DUCKERFRONTIER

2020 NORTH AMERICA LIGHT VEHICLE ALUMINUM CONTENT AND OUTLOOK

FINAL REPORT SUMMARY: July 2020

Prepared for

The Aluminum Association

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INTRODUCTION AND METHODOLOGY

INTRODUCTION AND METHODOLOGY

DUCKERFRONTIER & ALUMINUM ASSOCIATION PROJECT

- The Aluminum Association Auto & Light Truck Group (ATG) commissioned DuckerFrontier in October 2019 to determine the latest aluminum content in terms of net pounds per vehicle by vehicle and in aggregate for light vehicles produced in North America in CY 2019 through CY 2026. After 2026, DuckerFrontier agreed to provide a range of future aluminum scenarios based on current and anticipated EPA and CARB emission mandates

DATA AND INFORMATION SOURCES

- DuckerFrontier determined that in addition to our methodology of gathering the latest information and opinions on the future from our extensive internal database and network of OEMs and their suppliers, we would use all the latest data available from NHTSA, EPA and other published sources to establish an independent view of what the technology paths imply about weight savings by OEM, vehicle type and even specific vehicles through 2026
- The theoretical or top down analysis relies primarily on reports and databases provided by the EPA, NHTSA and CAR with insights and input from industry respondents throughout the supply chain with commentary on aluminum use out to 2030

PROCESS, GOALS, AND OBJECTIVES

- The goal of the top down analysis was to determine the weight savings* and material mix solutions implied by the latest government reports and their supporting documents and databases. The top down analysis examined the effect of fuel prices, vehicle mix, secondary weight savings, electrification, vehicle design, cost per pound saved, and vehicle launch cadence on the amount of weight that is expected to be shed by vehicle type to improve light vehicle emissions by 89 to 108 real world grams per mile from 2018 - 2026
- The top down analysis is not an attempt to predict what each OEM will do to meet the regulations. It provides a framework of what the regulators believe the OEMs could do to meet the regulations in the safest and most cost effective manner in the time period 2018 – 2026. The analysis will only show what the OEMs are most likely to do to meet the regulations. Vehicle segment analysis and where possible, specific vehicle weight savings are the key to the success for both the top down and bottom up analyses. After 2023, however, individual aluminum content for new vehicles is determined primarily from a ‘what is needed’ assessment
- The regulation driven weight reduction goals vary by type of vehicle and by OEM. Pickup trucks, large cars and SUVs, minivans and electric vehicles will bear most of the light weighting burden. Electrification is the primary area of focus for understanding aluminum use for both EVs and ICE vehicles going forward

**All weight savings references in the report are the direct savings from material substitution. Under the assumption that weight creep increases and secondary weight savings and engine resize weight decreases offset each other, the material sum after substitution is the equivalent of curb weight*

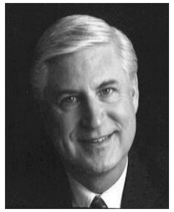
WORKING GROUP

Profiles of the DuckerFrontier team members involved in the study

Abey Abraham

Managing Director

Abey leads DuckerFrontier’s Automotive and Materials Practice and oversees 40+ engagements annually specific to M&A, strategy, transportation and materials verticals. Abey has extensive research and strategic planning expertise in metal materials and materials forming across multiple industry verticals. With over 12 years at Ducker Frontier, Abey has extensive experience in technology trend assessment, customer voice, market size and segmentation, and data modeling. Abey has managed global teams, and presented automotive lightweighting and EV conversion insights to numerous global audiences and has been interviewed for several automotive and international trade journals and publications



Richard Schultz

Material Consultant

As a consultant within DuckerFrontier’s automotive and materials practice, Mr. Schultz is widely recognized as one of the world’s leading experts in aluminum technology applications. Mr. Schultz holds a Bachelor of Science in Metallurgical Engineering from the University of Cincinnati and a Master of Business Administration from the University of Pittsburgh. Prior to joining DuckerFrontier, Mr. Schultz is a past President of Automotive Structures and a past Director of Worldwide Automotive Products for Arconic

Bertrand Rakoto

Senior Engagement Manager

Bertrand leads automotive market intelligence projects for DuckerFrontier. His expertise lies in market forecast, product strategy, new mobility technologies, and aftermarket parts and service solutions with almost 20 years experience in the automotive industry. Prior to joining DuckerFrontier, Bertrand held positions in market intelligence at original equipment manufacturer (OEM), Tier 1 &2 suppliers and consulting firms. Often quoted by international media, he is a member of the Society of Automotive Analysts (SAA), editor for the Society of Automotive Engineers (SAE), columnist for several automotive media, and published author. Bertrand holds a MBA from Cleveland State University

James Murphy

Senior Engagement Manager

James is a senior engagement manager at DuckerFrontier and leads global project teams across various industries. His expertise includes electric vehicles, tooling, food manufacturing, supply chain mapping, market opportunity analysis, and industrial diligence. Prior to joining DuckerFrontier, James was a senior manager at Harbour Results, Inc. and an operations team leader and financial analyst at General Mills. He is also a member of the Society of Automotive Analysts (SAA). James holds a bachelor’s degree in industrial technology from Purdue University and a Master of Business Administration from Indiana University Bloomington

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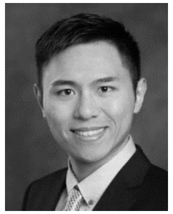


Leonard Ling

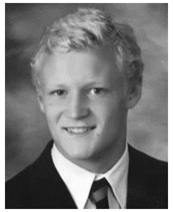
Senior Analyst

As a senior analyst with DuckerFrontier, Leonard is responsible for conducting in-depth, industry-specific research to support client engagements. His expertise lies primarily in the automotive and metal industry. Prior to joining DuckerFrontier, Leonard was a project consultant for The Dow Chemical Company and a category purchaser for Continental. He holds a bachelor’s degree in logistics management from East China University of Science and Technology and a master’s degree in business analytics from Michigan State University

Matt Merta

Senior Researcher

Matt is a senior researcher for DuckerFrontier’s market intelligence team. He works in primary based–fieldwork and market analysis by supporting the fact-finding efforts for various projects. Prior to joining DuckerFrontier, Matt was a customer resolution and retention remarketing coordinator for Modis International/Volkswagen Group of America. He holds a bachelor’s degree in education from Wayne State University



Joseph Dudley

Senior Researcher

Joe is a senior researcher for DuckerFrontier’s market intelligence team. Joe conducts primary research and market analysis, primarily in the automotive industry material research with experience at various projects on casting, extrusions and aluminum production and recycling. Prior to joining DuckerFrontier, Joe held a sales position at Navy Pier, Inc. He holds a bachelor’s degree in economics from Michigan State University

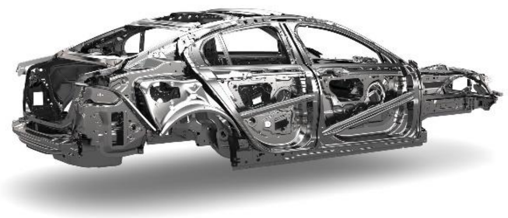
DEFINITIONS AND ACRONYMS

ACRONYMS

AA	Aluminum Association
ABS	Automotive Body Sheet
AEC	Aluminum Extruders Council
AL	Aluminum
AHSS	Advanced High Strength Steel
AISI	American Iron and Steel Institute
ATG	Aluminum Transportation Group
B&C	Body-in-White & Closures
BEV	Battery Electric Vehicle
BIW	Body-in-White
CARB	California Air Resources Board
CFRP	Carbon Fiber Reinforced Polymers
CY	Commercial Year (relates to sales)
EIA	Energy Information Administration
EPA	Environmental Protection Agency
EV	BEV & PHEV (excludes FHEV)
FCST	Forecast
FCEV	Fuel Cell Electric Vehicle
FHEV	Full Hybrid Electric Vehicle - No Charging Plug
FRP	Aluminum Flat Rolled Product (see ABS)
FMVSS	Federal Motor Vehicle Safety Standards
HSS	High Strength Steel
HT	Solution Heating and quenching
IIHS	Insurance Institute for Highway Safety
MHEV	Mild Hybrid Electric Vehicle (48V)
MPG	Miles Per Gallon
MY	Model Year
NHTSA	National Highway Traffic Safety Administration
PHEV	Plug-in Hybrid Electric Vehicle
PPV	Pounds per Vehicle averaged on the total production
PWT	Powertrain (engine, motor, transmission)
SAE	Society of Automotive Engineers
UHSS	Ultra High Strength Steel

PARTS CATEGORIES DEFINITIONS

Platform parts (formerly structural)	Platform category considers body-in-white parts and body closure, chassis, suspension and frame parts
Component parts (formerly non-structural)	Component parts consider mostly powertrain, driveline, transmission, trim and heat exchangers



Source: DuckerFrontier

LIST OF APPLICATION

Aluminum applications are classified into 2 categories (platform and component) and 13 groups. Platform Parts are at the heart of the aluminum content puzzle – they drive the content changes on a year to year basis. Component Parts are the building blocks to the aluminum content story; historically, and for the foreseeable future, these parts provide a foundation of content. Within a component group, the focus has been set on select main AL components

Sample displayed in this report

Platform-Parts

Closure	Hood
Closure	F/R Doors
Closure	Fender
Closure	Roof
Closure	Tailgate/Trunk
BIW	Crash Management System(CMS)
BIW	Pillars
BIW	Instrument panel structures
BIW	Radiator support
BIW	Door sills/rockers
BIW	Windshield frame
BIW	Shock tower
BIW	Cross beam
BIW	Tunnel
BIW	Roof bow
BIW	F/R longitudinal
BIW	Truck bed rail
BIW	Front end structure
BIW	Door beam
Chassis	Subframe/cradle
Chassis	Knuckle
Chassis	Control arms/links
EV	Battery housing

Component-Parts

Powertrain	Blocks
Powertrain	Cylinder heads
Powertrain	Oil pans
Powertrain	Intake manifolds
Powertrain	Pistons
Powertrain	Water pump housings
Powertrain	Alternator case
Powertrain	Fuel rails
Powertrain	Cam covers
Powertrain	Front covers
Powertrain	Timing chain covers
Powertrain	Bed plates
Powertrain	Mounts
Powertrain	Accessory brackets
Powertrain	Oil filter adapters
Powertrain	Thermostat housings
Powertrain	Water outlet tubes
Powertrain	Turbochargers
Powertrain	Starter motor housings
Driveline	Transmission mount
Driveline	Differential Carriers
Driveline	Drive shafts
Driveline	Yokes

Transmission	Automatic & CVT cases
Transmission	Manual transmission cases
Transmission	Manual clutch housings
Transmission	Extension covers
Transmission	Transfer cases/PTUs
Transmission	Brackets
Transmission	Valve-body Pistons
Transmission	Stators
Transmission	Valves
Transmission	Valve bodies
Transmission	Transfer plates
Heat Mgt.	Radiator
Heat Mgt.	Heater cores
Heat Mgt.	Transmission coolers
Heat Mgt.	Condensers
Heat Mgt.	Evaporators
Heat Mgt.	Compressors housings/ scrolls/ Piston
Heat Mgt.	Connection hardware
Heat Mgt.	Oil cooler
Heat Mgt.	Heat shield
Heat Mgt.	Heat sink
Heat Mgt.	Receiver/dryers

EV	Traction motor housing
EV	BMS/Converter housing
EV	Gearbox housing
EV	Battery Cables
Brake	Brake calipers
Brake	Master cylinders
Brake	Brake pistons
Brake	Anti-lock braking sys. housings
Steering	Column housings
Steering	Rack & pinion housings
Steering	Ball joint yokes
Steering	Tie Rod Ends
Wheel	Road wheel
Trim	Seat motor housings
Trim	Seat pans
Trim	Seat frames
Trim	Seat tracks
Trim	Seat belt spools/retractors
Trim	Sunroof motor housings
Trim	Sunroof rail
Trim	Airbag canisters
Trim	Computer/sensor housings
Trim	Overhead/luggage rails
Trim	Trims
Trim	Running boards
Trim	Wiper arms
Trim	Adjustment motor housings

STUDY HIGHLIGHTS

2020 HIGHLIGHTS

The aluminum content per vehicle continues its relentless growth for the foreseeable future as demand shifts towards light trucks and more electrified vehicles in the market mix utilizing more aluminum

1. The North American auto industry has recorded an average mass increase of 32 pounds per vehicle since 2016, primarily due to the recent market shift towards light trucks over smaller and lighter passenger cars. Aluminum content during the same period increased by 62 pounds per vehicle

2. Total aluminum content for 2020 is expected to reach 459 pounds per vehicle due to the increase in use of auto-body-sheet (ABS), and aluminum castings and extrusions, at the expense of conventional grades of steel

3. Although castings continue to account for the largest share of the average PPV, powertrain castings have declined in weight by 9 pounds per vehicle due to the past downsizing trend in the number of cylinders and displacement. The new trend turns toward partial conversion to PHEVs and BEVs to achieve CO_2 goals at fleet levels

4. The principal growth product for aluminum will be flat rolled sheet for ABS followed by platform aluminum high-pressure-die-castings. For example, aluminum hoods will grow from 50% penetration in 2016 to over 60% in 2020, while platform HPDC shock towers doubles penetration from 5% in 2016 to 10% in 2020

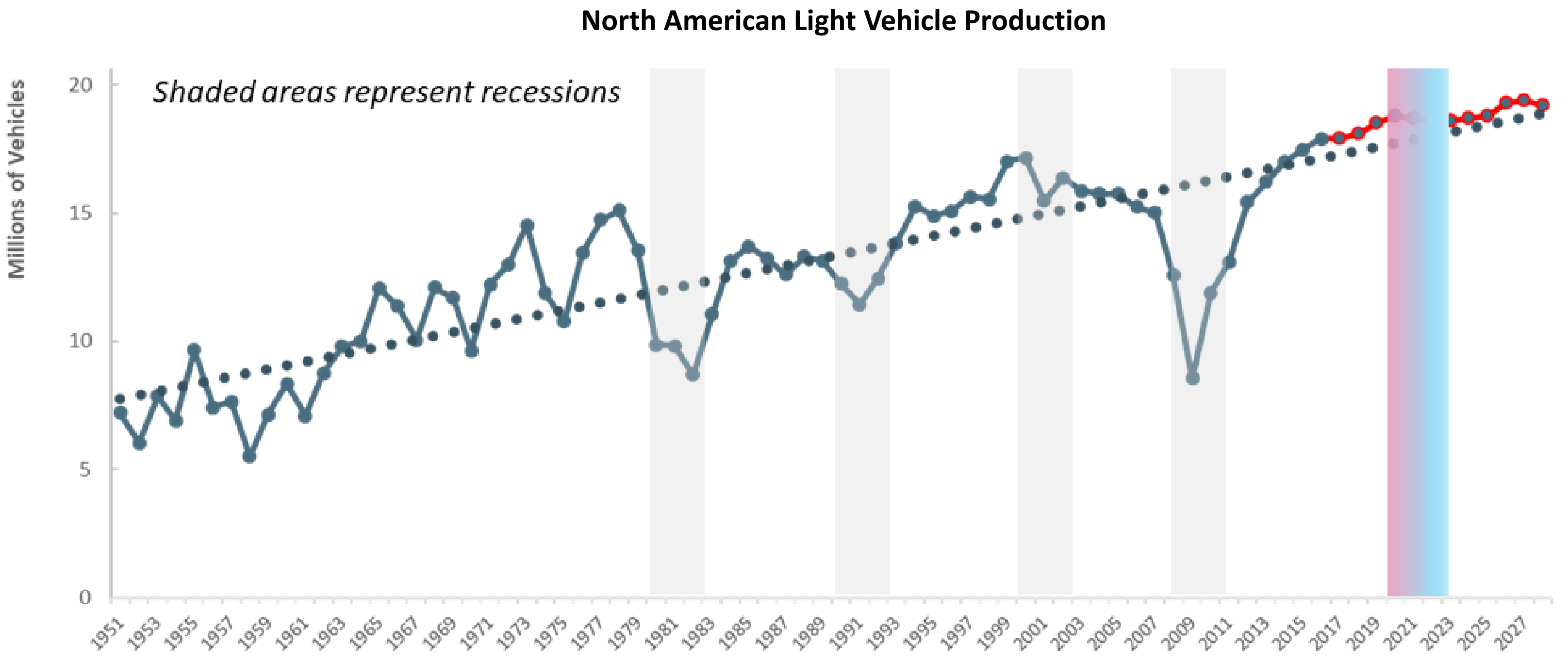
5. Aluminum extrusions and forgings have also recorded growth from 2016, with an increase of 4 PPV and 2 PPV respectively. There has been a 10% increase of vehicles utilizing extrusions for CMS applications in this time frame, a 7% increase in vehicles utilizing forged control arms as well as 2% growth of vehicles using forged steering knuckles

6. By 2026, net aluminum demand is expected to increase to 514 pounds per vehicle, due to penetration increases for all vehicles utilizing aluminum in closures, BIW and chassis to meet long range CO_2 goals as well as the ramp-up of electrified powertrain and BEV platforms that use greater amounts of aluminum sheet, extrusions, and castings for mass savings to achieve range targets

2020 HIGHLIGHT: MAJOR DISRUPTIONS AHEAD WITH COVID-19

Aluminum gross shipment calculations from 2020 to 2022 have been updated to reflect the new forecast including the COVID-19 March to May production stall. The market will remain unpredictable and uncertain at North American and Global levels due to factory temporary closings and weak demand. As of May 21st 2020, North American production volumes for 2020 are expected to be by 12.8 million units

- Although North American OEM light vehicle production volumes have historically shown contraction on a 10-15 year cycle, the unpredictable drop in production volume is due to COVID-19
- Based on discussions with our vehicle data provider, OEM and tier supplier respondents, and other experts, we believe production volumes from 2020 to 2022 will be impacted quite significantly, with some level of normalcy returning in 2023
- As the final production volume forecasts are not yet available, it will be nearly impossible to accurately forecast aluminum Gross Shipments from 2020 to 2022. After that period, gross shipment data estimates reach back the pre-COVID-19 forecast
- Due to the current and published long term forecast prices for oil and gasoline remaining low, we expect consumers to continue with their preference for SUVs and Pickup Trucks. Further, given the recent EPA announcements, do no predict any major deviations in material utilization strategies

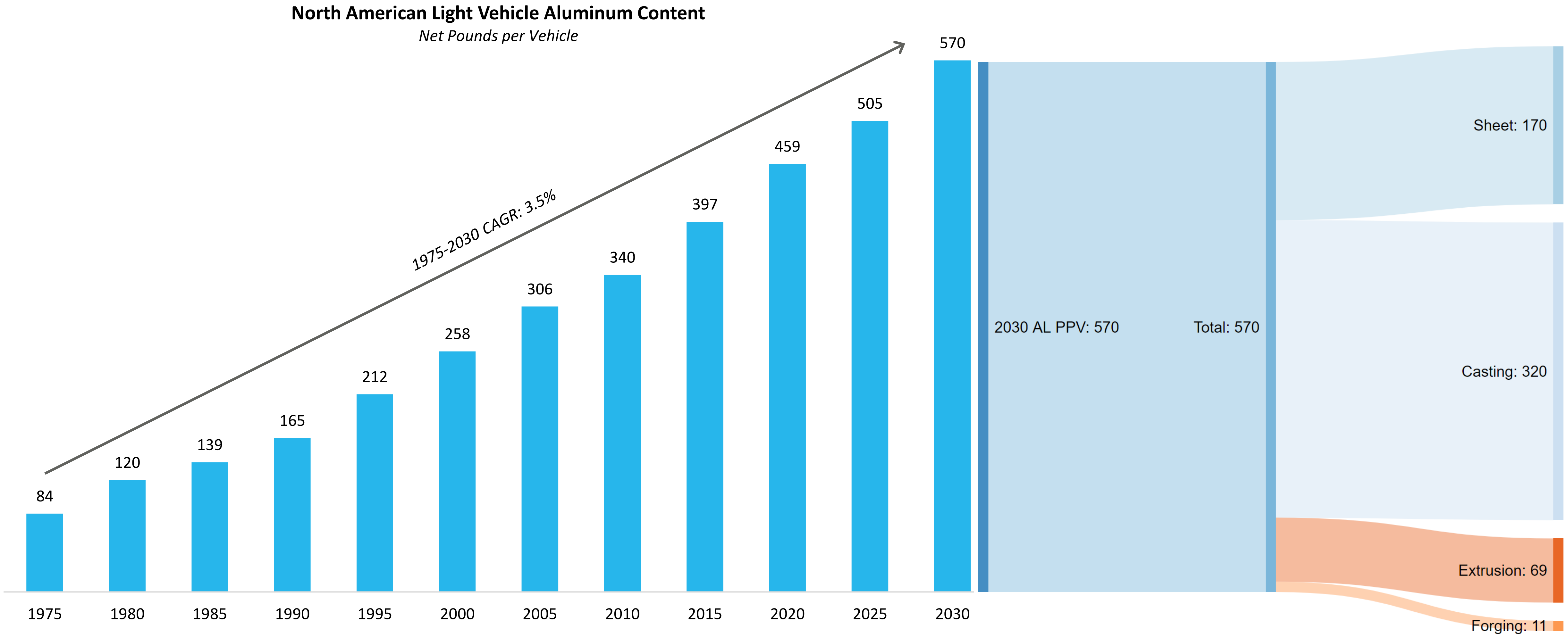


From 16.6 down to 12.8 million vehicle NA production forecast for 2020

Scenario 1: Optimistic	Scenario 2: Base-Line	Scenario 3: Pessimistic
Production resumes in spring 2020, production volumes dip by 10-15%	Production resumes in June 2020, COVID19 flare-up in other regions, disrupting supply chain for parts, production volumes dip by 15-20%	Extended production disruption at OEM and suppliers, productions volumes dip by >25-40%

LONG TERM ALUMINUM GROWTH

Automotive aluminum content continues to steadily grow within multiple product forms and vehicle applications



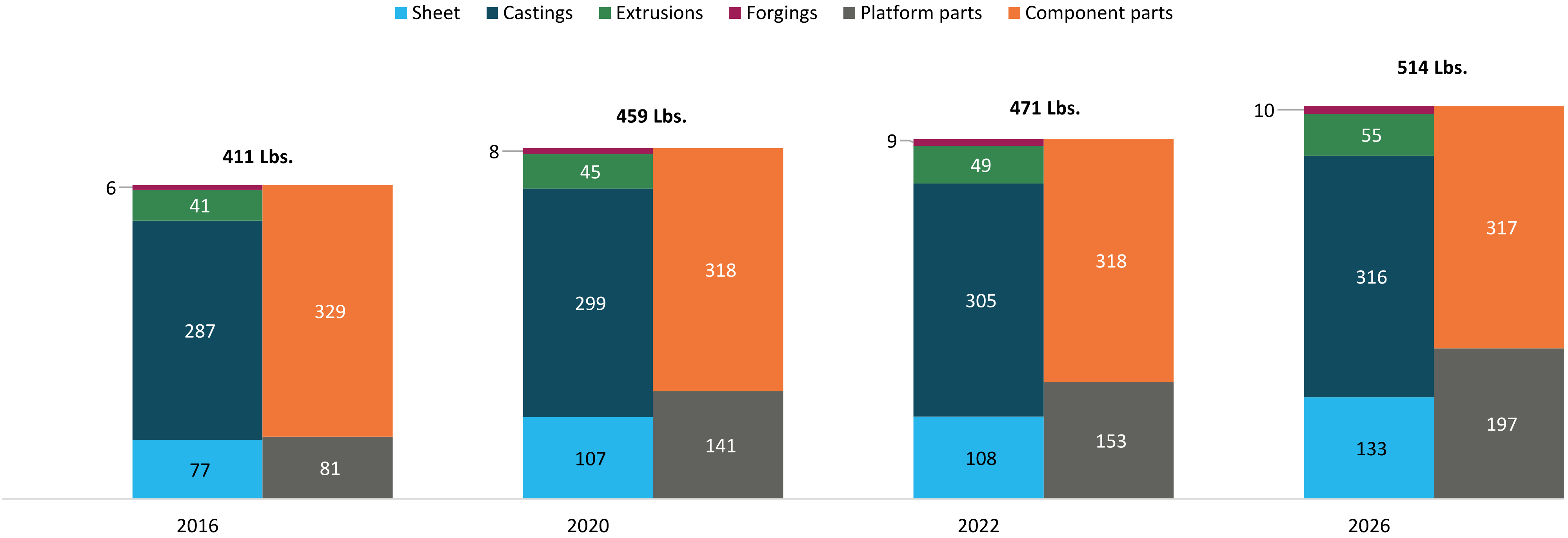
Source: DuckerFrontier April 2020

SHIPMENT BY PRODUCT FORMS

Total aluminum pounds per vehicle will increase from 411 lbs. in 2016 to 514 lbs. in 2026, resulting in over 10 billion pounds of total gross shipments. Sheet is one of the fastest growing product segments, rising from 77 lbs. in 2016 to 133 lbs. in 2026. Platform parts continue to displace component parts

Aluminum Content By Product Form And Parts Category

In PPV

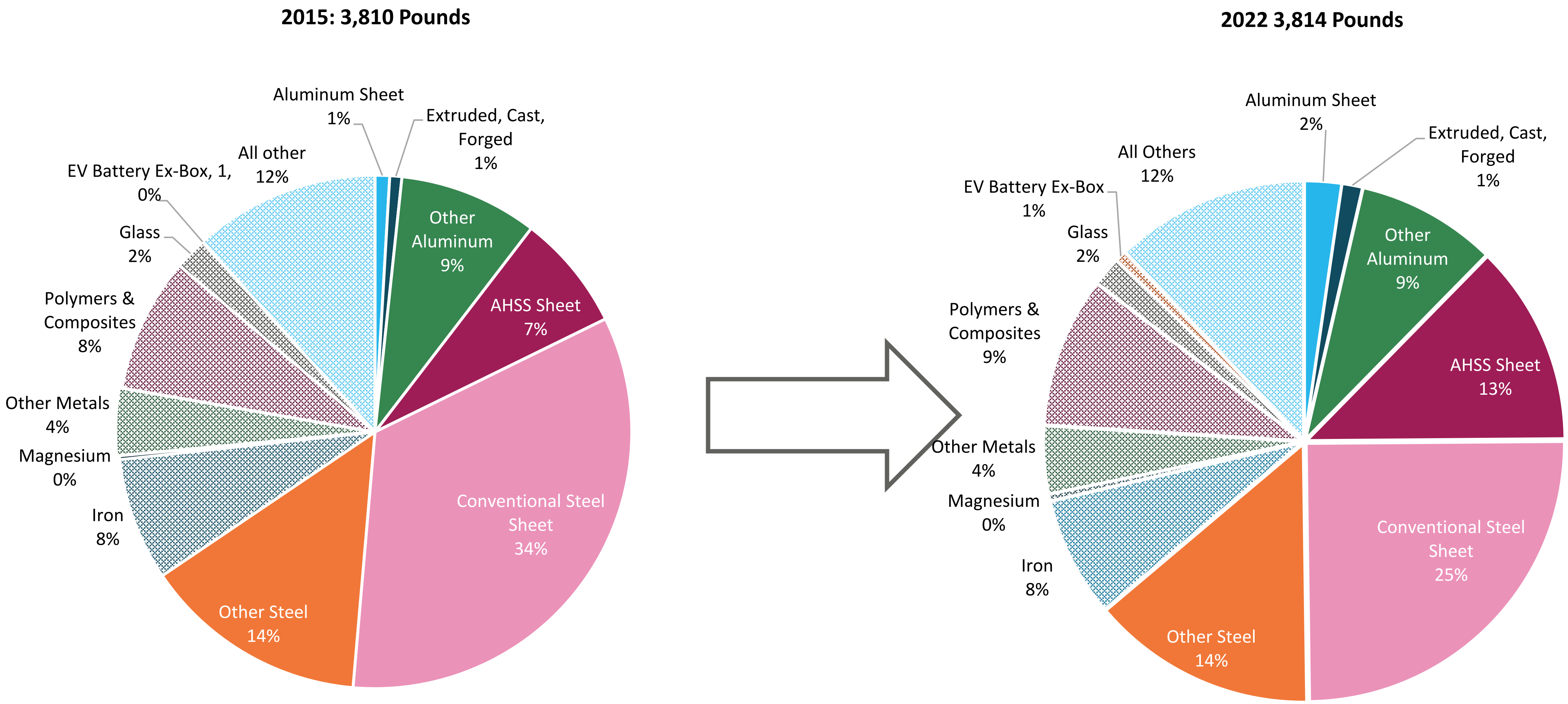


Product Forms	2016-2020 CAGR	2020-2022 CAGR	2022-2026 CAGR
Sheet	9%	1%	5%
Castings	1%	1%	1%
Extrusions	2%	4%	3%
Forgings	7%	6%	3%

Source: DuckerFrontier April 2020

ALUMINUM AND AHSS EXPANSION

Total aluminum content per vehicle grows from 397 lbs. in 2015 to 471 lbs. in 2022, nearly a 20% increase in aluminum content



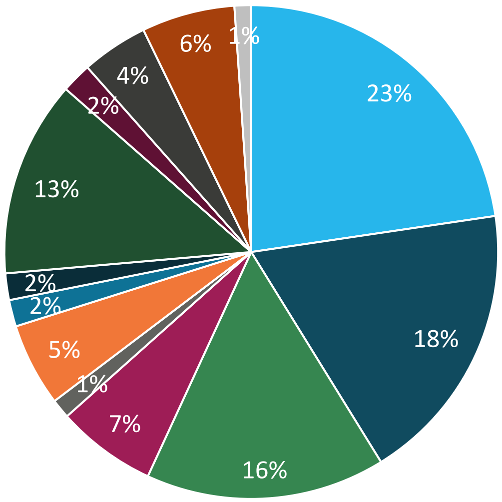
Source: DuckerFrontier

ALUMINUM CONTENT BY APPLICATION

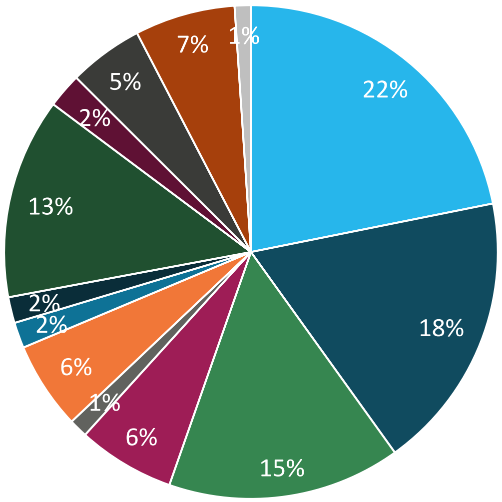
As closures and body structures continue to grow in aluminum penetration, suspension components are also projected to increase in share. Parts dedicated to battery electric vehicles (e.g. battery box, motor housing, converter housing, BMS housing, etc.) will also expand its use of aluminum to offset weight gain

System PPV	2016	2020	2022	2026
Engines	110	104	103	102
Transmissions & Drivelines	83	85	86	86
Wheels	65	72	72	73
Heat Exchangers	32	30	30	29
Heat Shields	6	6	6	6
Suspensions/Cradles/Subframes	21	25	27	37
Steering Components	8	8	8	8
Brakes	8	8	8	8
Closures	41	59	62	73
CMS	7	9	11	13
Body Stamping	11	20	23	33
Other Body	14	28	31	41
All others	5	5	5	5
Total	***411***	***459***	***471***	***514***

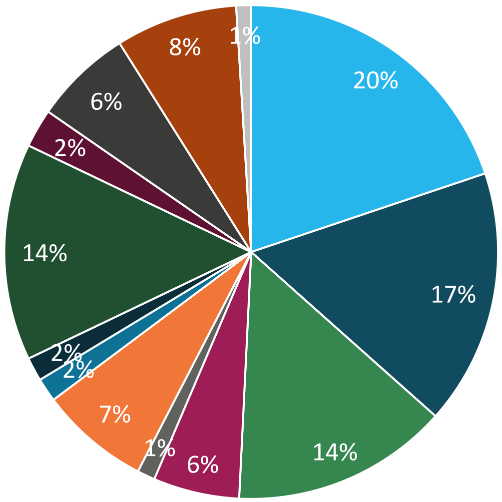
2020 | 459 LBS.



2022 | 471 LBS.



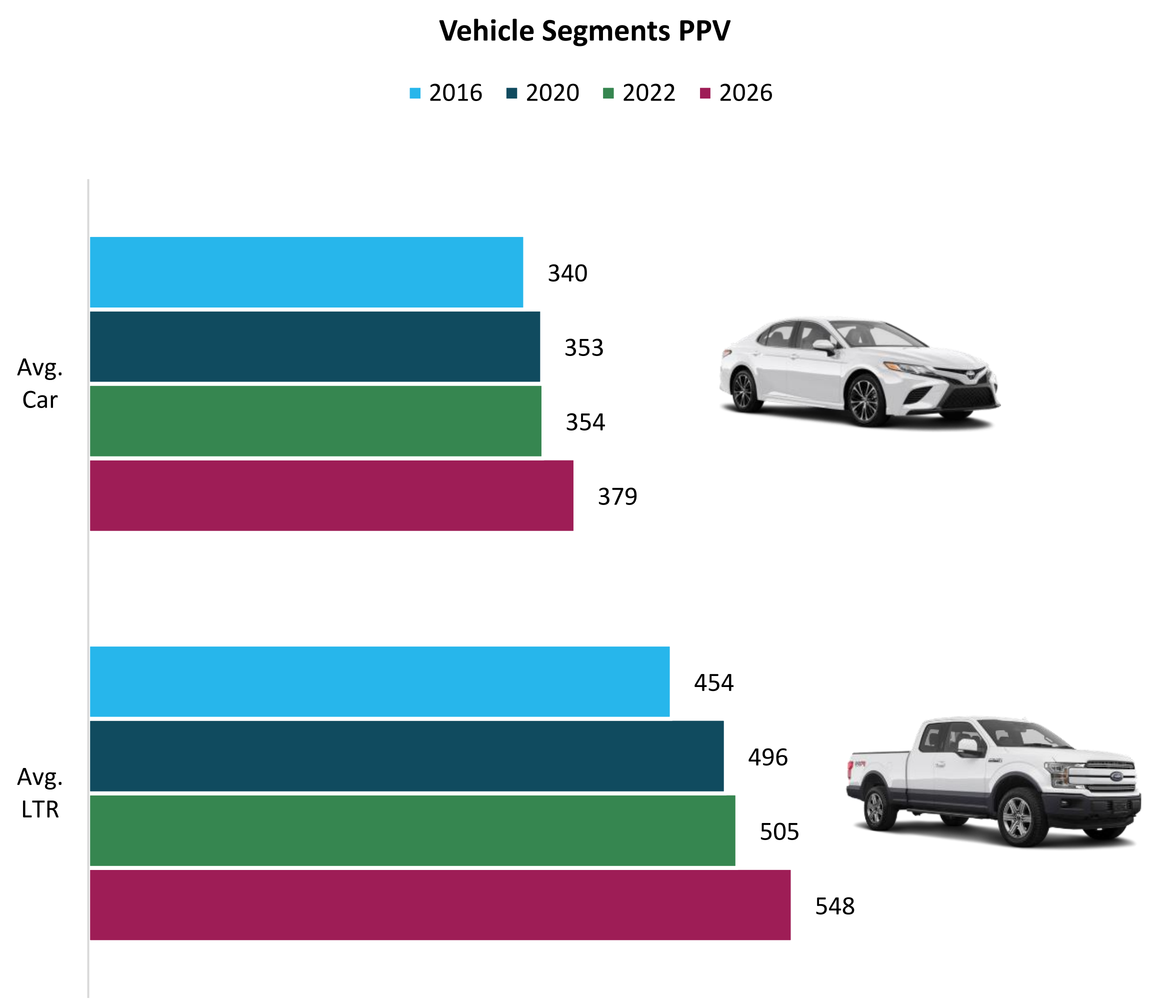
2026 | 514 LBS.



Source: DuckerFrontier April 2020

ALUMINUM CONTENT BY VEHICLE SEGMENT

Although light trucks are expected to have nearly 550 pounds of average aluminum content in 2026, E segment passenger cars like the Tesla Model S, and the Acura NSX will have over 800 pounds of aluminum content

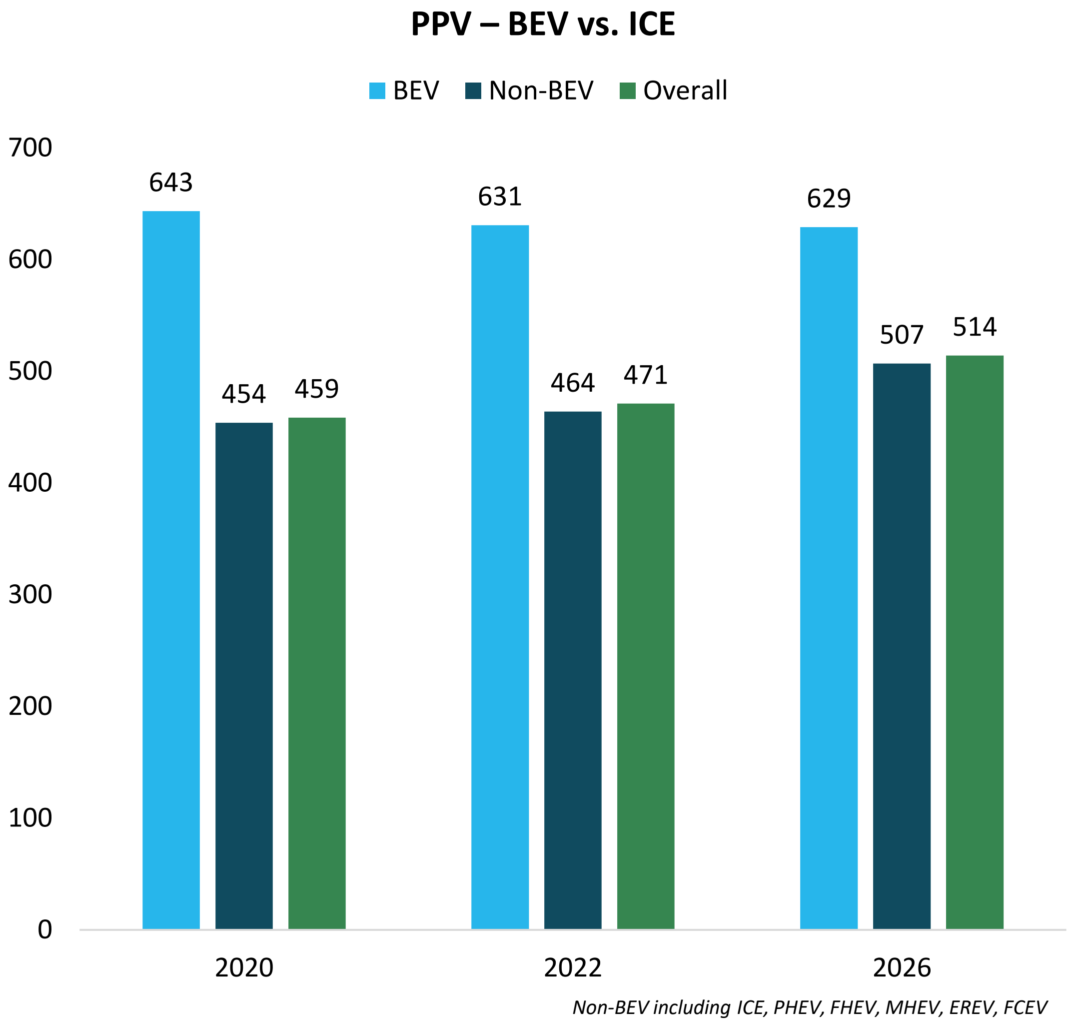


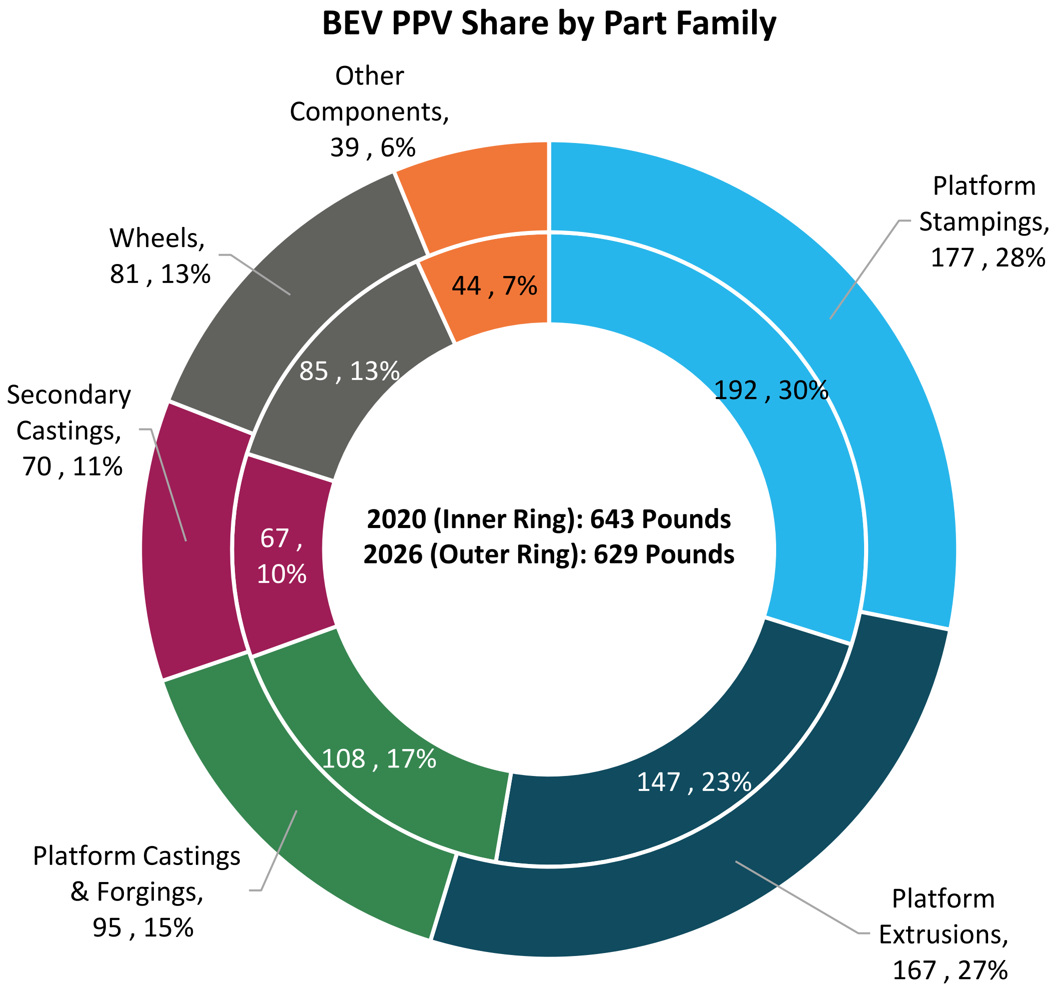
Segment	2016 PPV	2020 PPV	2022 PPV	2026 PPV
A Segment Car	297	304	N/A	N/A
B Segment Car	248	258	259	294
C Segment Car	285	270	278	288
D Segment Car	366	423	427	471
E Segment Car	537	519	626	834
Average Car	340	353	354	379
Segment	**2016 PPV**	**2020 PPV**	**2022 PPV**	**2026 PPV**
B Segment LTR	251	241	258	260
C Segment LTR	314	357	364	412
D Segment LTR	402	410	435	477
E Segment LTR	574	654	671	721
Average LTR	454	496	505	548
Segment	**2016 PPV**	**2020 PPV**	**2022 PPV**	**2026 PPV**
Total Average	411	459	471	514

Source: DuckerFrontier April 2020

BATTERY ELECTRIC VEHICLE ALUMINUM CONTENT

Although maintaining a lead over its ICE counterpart, BEV content will decline from 643 pounds in 2020 to 629 pounds in 2026, primarily due to the increasing share of lower segment BEVs. However, extrusions in BEVs are expected to grow, driven by battery housings, motor housings, body reinforcement beams, etc.





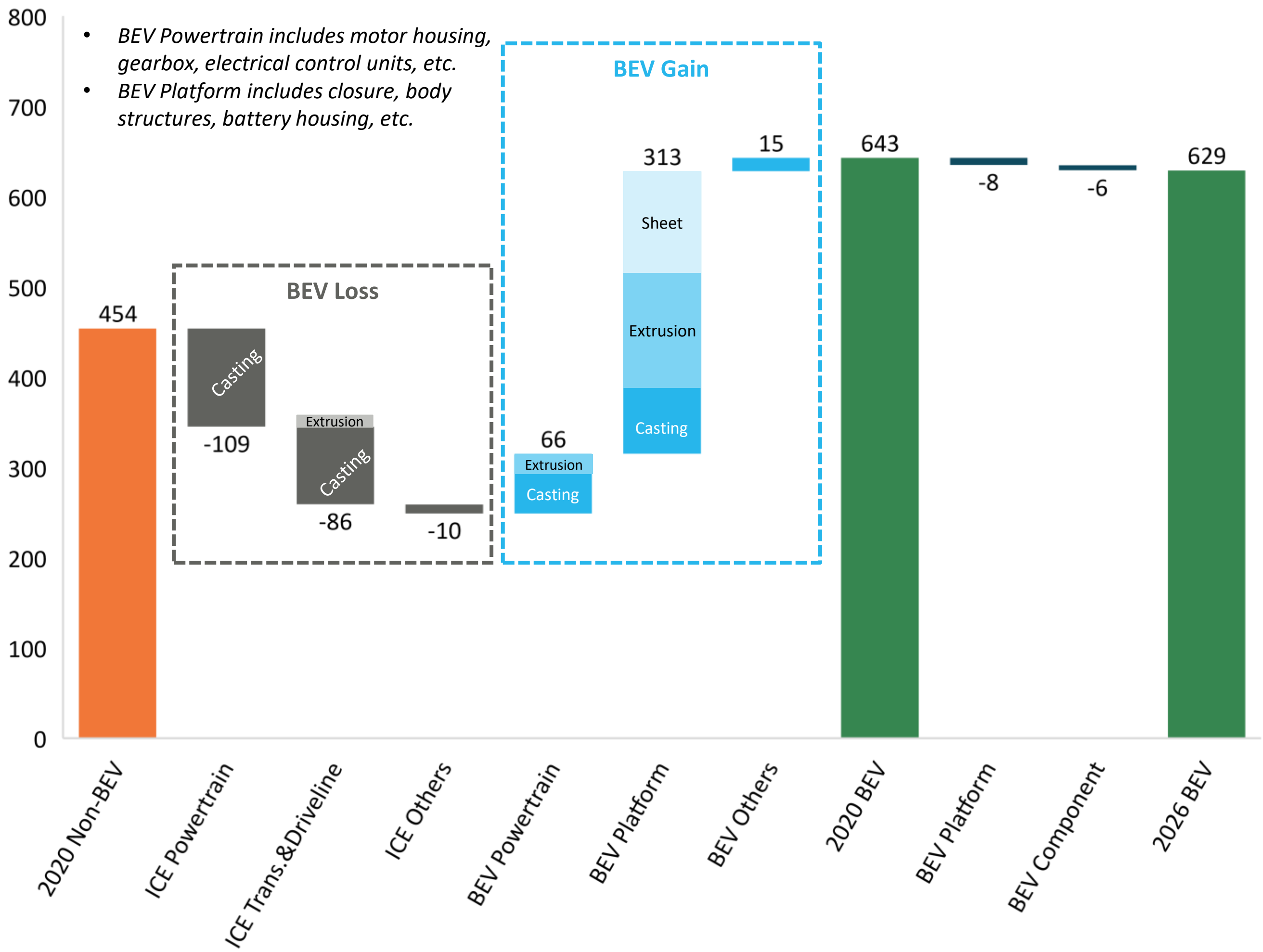
Source: DuckerFrontier April 2020

ALUMINUM CONTENT TRADEOFF

Although approximately 200 pounds of ICE aluminum content are eliminated on the average BEV, over 400 pounds of specific EV component based aluminum content is added back

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 use reduction gearboxes, typically utilizing 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

Aluminum Content Change –ICE to BEV



Source: DuckerFrontier April 2020

TOP DOWN ANALYSIS OF LIGHT VEHICLE ALUMINUM CONTENT 2018 - 2030

TOP DOWN ANALYSIS

The top down analysis uses published sources, engineering relationships between materials and math models to create detailed future scenarios for achieving emissions and fuel consumption goals. Traditional bottom up analysis relies on primary research interviews with OEMs and their suppliers to forecast future outcomes. A bottom up analysis was used for estimates through 2022 (utilizing a blended effort for 2023-2026)

MODEL SUMMARY

- The top down analysis for 2022 and beyond was required due to the uncertainty surrounding targets for light vehicle CO2 emissions and fuel savings after 2020/2021. The goal was to determine the most likely mix of fuel saving technologies that will be required to achieve a given emission target. It is meant to tell us what the industry can do and should do, not what the industry will do

- Using a base year of 2018, a range of real world emission targets for 2025/2026 were analyzed using our proprietary model to compare CO2 savings from a variety of technologies. 2018 was chosen as the base year because at the inception of the study, the EPA 2019 Trends Report provided the best source of current information on U.S. emission and fuel savings accomplishments by type of vehicle and OEM

- The range of CO2 savings from 2018 to 2025/2026 studied was 64 to 108 grams per mile (18% to 31%). The analysis showed that small changes of a few grams per mile in the target can have a significant impact on the need for mass savings and increased aluminum use

- The majority of the required savings going forward will come from continued improvements in conventional ICE powertrains. These improvements could provide 50% to 75% of the needed savings. Electrification (FHEV/PHEV/BEV) increases are the second most important source of savings. EV penetration of 9% to 14% by 2026 could provide 20% to 30% of the needed savings. In 2019, the U.S. EV penetration reached 8%

- A mass reduction from 2 percent to 7% between 2018 thru 2026 could provide 6% to 15% of the needed emission savings. Other savings will need to come from aerodynamic improvements, 48-volt ICE battery adoption and a variety of ‘credits’ for saving energy

- The most likely target emission reduction is 98.5 grams/mile. This is the average of the EPA 1.5% and CARB 2.7% rates of improvement from 2018 – 2026. This will require a 75% increase in conventional engine improvements, a 13% (FHEV/PHEV/BEV) electrification penetration and a mass reduction of 3.7%

- The 3.7% mass savings will require an increase of 84 pounds or 75% in platform aluminum parts PPV from 2018 to 2026. A significant increase in AHSS content will also be required to achieve the 3.7% mass reduction. Magnesium and polymers will only play a comparatively minor role

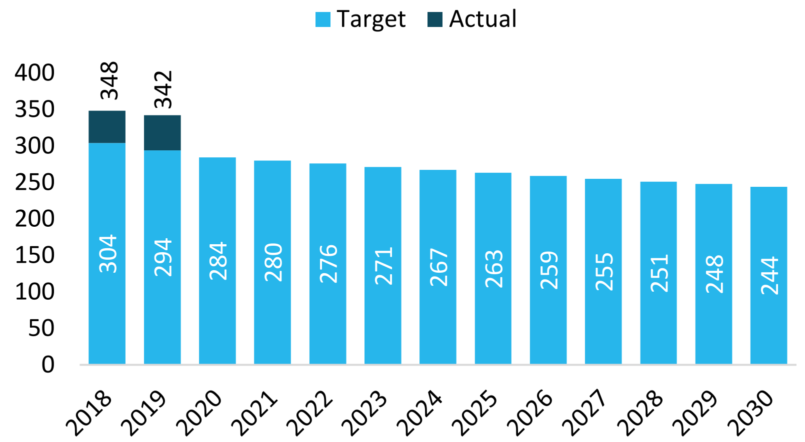
- A continuation of emission reduction through 2030 at the CARB 2.7% rate will require increases of 130% in both platform aluminum and AHSS from 2018 to 2030. Total aluminum content for all products and applications is forecast to be approximately 570 pounds in 2030

TOP DOWN ANALYSIS EMISSIONS AND FUEL CONSUMPTION TARGETS THROUGH 2030

The original Obama-era fuel economy and emission targets for 2025 will finally be achieved by 2030. Saving 10 grams per mile per year from 2019 to 2030 is a challenge for OEMs, but the technology path is becoming more clear with the help of electric vehicles

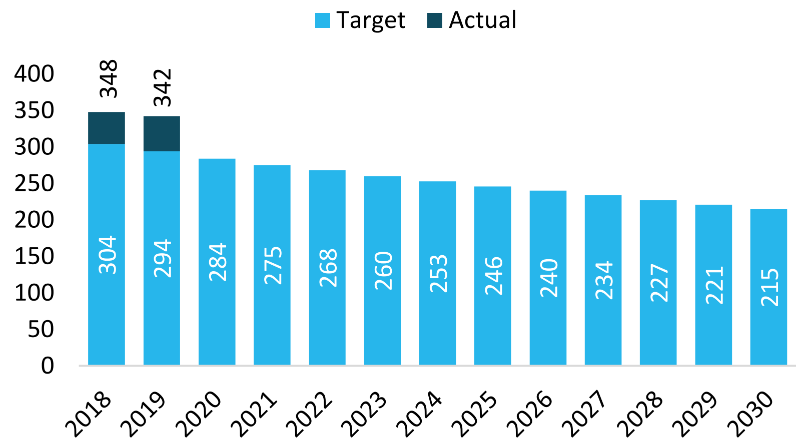
EPA SAFE Rule 1.5% Extended to 2030

Real World Value



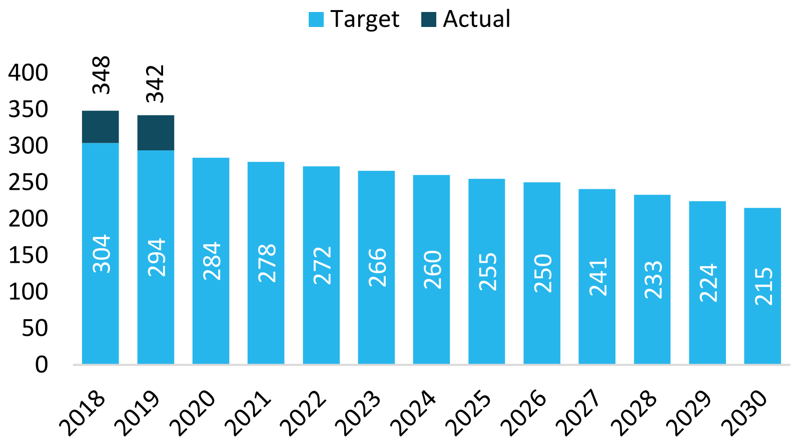
CARB 2.7% Extended to 2026

Real World Value



Compromise Used for the Study

Real World Value



Medium term assumption

The new standards have been revealed at the end of Q1 2020 keeping the 1.5% improvement assumption. The SAFE rule applies until 2025 unless the electoral outcomes from November 2020 opens the way to a new reevaluation. As of now, we expect tougher regulations for the 2025/2028 period. So far, 3 carmakers backed the government willingness to ease the standards.

4 OEMs support CARB and advocate for keeping the California Waiver along with higher standards state by state to keep with their technology investment and product plan for the upcoming years. The target for these OEMs is to make sure they will not be creeped by a price issue as new technologies will appear on their vehicles

The current situation opposing the CARB + 4 OEM to the EPA is likely to because of legal issues maintaining uncertainty and delay in the definition and implementation of the rollback of emission standards

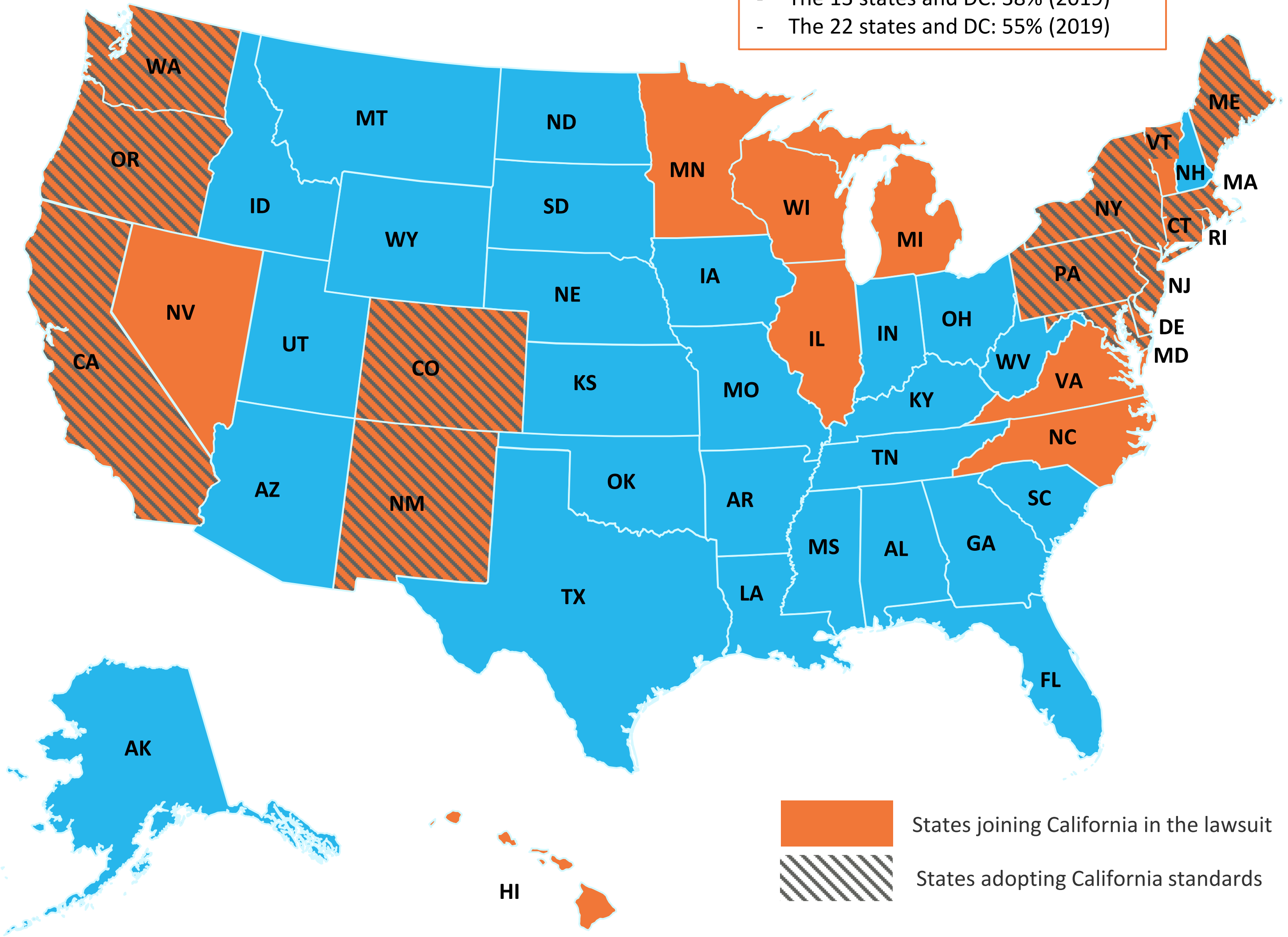
Source: DuckerFrontier, EPA, 1Q2020

ROLLBACK OF EMISSION STANDARDS

The rollback of emission standards by the EPA is facing resistance not only from California, but other states which have implemented CA standards or joined CA in the lawsuit against EPA's emission rule

- 13 states and the District of Columbia have adopted California's standards. Such states are frequently referred to as "CARB states" in automotive discussions because the regulations are defined by the California Air Resources Board
  - The states that have adopted the California standards are: Colorado, Connecticut, Delaware, Maine, Maryland, Massachusetts, New Jersey, New Mexico (2011 model year and later), New York, Oregon, Pennsylvania, Rhode Island, Vermont, and Washington, as well as the District of Columbia
- To block the Trump administration from ending its authority to set greenhouse gas emission and fuel economy standards for cars and trucks, California together with other 22 states, the District of Columbia and two cities are suing the U.S. Environmental Protection Agency
  - Joining California in the lawsuit are attorneys general of Colorado, Connecticut, Delaware, Hawaii, Illinois, Maine, Massachusetts, Maryland, Michigan, Minnesota, Nevada, New Jersey, New Mexico, New York, North Carolina, Oregon, Pennsylvania, Rhode Island, Vermont, Virginia, Washington, Wisconsin, and the District of Columbia; as well as the cities of Los Angeles and New York
- A worst-case scenario for automakers would be different standards in different states, which would result in a bifurcated auto market. The new policy may ultimately be decided by the U.S. Supreme Court, but the uncertainty waiting for that would exact its own toll on an industry that must plan years ahead

Share of vehicle sold by California and:
- The 13 states and DC: 38% (2019)
- The 22 states and DC: 55% (2019)

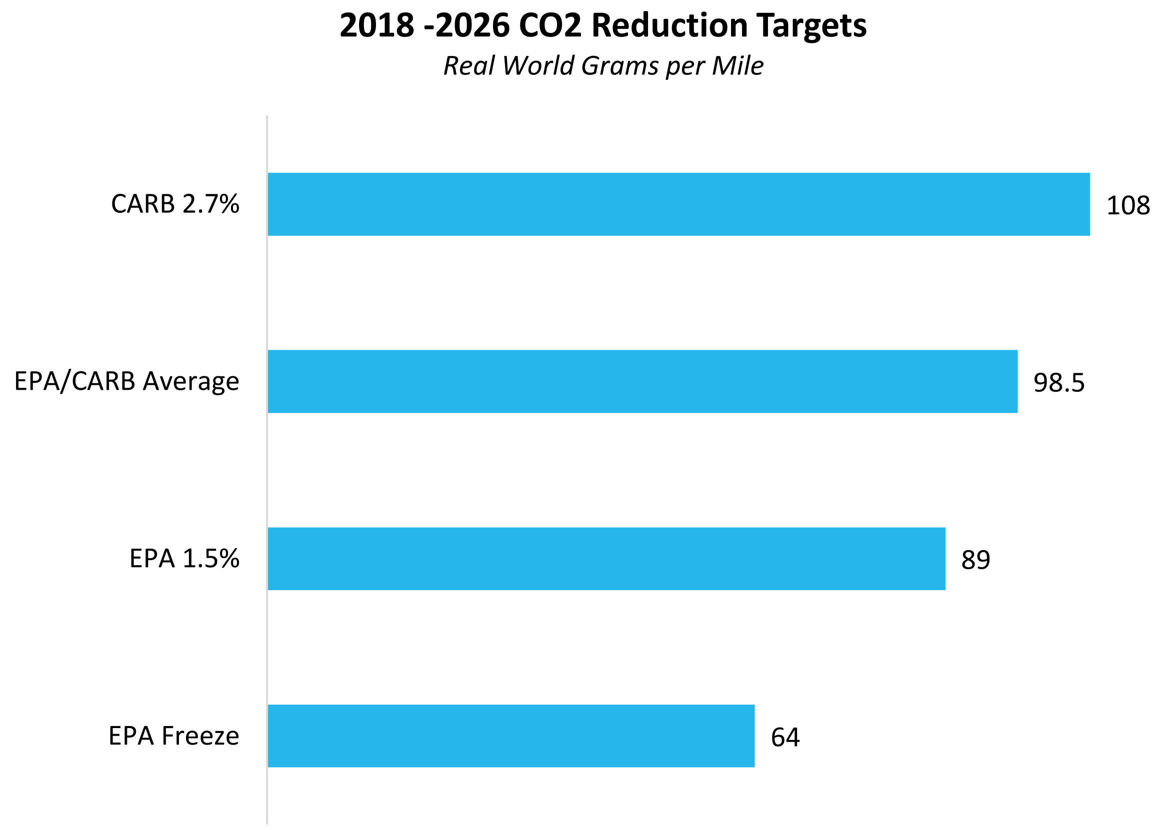


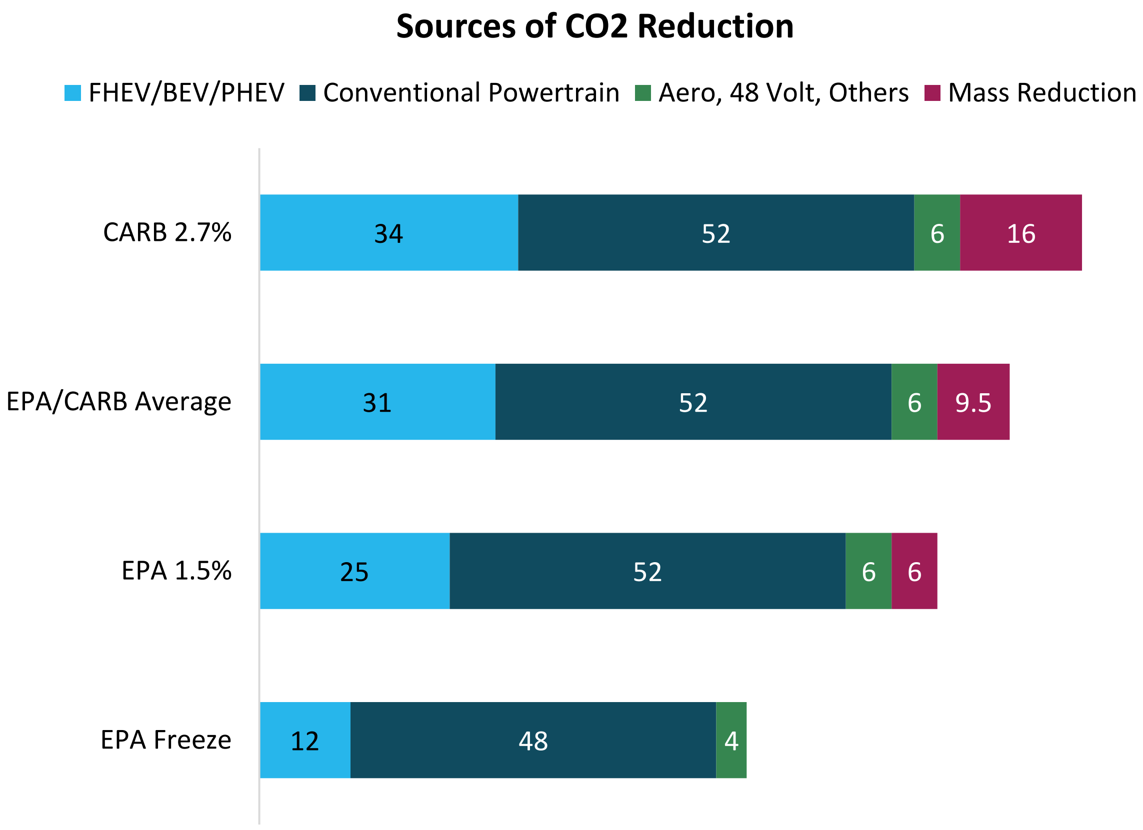
Source: DuckerFrontier, CBS, CARB, 1Q2020

SENSITIVITY ANALYSIS

The four scenarios for CO2 reduction we have chosen for the sensitivity analysis cover the full range of possible outcomes for the next five/six years

- CO2 improvements ranges from 64 to 108 grams/mile
- They cover a range of political outcomes, and all the possible technologies to save CO2 emissions and reduce fuel consumption. Under all the scenarios, conventional powertrain improvements and electrification from FHEVs, PHEVs and particularly BEVs will provide most of the improvement

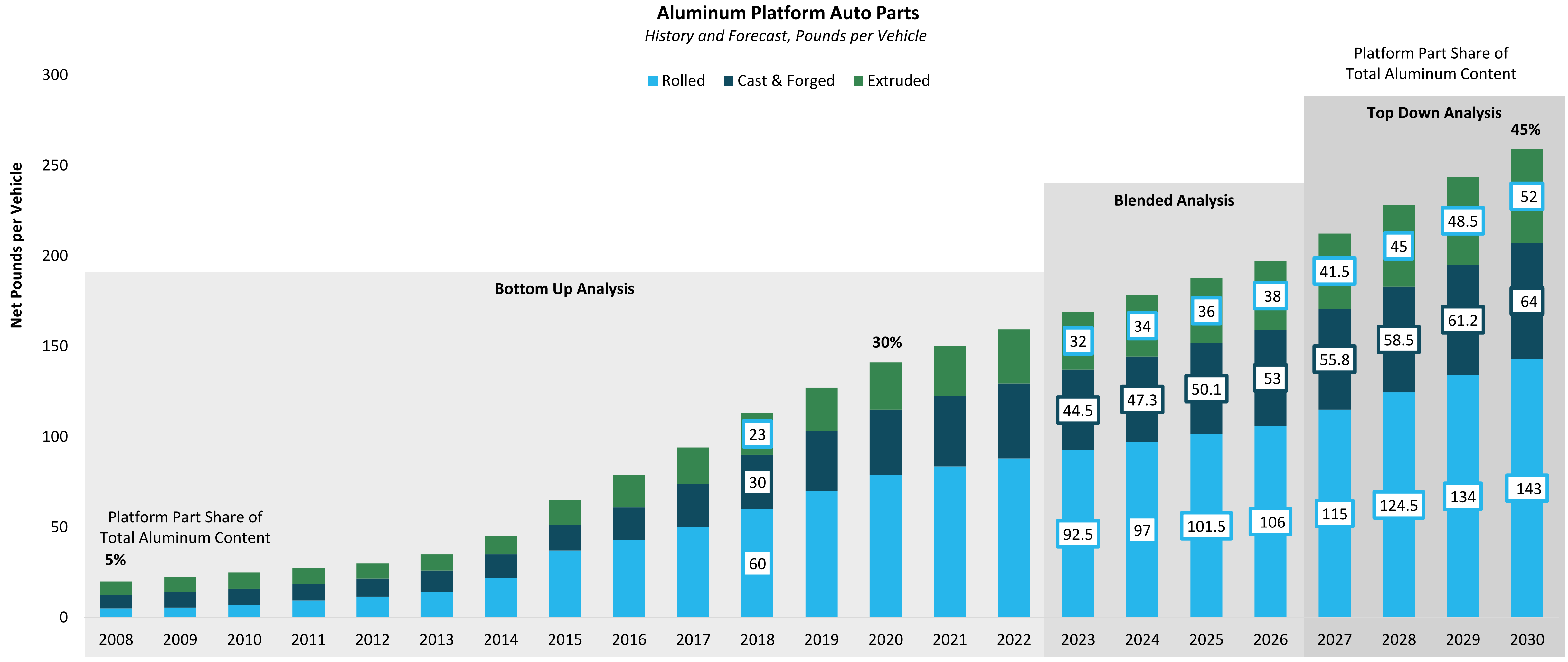




Source: DuckerFrontier 1Q2020

TOP DOWN PLATFORM ALUMINUM PPV

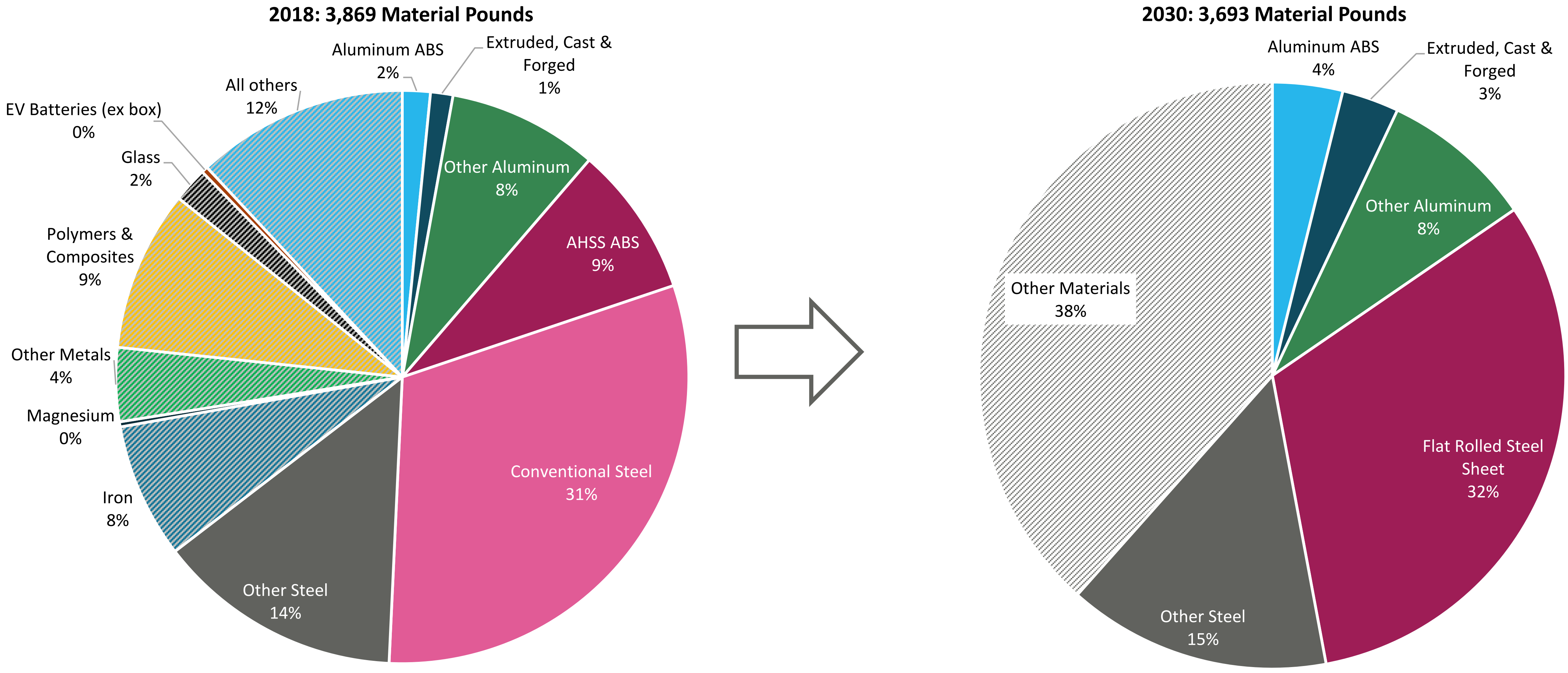
Starting in 2014, aluminum platform parts for closures, body structures, crash management and chassis and suspension applications began to grow in response to the tightening fuel economy regulations. These high value-added products have grown form 5% of total aluminum auto use to 30%. This is expected to continue this decade and reach 45% of total auto aluminum use by 2030



Source: DuckerFrontier April 2020

TOP DOWN ANALYSIS TOTAL MATERIAL MIX

In 2018, aluminum body parts were 3% of vehicle weight and overall aluminum was 11%. By 2030, aluminum platform parts will be over 5% and overall aluminum will be 15%. Flat rolled steel sheet, including advanced grades and conventional grades will total 32% in 2030. Small yet significant increase in the use of magnesium and composites are also required to achieve the weight savings by 2030



Source: DuckerFrontier April 2020

IMPACT OF ELECTRIFICATION AND OTHER MOBILITY TECHNOLOGIES

ELECTRIFICATION TRENDS

Electrification is growing with high constraints on vehicle budgets, limiting the choices for materials. Over time, OEMs will improve vehicle range by a combined effect of increased energy density for smaller batteries and reduced weight creep through light material solutions using magnesium, steel, and aluminum

- OEMs are currently implementing various strategies to electrify their offering in order to achieve CO2 emission targets at fleet levels. Investments consider more and more dedicated platforms for BEVs while PHEVs and MHEVs are set to ramp up for mainstream demand. As EV volumes are slow to ramp up, several carmakers deploy car-sharing solutions that are answering requests from major cities while increasing volumes of BEVs in the market
- Currently, most batteries are being added as a component of the vehicle. With dedicated platforms, the batteries are becoming platform part of the platform to both save weight and gain in stiffness and rigidity while saving. costs as well.
- As battery energy density increases in terms of kilo Watt hours per kilogram, the weight of the battery pack and the vehicle will decline for any given kWh capacity. A lighter vehicle requires fewer kWh to meet the acceptable level of 300mi range expected by most customers.
- Although regulations already exist in North America, Europe and China, more stringent and harmonized standards are expected to ensure crashworthiness and control over fire propagation. New regulations and norms are going to have a strong influence on battery designs materials and overall specifications.
- OEM use shared mobility solutions to increase BEV sales and secure compliance with regards to fleet average emissions.

Influencers

CATL, RIVIAN, TESLA, GM, LG Chem, TOYOTA, SK innovation, polestar, SAMSUNG SDI, A123 SYSTEMS, RENAULT NISSAN MITSUBISHI, NIO, LUCID, BYTON, chargepoint, saft, Panasonic

Near-Term (2018-2028)

- Majority of ‘EV’ launches will be on legacy platforms but ‘Skateboard’ platform technology is ramping up to help saving time and cost
- Several OEMs begin to launch vehicles with dedicated BEV platforms using Steel, HSS, AL, and composites

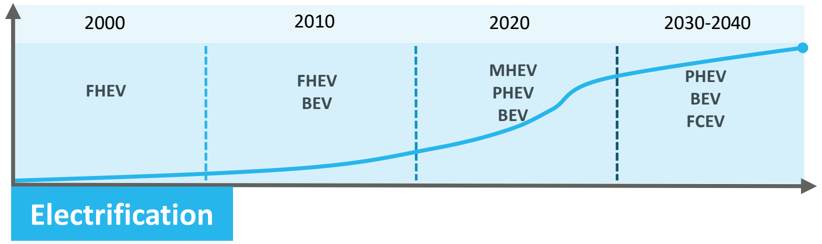
Mid-Term (2028-2035)

- Battery technology cost improve with productivity to get closer to parity with ICE despite material price increase
- First solid state applications are expected for the end of the decade to help reduce battery cost, increase energy density and improve safety

Long-Term (2035+)

- New technologies will support BEV and FCEV expansion along with sustainable infrastructure and production costs
- Demand meets larger offer as additional OEMs/Suppliers join EV industry

Maturity cycle



Source: DuckerFrontier April 2020

EV DESIGNS: FROM TRADITIONAL TO DEDICATED PLATFORMS

As most carmakers are still using traditional platforms the battery designs vary from one carmaker to the other, however, the vast majority of the models have their batteries located in the floorplan of the vehicle

	<u>Traditional Versatile Platform</u> **ICE, MHEV, FHEV, PHEV, FCEV, BEV**	**<u>Traditional Dedicated EV Platform</u>** **BEV and FCEV**	**<u>Skateboard Platform</u> (dedicated)** **BEV only**
Description	• The most common strategy is to modify or design a traditional platform to be able to integrate the EV powertrain and battery while reducing the financial burden and limit the CapEx to seek quick ROI. • Several carmakers such as Hyundai Kona, the Mini E are based on such modified architecture leading to more constraints for the battery design	• These platforms are using traditional architectures as the upper skeleton of the frame remains part of the design for the overall vehicle stiffness. • These are being developed for EV only with specific designs to integrate the battery sometimes as part of the platform elements. It prevents from constraints to integrate the transmission, exhaust system, etc. leading to reduced complexity and better weight reduction.	• These are based on the integration of the battery a part of the platform design to provide both a high level of stiffness and a low center of gravity. These platforms can be declined into various body types such as sedans, crossovers, and sportscars alike. Such strategy shows a strong willingness to benefit from high volumes. • Skateboard platforms imply that the battery housing is part of the platform.
Pros	• Lowest investment needed • Short and long term applications • Volume effect for amortization	• Often deeply modified traditional platforms • Better battery and BMS integration • No factory retooling necessary	• Short term applications with great versatility • Weight efficiency • Battery integration and creative design
Cons	• Weight creep impacting other elements of the vehicle (suspension, linkages) • Integration costs (architecture, electronics)	• Integration costs (architecture, electronics) • Specific costs and low volumes impacting amortization • Development costs	• Risks from solid state technology reducing battery sizes • Specific costs and low volumes impacting amortization • Manufacturing adaptation required
OEMs	Audi, HYUNDAI, Ford, FCA FIAT CHRYSLER AUTOMOBILES, BMW, Mercedes	Mercedes, VOLVO, RENAULT NISSAN MITSUBISHI, TESLA	Audi, VW, HYUNDAI, Ford, GM, RIVIAN, TESLA
Example	**Hyundai 3rd Generation PF** 	 **2020 Nissan Leaf**	 **Volkswagen MEB**

Source: DuckerFrontier April 2020

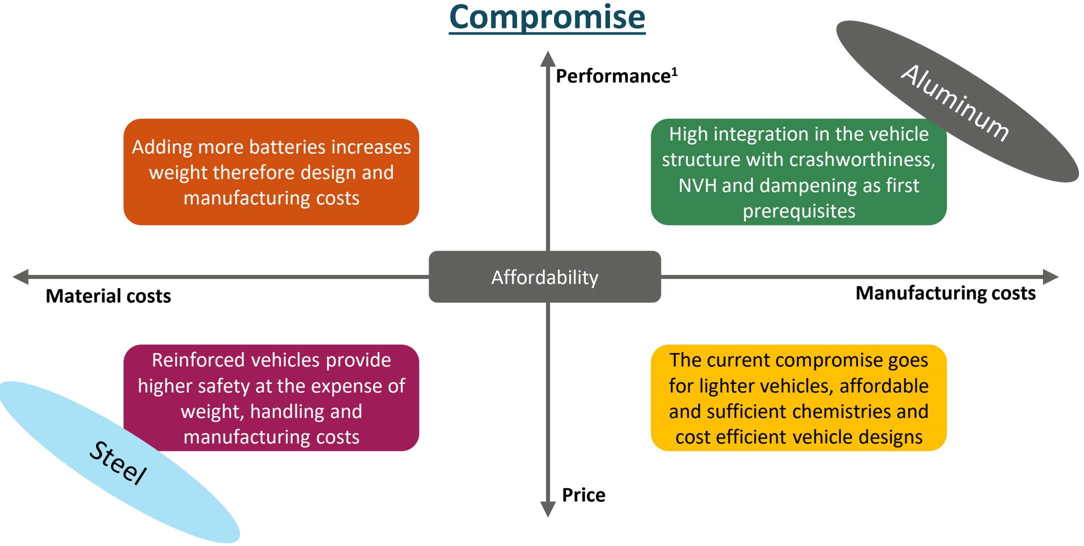
EV DESIGNS: ALUMINUM OFFERS THE APPROPRIATE ADVANTAGE

The current battery chemistries and manufacturing processes favor aluminum as it offers the compromise OEM are looking in terms of manufacturing costs , weight saving, performance and safety (crashworthiness with extrusion designs and sealing with chemical bonding)

OEM targets

- 300 miles range
- Max 8h charging time on a level 2 connector
- Manufacturing costs
  - Welding
  - Gluing
  - Corrosion treatment
  - Sealing
  - Shielding
  - Coating
- Vehicle design cost
  - Reinforcement
  - Steering and suspension costs
- Li-ion chemistries
  - LTO: safest but most expensive
  - LFP: safe and cheap but low energy density
  - LMO: most versatile and best compromise
  - NMC: good performance but high cobalt content (price) therefore often mixed with LMO to achieve better compromise
  - NCA: highest energy density but more prone to runaway cells (fire)

Compromise



Technical requirements

Mandatory requirements

- Crashworthiness
- Fire resistance (slow propagation)
- Electromagnetic compatibility
- Shock resistance (or dampening)

Must have / Critical

- Manufacturing cost management
- Thermal management to optimize energy usage
- Design efficiency to keep low development costs
- NVH management for durability

Vehicle synthesis

Vehicles must show the correct consistency to appeal to consumers and fleets

- Affordability
- Performance[1]
- Handling
- Safety
- Conformity
- Production costs
- Margin
- Sales price
- Warranty costs
- Recyclability
- Serviceability

Material choices for platform, BIW and components are limited to steel and aluminum. Steel achieves better fire resistance but adds weight and manufacturing costs (corrosion treatment, welding, sealing, etc.)

Source: DuckerFrontier

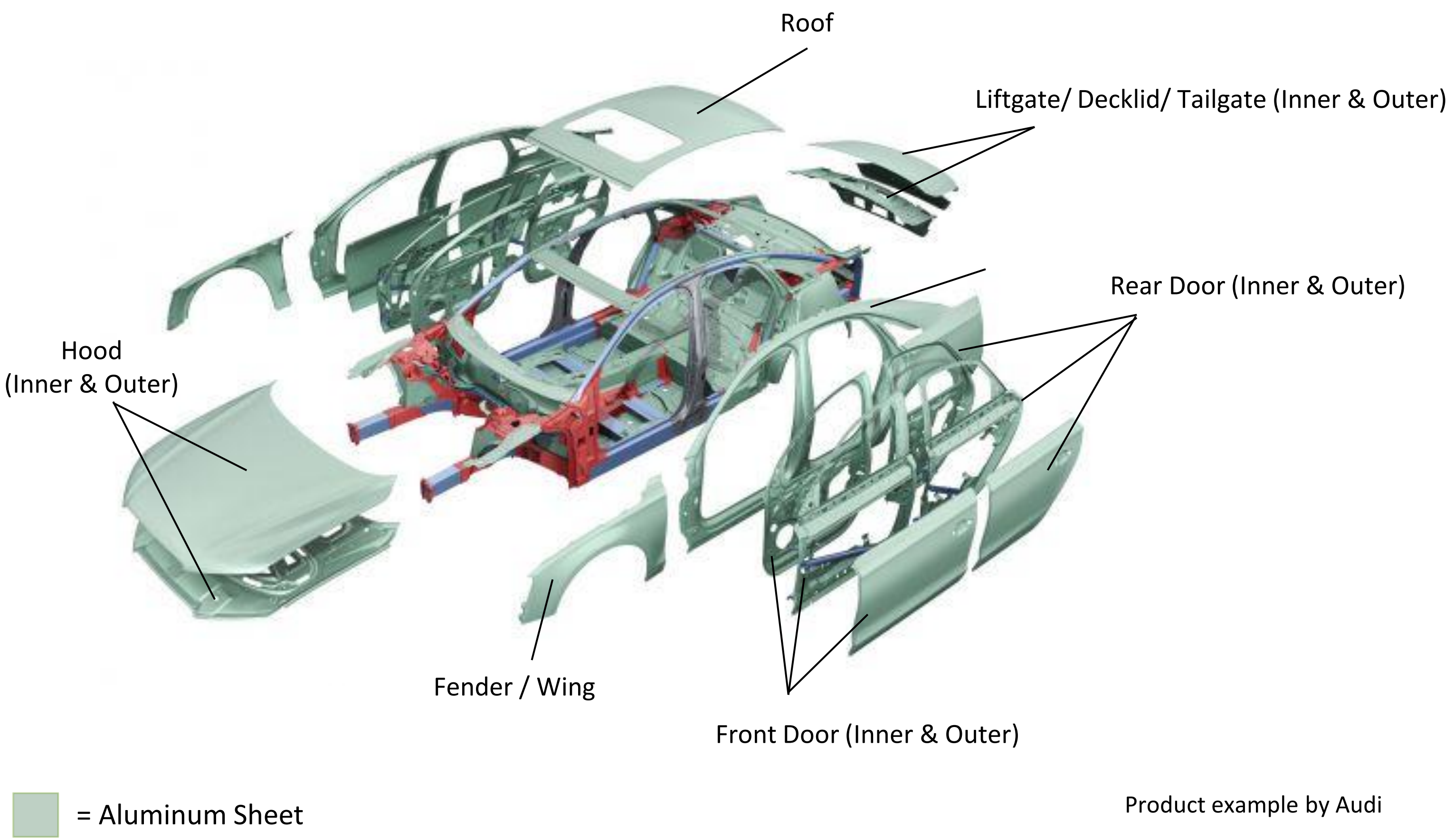
[1] *Considers speed, charging time and range*

STUDY RESULTS BY AUTOMOTIVE APPLICATION BODY SHEET SAMPLE

BODY CLOSURES: OVERVIEW

Part list of body closure

Main Aluminum Closure Components



Product example by Audi

Parts
Body Sheet
F Doors
R Doors
Fender/wings
Boots/gates
Roofs
Hoods

PART LIST - CLOSURES

Part	Process Category	Process	Aluminum	Installation Rate Trend	Al Penetration Trend
Body Sheet	Sheet	NHT & HT sheet	Primary	Stable	Increasing
Hoods	Sheet	HT sheet	Primary	Stable	Increasing
F Doors	Sheet	HT sheet	Primary	Stable	Increasing
R Doors	Sheet	HT sheet	Primary	Stable	Increasing
Fender/wings	Sheet	HT sheet	Primary	Stable	Increasing
Boots/gates	Sheet	HT sheet	Primary	Stable	Increasing
Roofs	Sheet	HT sheet	Primary	Stable	Flat

Source: DuckerFrontier

INDUSTRY TRENDS - CLOSURE

Aluminum penetration for closures continues to increase as one of the major lightweighting solutions

CURRENT MARKET

- Hood is the most penetrated closure parts with 63% penetration rate in 2020, followed by tailgate of which penetration rate as 28%, less than half of hoods
- Aluminum doors are mostly used by European premium brands; BMW has the highest penetration for aluminum doors as most of their models at least have aluminum front doors, and large SUVs (X5, X7) have both front and rear door made of aluminum
- Roof penetration in 2020 is at 7% with no expectation to change
- Toyota is using aluminum for hood, fender, and tailgate on the new RAV4, Nissan is also moving to aluminum with the new Rogue proving the use-case for aluminum closures is moving to higher volume segments
- Ford F-150 is the largest contributor as single model to overall aluminium closure demand

2020-2026 ESTIMATED CAGR

3.6% — **Average AL Content per Car**

5.1% — **Total AL Gross Shipment (incl. car production growth)**

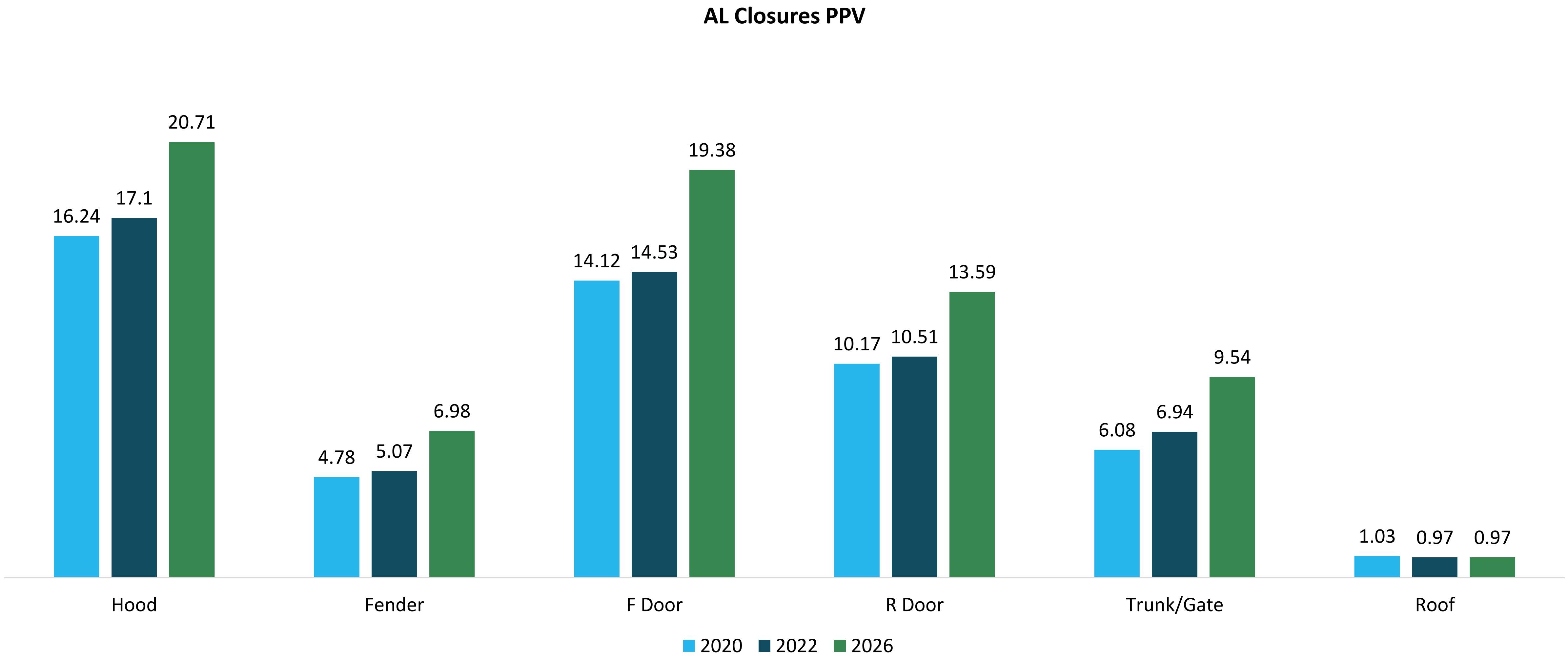
Drivers/ deterrents for aluminum demand:

+ Vehicle production growth
+ Increasing aluminum penetration
+ Increasing EV production
+ Less efforts to convert “hang on” parts from steel to aluminum
− Achieve emission goal through powertrain improvement
− Blanking and stamping line modification

Source: DuckerFrontier

CLOSURES PPV

In 2020, hood accounts for 27% of total closure content per vehicle, followed by front door and rear door. Front doors represent the highest net growth of aluminum content per vehicle from 2020 to 2026, resulting in more than 5 pounds increase

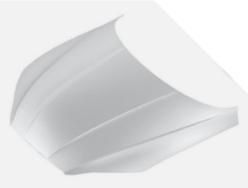


**Weights of fender and door are for one piece*
Source: DuckerFrontier

MARKET SIZE AND SEGMENTATION

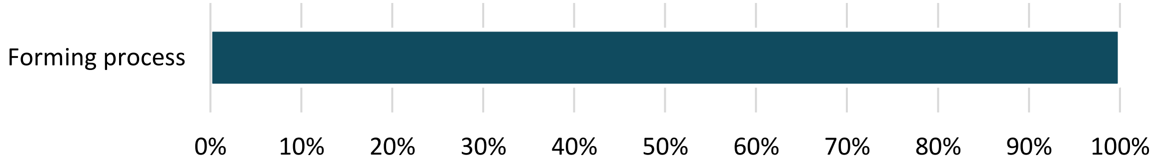
Aluminum content for hoods is estimated at 561 M pounds in 2026 - 82% aluminum sheet

HOOD



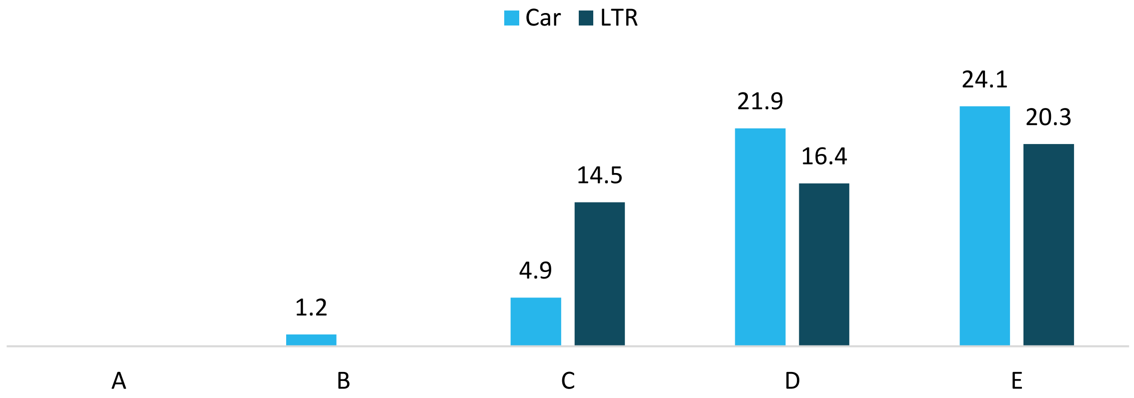
Year	2020	2026
Avg. AL Penetration (at least one AL component)	63%	81%
Avg. AL Content per Vehicle	16.2 lb.	20.7 lb.
Total Gross Shipment	310 M lb.	561 M lb.
CAGR 2020-2026	Per vehicle: 4% Total market: 10.4%	

2020 Total AL Content by Forming Process

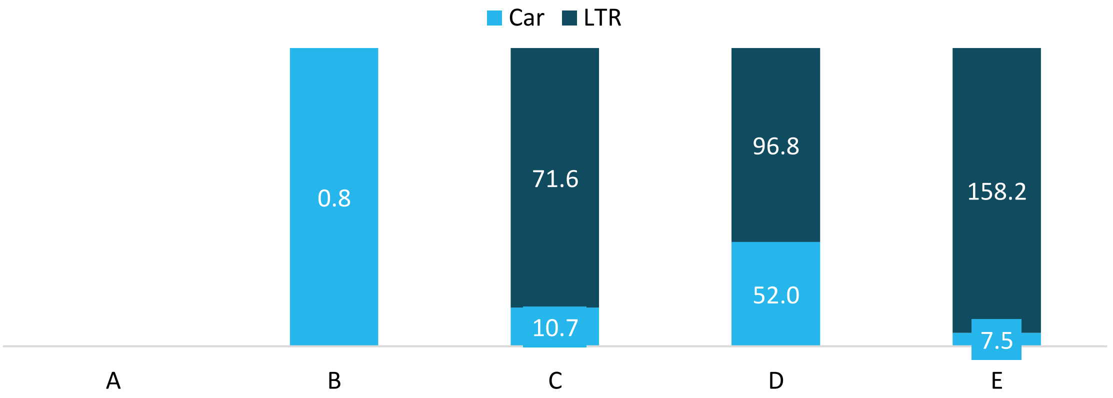


	Forming process
Cast	0%
Sheet	100%
Extrusion	0%
Forging	0%

2020 Avg. AL PPV per Vehicle by Segment



2022 Avg. AL Gross Shipment by Vehicle Segment (M Lbs.)



Source: DuckerFrontier

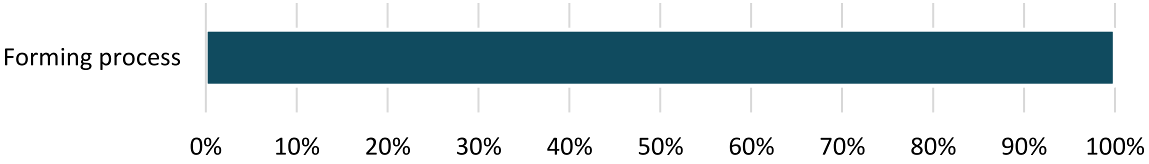
MARKET SIZE AND SEGMENTATION

Aluminum content for front doors is estimated at 525 M pounds in 2026 - 31% aluminum sheet

FRONT DOOR

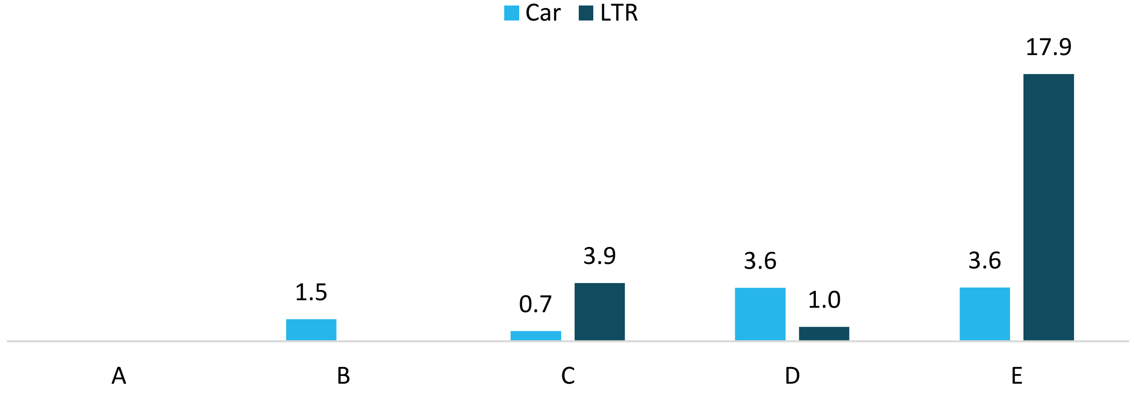
Year	2020	2026
Avg. AL Penetration (at least one AL component)	21%	30%
Avg. AL Content per Vehicle	14.1 lb.	19.4 lb.
Total Gross Shipment	270 M lb.	525 M lb.
CAGR 2020-2026	Per vehicle: 5% Total market: 11.7%	

2020 Total AL Content by Forming Process

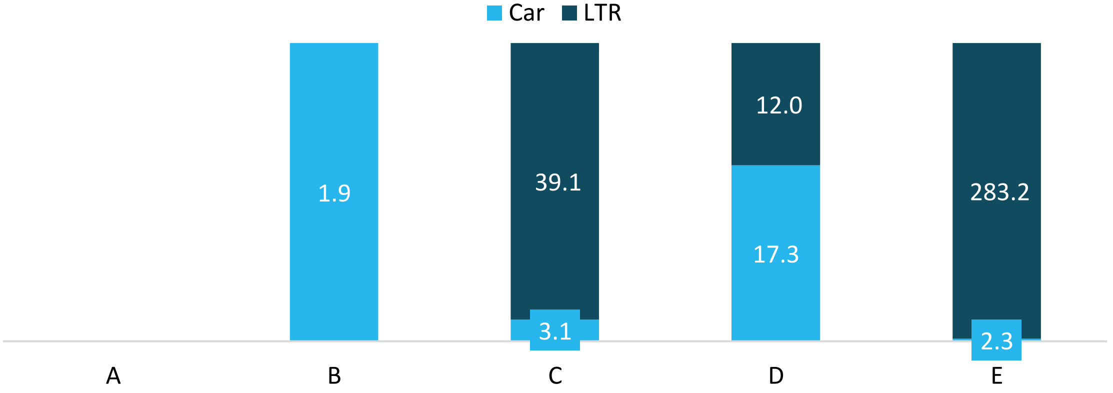


	Forming process
Cast	0%
Sheet	100%
Extrusion	0%
Forging	0%

2020 Avg. AL PPV per Vehicle by Segment



2022 Avg. AL Gross Shipment by Vehicle Segment (M Lbs.)



Source: DuckerFrontier

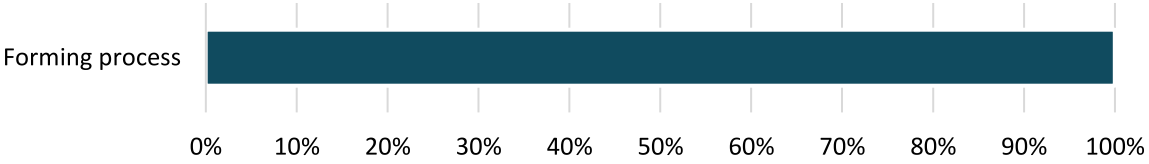
MARKET SIZE AND SEGMENTATION

Aluminum content for rear doors is estimated at 368 M pounds in 2026 - 29% aluminum sheet

REAR DOOR

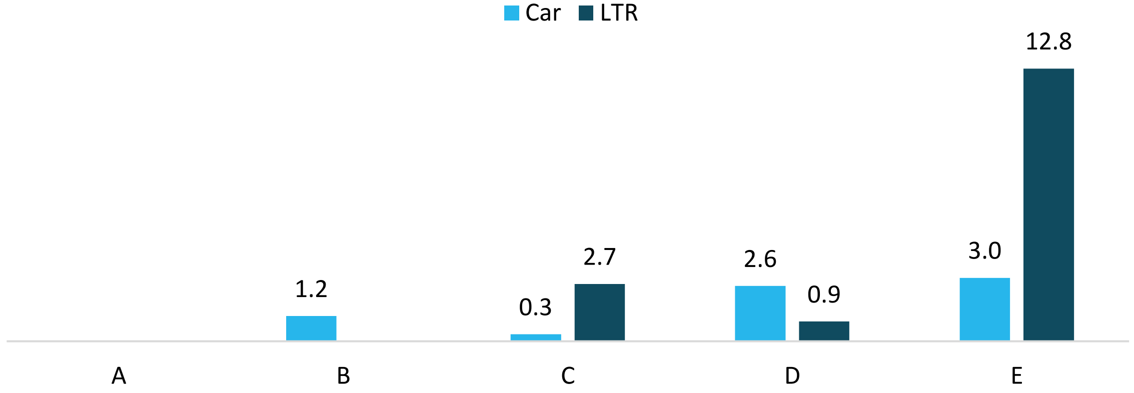
Year	2020	2026
Avg. AL Penetration (at least one AL component)	21%	29%
Avg. AL Content per Vehicle	10.2 lb.	13.6 lb.
Total Gross Shipment	195 M lb.	368 M lb.
CAGR 2020-2026	Per vehicle: 5% Total market: 11.1%	

2020 Total AL Content by Forming Process

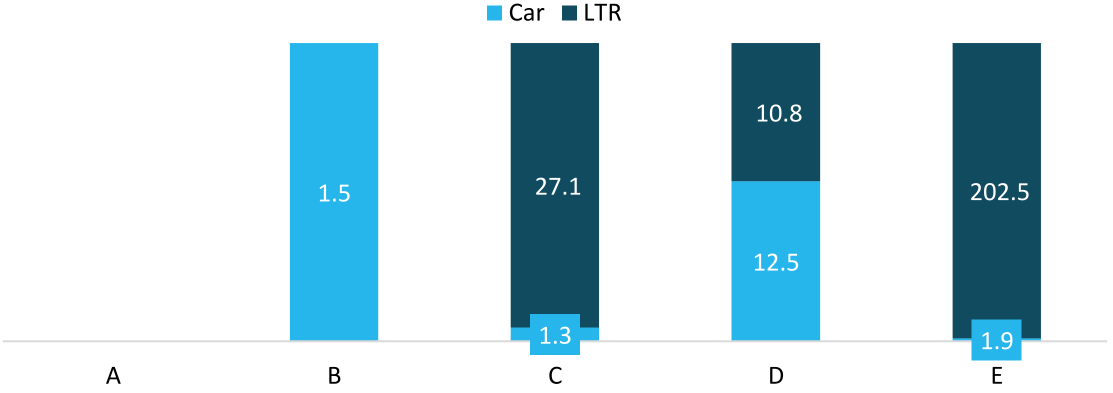


	Forming process
Cast	0%
Sheet	100%
Extrusion	0%
Forging	0%

2020 Avg. AL PPV per Vehicle by Segment



2022 Avg. AL Gross Shipment by Vehicle Segment (M Lbs.)



Source: DuckerFrontier

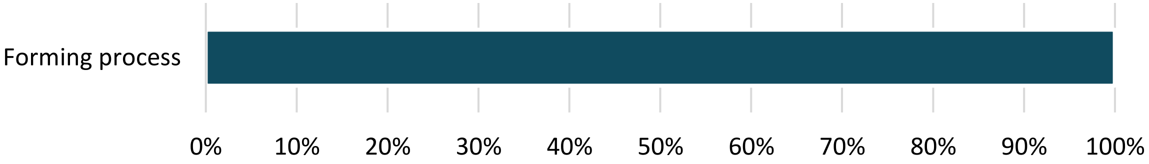
MARKET SIZE AND SEGMENTATION

Aluminum content for fenders is estimated at 189 M pounds in 2026 - 35% aluminum sheet

FENDER

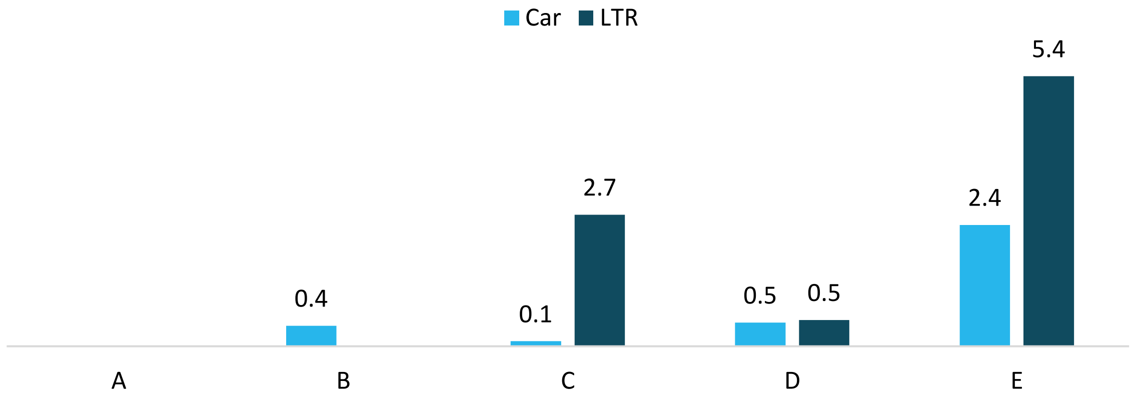
Year	2020	2026
Avg. AL Penetration (at least one AL component)	19%	34%
Avg. AL Content per Vehicle	4.8 lb.	7 lb.
Total Gross Shipment	92 M lb.	189 M lb.
CAGR 2020-2026	Per vehicle: 6% Total market: 12.8%	

2020 Total AL Content by Forming Process

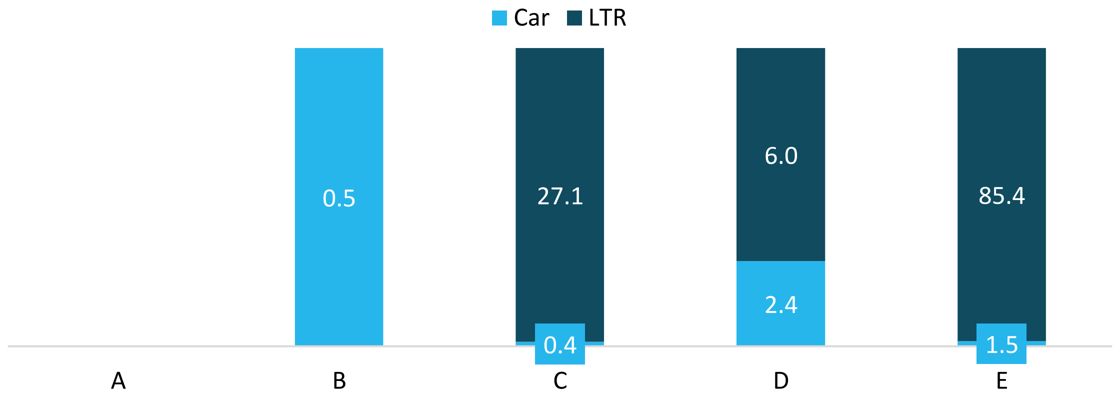


	Forming process
Cast	0%
Sheet	100%
Extrusion	0%
Forging	0%

2020 Avg. AL PPV per Vehicle by Segment



2022 Avg. AL Gross Shipment by Vehicle Segment (M Lbs.)



Source: DuckerFrontier

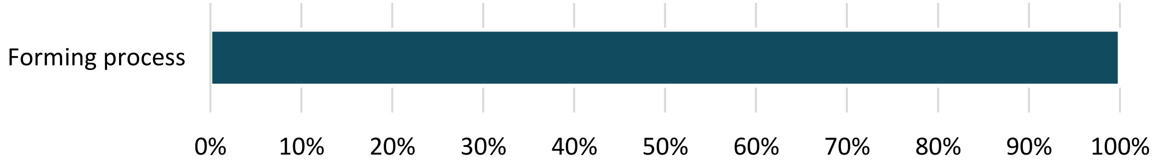
MARKET SIZE AND SEGMENTATION

Aluminum content for liftgate/tailgate is estimated at 258 M pounds in 2026 - 46% aluminum sheet

LIFTGATE / DECKLID

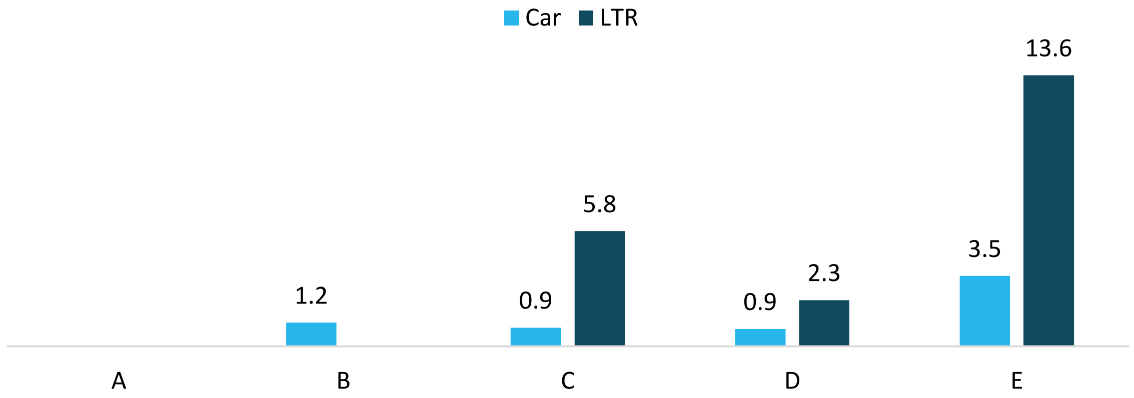
Year	2020	2026
Avg. AL Penetration (at least one AL component)	28%	44%
Avg. AL Content per Vehicle	6.1 lb.	9.5 lb.
Total Gross Shipment	116 M lb.	258 M lb.
CAGR 2020-2026	Per vehicle: 8% Total market: 14.1%	

2020 Total AL Content by Forming Process

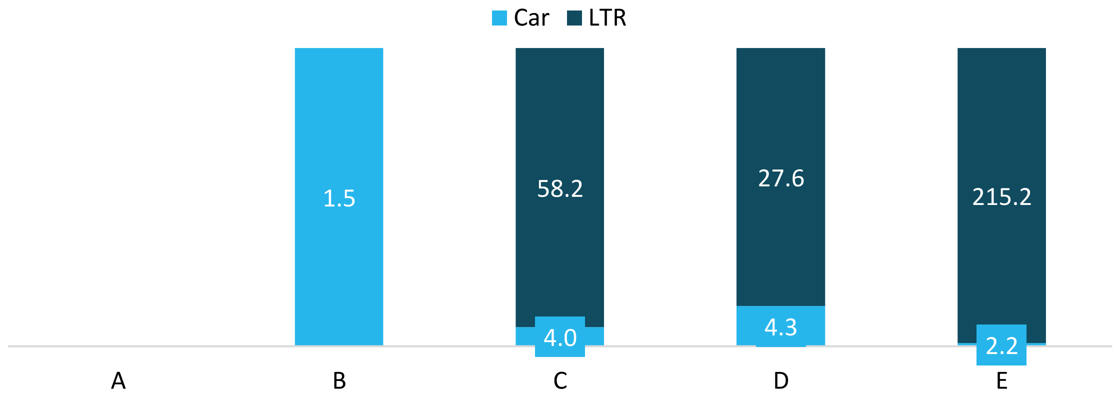


	Forming process
Cast	0%
Sheet	100%
Extrusion	0%
Forging	0%

2020 Avg. AL PPV per Vehicle by Segment



2022 Avg. AL Gross Shipment by Vehicle Segment (M Lbs.)



Source: DuckerFrontier

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