2017 Summer Professional Development Course
Advanced Automotive Technology

Topic 3:
Lightweight Materials for Automotive Applications

July 10 ~ 11, 2017

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Center for Advanced Automotive Technology
C A A T

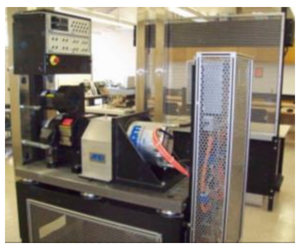
Macomb Community College

Introduction

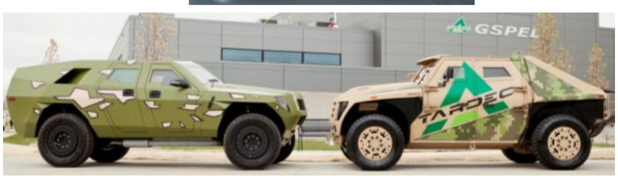
Y. Gene Liao

- Professor and Director of Electric-drive Vehicle Engineering & Alternative Energy Technology; Engineering Technology, Wayne State University.
- Doctor of Engineering, University of Michigan-Ann Arbor, 1999.
- Worked as a practicing engineer for over 16 years in automotive sector.
- Consultant to: ASRC Primus/TARDEC, 2007-present.
- University projects: NSF, DOE, DOL, DOC, 2003-present.

Series HEV project with TARDEC



Electric Propulsion Integration Lab – HIL (Hardware-In-the-Loop)



Full HEV project with TARDEC

Outline

- **Background and Motivation**
- **Weight Effect on Fuel Consumption**
- **Light Weighting Material Implementations**
  - ✓ Lightweight Design
  - ✓ HSS, AHSS
  - ✓ Aluminum
  - ✓ Magnesium
  - ✓ Composites
- **Multi-Material Enabling**
- **Joining Processes - Current and Emerging**
- **CAE Tools and Methods for Material Choices**
- **Summary**

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Background and Motivation

- ✓ Automotive industry traditionally has reduced weight primarily by downsizing. Today, the strategy of downsizing vehicle has reached its limits.
- ✓ Automotive OEMs are facing substantial increases in Corporate Average Fuel Economy requirements in the US. Also the fuel economy requirements are increasing globally.
- ✓ Significant vehicle light weighing is needed, and appropriate use of a variety of lightweight materials will be necessary to meet the mass targets.
- ✓ OEMs are learning how to cost effectively weld, rivet, form and cast lightweight vehicles on a global platform.

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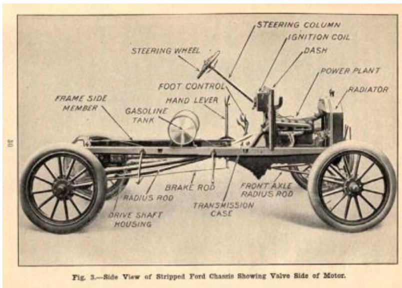
Some Background...

- Cars at first were built entirely of wood, and later of wood frames with steel body panels.
- In the early 1900's, the idea of a body-on-frame design came about.
- These vehicles had a load-bearing chassis that supported all the mechanical parts and a body usual made of steel.



Ford Model T
Courtesy Car Body Design
http://www.carbodydesign.com/articles/2005-04-13-chassis-history/2005-04-13-chassis-history.php

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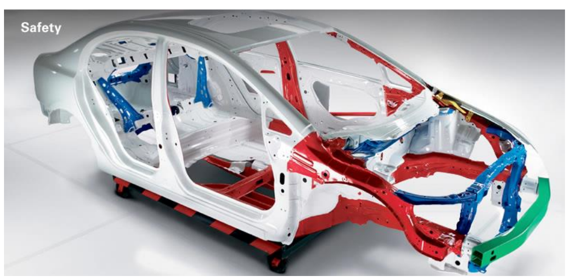
Moving Forward...

- Today, most smaller vehicles such as small SUV's and sedans use a unibody (or monocoque) construction.
- Heavy-duty vehicles like trucks and busses still use the idea of body-on-frame.
- Regardless of the construction technique, steel is still the predominant material used in automotive frames.



Honda Civic Frame
http://automobiles.honda.com/images/2009/civic-sedan/safety/safety-header.jpg

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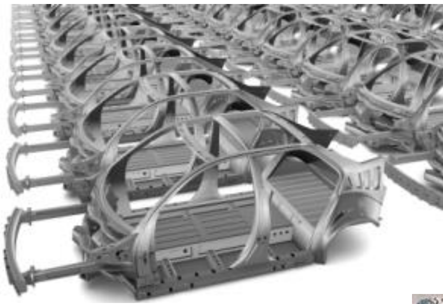
A Quick Comparison



Monocoques

Typical Ladder Frame

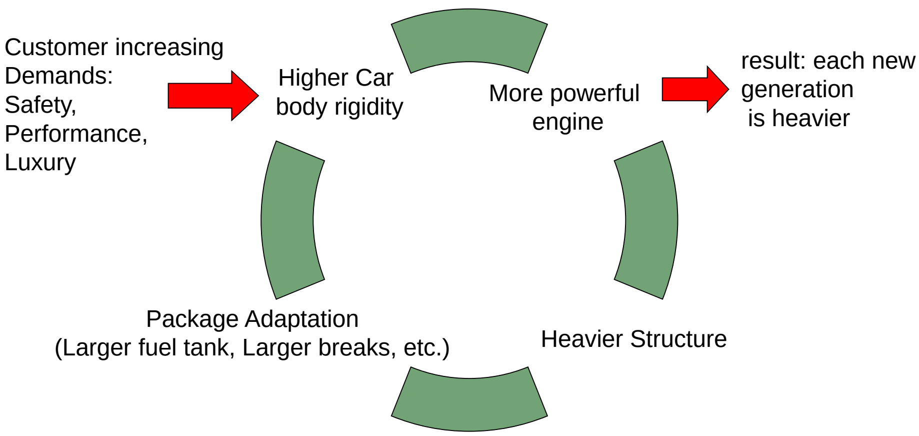
Lightweight Necessity

Medium sized vehicles are almost twice as heavy as 20 years ago.

Volkswagen Golf

1976	2006
Golf GTI MKI (820kgs) 108 hp 	Golf GTI MKV (1340kg) 200hp 
	Polo (1194Kg) 
	Fox (1100kg) 

Malicious Cycle of Weight



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Value x Weight

- ✓ From the manufacturers point of view, adding weight is a way to add value - to make cars bigger and more comfortable and more powerful and raise the profit margins.
- ✓ “Small-vehicles – small profits”.
- ✓ We argue that to add value the increase in weight must not occur.

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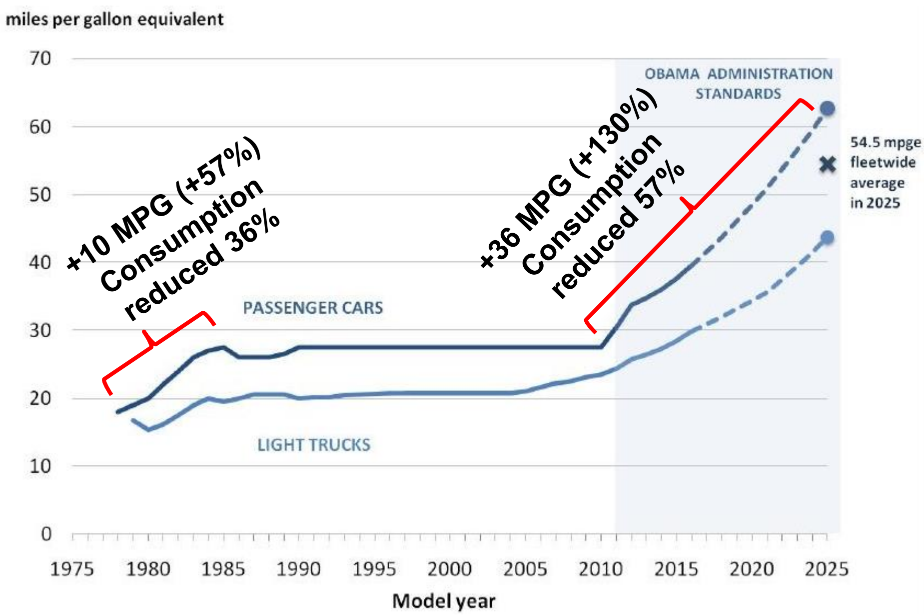

MY1978-2011figures are NHTSA Corporate Average Fuel Economy (CAFE) standards in miles per gallon. Standards for MY2012-2025 are EPA greenhouse gas emission standards in miles per gallon equivalent, incorporating air conditioning improvements. Dashed lines denote that standards for MY2017-2025 reflect percentage increases in Notice of Interest.

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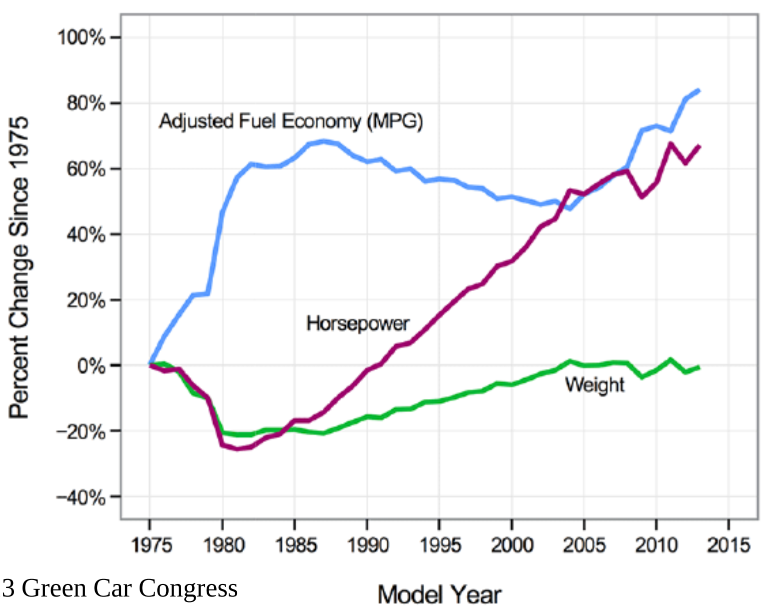
Change in Adjusted fuel economy, weight, and horsepower MY1975---2013



2013 Green Car Congress

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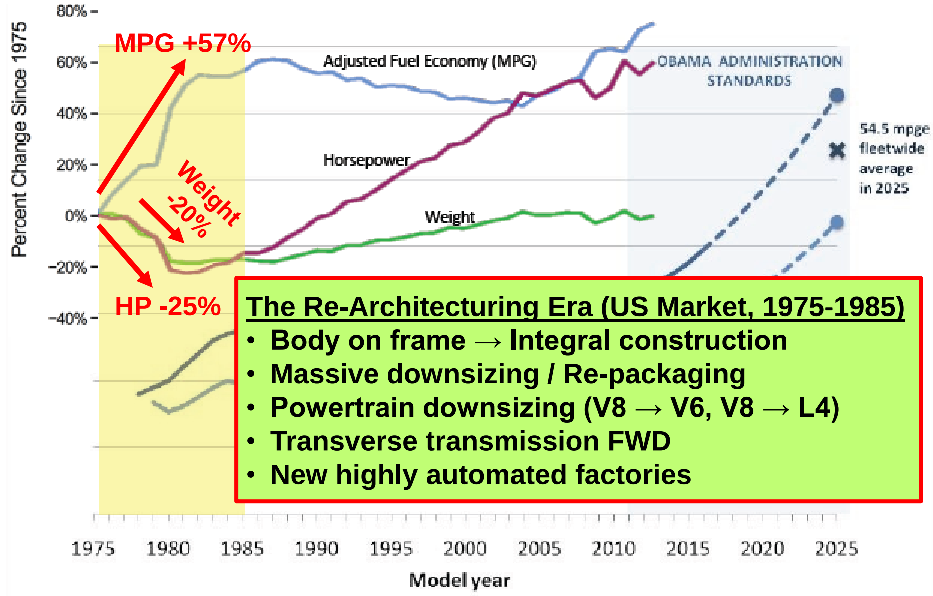
Percent Change Since 1975
80%
60%
40%
20%
0%
−20%
−40%
MPG +57%
Weight -20%
HP -25%
Adjusted Fuel Economy (MPG)
Horsepower
Weight
OBAMA ADMINISTRATION STANDARDS
54.5 mpge fleetwide average in 2025
The Re-Architecturing Era (US Market, 1975-1985)
• Body on frame → Integral construction
• Massive downsizing / Re-packaging
• Powertrain downsizing (V8 → V6, V8 → L4)
• Transverse transmission FWD
• New highly automated factories
1975 1980 1985 1990 1995 2000 2005 2010 2015 2020 2025
Model year

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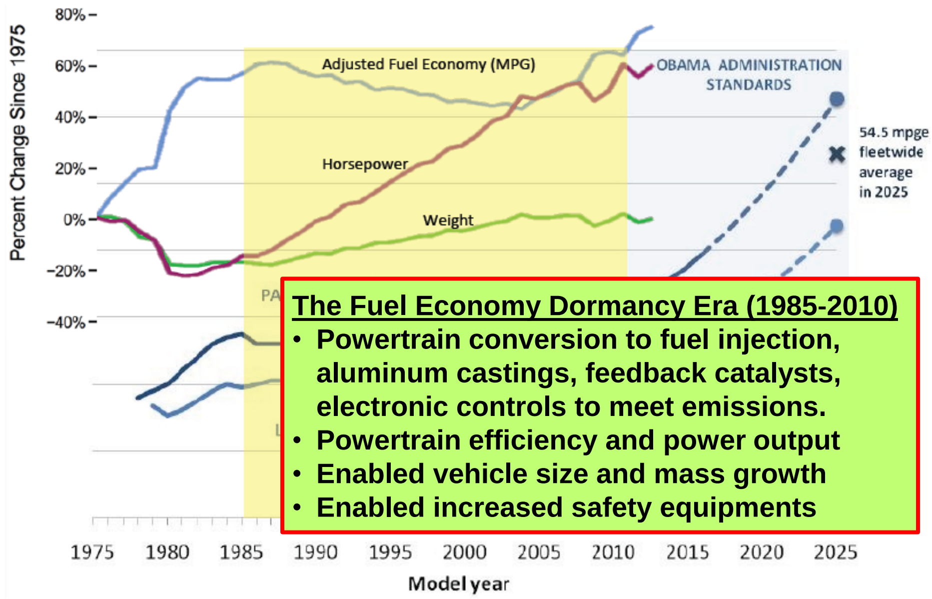
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Adjusted Fuel Economy (MPG)
Horsepower
Weight
OBAMA ADMINISTRATION STANDARDS
54.5 mpge fleetwide average in 2025
The Fuel Economy Dormancy Era (1985-2010)
• Powertrain conversion to fuel injection, aluminum castings, feedback catalysts, electronic controls to meet emissions.
• Powertrain efficiency and power output
• Enabled vehicle size and mass growth
• Enabled increased safety equipments
1975 1980 1985 1990 1995 2000 2005 2010 2015 2020 2025
Model year

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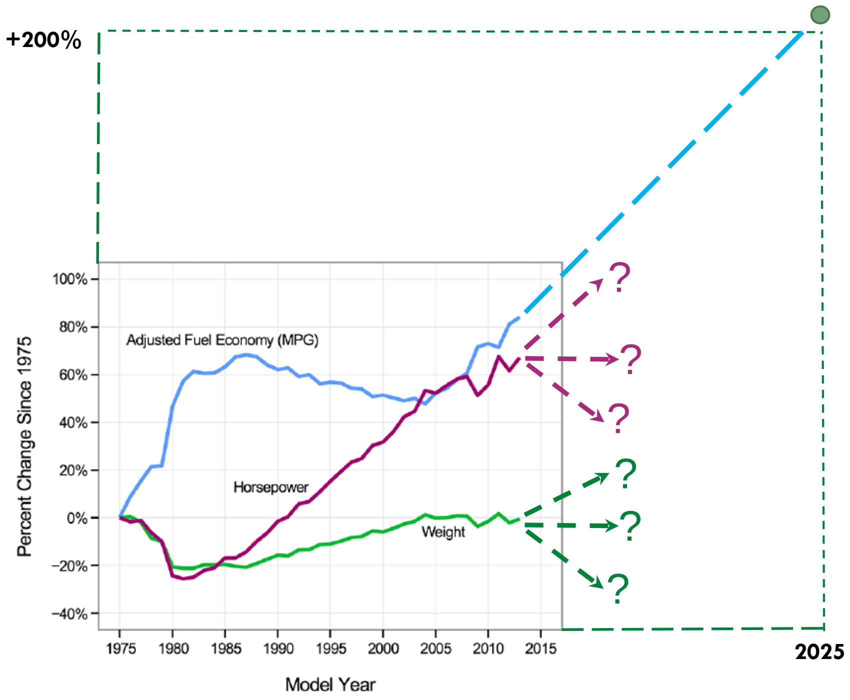

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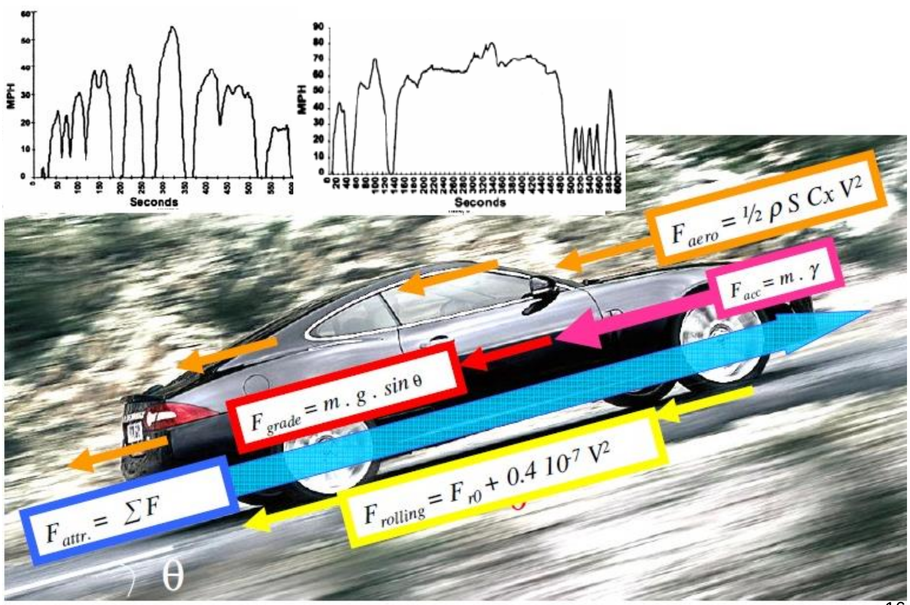
Weight Effect on Fuel Consumption



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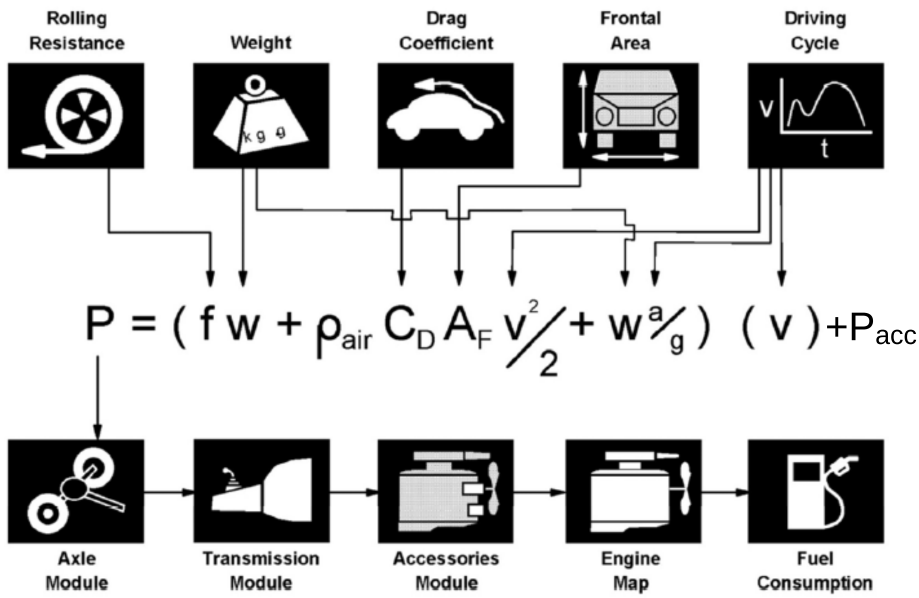

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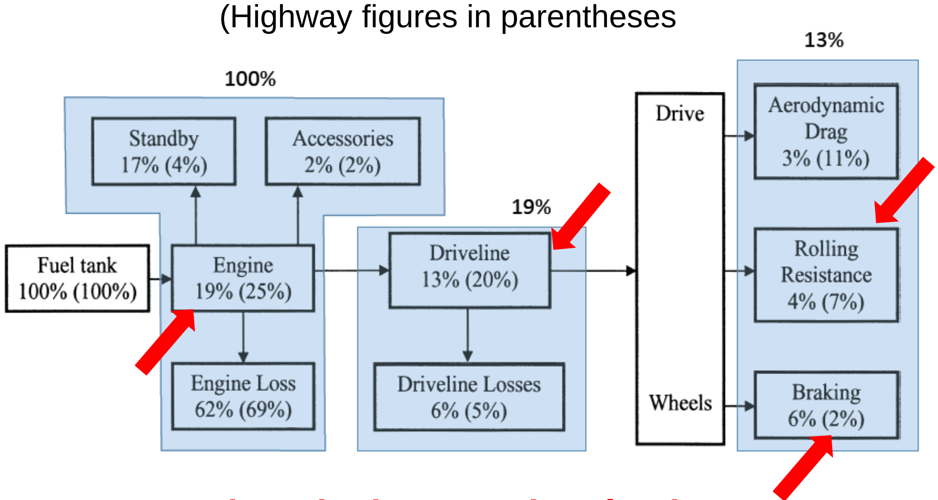
Uses and Losses of Fuel Energy in a Vehicle

Estimate of city and Highway usage
(Highway figures in parentheses



Where is the Mass involved?

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WardsAuto Annual Survey of Industry Engineers on Fuel Economy Strategies

- Question: What technology is your company focused on to help the industry meet 2025 fuel economy standards (multiple answers permitted)?
  - 49%, light weighting
  - 39%, engine efficiency
  - 26%, vehicle electrification
  - 11%, downsizing

- For the 2011 survey, engine efficiency was the area of largest focus.

Source: 2014 WardsAuto, DuPont Automotive Trends Benchmark Study

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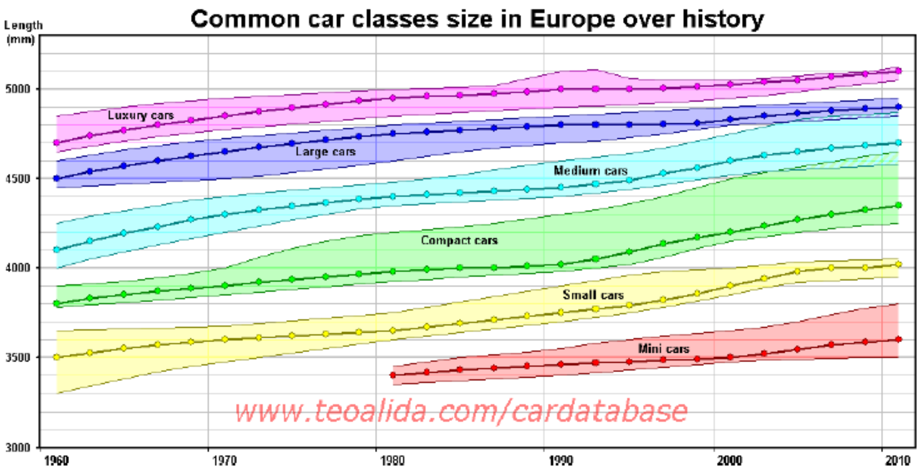
Trend of Historical Vehicle Size Increases (Europe)



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Example of the Old vs New Fiat 500

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How Does Mass Reduction Achieve Fuel Economy Savings?

- Less energy required to accelerate the vehicle (F = ma)
- Less rolling resistance at speed
- Light weighting begets light weighting:
  - ✓ Smaller powertrains
  - ✓ Lighter chassis and brake components
  - ✓ Smaller gas tanks
  - ✓ Smaller wheels and tires

Weight Facts

- **250 pound** of weight savings = 1 MPG savings
- **Weight breakdown** of a vehicle is 35% body, 34% chassis, 27% powertrain, and 4% other
- **Aluminum** can save 50% weight
- **Magnesium** can save 60% weight
- **Glass fiber composite** can save 25% weight
- **Carbon fiber composite** can save 60% weight

Materials Rank by Density (gm/cc)

Material	d	Material	d
Air	0.001	Aluminum	2.7
Water	1.0	Titanium	4.5
Plastics	1.1	Zinc	7.1
Carbon fiber composite	1.3	Iron	7.2
Glass fiber composite	1.8	Steel	7.9
Carbon fiber	1.8	Nickel	8.8
Magnesium	1.8	Copper	8.9
Glass Fiber	2.5	Lead	11.3

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Materials Rank by Cost

Material	Cost $/lb
Iron	0.27
Steel	0.30
SMC	0.80
Aluminum casting	0.70
Plastics	0.90
Magnesium	1.2
Glass fiber composite	1.4
Aluminum Sheet	1.2
Carbon fiber composites	6.0

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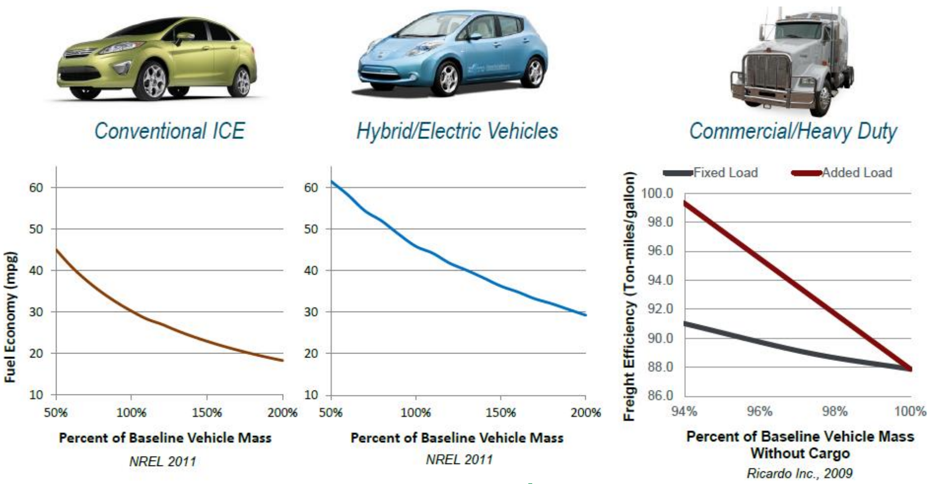

6% ~ 8% fuel economy improvement for 10% reduction in weight

Improvement in range, battery cost, and/or efficiency

13% improvement in freight efficiency for 6% reduction in weight

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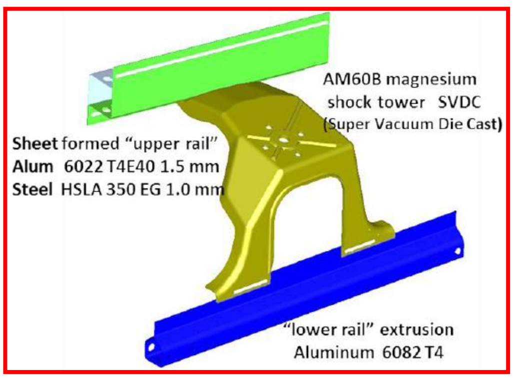
Ford Go Further

Ford
Go Further

Light Weighting Material Implementations

- **Material Independent Lightweighting**
- **Steel**
  - ✓ Press Hardened Steel (PHS), Gen-3 High Strength Steel (HSS)
- **Aluminum**
  - ✓ Joining
  - ✓ Cost
  - ✓ Alternative Forming
  - ✓ "High Strength" sheet
- **Magnesium**
  - ✓ Die Casting
  - ✓ Sheet
- **Composites**
  - ✓ Closures
  - ✓ CF structure and closure



Front-end structure employing dissimilar metals

Automotive Lightweight Solutions

- Lightweight Materials
  - ✓ Material designed to have the best-in-class weight
- Alternative Lightweight Design
  - ✓ Component engineered to use lighter material and innovative design to replace traditional material
- Technology enabling reduced material usage
  - ✓ Technology which facilitates and allows for reduced material usage such as reduced sheet metal thickness or elimination of existing component without sacrificing functionality
- Technologies enabling lightweight vehicle system
  - ✓ Technology which facilitates the joining of lightweight materials such as aluminum to aluminum, aluminum to CFRP, steel to CFRP and other material combinations

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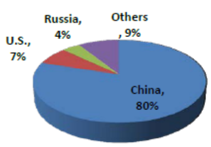
Lightweight Automotive Materials

Magnesium Alloys

When it "works" → 40-70% weight reduction

Otherwise → *Cost (~$3-10/ lb-saved)*

- Lack of domestic supply, unstable pricing
- Challenging corrosion behavior
- Inadequate strength, stiffness, and ductility
- Difficult to model deformation behavior



Aluminum Alloys

When it "works" → 25-55% weight reduction

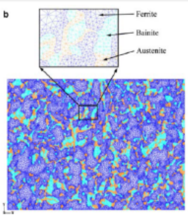
Otherwise → *Cost (~$2-8/ lb-saved)*

- Insufficient strength in conventional automotive alloys
- Limited room temperature formability in conventional automotive alloys
- Difficult to join/integrate to incumbent steel structures

Advanced High Strength Steel

15-25% weight reduction→

- Inadequate structure/properties understanding to propose steels with 3GAHSS properties
- Insufficient post-processing technology/understanding
- What other relevant properties should be considered? Hydrogen embrittlement, local fracture, etc.



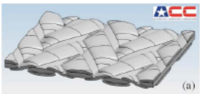
Choi et. al., Acta Mat. 57 (2009) 2592-2604

Carbon Fiber Composites

When it "works" → 30-65% weight reduction

Otherwise → *Cost (~$5-15/ lb-saved)*

- High cost of carbon fiber (processing, input material)
- Joining techniques not easily implemented for vehicles
- Difficult to efficiently model across many relevant length scales



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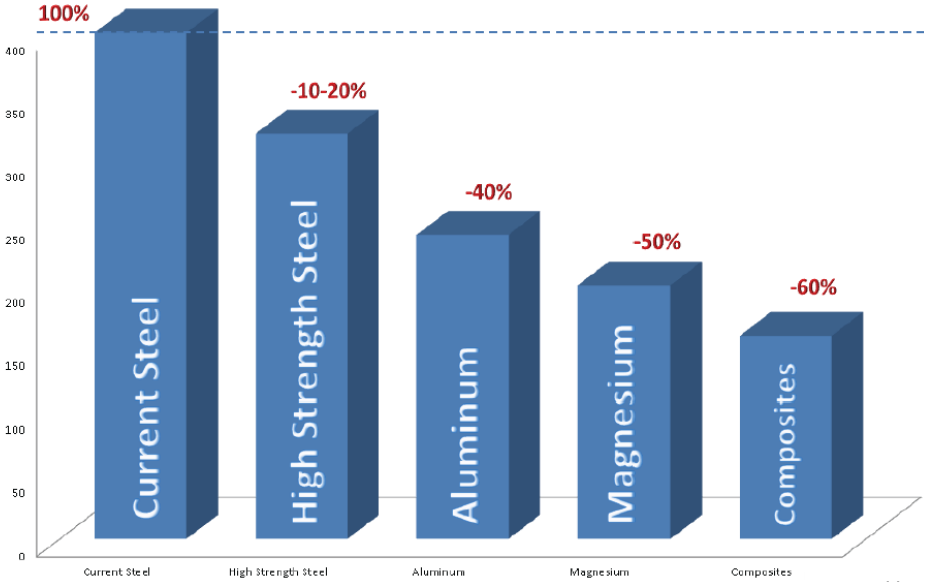
Material Weight Reduction Potential



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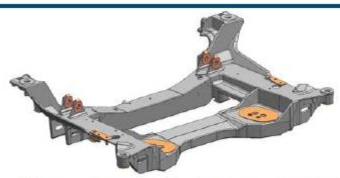
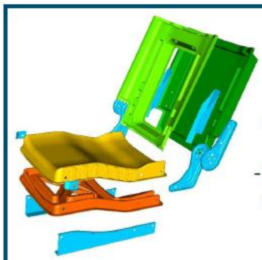
Example Component Light Weighting



- Mg engine cradle for Corvette Z06
- 35% lighter than Al
- Single piece Mg casting vs. multi-piece steel assembly

- AHSS rear cradle for RWD vehicles
- 27% lighter than conventional design, no loss of stiffness
- Cost neutral



- Carbon Fiber Composite seat structure
- 58% lighter than standard design

- Mg engine block, bedplate, oil pan, and engine cover
- 28% lighter than Al version

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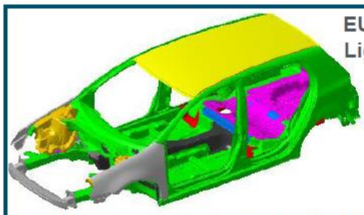
Example System Light Weighting



EU Super Light Car

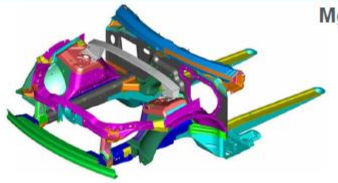
- Multi-material vehicle, Al intensive
- 30% weight reduction for BIW

Energy Foundation - Lotus

- AHSS intensive vehicle
- 16% weight reduction for BIW

PNGV

- Multi-material vehicles
- ~25% overall vehicle weight reduction



Mg Front End

- Mg intensive front end structure
- 45% weight reduction compared to steel
- 56% reduction in part count

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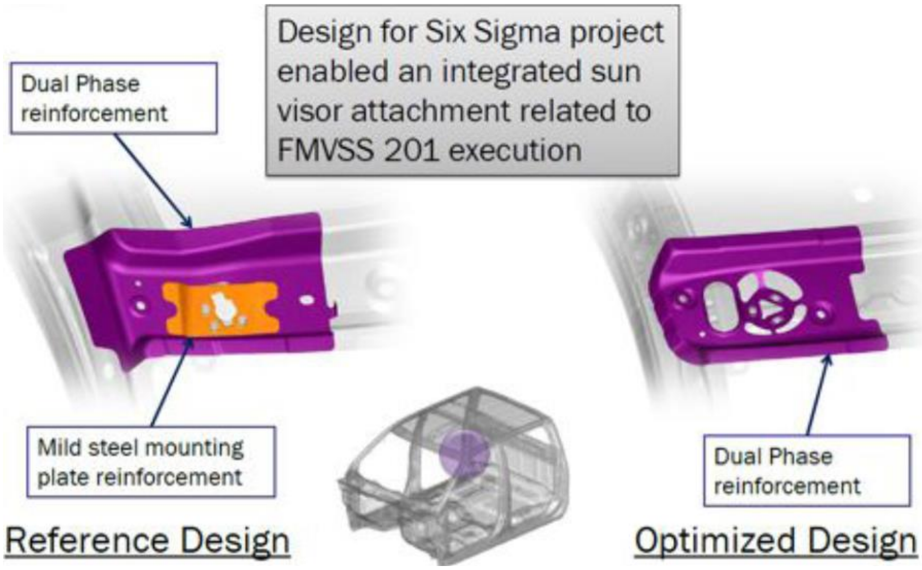
Efficient Material Utilization

Mass Reduction – Part consolidation



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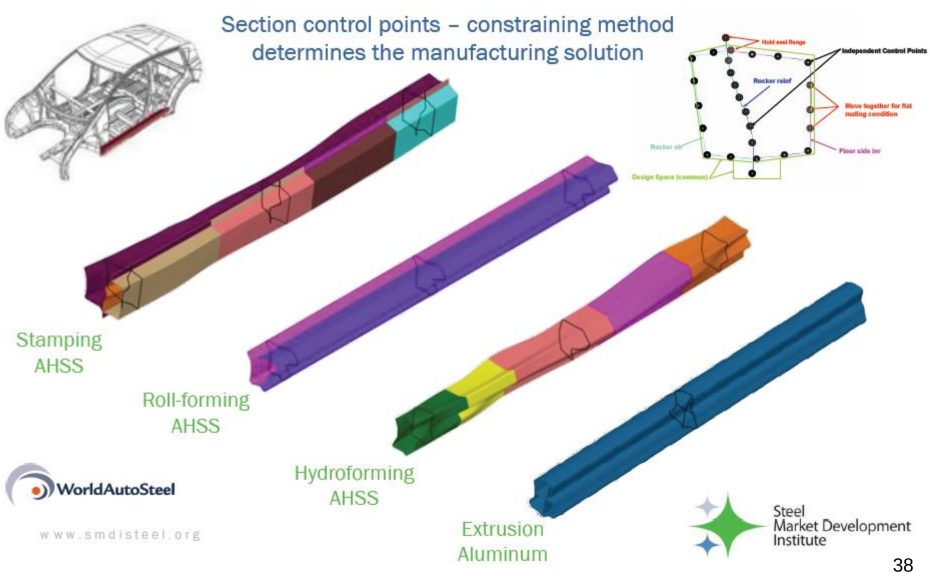
Mass Reduction Through Subsystem Optimization



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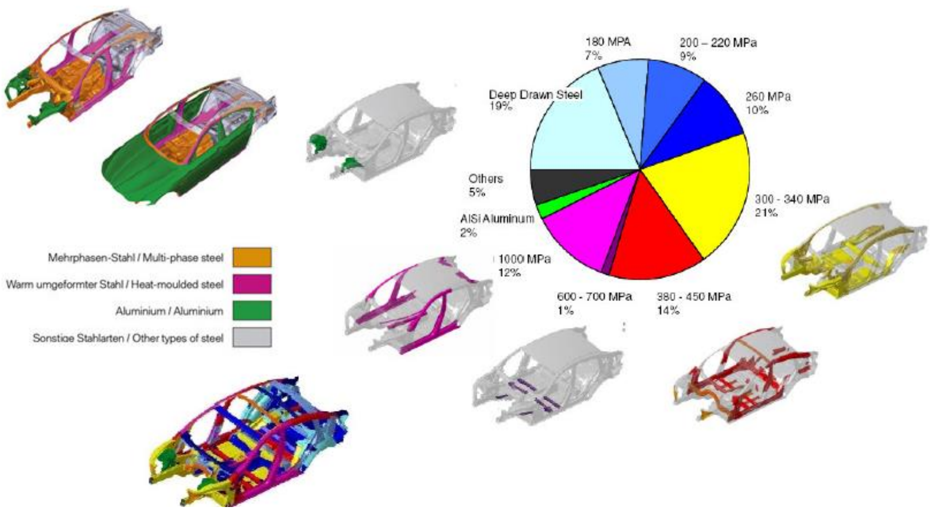
High-Strength Steel Applications

Steel Body-in-White (BIW)



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Automotive Steel Families

Family	Quality	AM offer	Eu Norm	Example of application
Drawing	DC01- DC07	ArcelorMittal 01-07 ArcelorMittal 51-57	EN10111 EN10130 EN10152 EN10327	Bodyside, roof, floor, hood panels, crossmembers
High Strength steels	IFHSS	IF180 – IF300	EN10268 EN10292 EN10152 EN10149	Door, hood, decklid outer panels Members, crossmembers
	BH	180BH – 300BH		
	Rephosphorized	H220 – H300		
	Isotropic	E220i – E260i		
	HSLA	CR HSLA 260 – 420 HR HSLA 320 -550		
Advanced High strength steels	Dual Phase Complex Phase TRIP Martensitic	DP450 -1180 DP HY and HHE TRIP 690 – 780 MS1200	EN10336 prEN10338	A, B, C Pillar R/F Member R/F Bumper, door beams Rocker panel
Press hardened steels	22MnB5 USIBOR	22MnB5 USIBOR1500AS		A Pillar, member, bumper beam
Composite steels	Vibration damping structural	Quietsteel smoosteel		Dash panel, engine cover, oil pan

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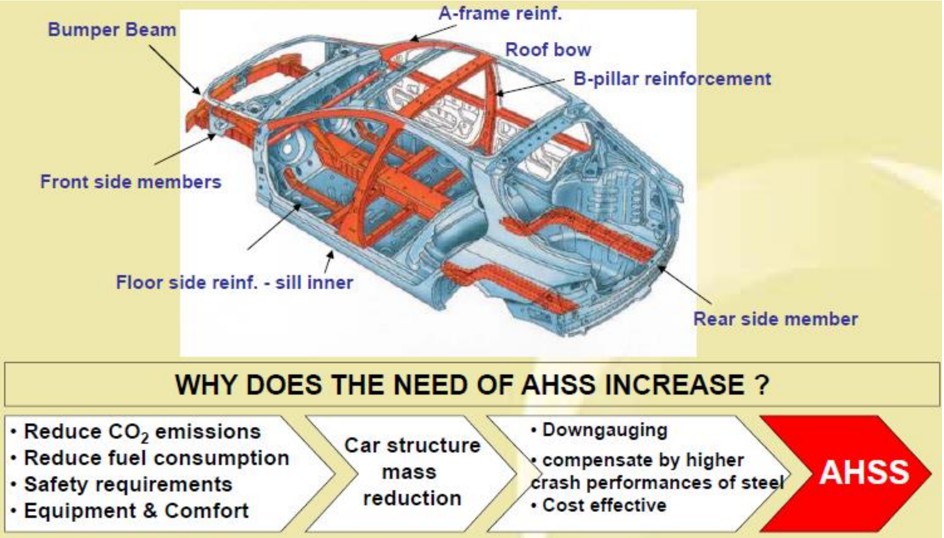
AHSS: Dedicated to Structural Parts



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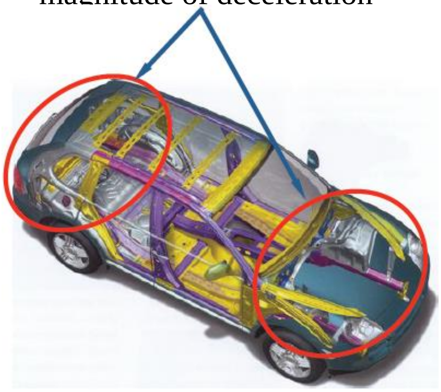
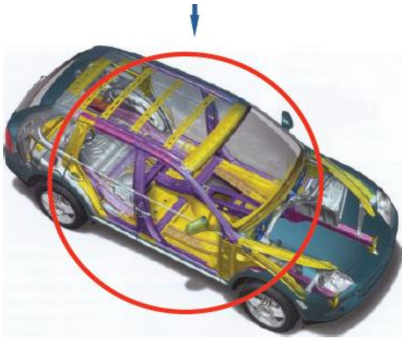
Advanced High-Strength Steel (AHSS) Advancements for Crash

Crashworthiness Fundamentals – Two Key Zones

Crumple Zones (engine compartment, trunk) deform to absorb energy and control magnitude of deceleration

Safety Cage (passenger compartment) resists deformation to prevent intrusion





Source: AISI

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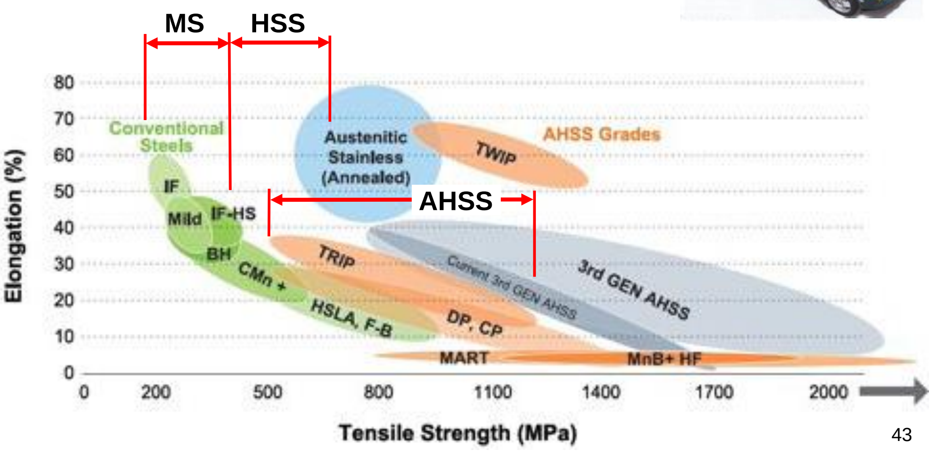
AHSS Advancements for Crash

Steels for Safety Cage Zone
• Highest Strength
• Boron Hot Formed, Martensite, 3GAHSS



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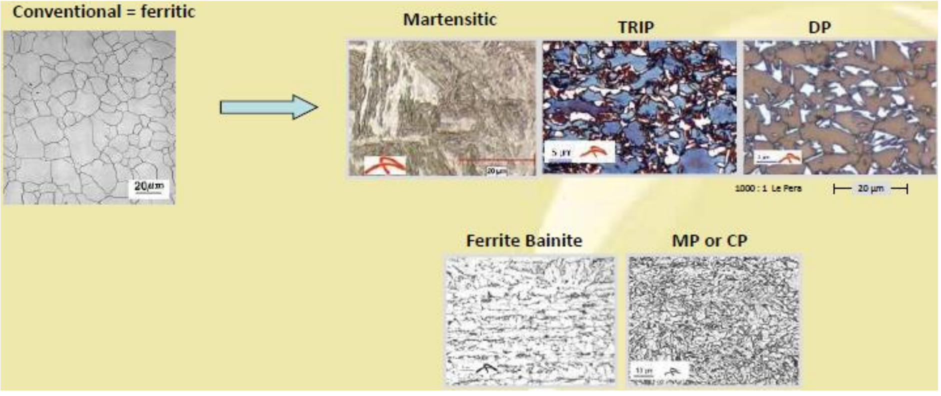
AHSS = Multiphase Steels

Strengthening by quenching generated hard phases: martensite, bainite, retained austenite



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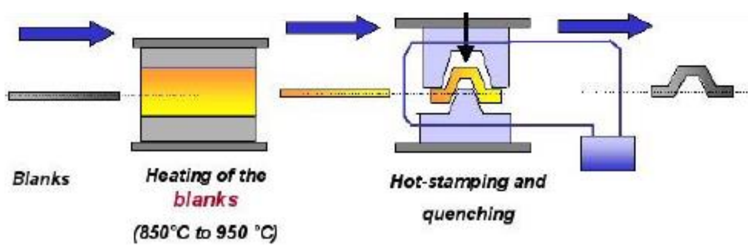
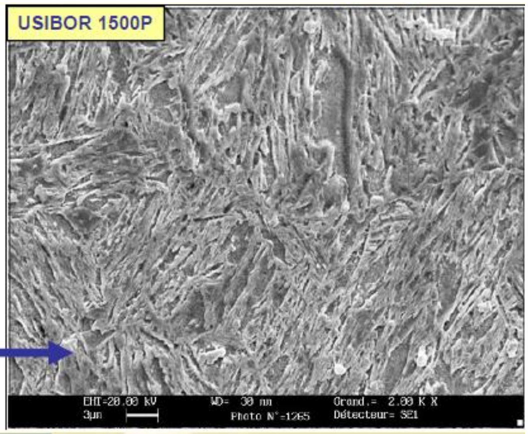
AHSS = produced by conventional process



Metallurgical Structure after Hot-stamping



100% martensitic

Hardness : 400 to 500 HV_1

Homogeneous mechanical properties in any point of the parts :
Ys ≈ 1100 MPa, Ts ≈ 1500 MPa, E (ISO) ≈ 6%

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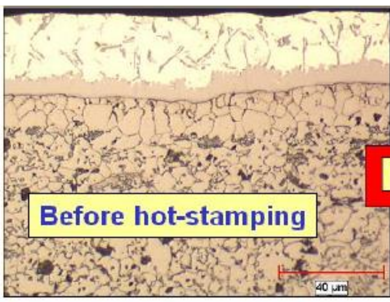
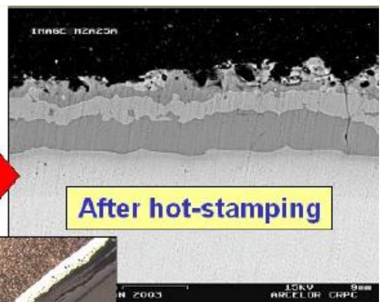
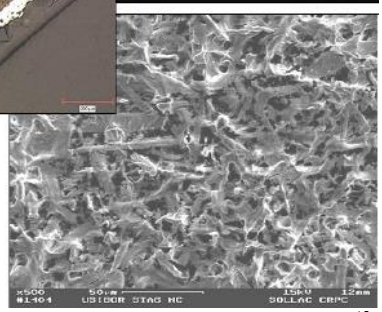
AlSi Coating after Hot-stamping



USIBOR 1500P





During the heat-treatment (900 to 950°C – 5 to 10 min) the coating is transformed into an alloyed intermetallic layer (Al, Fe, Si)

→High Adhesion

→ High Roughness

→ No scale !

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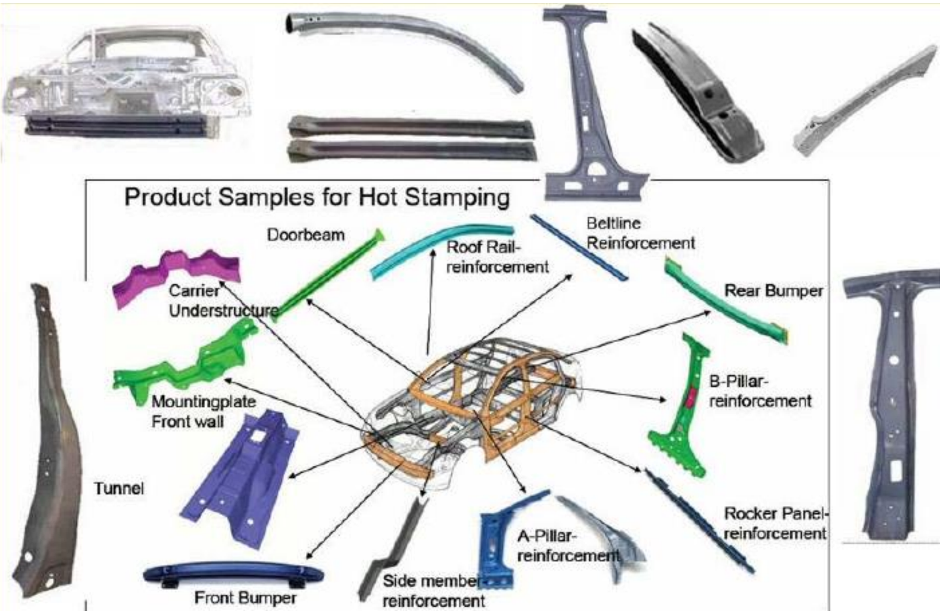

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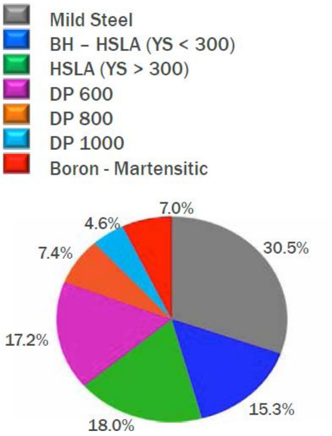
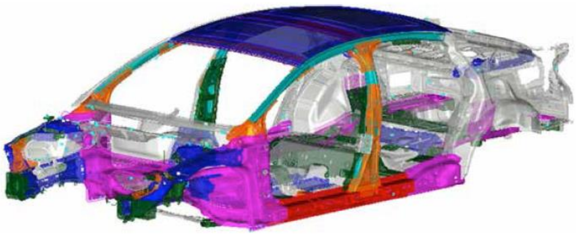
Material - BIW





Average Yield Strength = 348 MPa

Go Further

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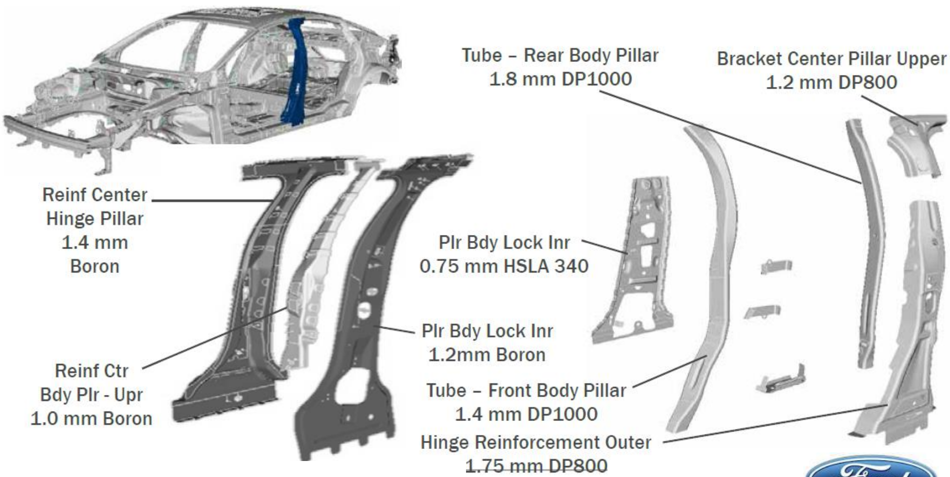

Ford
Go Further

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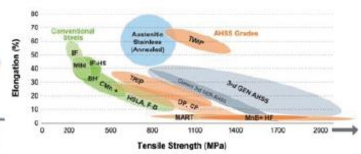
DOE Funded ICME Project
~ Integrated Computational Materials Engineering

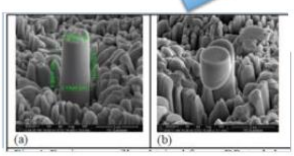
A/S P Auto/Steel Partnership

Integrated Modeling for 3rd Generation AHSS

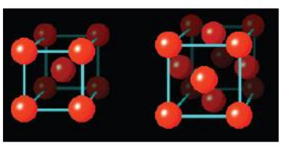
USAMP
UNITED STATES AUTOMOTIVE MATERIALS PARTNERSHIP LLC

- Brown
- Clemson
- Colorado (Mines)
- Illinois
- Mich. State
- PNNL
- EDAG
- LSTC





ICME: Integrated Computational Material Engineering



$6 million over four years

www.smdisteel.org

Steel Market Development Institute

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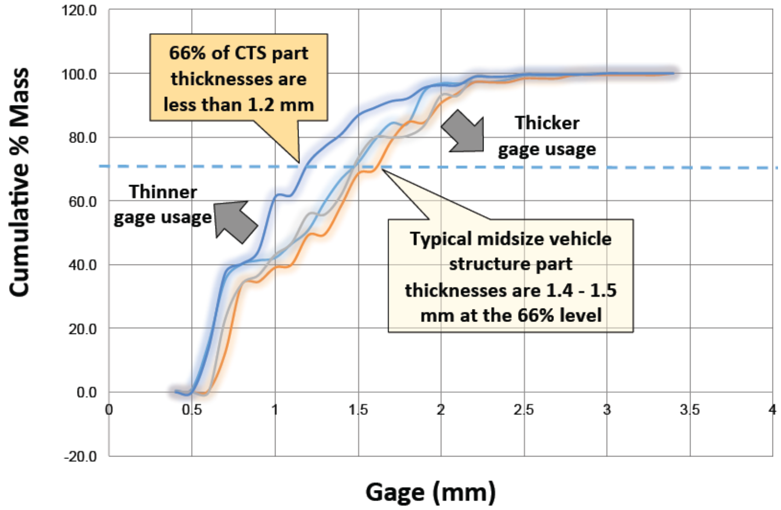
General Motors Cadillac CTS: '3G' Approach
- **Gage**
- **Grade (Material)**
- **Geometry, CAE Tools and Methods**



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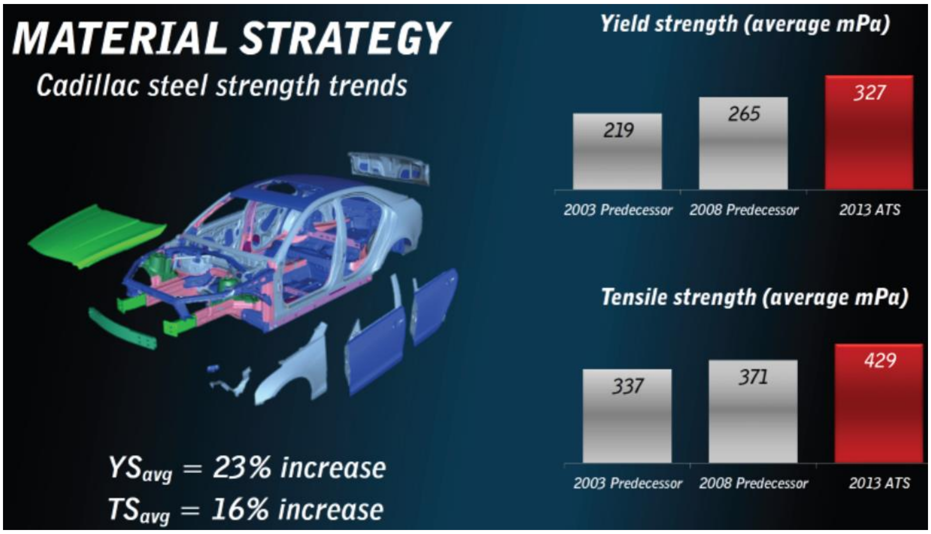

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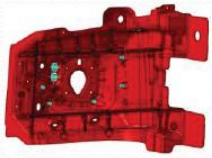
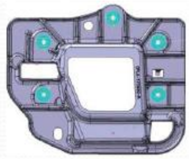
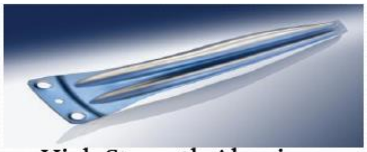
Aluminum Applications



Front Suspension Casting



Bumper Housing Casting



High Strength Aluminum Side Impact Beam

Crash Box

Seat Frame

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The Move to Aluminum

- The first production vehicle to move to an Al frame was the Audi A8 in 1994.
- This allowed Audi to make their full-size car lighter than the competitions (BMW, Mercedes,Lexus...), thus giving them the edge in performance & handling.
- This comes at a price premium though, for instance compared to a Lexus LS460 (Steel framed) which costs around $65,000. The A8 starts at $75,000

Audi A8

Lexus LS460

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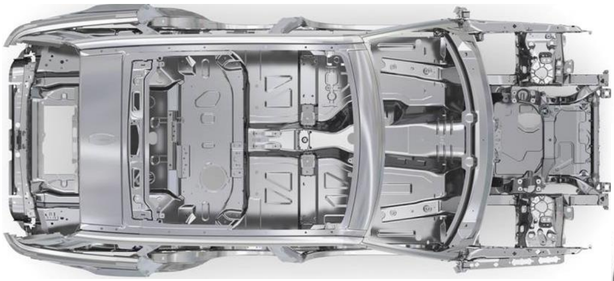
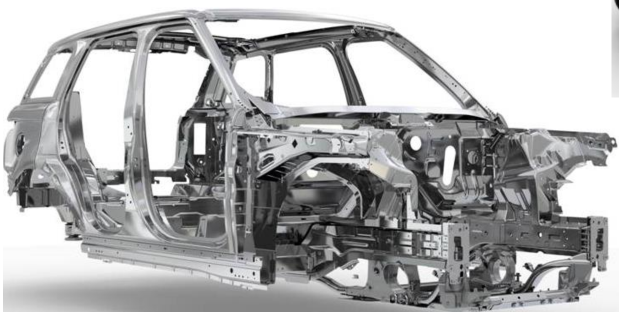
Range Rover Sport





Ford Takes a Leap: the New 2015 All Aluminum F150 Pickup Body

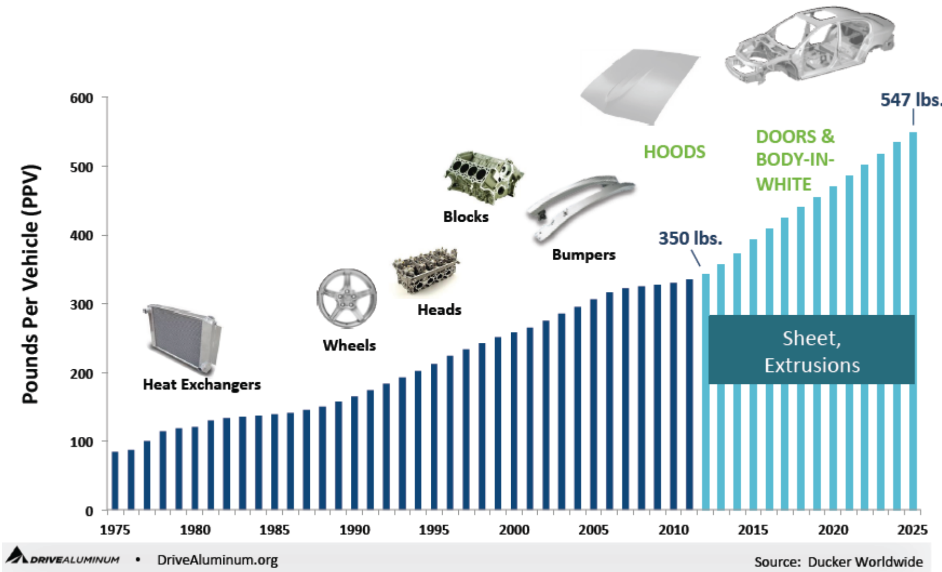
The Ford F150 truck is the first high volume application of LWV technology in the USA

Ford worked with aluminium suppliers & technology providers to ensure capacity is in place

Further Capacity will be put in place in the USA as further models require LWV technology

Shifts the aluminium needle, but still less than 5% of total Auto Body Sheet requirement

50 Years of Automo8ve Aluminum Growth



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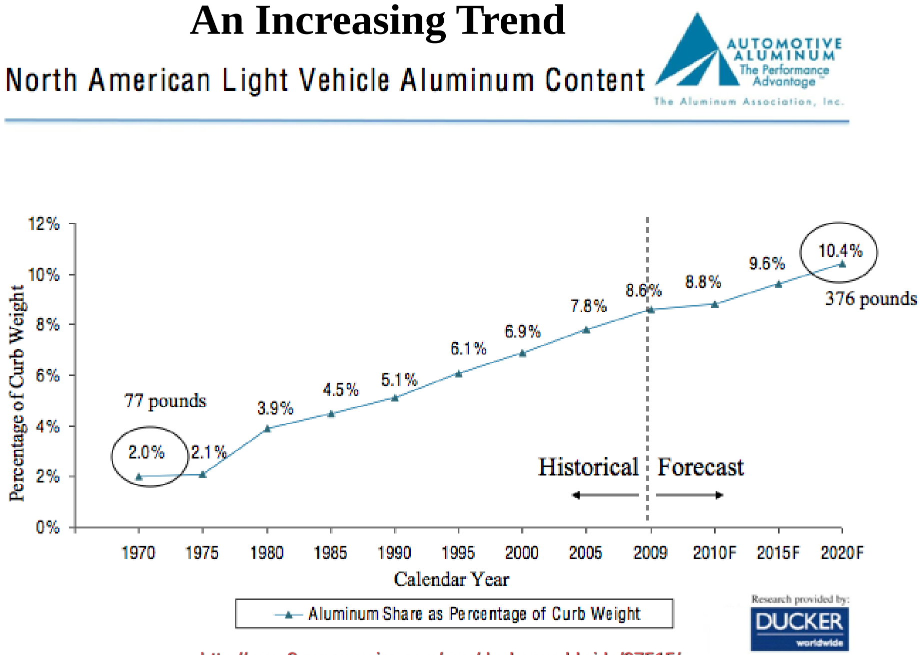
An Increasing Trend

North American Light Vehicle Aluminum Content

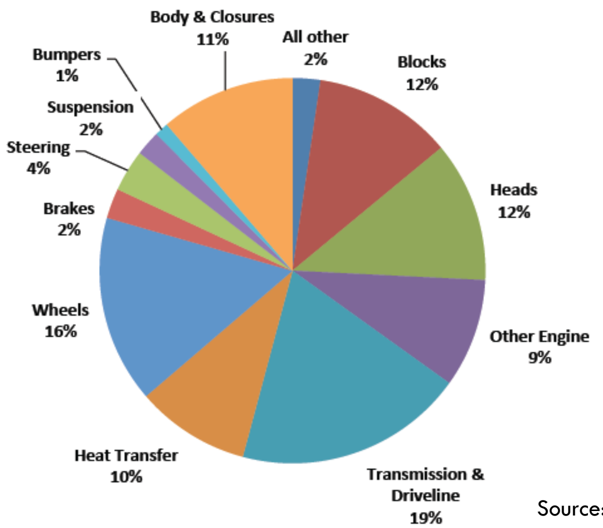


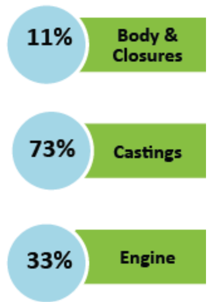
http://www2.prnewswire.com/mnr/duckerworldwide/37515/

60

2015 Total Aluminum Content

Aluminum Component Share by Weight





6.9 Billion Pounds

Source: Ducker Worldwide

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Aluminum Joining Technology Opportunities

- CAE models for all welding technologies with improved representation of heat affected zones and weld nuggets and improved statistical predictions for failure.
- Steel to aluminum fusion welding
- Adhesive bonding with AHSS and composites
- Common / flexible solutions for multiple materials and processes

MATERIAL TYPES:

- 6061 - T6
- 5000 Series 90 MPa
- 6000 Series 90- 115 MPa
- 6063 – T6
- 6111 – T4
- A5023 – H24
- EN-AW 6082
- BG- AlSi 12- 230

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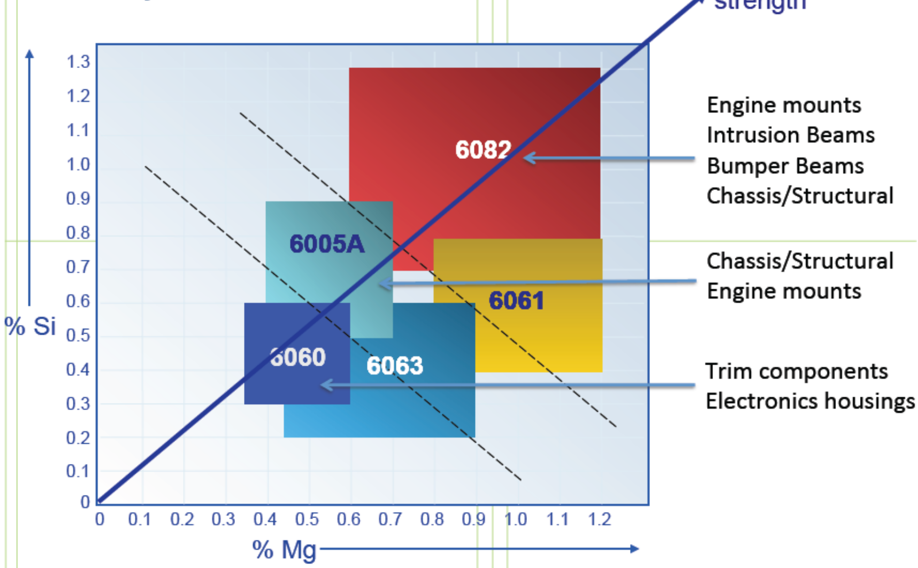
Strength is one key consideration … 6XXX alloy series



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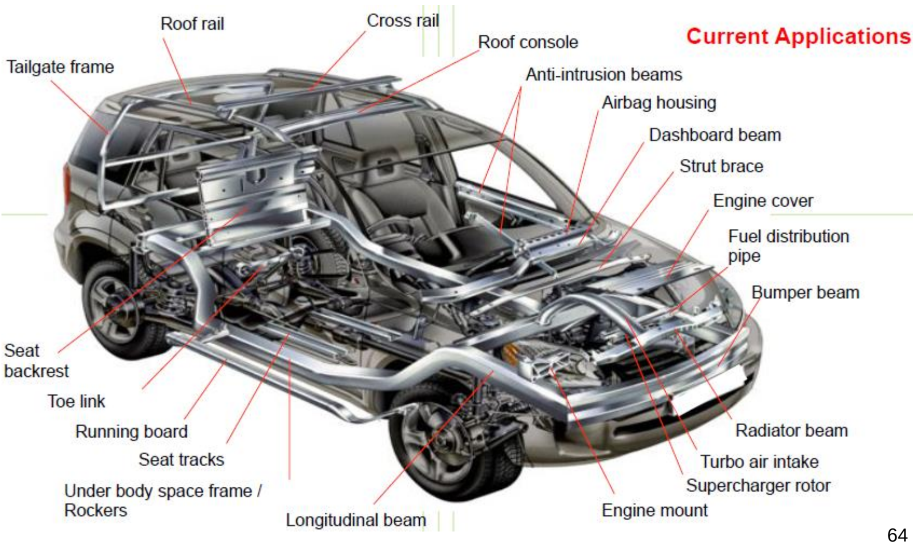
Application of Aluminum Extrusion to Light Weighting

While most growth is projected for chassis/body applications, extrusions are being used in virtually all vehicle systems.



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Cases of Aluminum Extrusion Applications

Trim for Mercedes Vehicles

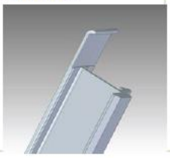
- The Pillar Cover and Window Guides were initially roll formed and stamped steel products, requiring buffing before painting due to the high visual requirements

Pillar Cover

Window Guide

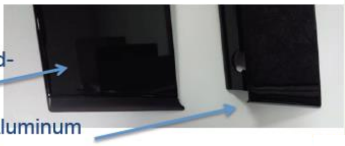
Extruded Window Guide

- 35% weight reduction
- multiple parts incorporated into 1 extrusion
- polishing of Visual Surfaces eliminated
- Improved corrosion performance
- Tighter bend tolerances achieved



Extruded Pillar Cover

- 40% reduction in weight
- Polishing of visual surfaces eliminated
- Separate plastic end-cap eliminated



Plastic End-cap

Formed Aluminum Extrusion

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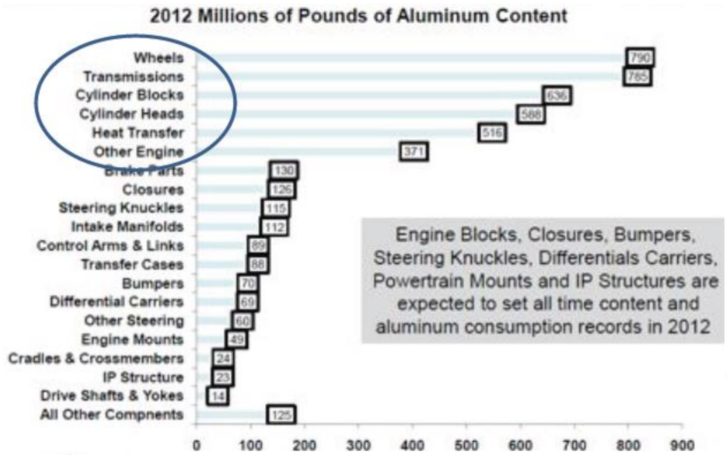
Aluminum Castings



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Continuous Casting

- Strip cast Al sheet implemented on narrow width low Mg 5XXX series alloys
- Demonstration trials complete with higher Mg alloys and 6xxx series alloys.
- Need to explore new alloys enabled by faster cooling rates.
- Need to explore economic opportunity

Improve Formability

- Retrogression heat treatment
- Warm forming
- Super plastic forming
- Quick plastic forming
- Fast
- Hydroforming
- Perform annealing
- Electromagnetic forming

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Aluminum Intensive Vehicles


Ford AIV


Ford P2000

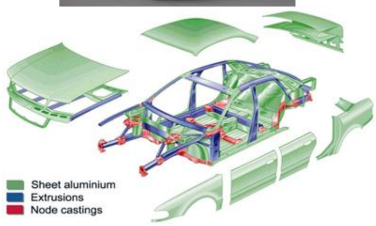

Ford Contour


Jaguar XJ

Audi A8


Jaguar XF


Audi A2




Jaguar XK

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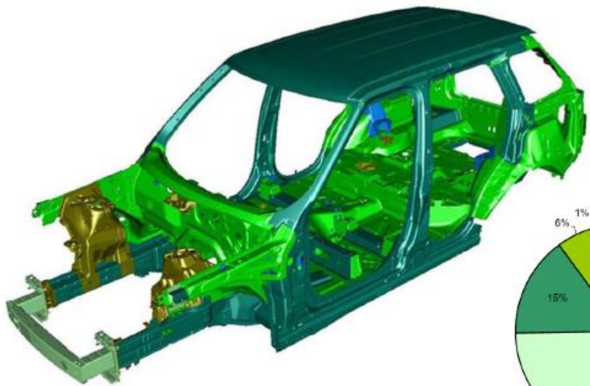
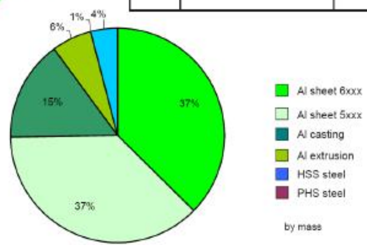
Range Rover Sport

Aluminum body, weight saving 300 kg vs. previous model
39% = 180 kg lighter than the steel equivalent



	Component Type	New RR % part no.
	Stampings	88%
	Castings	5%
	Profiles	3%
	Tubes	3%
	Other	1%



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Cars Utilizing Al Frames

Audi A8
Jaguar XJ
Corvette Z06
Honda NSX
Audi A2
Audi R8

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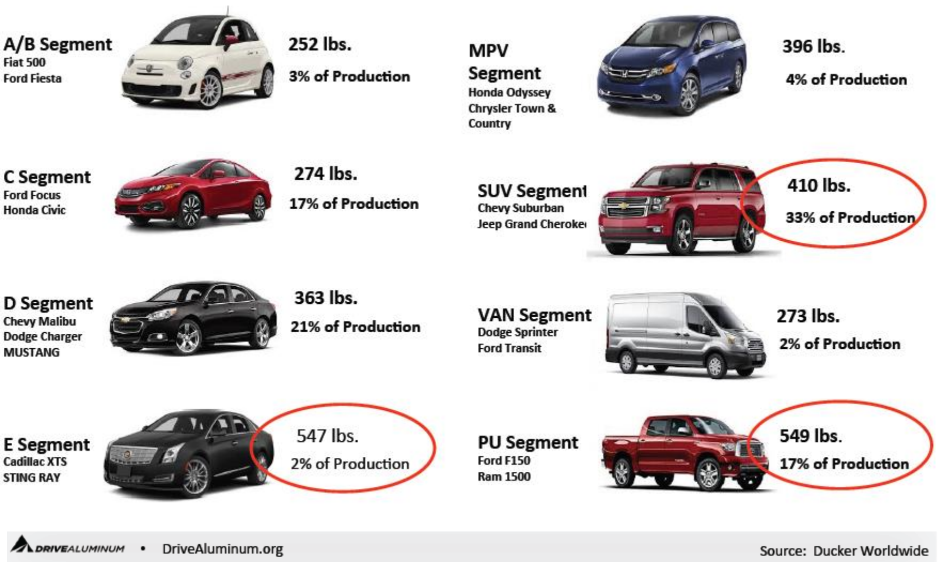
2015 Aluminum Content by Segment



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Weight

- The most obvious advantage to using aluminum in place of steel in cars is aluminum weighs less.

Safety

- Not too many safety tests have been performed on Al framed vehicles due to their usually higher price.
- However, the Audi A2 is an inexpensive compact car that has been tested, and received overall favorable reviews compared to its steel bodies counterparts.

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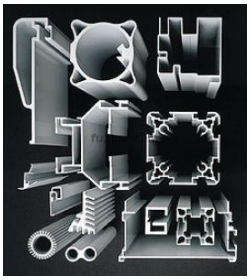
Some other advantages...

- There are some manufacturing methods that can only be done with aluminum, such as extrusions.
- These extrusions allows the Al Space Frame to have about half the amount of parts as a traditional steel monocoque.
- Because of all this, Al is already a cheaper material to use for low volume production cars (under 100,000 units a year or so).



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A Few Other Facts...

- Today, the average car contains about 200 pounds of aluminum parts.
- Aluminum space frames (like that from Audi), contain fewer parts and fewer connection nodes, which helps keep production costs lower.

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Mainstream Methods to Join Aluminum BIWs

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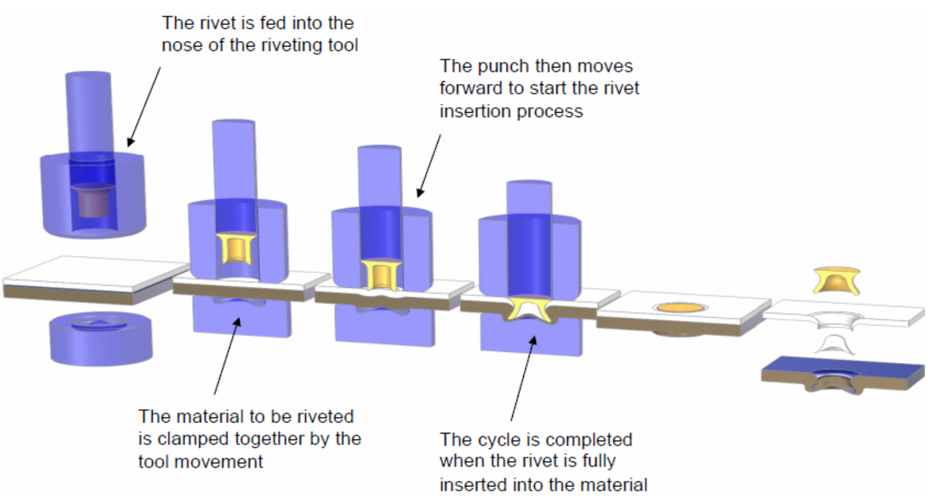
Self-Pierce Riveting Process



Courtesy of Henrob Corp., USA

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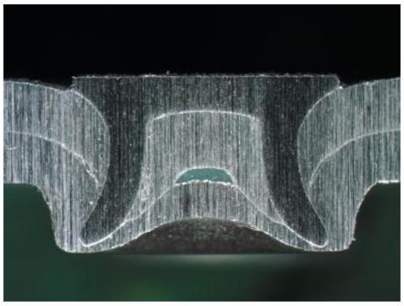
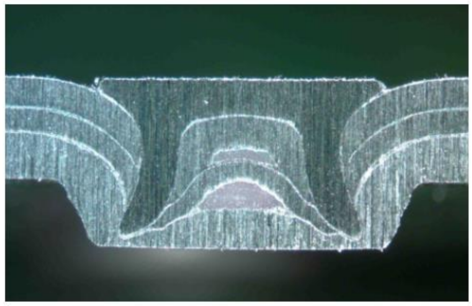
Self-pierce Rivets and Adhesive = Hybrid Joint



2T Stack with Adhesive



3T Stack with Adhesive

Aluminum Sustainability

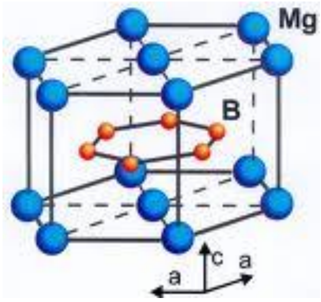
- Lower cost material production
  - ✓ Continuous casting
  - ✓ Coordinate with mill capacity upgrades
- Facilitate closed loop recycling
  - ✓ Industry purity commonality
  - ✓ Uni-alloy
- Higher strength alloys
  - ✓ > 500 MPa with standard processing
- Design with aluminum
- Improved formability or forming processes
- CAE models for materials and joints

Magnesium Applications

- New interest in magnesium has been recently aroused due to the expansion of use of magnesium alloys in the 1990s and, especially, due to an appearance of high-strength magnesium matrix composites as lightweight advanced structural materials for automotive and aerospace.
- Magnesium alloys are considered as possible replacements for aluminum, plastics, and steels, primarily because of their higher ductility, greater toughness, and better castability.
- Production of magnesium almost tripled last decade, and the world production capacity reached 515,000 tons per year in 2009.

Characterization of Base Magnesium

- Magnesium is the eighth most abundant element and constitutes about 2% of the Earth's crust, and it is the third most plentiful element dissolved in seawater.
- Although magnesium is found in over 60 minerals, only dolomite, magnesite, brucite, carnallite, and olivine are of commercial importance.
- Magnesium and other magnesium compounds are also produced from seawater, well and lake brines and bitterns.



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- Magnesium is the lightest and one of the cheapest structural metals.
- Lighter than aluminum (only 2⁄3 of aluminum and 1⁄3 of titanium specific weights), better in heat dissipation and heat transfer due to high thermal conductivity of 51 W/m·K, and exhibit excellent ability in shielding electromagnetic interruption.
- Low density, ~1.75 g/cm3, in combination with relatively a high tensile strength of 228–290 MPa, heat resistance up to (450°C), and oxidation resistance up to 500°C make magnesium alloys attractive for various structures in the automotive industries.
- Especially attractive for various aerospace industries, as well as in textile and printing machines where lightweight magnesium parts are used to minimize inertial forces at high speed.
- Recyclable
- the surface of magnesium alloys should be protected because they corrode easily when exposed to atmosphere.

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- Mechanical properties (especially plasticity) of magnesium alloys depend on the fabrication parameters and the testing temperature. For example, a considerable change in mechanical properties was observed for Alloy AZ31 fabricated by casting, extrusion, and rolling.
- The strength weakening is accompanied by a remarkable increase in ductility. The elongation increased from 21.5% to 66.5% as the test temperature changed from RT to 250°C.
- Magnesium alloys with reduced aluminum content AM60, AM50, and AM20 are suitable for applications requiring improved fracture toughness. However, the reduction in aluminum results in a slight decrease in strength for AM alloys.
- Alloys AS41, AS21, and AE42 are employed for applications requiring long-term exposure at temperatures above 120°C and creep resistance.

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Magnesium Properties

- Lightest structural metal (33% lighter than aluminum)
- Highest strength to weight ratio of light metals
- Better machinability than aluminum
- 100% recyclable

Material	Strength to weight ratio
Steel	0.04 – 0.06
Al	0.11
Mg	0.13
Ti	0.12

Material	Mass savings (% of vehicle)	Annual fuel savings (L/vehicle/yr)	Total energy savings (Q/yr)
Al	33%	328	2.58
Mg	41%	407	3.21
Ti	19%	188	1.48

Assumptions:
- 0.0036L/km fuel reduction per 100 kg reduced vehicle mass
- 20,000km traveled/car/yr (~12,500 mi)
- 239 million cars on the road (US 2012)
- 5MJ/L energy content of gasoline
- All steel replaced by light metal (equal bending stiffness/strength basis)

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Magnesium Alloys Utilization
(Mg content averaging 95%)




Magnesium sheet

- ✓ Significant R&D and industrial runs have been done successfully in the last years
- ✓ Mg sheet fabrication processes are mature
- ✓ Mg sheet consumption is forecast to increase sharply

Magnesium casting

- ✓ Magnesium remains a light metal of choice for cast parts, capable of thinner wall castings, and being much less aggressive on metal moulds.

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Magnesium in Aluminum

- Aluminum Alloys: Mg content from 0,15% to 10 %
- More non-ferrous lightweight metal used
  ➡ more Mg consumed
- Non-ferrous light metals are the most promising solution for OEMs to meet the stringent fuel economy standards
  - ✓ Lighter and durable material
  - ✓ Infinite recycling capacity, for almost any mix of alloys.

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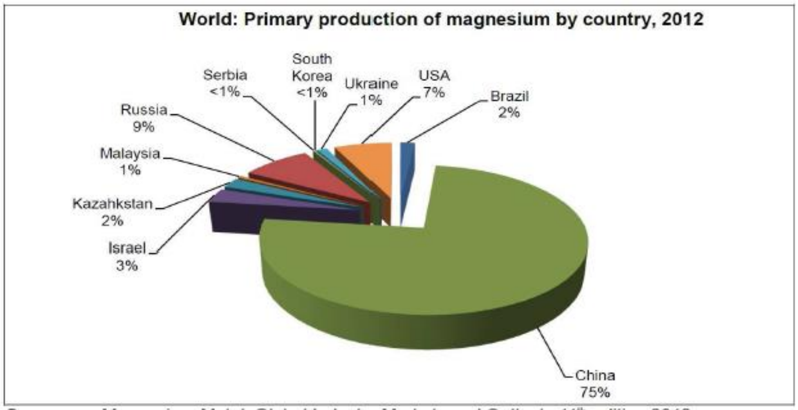
Magnesium Production - Primary Metal

Primary production reached 905K MT in 2012

- Chinese Mg industry is still largely fragmented, where small plant production accounts for 33% of total Chinese output
- Mg is now listed as a strategic material by the US government



Source : *Magnesium Metal: Global Industry Markets and Outlook, 11th edition 2013, Roskill Information Services Ltd.*

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Magnesium Die Casting on Corvette

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Potential Growth of Mg Closures

High Volume Integration :
2014 Ford Mondeo Lifegate / Hatchback

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Magnesium Sustainability

- Corrosion, Corrosion, Corrosion
- Innovative design to consolidate parts
- Room temperature formability or high volume forming process.
- Higher strength alloys

  > 500 MPa with standard processing
- CAE models for materials and joints
- Lower cost raw materials

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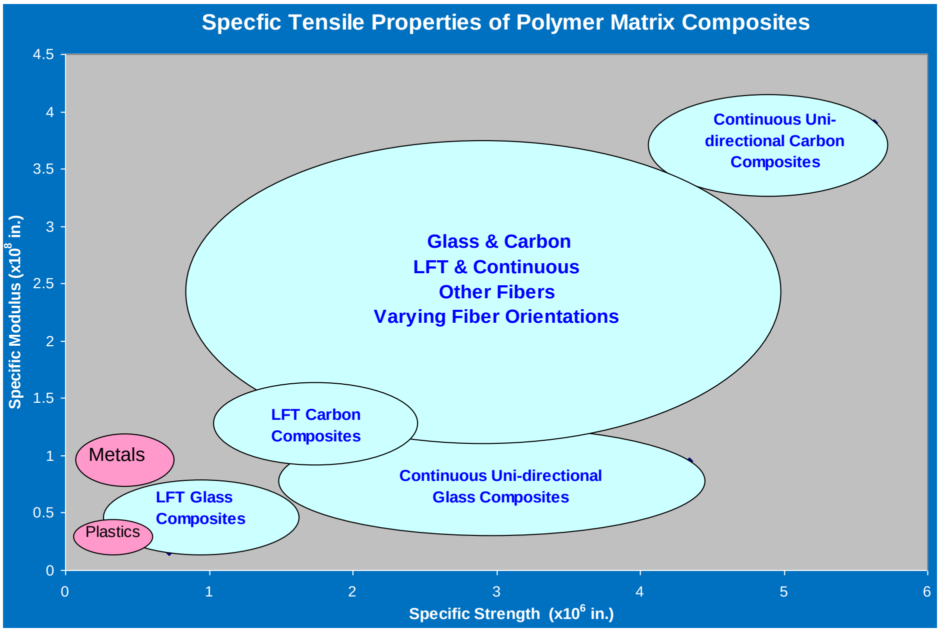
Composites Applications

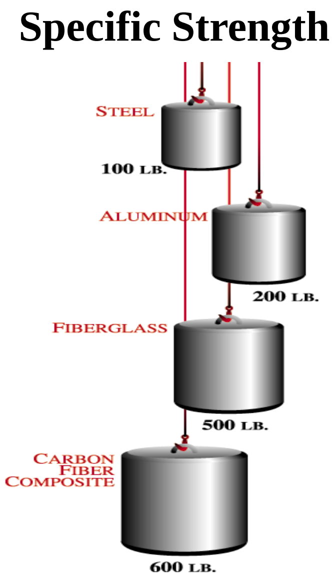
Corvette Composites

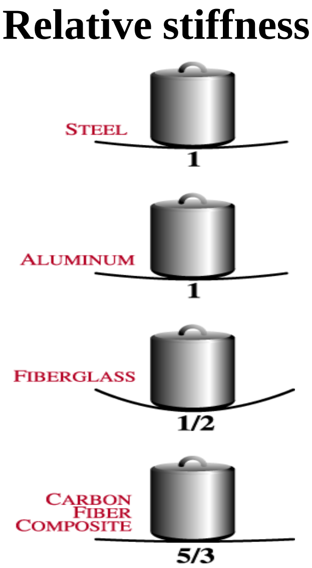
Chevrolet Corvette Z06 & ZR-1



CARBON FIBERS –

The 21st Century Material





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Thermoplastic Composites

Benefits

- Unique properties
- Vibration dampening
- Light weight
- Potential for low cost
- Shelf life
- Recyclable
- Durability
  - Fatigue
  - Corrosion
  - Toughness

Limitations

- Cost
  - Materials
  - Manufacturing
  - Tooling
- Design know-how
- Manufacturing know-how
- Use temperature

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Thermoplastic Composites

Many Polymer Options
- Polyethylenes
- Polypropylenes
- Nylons
- Polycarbonates
- Acrylics
- Polyesters
- Polyimides
- Polysulfones
- Polyketones
- Polyurethanes
- the list continues

Many Property Options
- ultimate strain > 100%
- no microcracking
- no delamination
- dampening
- no water uptake
- low dielectric properties
- melt formable
- weldable
- elastomeric - plastic - elastic behavior
- the list continues

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- Properties are fiber dominated
- Oriented long or continuous fiber reinforcement
- High volume fiber fraction (up to 65% by volume)

Key benefits:

✓ Reducing thermal limitations (e.g. creep) caused by the TP matrix system

✓ Reducing costs and weight and retaining toughness, formability, weldability, short cycle times, recyclability benefits of the thermoplastic matrix.

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Commercial Materials

- GMT (Glass Mat Reinforced Thermoplastics)
- Pultruded Products
  - LFT (Long Fiber Reinforced Thermoplastics)
  - CFT (Continuous Fiber Reinforced Thermopastics)
- Wire coated products
- Commingled fibers
- Powder coated materials
- Film sticking
- Slurry processes

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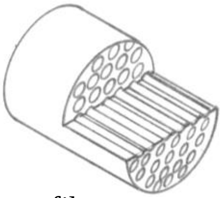
Short Fiber, Long Fiber and Continuous Fiber Composites

Typical short fiber thermoplastic material, granules with fiber length of approx. 2 to 4 mm, resulting fiber length in a part of approx. 0.4 mm



Long fiber thermoplastic material, pellets of ½” and 1 “ fiber length, resulting fiber length in a part of approx. 4-6 mm in injection molding and approx. 20 mm in compression molding

Continuous reinforced thermoplastic material, tape used for woven sheets (thermoforming), filament winding or pultrusion

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CFRP engine hood

Nissan liftgate

Audi A8 front end structure

Nissan Leaf battery pack cover

Door trim panel

Diesel exhaust treatment

Seat panel

99

Some Body in Polymers Vehicle Concepts

Chrysler 6000$ concept

Renault Matra Body in SMC (Polyester / GF)

MDI (Glass Fiber intensive structure)

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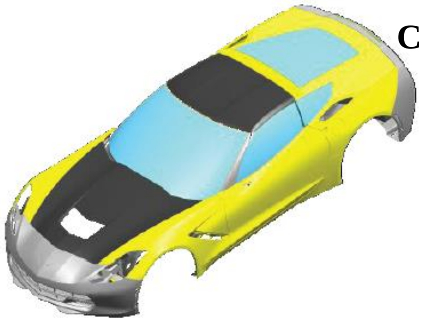
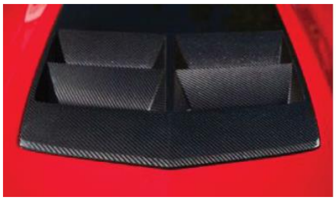
Corvette Stingray



Camaro ZL1 Hood Scoop



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Vehicles with Reinforced Carbon Fibers


Mercedes McLaren


Aston Martin DBS


McLaren MP12


Chevy Corvette


Bugatti Veyron


Riversimple

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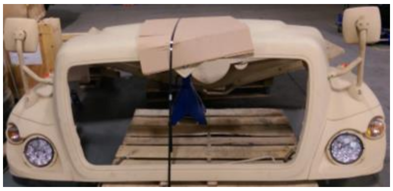
Navistar Defense Mine-Resistant-Ambush-Protected (MRAP) Vehicle

CFRP engine hood



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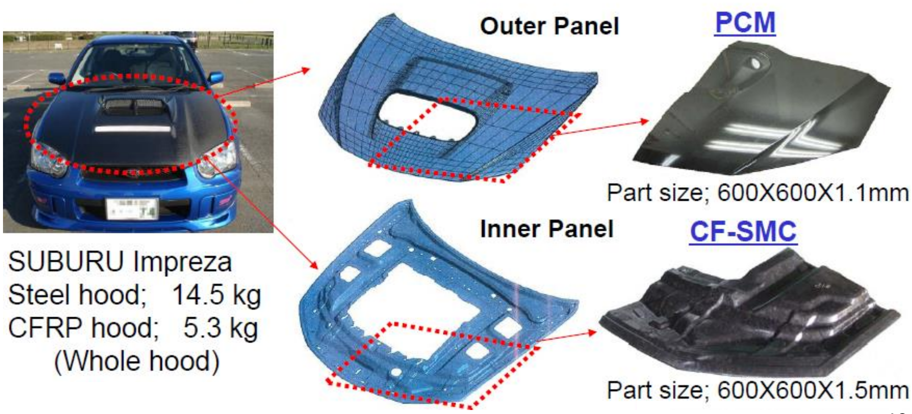
Engine Hood Model Part Development

- A quarter part of engine hood was developed to demonstrate feasibility of PCM body panels.
  - PCM outer and CF-SMC inner panels were bonded to produce a body panel structure consisting of two parts.
  - CFRP engine hood is 63% lighter than steel hood.



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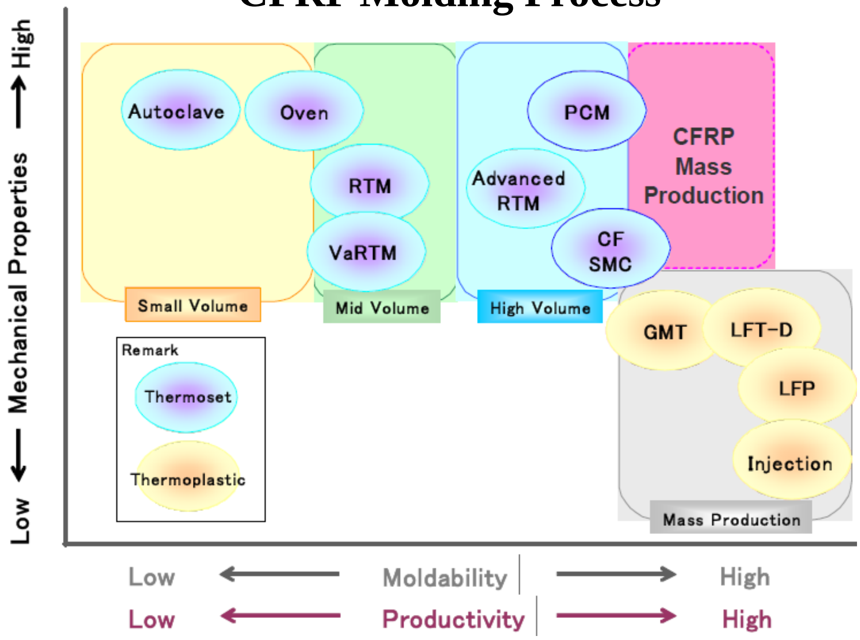
CFRP Molding Process



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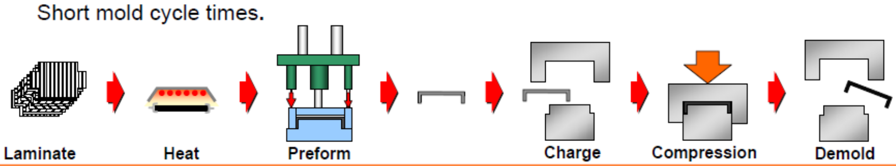
High Cycle CFRP Molding Process

PCM has a potential for CFRP mass production

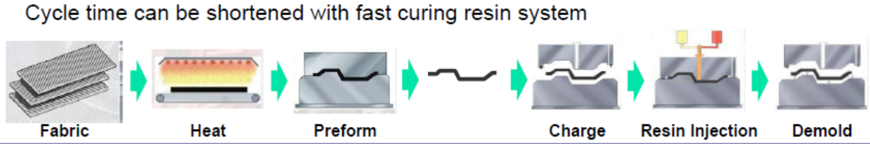
PCM (Prepreg Compression Molding)

Newly developed fast curing prepreg is preformed, and then cured in heated steel tool. Short mold cycle times.



Advanced RTM

Dry fabric is charged in heated tool, then resin is injected into the mold.
Cycle time can be shortened with fast curing resin system



CFRP - Carbon Fiber Reinforced Polymer **SMC** - Sheet Molding Composites

MDI - Methylene Diphenyl Diisocyanate

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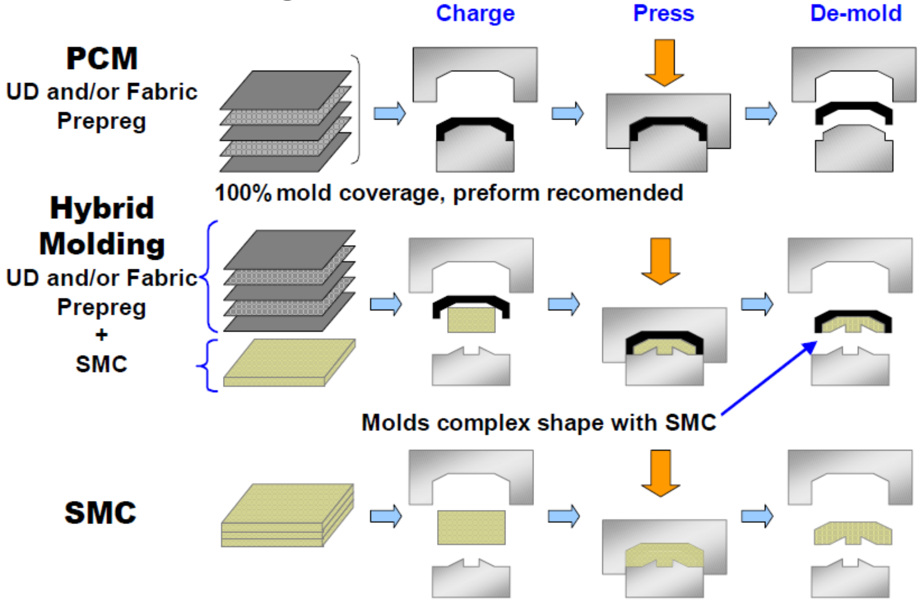
PCM Molding Process



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Composite Sustainability for Body/Closures

- Painting and repair solution
- Lower cost fiber production.
- Higher volume molding processes.
- Faster curing resins which don't trap gas / defects
- Improved forming process / cycle time.
- Damage detection and prediction.
- Increased ductility during deformation / crash
- Material models for defect / failure prediction

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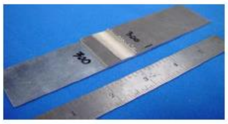
Multi-Material Enabling

Magnesium

- Corrosion (galvanic and general)
- Difficulty Joining
  - Mg-Mg
  - Mg-X
  - Riveted Joints
- Questionable compatibility with existing paint/coating systems



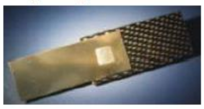
Aluminum

- HAZ property deterioration
- Difficulty joining mixed grades
  - Joint integrity
  - Joint formability
- Difficulty recycling mixed grades

	Mg	Si	Cu	Zn
5182	4.0 - 5.0	< 0.2	< 0.15	< 0.25
6111	0.5 - 1.0	0.6 - 1.1	0.5 - 0.9	< 0.15
7075	2.1 - 2.9	< 0.4	1.2 - 2.0	5.1 - 6.1

Carbon Fiber Composites

- Corrosion and environmental degradation
- Some difficulty joining
- Questions regarding non-destructive evaluation



AHSS

- HAZ property deterioration
- Limited weld fatigue strength
- Tool wear, tool load, infrastructure

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Key Material Properties to Know

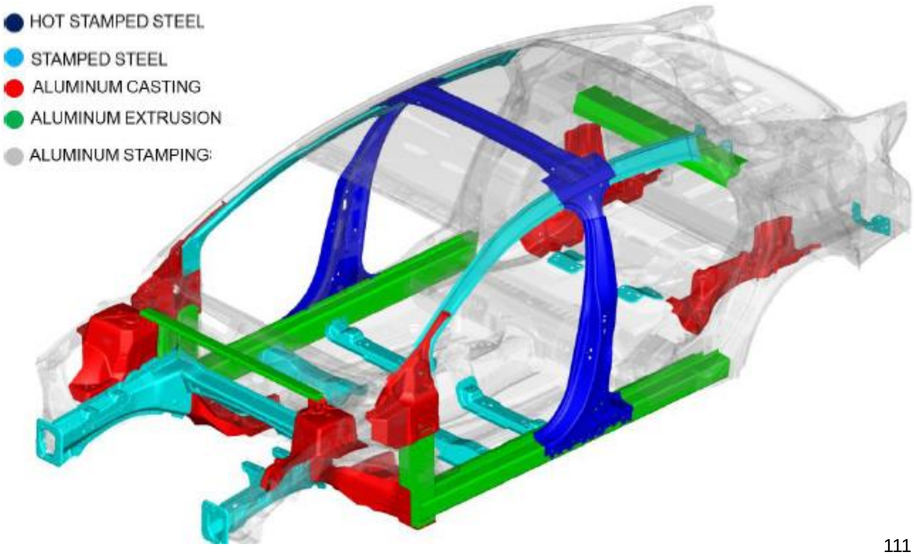
Steel
- Stamping
- Welding
- Corrosion
- Easy repair

Aluminum
- Extruding
- Riveting
- No Corrosion
- Difficult to repair

Magnesium
- Die casting
- Bolting
- Sensitive to heat
- Difficult to repair

Carbon Fiber
- Bag. molding
- Bonding
- Breaks during crash
- Difficult to repair

Multi-Material Lightweight Vehicle (MMLV) – Mach-I & II BIW
Vehma International and Ford Motor Company, 2013/2014



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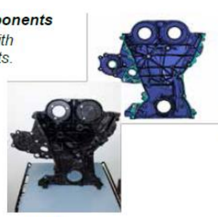
MMLV - Powertrain

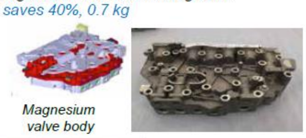
ENGINE – Weight reduction of 20% to 48% on components
- Cast aluminum engine block for 1.0 liter I3 engine with Powder Metal forged billet crackable bulkhead inserts.
  - saves 48%, 11.8 kg
- Carbon fiber structural oil pan.
  - saves 30%, 1.2 kg
- Carbon fiber front cover with mount.
  - saves 30%, 1.0 kg
- Carbon Fiber + Aluminum cam carrier.
  - saves 20%, 1.3 kg
- Forged aluminum connecting rods.
  - saves 40%, 0.7 kg



PA/CF Front Engine Cover

Forged Aluminum connecting rods

Bulkhead Insert in AL block



Magnesium valve body

Aluminum + Steel Clutch Hub

Aluminum pump cover

PA/CF Oil Pan

TRANSMISSION – Weight reduction of 30% to 60% on components for reduced torque automatic
- Cast magnesium (AZ91D) case and bell housing
  - saves 30%, 5.0 kg
- Aluminum pump cover
  - saves 55%, 1.8 kg
- Cast magnesium valve body
  - saves 35%, 1.0 kg
- Steel + Aluminum clutch hub (friction spin weld)
  - saves 60%, 0.4 kg

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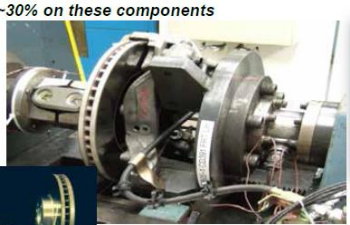
MMLV - Chassis

SUSPENSION COMPONENTS – Weight reduction of ~30% on these components

- Tall, Narrow Tires 30% save
  - 155/70R19 new materials and constructions
- Wheels 19 inch x5 inch 30% save
  - cast aluminum or carbon fiber
- Delete Spare Tire/Wheel
- Aluminum Brake Rotors 35% save
  - Cast A356 Al, Thermal Spray Coated
- Coil Springs 35% ~ 55% save
  - hollow micro alloy steel with intensive shot peening, Glass Fiber composite
- Stabilizer Bars 35% ~ 55% save
  - high hardness steel, with internal and external shot peening



Aluminum brake rotor with thermally sprayed wear resistant coating

Evaluate composite & hollow steel coil springs

Carbon fiber wheels

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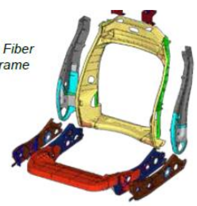
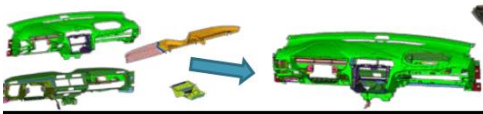
MMLV - Interiors

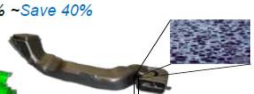
INTERIOR COMPONENTS

- Carbon Fiber Seat designs save ~28 kg, Save 40% (driver -8 kg, passenger -8 kg, rear -12 kg)
- Carbon Fiber (or magnesium) Instrument Panel beam and ducts save ~8 kg, Save 35%
- MuCell and chemically foamed interior plastic trim saves 15% ~Save 40%

Carbon Fiber Seat Frame





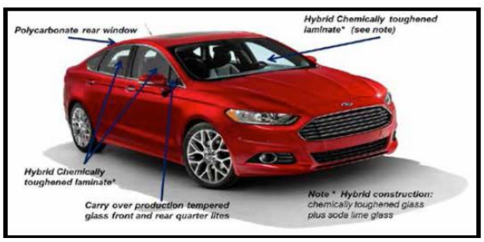


40% weight reduction improved air insulation

GLAZINGS -

- Mix of Lightweight Glazings saves 14 kg Save 35%)
- Laminated chemically toughened* windshield,
- Side door movable glazings,
- Polycarbonate Glazing Backlite (Rear Window)

Side Door Glass - Door Slam Durability Test



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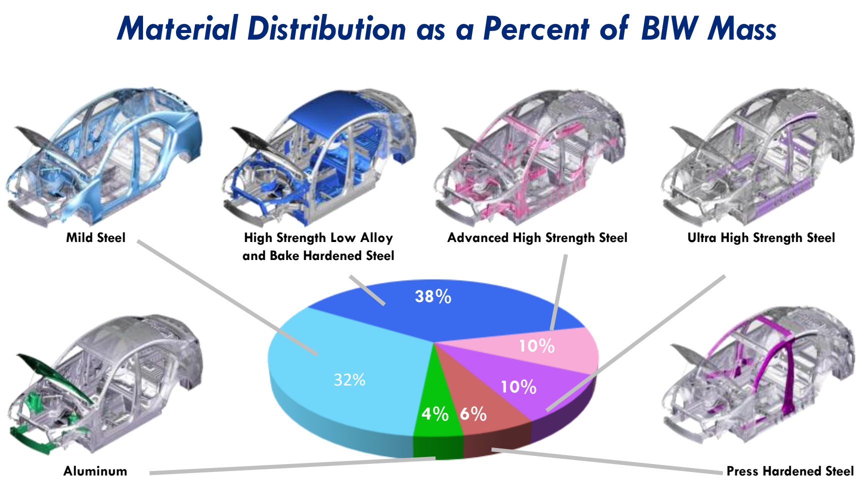
Multiple Materials In Body-In-White



ATS Example

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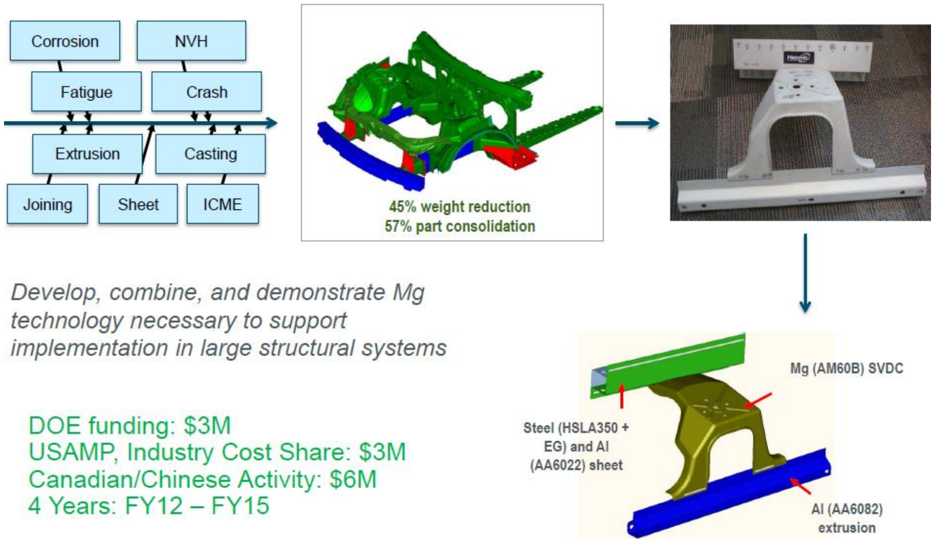
Magnesium Intensive Vehicle Front End



Develop, combine, and demonstrate Mg technology necessary to support implementation in large structural systems

DOE funding: $3M
USAMP, Industry Cost Share: $3M
Canadian/Chinese Activity: $6M
4 Years: FY12 – FY15

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Hybrid Design

Alu Steel

Alu + Carbon fiber

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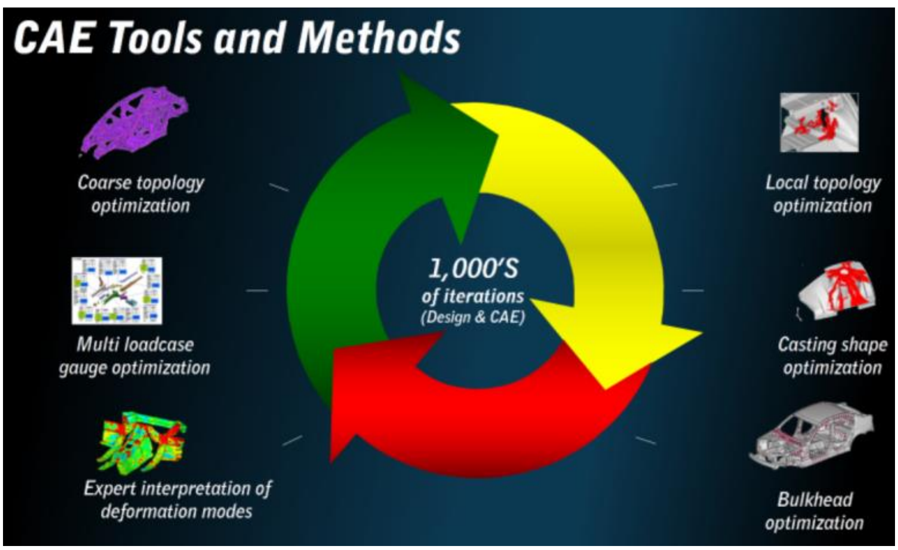
Enabling Computer-aided Engineering (CAE) Can Limit Material Choices



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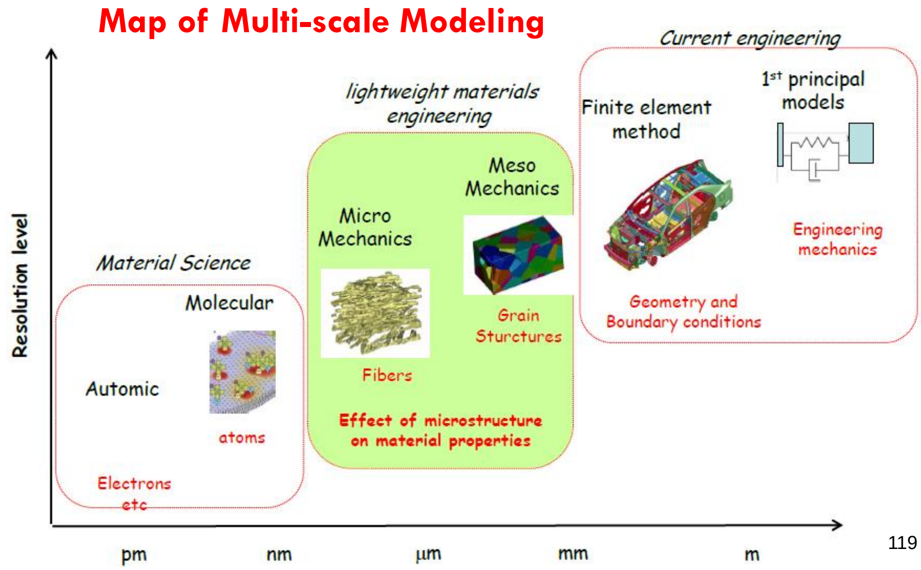
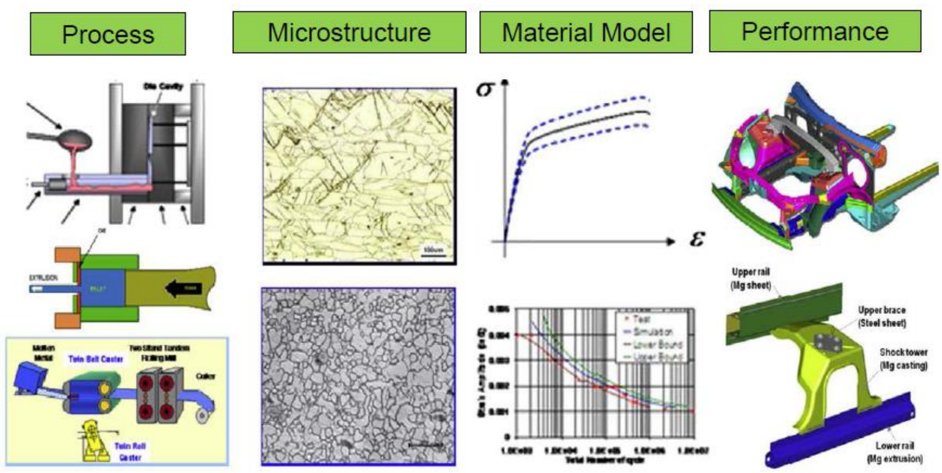
CAE analysis and simulation methods for modeling of lightweight materials



Magnesium: Multi-scale Modeling Approach



Lou, A., *Journal of Magnesium and Alloys*, 1/2013, pp. 2-22

ICME: Integrated Computational Material Engineering

Joining Processes - Current and Emerging

- RSW
- RPW
- Clinching
- Mechanical fastening
- Laser welding
- Continuous resistance welding
- Friction stir welding
- Friction spot joining
- Bonding (structural adhesives)
- Riveting
- EMP joining
- Other

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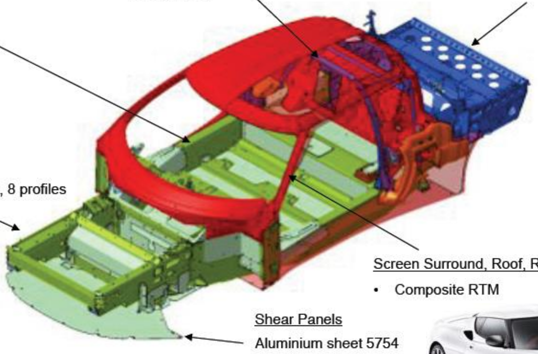
Production Multi-Material Body Structure: Lotus Evora



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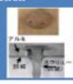
Assemblies of Advanced and Multiple Materials Complicate Joining

Joining technology

○=Candidates to use/develop in Toyota

LSS: Low Strength Steels
HSS: High Strength Steels (～780MPa)
USS: Ultra High Strength Steels , Hot Stamping Steels (980MPa～)
AL : Aluminum

Combination of materials	SPR Self Piercing Rivet 	FDS Flow Drill Screw 	FSW Friction Stir Welding	FSJ Friction Spot Joining 	LSW Laser Screw Welding 	adhesive	・・・
Steel x Steel					○	○	
AL x AL	○	○	○		○	○	
Steel (LSS,HSS) x AL	○	○	○	○		○	
Steel(UHSS) x AL			○	○		○	
AL x CFRP(Random)	○			○		○	
Steel (UHSS) xCFRP(Random)	○			○		○	
CFRP x CFRP	○			○		○	

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Typical Rivet Types

Self-Pierce Rivet.

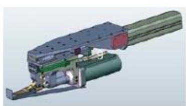
Requires double sided access.

Typical Gun and Robot Configura tion

Typical Gun shape and size

Flow Drill Screw.

Requires single sided access.



Typical Gun shape and size

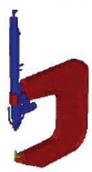
Typical Gun and Robot Configuration

Self-Pierce Stud.

Requires double sided access.

Blind Rivet Stud.

Requires single sided access.



Typical Gun shape and size

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Summary

- Automobiles will be getting significantly lighter over the next 10 years.
- Good engineering and design cannot account for all mass reduction necessary.
- Appropriate use of a variety of lightweight materials will be necessary to meet the mass targets.
- Lightweight materials community needs to focus on:
  - Improving existing materials and forming processes.
  - Developing new materials with improved properties.
  - Resolving engineering issues during materials development.
  - Providing accurate CAE predictions with improved material models.

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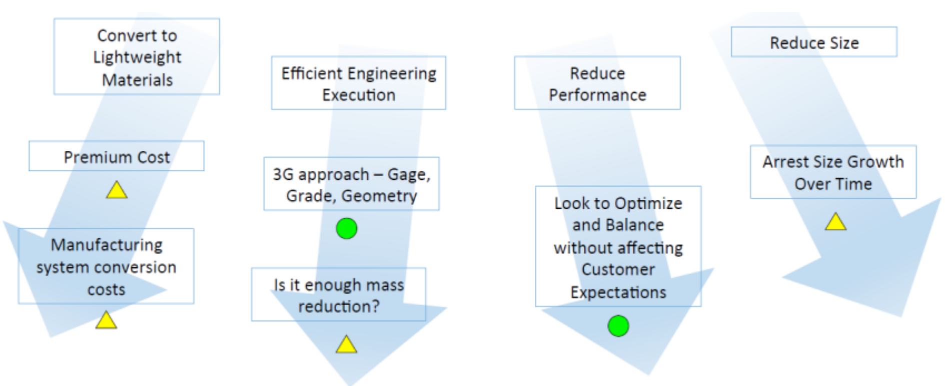
Mass Reduction Approaches for Body Structures and Closures



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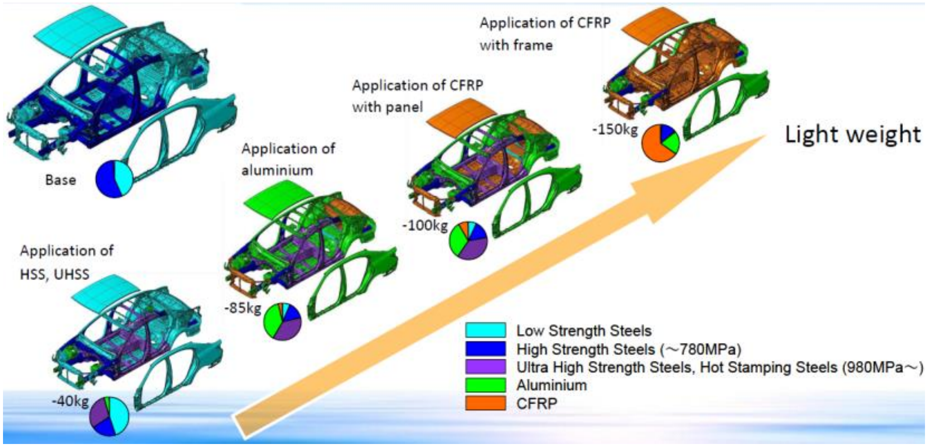
Toyota's View of Light Weighting Technologies (1)



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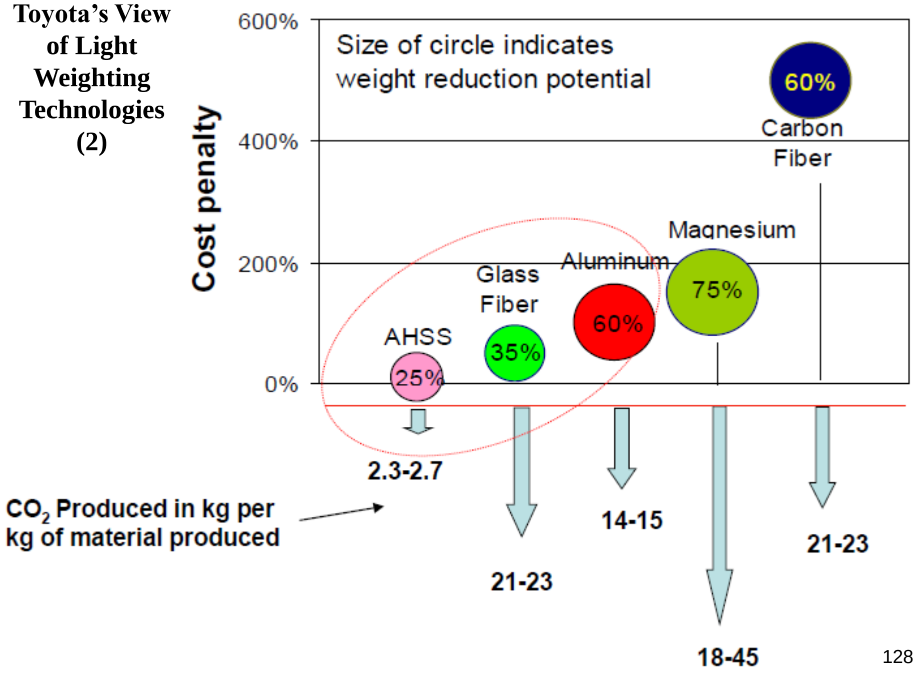
Toyota's View of Light Weighting Technologies (2)



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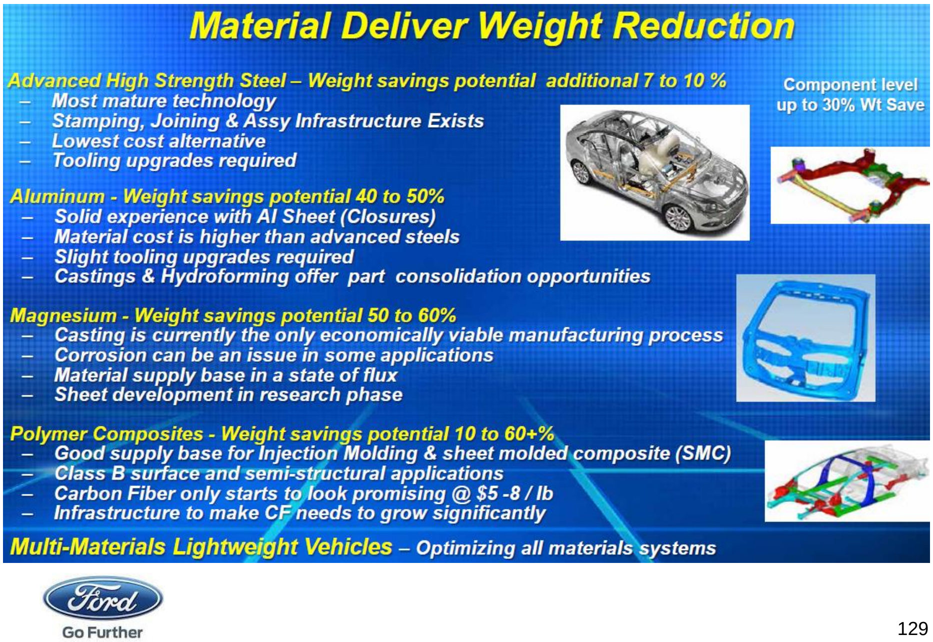

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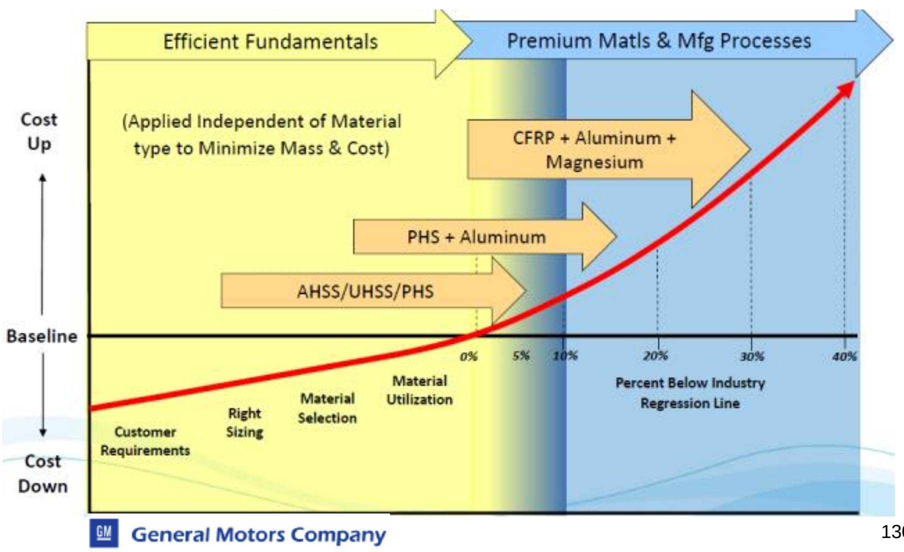
Progression of Light weighting Strategies by Cost



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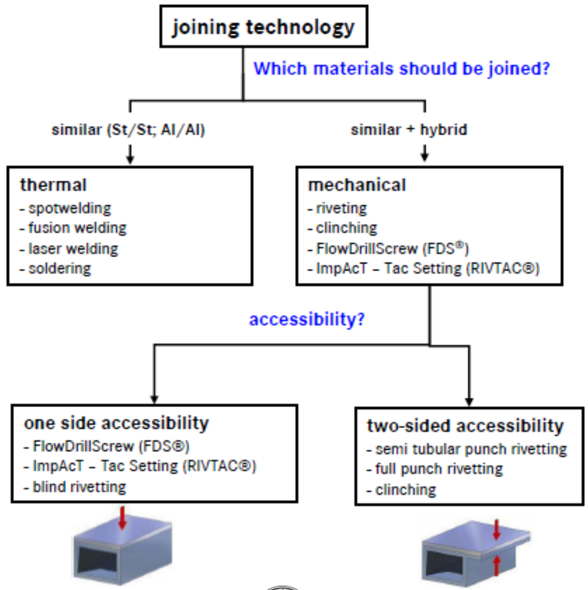
- Increase of crash-performance and torsional stiffness
- Weight reduction by the use of highstrength steel and lightweight materials
- Cost reduction

➡ New challenges for joining technologies



Mercedes-Benz

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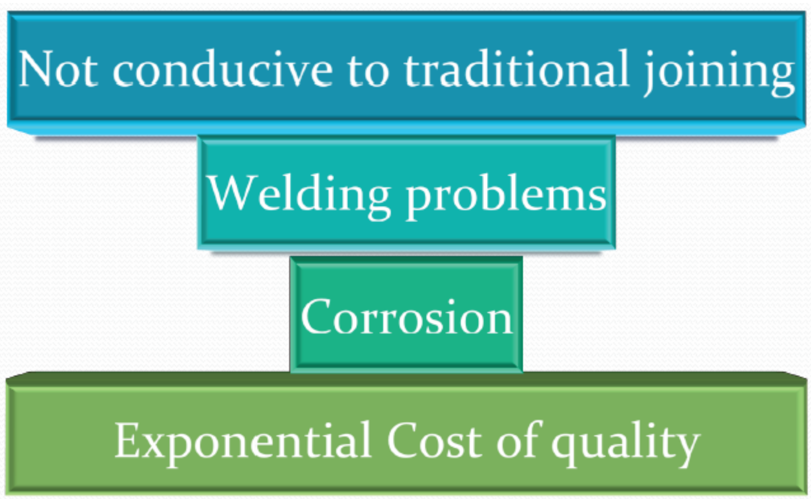
Lightweight Material Issues Impacting the Industry



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Big Picture

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Energy and Vehicle Weight Reduction

- U.S. transportation energy accounts for 28% of total consumption
- 94% of transportation energy is from petroleum
- The relationship between weight and energy savings is complicated…
- …but significant fuel economy and energy savings are likely

Vehicle Weight Reduction Today

- Lightweight materials (including steels) have seen wider application in vehicles…
- …but vehicle weight has increased!
- Demand for improved safety, comfort, emissions control, etc. has offset weight reduction
- Development of lightweight materials provides a strong foundation for future weight reduction

Moving Forward with Lightweight Materials

- Steel, Aluminum, Magnesium, Carbon Fiber Composites, and other materials will likely play a roll in continued weight reduction
- Significant unanswered questions exist in properties, manufacturing, multi-material enabling, and modeling/simulation of these materials
- **Where does steel need to go from here?**

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Conclusion

- The issue of weight is likely to become more important to manufacturers and customers due to fuel economy.
- The economic feasibility of producing vehicles with alternative materials has been completely addressed.
- Consumers may not abandon large vehicles. The shift away form heavy cars can only came from alternative materials.
- Weight reduction involves all materials and components suppliers.

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