Vehicle Mass Reduction Opportunities

October 5, 2010

Background

- Phase 1 Study (report issued April 2010)
  - Baseline vehicle selected was 2009 Toyota Venza (new CUV)
  - Paper study investigating mass reduction opportunities for 2017 production and 2020 production
  - Targeted a 20% mass reduction for 2017 with a technology feasibility target of 2014 (Low Development)
  - Targeted a 40% mass reduction for 2020 with a technology feasibility target of 2017 (High Development)
  - Sponsored by ARB, funded by the Energy Foundation with EPA participation
  - 300 page report published by International Council on Clean Transportation

- Phase 2 Study (in process)
  - Structural and impact CAE analysis of the High Development body structure (Body in White)
  - Best in Class bending and stiffness targets
  - Impact performance is based on meeting or exceeding NHTSA published Venza crash results
    - Target for front impact is 20% lower peak acceleration than Venza
    - Rear and side impact targets are “pass”
    - Roof crush target is four times vehicle mass (vs. 2012 standard of 3x vehicle mass)
  - April, 2011completion date
  - ARB funded, cooperation from ARB/EPA with NHTSA participation in analyzing impact performance

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Objectives

- Create a low mass vehicle utilizing materials and processes feasible in the 2017 time frame for 2020 MY production for an annual volume of 60,00 units
- Minimize piece cost through component integration, parts elimination and material selection
- Utilize reduced energy and reduced scrap processes
- Utilize the above steps to meet the low mass target while minimizing the total vehicle cost

Process

- Establish baseline vehicle mass, external and internal dimensions
- Set timing, mass and cost parameters
- Investigate technologies, including processing/manufacturing, and materials and select key suppliers for technical support
- Design the advanced vehicle based on interior and exterior dimensional targets
- Develop vehicle BOM
- Iterate to a solution based on mass and cost tradeoffs and timing requirements

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Overview

- A baseline CUV was disassembled, measured and weighed to develop a BOM and component masses.
- Mass reduction target set relative to baseline BOM.
- Dimensional and volumetric targets comparable to or improved relative to baseline vehicle.
- Selected suppliers provided technical and cost support for specific areas.
- The vehicle components were segregated into eight vehicle systems. The systems were:
  - Body in White (BIW)
  - Closures/Fenders
  - Interior
  - Chassis/Suspension
  - Front and rear bumpers
  - Thermal (HVAC)
  - Glazing
  - Electrical

Mass and Cost Targets

	Low Mass Vehicle Constraints	
	Mass Reduction Target	On cost to Baseline Piece Cost
Vehicle	40%	+50%
System Level	40%	+50%
Sub-system	40%	Not cost constrained
Component Level	40%	Not cost constrained

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Mass Reduction Approaches

- Efficient Design
  - Optimize load paths within structure
    - Reduce stresses on components
    - Stress all components
    - Minimize torques
    - Use computer-aided engineering (CAE) design tools
  - Parts integration/reduction of fasteners
  - Optimize structural sections
  - Parts elimination
  - Aerodynamic considerations
  - Vehicle stability – C of G, track width, height

  Materials Selection (recylable – automotive and non-automotive)
  - High-strength steels
  - Aluminum
  - Magnesium
  - Plastics and composites (thermoplastics)

- Maunfacturing and Assembly (automotive and non-automotive)
  - Reduce tool/component count through parts integration & parts elimination
  - Reduce forming energy requirements
  - Reduce or eliminate fixtures
  - Reduce part joining energy requirements
  - Minimize scrap materials

- Ancillary system weight reduction through total vehicle mass reduction
  - Brakes, suspension, tires, powertrain…..

- Low mass concepts are generally applicable to multiple vehicle classes

Low Mass Exterior Styling & Engineering Parameters

- All key interior and exterior dimensions and volumes were retained
- Target: must meet or exceed baseline crash and structural performance
- Vehicle styled to match packaging constraints
- Vehicle styled to accommodate key safety and structural dimensional targets, e.g., front crush zone
- Styling included provisions for:
  - low speed impact protection
  - increased wheelbase and track
  - more vertical “tumblehome” for roof crush
- Exterior styling used as basis for all internal structure

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Body in White System

- The Body in White consists of all components that make up the basic vehicle structural element
- The baseline CUV BIW is all steel and utilizes over 400 parts

Low Mass Body in White

Body in White Modules:
Floor and underbody
Dash panel assembly
Front structure
Body sides
Roof assembly

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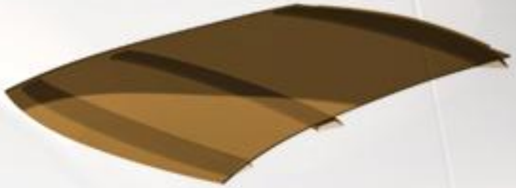
Body in White Modules

Modules: 6
BIW parts count: 211

Front structure

Dash panel assembly

Floor and underbody



Roof assembly

Body sides

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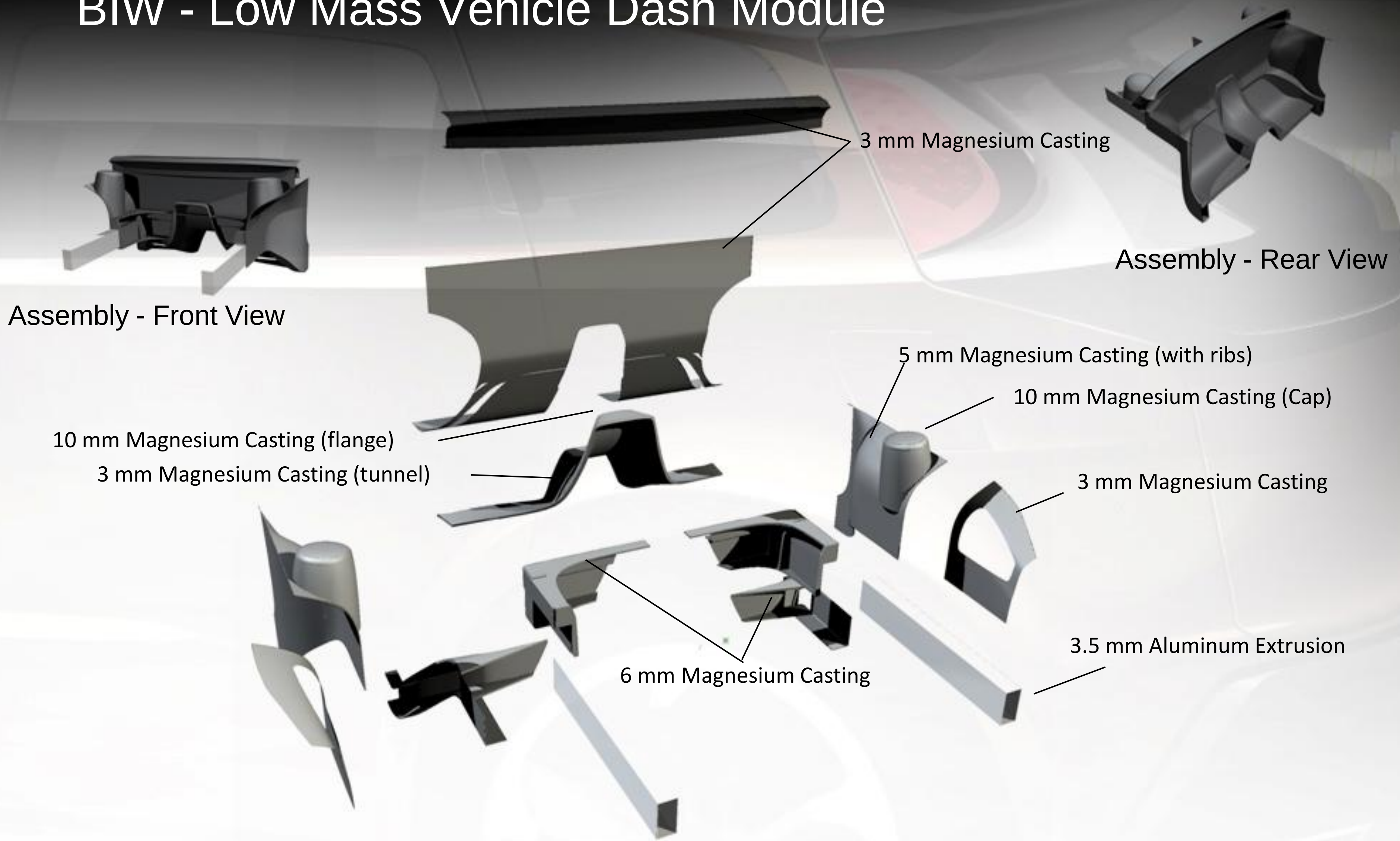
BIW - Low Mass Vehicle Dash Module



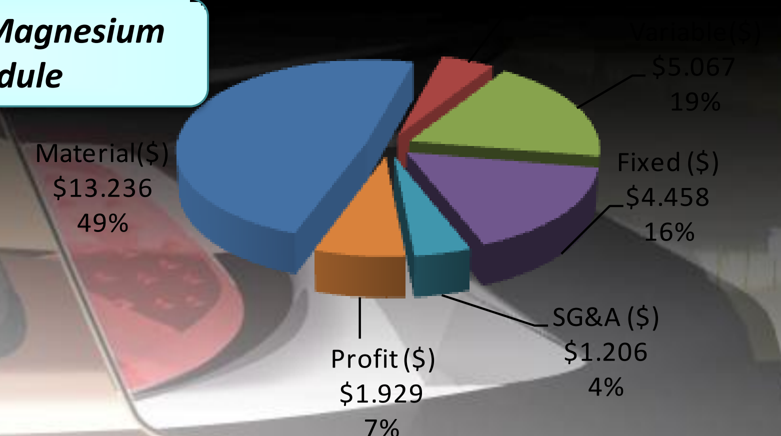
BIW - Cost Analysis

(Phase 2)

High Development Magnesium Front End Module

Assumptions:

1. Part weight and size calculated from provided math data
2. Magnesium price/pound based on AMM 09/29/2009
3. Die casting cycle times based on 25% reduction AL die casting calculation
4. Aging operation added
5. Two piece construction, friction stir butt welding assembly process
6. Eight (8) mounting holes (four per side) included



Op	Machine	Capital (Millions $)	Qty	Cycle Time	Num Out	Manpower	Comments	Mat Price ($/kg)	Usage (g)	Labor Rate	Fringe (%)	Indirect(%)	Material($)	Direct($)	Variable($)	Fixed ($)	SG&A ($)	Profit ($)	Total Cost ($)
20	Melt Furnace - Melt Mg	$1.500	1	1.8	2	3	7% Melt Loss included in process usage. Adjust Melt Furnace capital to account for second furnace down time. Mg priced based on AMM 08/11 latest data. $2.40/lb.	$5.286	5007.6	$20.72	50.0%	45.0%	$13.236	$0.016	$0.043	$0.023	$0.666	$1.065	$15.049
30	3500 Ton Cold Chamber Die Casting	$3.261	1	47.2	1	0.5	Cycle Time, and tonnage based on off line calculator allowing 25%reduction over Al die casting.	$0.000	0	$20.72	50.0%	45.0%	$0.000	$0.147	$2.278	$3.364	$0.289	$0.463	$6.541
40	Robot Unload of Diecasting, Quench and Trim - Trim	$0.280	1	47.2	1	0.5	Additional capital to account for Robot, cycle time to match die casting operation, floor space adjacent to die casting operation.	$0.000	0	$20.72	50.0%	45.0%	$0.000	$0.144	$0.329	$0.286	$0.038	$0.061	$0.858
50	Low Temperature	$0.299	1	18	1	0	Zero operator - material handlers load and unload	$0.000	0	$20.72	50.0%	45.0%	$0.000	$0.000	$0.201	$0.114	$0.016	$0.025	$0.356
55	Vibratory Finish	$0.065	1	47.2	1	1	0	$0.000	0	$20.72	50.0%	45.0%	$0.000	$0.287	$0.457	$0.067	$0.041	$0.065	$0.916
58	EC-630 - drill 4 mounting holes	$0.450	1	38.6	1	1	0	$1.000	0	$15.25	50.0%	45.0%	$0.000	$0.179	$0.808	$0.390	$0.069	$0.110	$1.556
60	Friction Stir	$0.175	1	47.2	1	1	79inches per minute for Friction Stir	$0.000	0	$20.72	50.0%	45.0%	$0.000	$0.290	$0.510	$0.175	$0.049	$0.078	$1.101
70	Crack	$0.030	1	47.2	1	1	0	$0.000	0	$20.72	50.0%	45.0%	$0.000	$0.287	$0.441	$0.040	$0.038	$0.061	$0.868
							Sub Total						$13.236	$1.350	$5.067	$4.458	$1.206	$1.929	$27.245
							Total						$13.236	$1.350	$5.067	$4.458	$1.206	$1.929	$27.245

Total Manufacturing Selling Price for the HD Front End Module is $27.25 each
Market pricing estimate: $32.70 each

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Low Mass Body in White BOM

System	Sub system	Standard Venza	% of Body Structure	Material Mass (kg)				Revised Structure Total	Cost relative to Venza
		kg		Composite	Steel	Al	Mg	kg	
Body complete		403.24						235.61	
	Windshield wipers/washers	9.15						8.00	
	Body exterior trim items	11.59						6.55	
Body structure		382.50						221.06	
	Underbody & floor	113.65	29.71	32.4	14.5	24.46	12.4	83.76	110%
	Dash panel	15.08	3.90	0	0	0	12	12.00	141%
	Front structure & radiator crossmember	25.15	5.78	0	0	7.6	11.0	18.6	167%
	Body side LH	65.22	13.56	6.96	0	19.69	12.3	38.95	117%
	Body side RH	65.22	13.56	6.96	0	19.69	12.3	38.95	117%
	Roof	27.83	4.22	0	0	10.3	6.5	16.80	298%
	Internal Structure	58.35	15.25						
	NVH	8	2.09					8	100%
	Paint	4	1.05					4	100%
Total		**382.5**		**46.32**	**14.5**	**81.74**	**66.5**	**221.06**	**135%**
Percentage reduction relative to base								**42.2%**	

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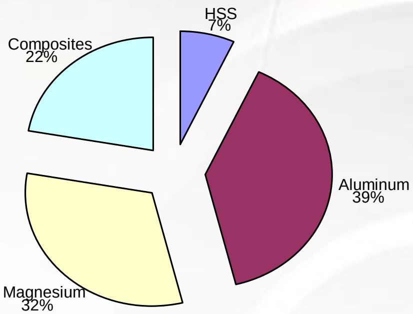
Body Structure Comparison

Low Mass Vehicle

Materials
•Aluminum
•Magnesium
•Steel
•Composite



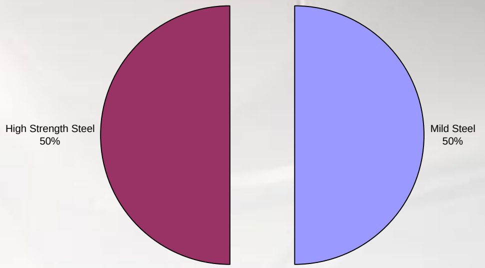
•Parts Count: 211

•Mass: 221 kg. (42% reduction)

•Cost factor: 135% (vs. baseline)

Baseline CUV

Materials
•Steel



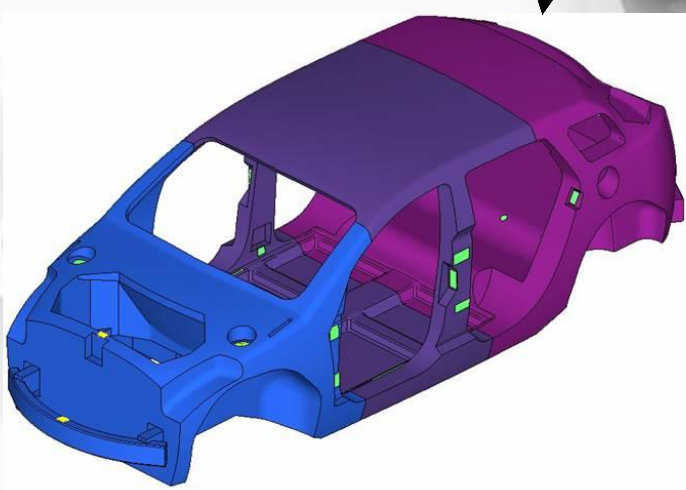
•Parts Count: 419

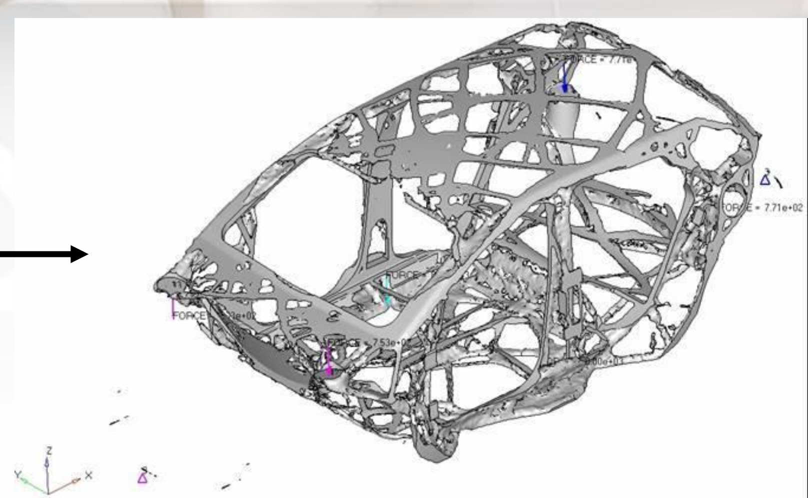
•Mass: 382 kg

•Cost: 100%.

Topology Analysis (Phase 2)

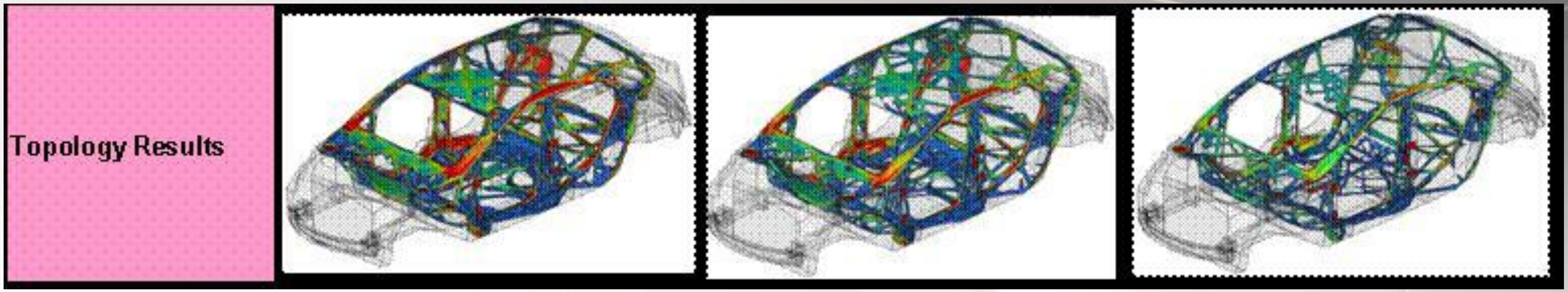
Converting CAD model to
an optimized body structure





CUV Topology Analysis (Phase 2)

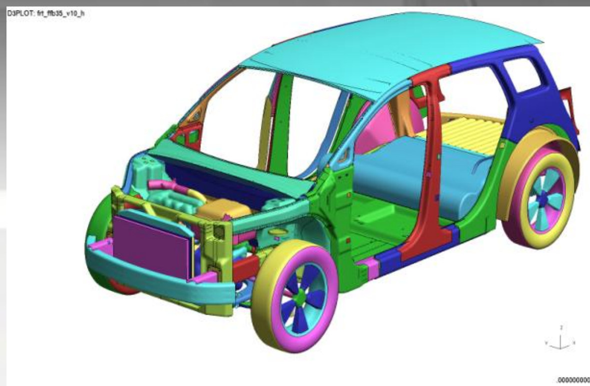
Relative Material Strain Levels



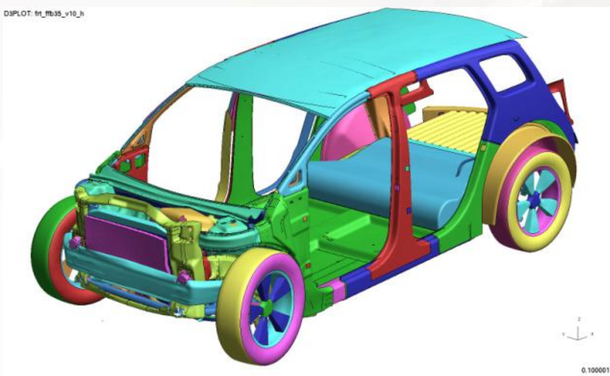
Magnesium Aluminum Steel

Preliminary Impact Analysis – Phase 2

FMVSS 208 Front Impact (35 MPH)

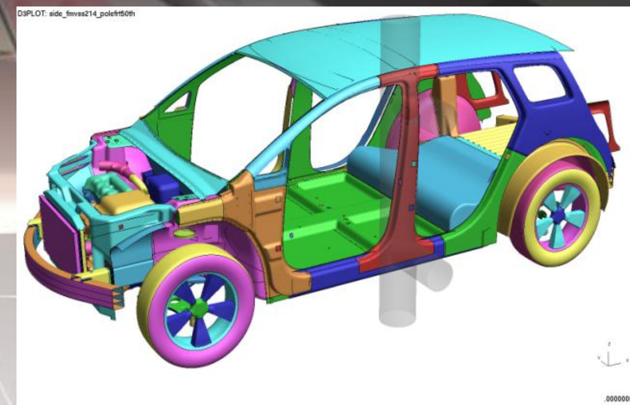


Before

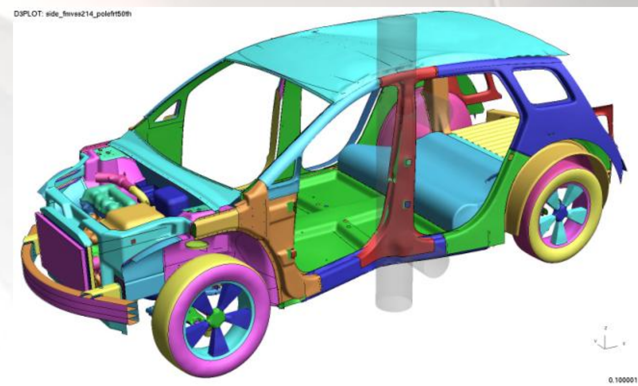


After

FMVSS 214 Side Impact (Pole)

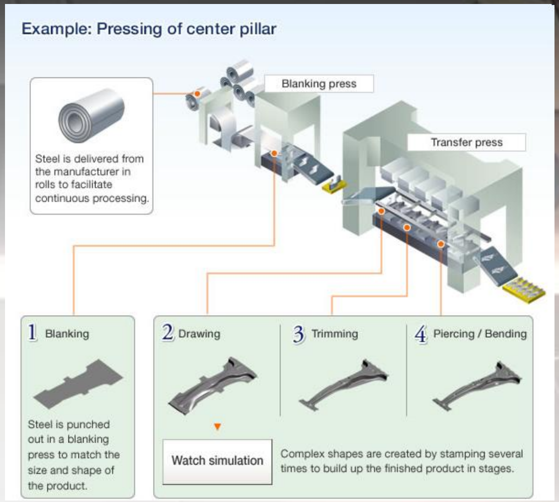


Before

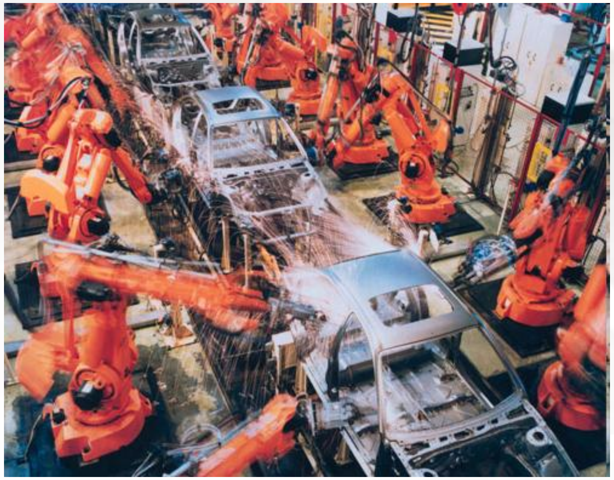


After

Traditional BIW Assembly Process

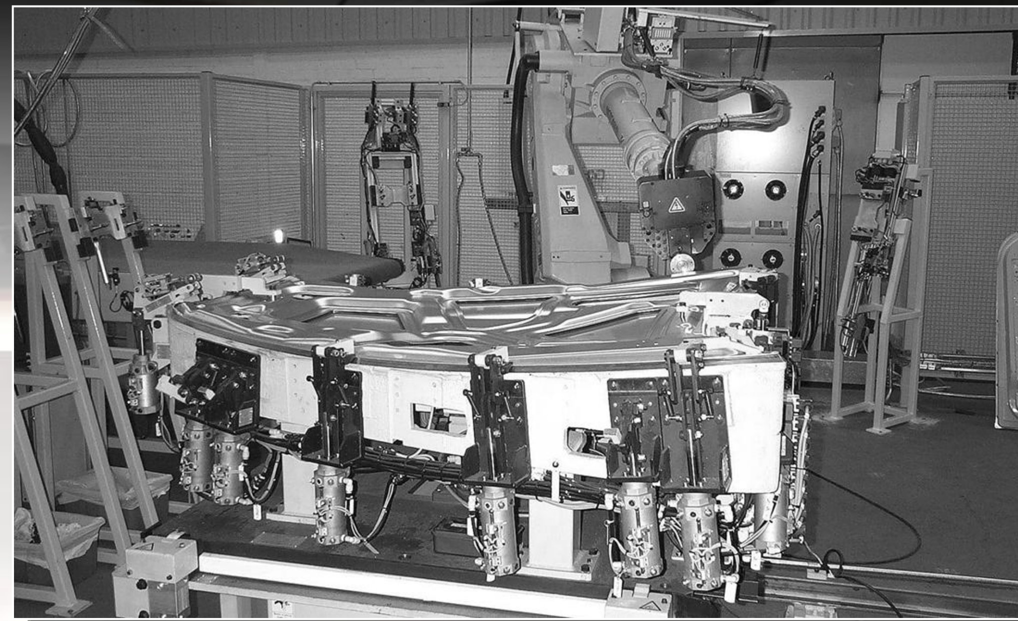



Underframe assembly in a heavy jig where the solebars and transoms are welded. It is essential to ensure all parts are held to strict limits to prevent distortion during welding.



Low Mass BIW Assembly Process

Low energy, low heat friction stir welding



Programmable robotic fixturing

Versatile process can be used for small and large assemblies

Proven on high speed trains

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Closures/Fenders System

- The closures include the front and rear doors and the rear liftgate, i.e., all hinged exterior elements

- The primary hood section was fixed to improve structure, reduce mass and limit exposure to high voltage systems/cables; a small fluid access door was provided.

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Closures/Fenders System

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Door Assembly – Exploded View

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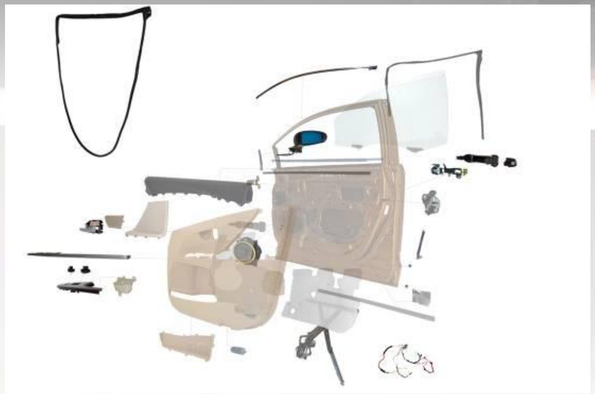
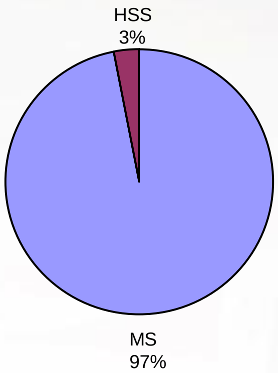
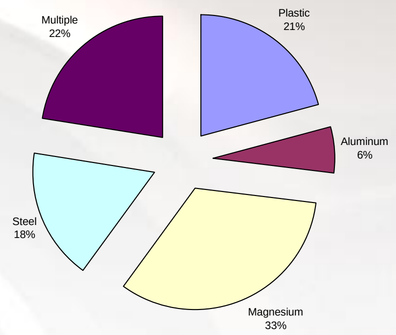
Closures/Fenders System – Mass and Cost Summary

Mass savings: 41% (reduced from 143.02 kg to 83.98 kg, a 55.04 kg reduction)
Cost Savings: 24%





Baseline CUV Closure Materials



Low Mass CUV Closure Materials

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Closures/Fenders System – Mass and Cost Summary Table

System	Sub system	Standard Venza	Baseline material	Revised Design	Revised mass	Mass saving	Material	Cost Factor
		kg			kg	kg		
Exterior panels								
	Front Fender LH	3.04	Mild steel	Injection molding	1.69	1.35	PPO-PA	
	Front Fender RH	3.03	Mild steel	Injection molding	1.69	1.34	PPO-PA	
Side door front								
	Front Door Outer LH & RH	11.30	Mild steel	Molding	5.44	5.86	Thermoplastic	38%
	Front Door Inner LH & RH	8.48	Mild steel	Casting	12.00	6.56	Magnesium	57%
	Glass run channel front LH & RH	4.91	Mild steel	Part of module				
	Door reinforcements		Mild steel	Part of casting				

Low Mass Driver Seat BOM

Interior System

- The interior systems consists of the instrument panel, seats, soft and hard trim, carpeting, climate control hardware, audio, navigation and communication electronics, vehicle control elements, and restraint systems

Interior System

- High level of component integration
- Modular systems
- Electronic interfaces replace mechanical controls, i.e., transmission, parking brake
- HVA/C module part of console

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Interior System – Front Seat

- Front seat mass savings: 30% to over 50%
- Projected cost savings

Baseline seat

Low Mass Driver Seat BOM

Driver's Seat Mass Reduction Analysis	VENZA BASELINE (kg)	Ford Fiesta Seat Starting Point (kg)
Starting Mass (kg)	26.92	18.47
Itemized Mass Deltas to baseline		High Development
Normalization to Venza		
Best A2MAC1 Power Equipment (300C+Venza Lumbar	--	0.00
Safety Equipment delta to From Fiesta - Venza	--	-0.12
Azera Frame	--	0.00
Composite Seat Frame	--	-3.25
Sizing Adjustment	--	
Back	--	-1.52
Cushion	--	0.66
Light weighting Content (Benchmark based)		
300C Power equipment replacement (with Venza lumba	--	6.74
Remove springs (back and cushion)	--	-0.27
Remove Foam volume (ergo foam replacement	--	-0.39
	--	
Remove Garnish and trim	--	-1.50
	--	
Mass Results (kg)	**26.92**	**18.81**
Mass Reduction (kg)		**-8.11**
Mass Reduction Percentage		**-30%**

Low Mass Passenger Seat BOM

Passenger's Seat Mass Reduction Analysis	VENZA BASELINE (kg)	Ford Fiesta Seat Starting Point (kg)
Starting Mass (kg)	23.18	16.96
Itemized Mass Deltas to baseline		High Development
Normalization to Venza		
Safety Equipment delta to From Fiesta - Venza	--	-0.12
Azera Frame replacement	--	0.00
Composite Seat Frame	--	-3.25
Longitudinal Rails from 300C (Fiesta is a hybrid rail/str	--	0.00
Sizing Adjustment	--	
Back	--	-1.52
Cushion	--	0.66
Light weighting Content (Benchmark based)		
300C Power equipment replacement (with Venza lumb	--	0.00
Remove springs (back and cushion)	--	-0.26
Remove Foam volume (ergo foam replacement	--	-0.39
Add Manual Seat Adjustment Bar	--	
Remove Garnish and trim	--	-1.10
	--	
Mass Results (kg)	**23.18**	**10.98**
Mass Reduction (kg)		**-12.20**
Mass Reduction Percentage		**-53%**

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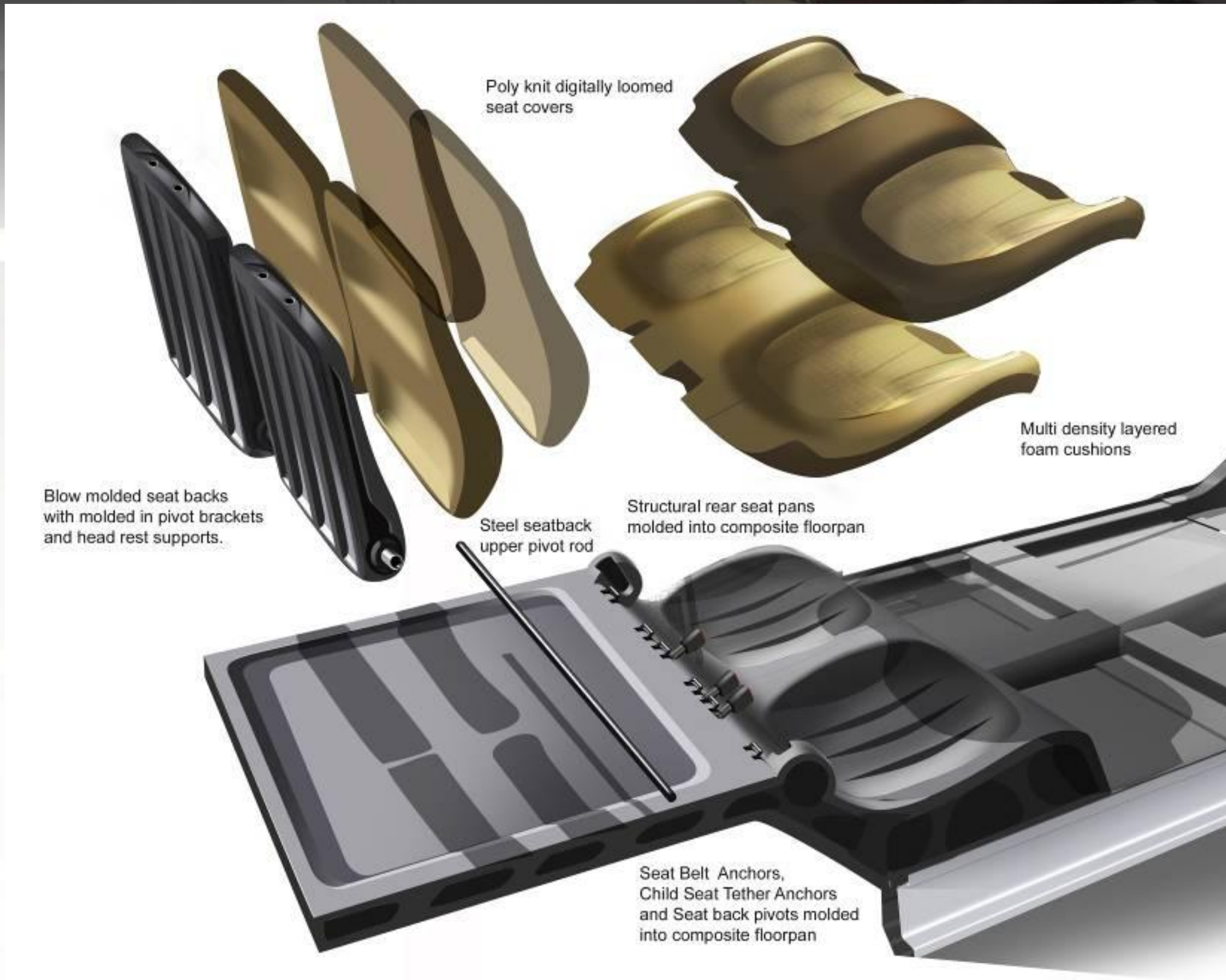
Low Mass Rear Seat



Low Mass Rear Seat BOM

Rear Seat Mass Reduction Analysis	VENZA BASELINE (kg)	Nissan Qashqai starting point (kg)
Starting Mass (kg)	47.808	26.478
Itemized Mass Deltas to baseline		High Development
Normalized to Venza Volume	47.81	28.27
Normalization to Venza		
Remote Rear Cargo unlocking system	--	0.33
Back Frame normalized for center seatbelt (2-3)section	--	0.00
Add Venza Seatbelt Anchor		1.75
Modular seatback Laser welded roll formed		
Mold seat lower into composite floor proposal		-1.22
Utilize blow molded reinforced seatback frame (30% reduction)		-3.70
Mass Results (kg)	**47.81**	**25.43**
Mass Reduction (kg)		**-22.38**
Mass Reduction Percentage		**-47%**

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Low Mass Interior Summary BOM

- Mass reduction total: 97.8 kg (39%)
- Projected cost: 4% savings vs. baseline

System	Sub-System	Venza Baseline mass	% of Interior	High Development Mass	High Development Cost
Interior					
	Seats	**97.9** kg	39%	55.2 kg	94%
	Instrument Panel|Console|Insulation	**43.4** kg	17%	25.8 kg	105%
	Hard Trim	**41.4** kg	17%	24.3 kg	105%
	Controls	**22.9** kg	9%	16.0 kg	108%
	Safety	**17.9** kg	7%	17.9 kg	100%
	HVA/C and Ducting	**13.7** kg	5%	11.3 kg	81%
	Closure Trim	**13.3** kg	5%	2.4 kg	75%
Total		**250.6** kg		**152.8** kg	**96%**

Chassis/Suspension System

- The chassis and suspension system was composed of:
  - suspension support cradles
  - control links
  - springs
  - shock absorbers
  - bushings
  - stabilizer bars & links
  - steering knuckles
  - brakes
  - steering gearbox
  - bearings
  - hydraulic systems
  - wheels
  - tires
  - jack
  - spare tire (deleted)
  - steering column

Chassis/Suspension System

- Tires and wheels

Chassis/Suspension System

- Curb weight calculation
- Gross vehicle weight calculation
- Gross vehicle weight used to calculate front and rear Gross Axle Weight Ratings (GAWR's)
- GAWR's used to determine wheel load capacity requirements

	Baseline	Delta	Low Mass
			40.9% curb mass reduction on all but powertrain
Curb Weight	**1699.6**	**581.4**	**1118.21**
% of change			**-34%**
Powertrain	**410.41**		**356.3**
Payload	**549**	**0.0**	**549**
GVW	**2249**	**581.4**	**1667.21**
% of change			**-26%**
GAWR-Front (kg)	**1400**		**1090.52**
GAWR-Rear (kg)	**1230**		**958.10**
GAWR-Front (%)	**53%**		**53%**

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Chassis/Suspension System

Based on the projected gross vehicle weight, including baseline cargo capacity, the chassis and suspension components were reduced in mass by 43%. The projected cost savings was 5%.

	Mass (kg)			Cost(% of baseline)	
	Baseline	High Dev		Baseline	High Dev
Front Chassis Total	101.3	57.3		100%	101%
Rear Chassis Total	67.8	39.5		100%	92%
Tires&Wheels	144.5	76.0		100%	81%
Brakes	65.2	44.3		100%	117%
Total Chassis	378.9	217.0		100%	95%
% Reduction		43%			5%

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Non-Primary Mass Systems

- The preceding methodology was also applied to the five remaining systems which comprised 11% of the non-powertrain mass. Some vehicle safety and comfort systems, including inflatable restraints (air bag systems), lighting and air conditioning hardware, were left at the production mass and cost to maintain current levels of performance.

- The remaining systems were:
  - Front and rear bumpers
  - Front and rear lighting
  - Thermal (HVAC)
  - Glazing
  - Electrical

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Front and Rear Bumper Systems

- Very similar materials used on benchmarked vehicles
- Aluminum beams are in production
- Magnesium beams and energy absorbing foams are under development
- The cost for a magnesium beam exceeded the allowable price factor
- Estimated 11% total mass reduction (17.95 kg to 15.95 kg) based on replacing front steel beam with an aluminum beam

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Thermal (HVAC) Underhood Components

- The air conditioning system was divided into a passenger compartment system and an engine compartment system. This section addressed the under hood components which included the compressor, condenser and related plumbing. The under hood components were investigated for technologies and for mass.

Thermal (HVAC) Underhood Components

- The benchmarking study showed a relatively small mass difference for the underhood air conditioning components based on both vehicle mass and interior volume.
- A Toyota Prius which had a smaller total interior volume (110.6 ft3 vs. 142.4 ft3) had underhood air conditioning components that weighed within 0.7 kg of the equivalent baseline hardware.
- Because of the highly evolved nature of these components, the requirement for equivalent air conditioning performance and the lack of a clear consensus for a future automotive refrigerant, the mass and cost of the Venza compressor, condenser and associated plumbing were left unchanged for both the Low and High Development models.

Note: The baseline system mass was 8.024 kg without the compressor pulley mass (1.228 kg); Prius compressor is electric motor driven & has no pulley

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Glazing

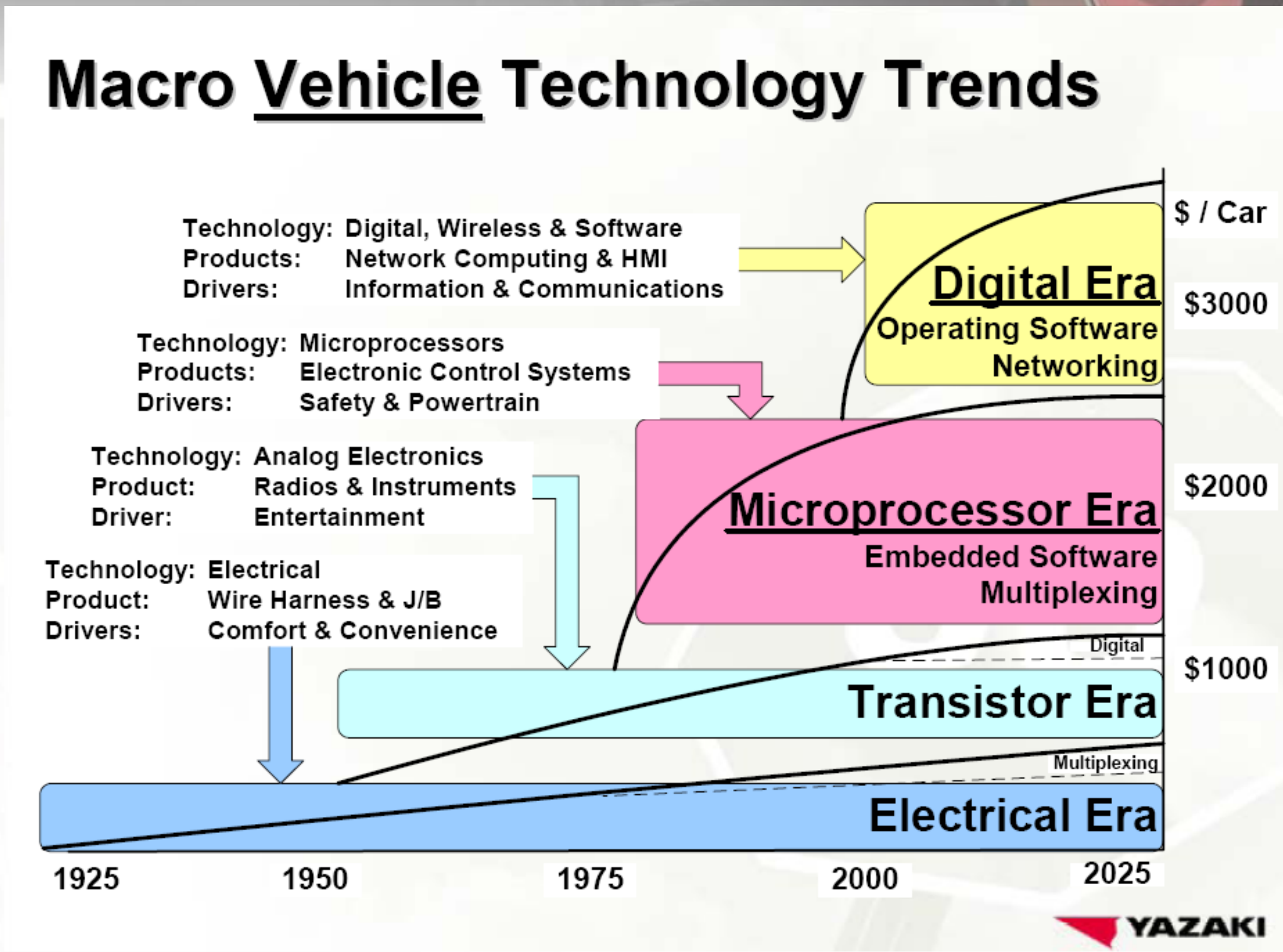
- The glazing of the baseline vehicle was classified into two groups:
  - Fixed
  - Moving
- The fixed glass is bonded into position using industry standard adhesives and was classified into two sub groups:
  - Wiped
  - Non wiped
- Factors involved in making decisions about glazing materials include:
  - The level of abrasion it is likely to see during the vehicle life
  - The legislative requirements for light transmissibility
  - The legislative requirements for passenger retention
  - The contribution it will make to interior noise abatement

Glazing

- The specific gravity of glass is 2.6 and the thickness of a windshield is usually between 4.5mm and 5.0mm so the mass per square meter of 5mm glass is approximately 13kg. This is almost double the weight/area of 0.8mm thick steel (the mass per square meter of 0.8mm steel is 6.24kg).
- The high mass of glass provides a strong incentive to: 1.reduce the glazed area of the body; 2. reduce the thickness of the glass; or 3. to find a suitable substitute that is lighter.
- Coated polycarbonate is an alternative to glass but it is more expensive and is not yet developed to the point of providing the required level of abrasion resistance that would allow its use on wiped surfaces such as windshields or dropping glasses.
- Fixed glass on the side of the vehicle offers the best opportunity for mass reduction per Exatec and Bayer (polycarbonate glazing suppliers).

Electrical/Lighting

Lowest mass, least cost wire is one that has been eliminated: wireless networking



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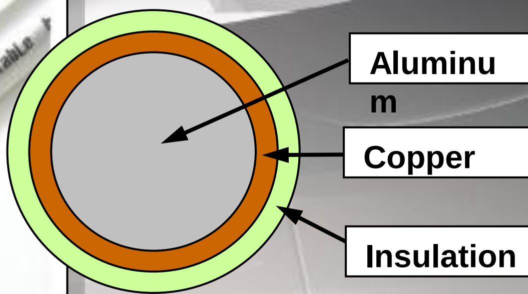
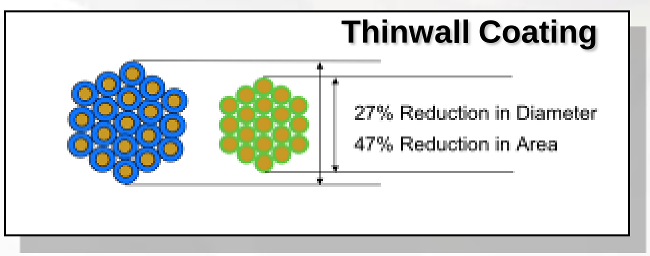
Electrical/Lighting

The estimated mass savings for using the thinwall cladding and the copper clad aluminum (CCA) wiring was 36% and a projected cost savings.

The 2011 Toyota Yaris, a subcompact car, will use an aluminum based wiring harness that is nearly 40% lighter and is expected to cost less than a conventional copper wire harness



Delphi Packard Electric has collaborated with SABIC Innovative Plastics to develop a wire coating that could provide up to a 25% mass savings compared to conventional coatings



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Electrical/Lighting

Lighting technologies reviewed included diodes, xenon, and halogen

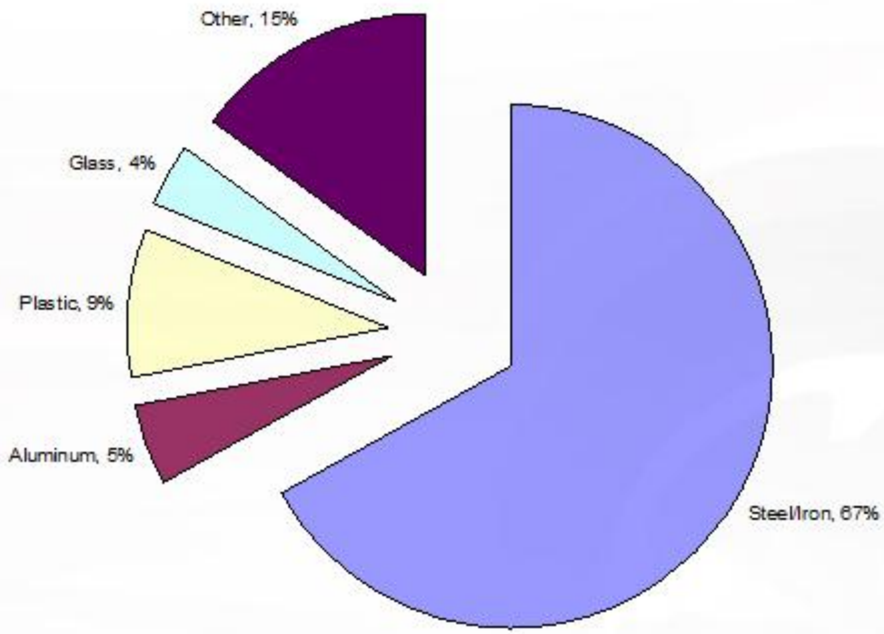
Simplify lamp assembly by separating lamp from cover

Reduce cost by integrating cover into body exterior panels

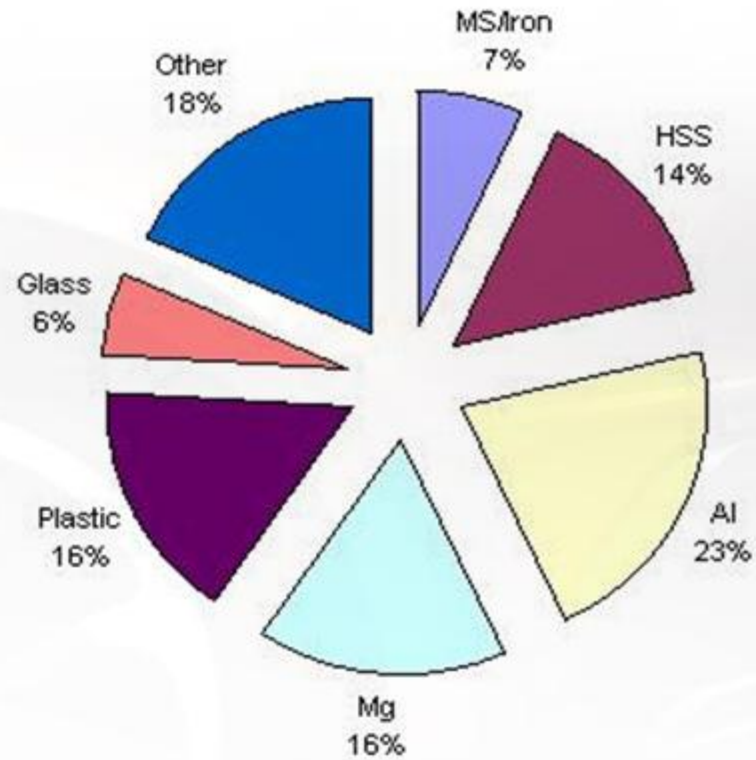
Move headlamps rearward to minimize damage in low speed impacts

Summary of Material Changes – Complete Vehicle

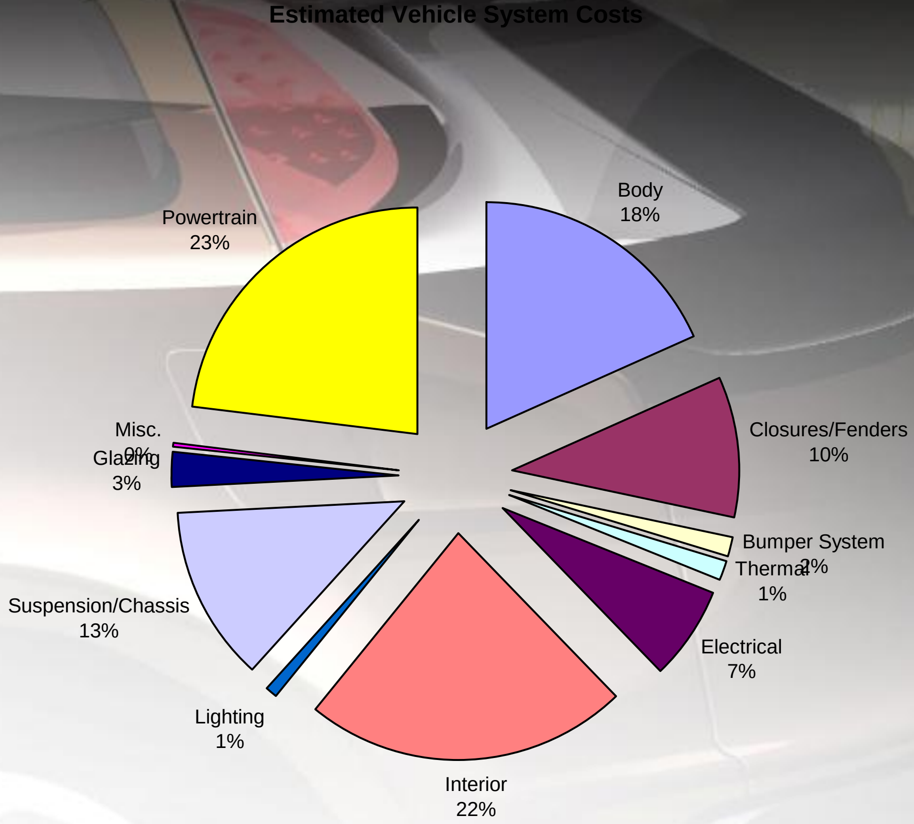
Baseline CUV Material Make-up By Mass



Low Mass CUV Material Make-up By Mass



Estimated Cost Weighting



- The baseline system costs were estimated based on Lotus experience and supplier input to establish a generic weighting value
- This value was then multiplied by the system cost factor to determine the percentage of the vehicle cost, e.g., Low Mass BIW = 135% x 18% = 24.3%
- The system values were then summed to create a total vehicle cost

Mass and Cost Summary

The estimated mass was 38.4% less than the baseline vehicle with a projected piece cost factor of 103%.

These mass reductions were achieved through a synergistic "Total Vehicle" approach where every vehicle system contributed. Increased costs were partially offset through cost reductions created in other systems as a result of mass reduction, parts count reduction and material utilization.

Mass and Cost Summary	Baseline CUV	Low Mass	Low Mass
		Mass	Cost Factor
Body	382.50	221.06	1.35
Closures/Fenders	143.02	83.98	0.76
Bumpers	17.95	17.95	1.03
Thermal	9.25	9.25	1.00
Electrical	23.60	15.01	0.96
Interior	250.60	153.00	0.96
Lighting	9.90	9.90	1.00
Suspension/Chassis	378.90	217.00	0.95
Glazing	43.71	43.71	1.00
Misc.	30.10	22.90	0.99
Totals:	1289.53	793.76	
Base CUV Powertrain Mass	410.16	Mass	Wtd. Cost
Base CUV Total Mass	1699.69	61.6%	103.0%

Cost Sensitivity Analysis

- **Revise the estimated body in white plus cost from 35% to 50%**
- **Revise the estimated cost contribution from 18% to 20%**
- **Use a cost reduction of 5% for all non-body/powertrain systems (removing 2 kg from every 5 kg of vehicle mass)**

	Cost Factor	Cost Weighting Factor	Weighted Cost Factor
Body	150%	20%	30%
Non-Body	95%	80%	76%
Totals:		100%	106%
Cost Differential			+6%

- **A total vehicle, holistic approach to mass reduction can help substantially offset the increased cost of a low mass body structure**

Recommendations

- Build the Phase 2 low mass body in white
    - Perform structural stiffness testing
    - Perform impact testing

Thank you

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