than 2014 steel model

America's best-selling vehicle for over 40 years

Upgraded to five-star safety rating:

2014 Steel F150 ★★★★☆ OVERALL SAFETY RATING

2015 Aluminum F150 ★★★★★ OVERALL SAFETY RATING

Contributed to CAFE improvement for first time

Ford Super Duty, Expedition, Lincoln Navigator – All Aluminum

2019 Silverado

Aluminum hood, doors and tailgate

2022 Toyota Tundra

Aluminum hood, fenders, front doors, bodyside and tailgate

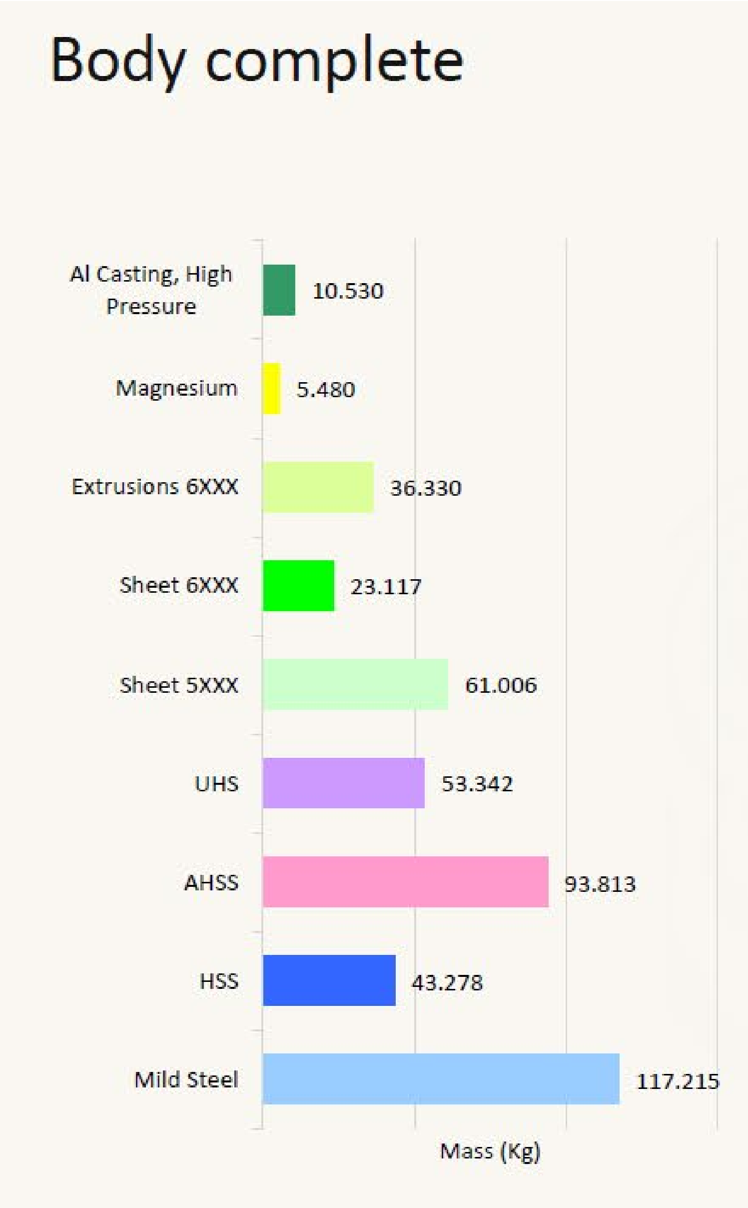
Jeep Wrangler and Gladiator

Aluminum hood and doors

Tesla Aluminum Vehicles

Model S

Rivian R1T



Source: IABC 2022

Commercial Vehicles - LMDV

Daimler Truck

Class 8 Cascadia cab
Aluminum since 1992

Business Class – M2 cab
Aluminum since 2001

Kenworth and Peterbilt Trucks

Class 8 Kenworth T680

Class 8 Peterbilt 579

Weight-Sensitive Trailers

Gasoline tankers

Dry bulk trailers

Weight-Sensitive Trailers

All aluminum flatbeds

Dry van and refrigerated trailers

Questions?

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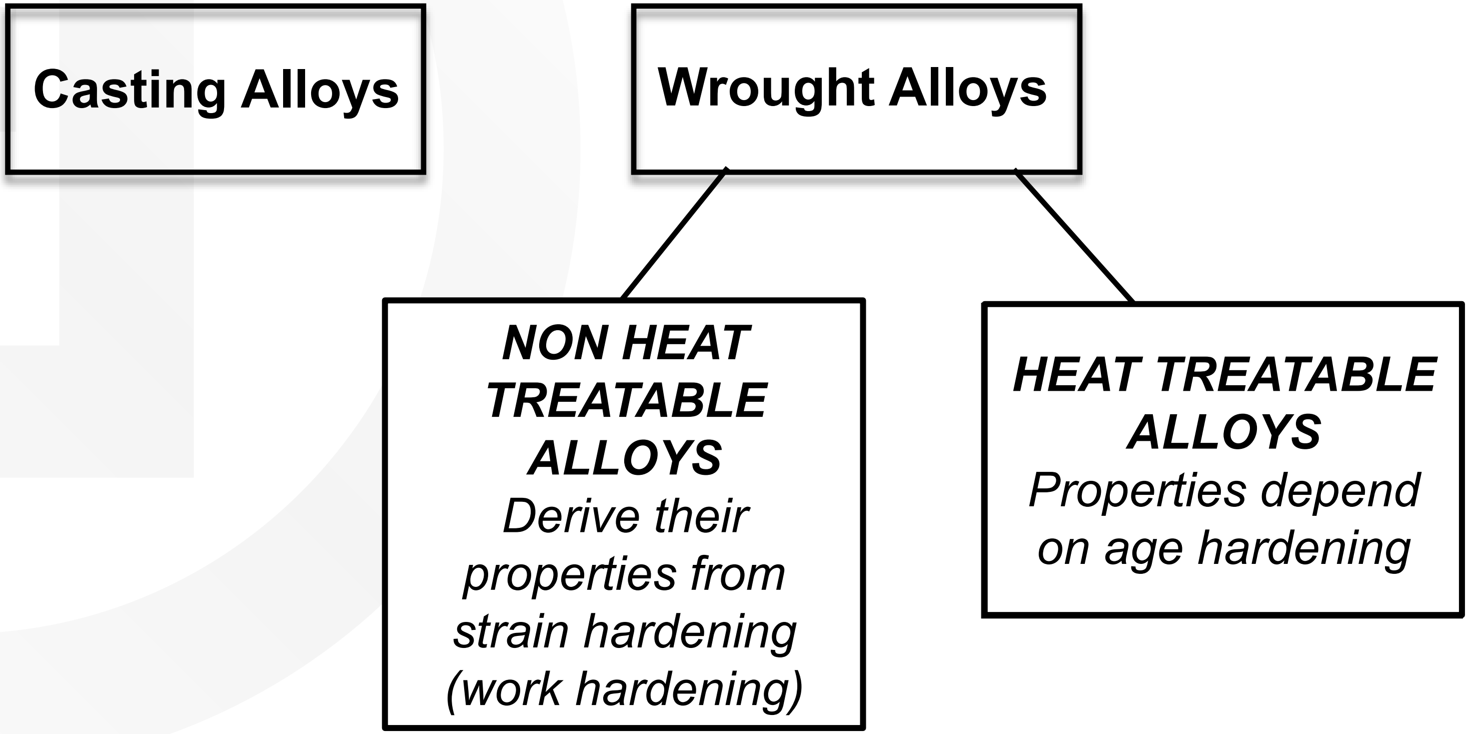
Aluminum Alloy Designations

The Aluminum Transportation Group

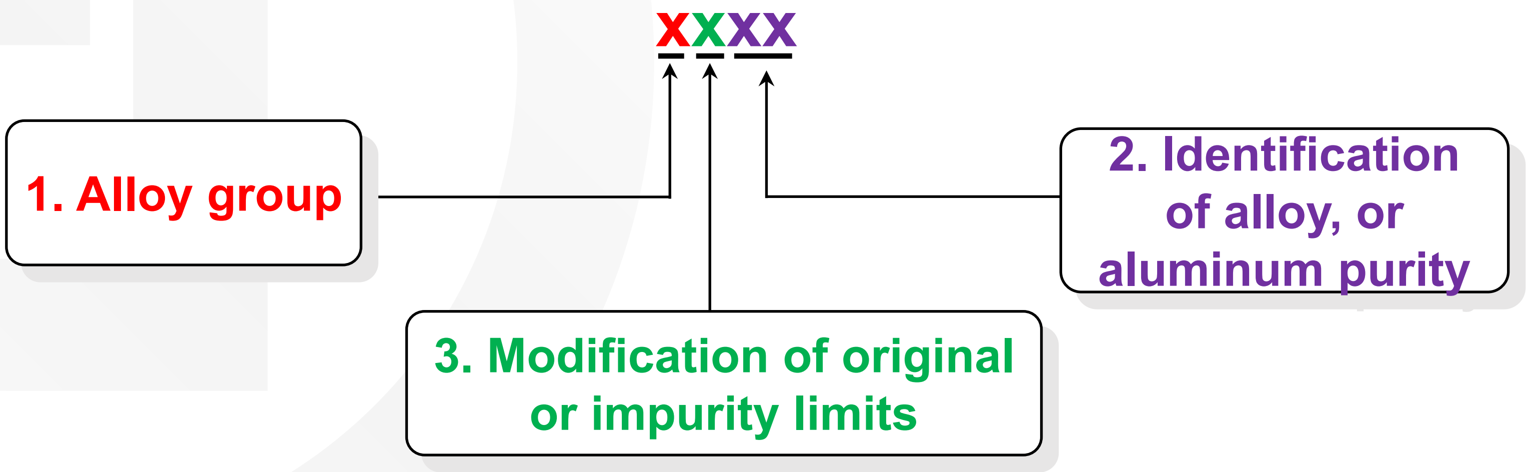
Aluminum Alloy Classifications

- Aluminum alloys are categorized by two main groups
- Wrought alloys are further divided into two subgroups



Aluminum Alloy Designation and Nomenclature

- The Aluminum Association system was adopted in 1954



Aluminum Alloy Designation and Nomenclature

1. Alloy group

xxxx

↓

1xxx at least 99.00% aluminum (Al)
2xxx main alloying element is copper (Cu)
3xxx main alloying element is manganese (Mn)
4xxx main alloying element is silicon (Si)
5xxx main alloying element is magnesium (Mg)
6xxx main alloying elements are magnesium AND silicon (Mg and Si)
7xxx main alloying element is zinc, Zn (usually also magnesium, Mg)
8xxx alloyed with other elements (e.g. Fe, Li)

Non-heat treatable alloys
Heat-treatable alloys
The ‘catch all’ (mainly NHT, but some HT alloys also)

Why So Many Alloys?

- Aluminum Alloy Development
- Answer: “Suitability for use”
  - Strength
  - Formability
  - Corrosion resistance
  - Toughness
  - Etc…
- Pure/commercially pure aluminum (1xxx) has many attractive properties and is used in many applications, but we add elements (alloying) to enhance properties, especially strength
- Blending the mixture of added elements (‘alloying’) can furnish the optimum combination of properties for the application (further enhanced by processing)

AA Temper Definitions

1050-O

3003-H24

6111-T4

5052-H32

7075-T6

Temper

AA Temper Definitions

Heat Treatable Alloy: "T" - tempers

"An alloy which may be strengthened by a suitable thermal treatment" 2xxx, 6xxx, 7xxx are heat-treatable. Examples: 2024-T3, 6061-T6

Non-Heat Treatable Alloy: "H" - tempers

"An alloy which can be strengthened only by cold work" 1xxx, 3xxx, 5xxx, and some 8xxx are non-heat-treatable. Examples: 3003-H19, 5052-H32

Basic Temper Designations

F	As-Fabricated (e.g. as-hot rolled, as-cold rolled)
O	Fully Annealed
Hxx	Strain-Hardened (NHT wrought products only)
W	Solution Heat-Treated (HT) and quenched (unstable)
Tx	Thermal Treatment (HT)

F, O, and W are single digit temper designations, e.g. 6061-O, 7075-W, 3004-F

The H and T tempers have two or three further digits (and sometimes more) to describe the temper

Aluminum Alloy Temper Nomenclature: Non-Heat-Treatable Alloys

Most of these temper designations are in the form:

Hxx

Strain hardened temper → H

Condition → first x
- 1 = Strain hardened only
- 2 = Strain hardened and partial annealed
- 3 = Strain hardened and stabilized
- 4 = Strain hardened and lacquered or painted

Strength level → second x
- 2 = Quarter hard
- 4 = Half hard
- 6 = Three quarters hard
- 8 = Full hard
- 9 = Extra hard

The 'T' Tempers

- T1 cooled from an elevated temperature shaping process and naturally aged to a substantially stable condition.
- T2 cooled from an elevated temperature shaping process, cold worked, and naturally aged to a substantially stable condition.
- T3 solution heat-treated, cold worked, and naturally aged to a substantially stable condition.
- T4 solution heat-treated and naturally aged to a substantially stable condition.
- T5 cooled from an elevated temperature shaping process and then artificially aged.
- T6 solution heat-treated and then artificially aged.
- T7 solution heat-treated and overaged/stabilized.
- T8 solution heat-treated, cold worked, and then artificially aged.
- T9 solution heat-treated, artificially aged, and then cold worked.
- T10 cooled from an elevated temperature shaping process, cold worked, and then artificially aged.

Other digits may be added to signify additional processing:
e.g. Tx<u>51</u> Stress-relieved by <u>stretching</u>

OEM Specific Designations

- Most Auto OEMs purchase to one of their internal specifications
- For example: Ford

Ford Spec	Typical Application	AA Designation
6EH	6xxx outer panel with enhanced hemming	6022, 6014, 6005
6DR1	6xxx exterior or interior	6022, 6451, 6005
6HS2	6xxx high strength	6111
6ST1	Alternative high strength	6061
5HF	5xxx High form	5182
5ST	5xxx standard	5754

OEM Specific Designations

- Most Auto OEMs purchase to one of their internal specifications
- For example: GM

GM Spec	Typical Application	AA Designation
Al-S-6000-S-90	6xxx exterior or interior	6022, 6014, 6016
Al-S-6000-IBR-100	6xxx exterior or interior– improved paint bake	6022, 6016, 6451
Al-S-6000-IH-90	6xxx exterior enhanced hemming	6014, 6016, 6022
Al-S-6000-HS-115	Alternative high strength	6111
Al-S-6000-R-110-U	6xxx reinforcement	6022-T4, 6016-T4
Al-S-5000-S-110	5xxx High form	5182
Al-S-5000-RSS-100	5xxx High form – reduced stretcher strain	5182
Al-S-5000-ST-90-90	5xxx Standard	5754, 5454

Questions?