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Multi-Material Lightweight Vehicle
MMLV
ENERGY Ford MAGNA

Multi Material Lightweight Vehicle (MMLV) Architecture

David Wagner
for the MMLV Team
GALM June 18, 2015

4th Annual GLOBAL AUTOMOTIVE
LIGHTWEIGHT MATERIALS DETROIT 2015

Acknowledgement

The authors thank our colleagues in Magna, Ford and all our suppliers who have assisted with the design, build and testing of the MMLV. Over 200 scientists, engineers and technicians have contributed to this project. Finally the authors thank the U.S. Department of Energy, Vehicle Technologies Office for support and ongoing guidance and reviews.

This material is based upon work supported by the Department of Energy National Energy Technology Laboratory under Award Number No. **DE-EE0005574.**

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Project Description

Multi-Material Lightweight Vehicle
MMLV
U.S. DEPARTMENT OF ENERGY · Ford · MAGNA

GOAL: "The goal of this topic is to design, build and validate that the vehicle and vehicle sub-systems fall within an acceptable range of the functional and safety requirements using OEM standard experimental procedures."
(from FOA 239 Area of Interest 3)

DESCRIPTION

- Collaborative effort between Ford Motor Company, Magna International and US Department of Energy
- Drivable Vehicle – Design, build and test a lightweight vehicle using commercially available lightweight materials and manufacturing technologies, capable of 250,000 vehicles per year volumes.

FUNDING

- US DOE- Funded Program
- 4 Year program, FY2012-FY2015
- $20M (US) total project funding
  - $10M in direct funding to Magna and Ford
  - $10M industry cost share

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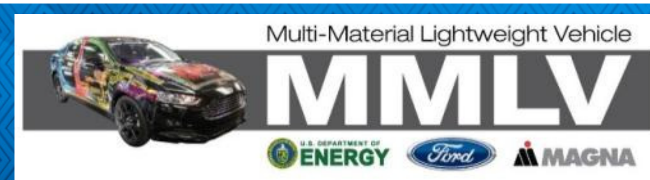
Multi Material Lightweight Vehicle (MMLV) Concept



GOAL

- Mass reduction of 2013 Fusion, CD segment
- Deploy materials and methods suitable for high volume manufacturing -- 250,000 vehicles per year
- Maintain safety and performance requirements
- Utilize currently available and previously demonstrated materials and manufacturing technologies

DELIVERABLE

23.3%
mass reduction
CD vehicle equivalent to B segment vehicle

16%
reduction in
GWP & TPE

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Subsystem Description	2002 Taurus	2013 Fusion	MMLV Mach I DESIGN FINAL	MMLV Mach I Prototype NVH+Mgt
Body Exterior and Closures (kg)	**574**	**594**	**456**	**492**
Body-in-White	n.a.	326	250	250
Closures-in-White	n.a.	98	69	88
Bumpers	n.a.	37	25	31
Glazings - Fixed and Movable	n.a.	37	25	25
Remainder - trim, mechanisms, paint, seals, etc.	n.a.	96	87	97
Body Interior and Climate Control (kg)	**180**	**206**	**161**	**191**
Seating	n.a.	70	42	61
Instrument Panel	n.a.	22	14	15
Climate Control	n.a.	27	25	27
Remainder - trim, restraints, console, etc	n.a.	88	80	88
Chassis (kg)	**352**	**350**	**252**	**269**
Frt & Rr Suspension	n.a.	96	81	85
Subframes	n.a.	57	30	44
Wheels & Tires	n.a.	103	64	58
Brakes	n.a.	61	49	51
Remainder - steering, jack, etc.	n.a.	33	29	32
Powertrain (kg)	**350**	**340**	**267**	**280**
Engine (dressed)	n.a.	101	71	83
Transmission and Driveline	n.a.	106	92	54
Remainder - fuel, cooling, mounts, etc.	n.a.	133	104	142
Electrical (kg)	**67**	**69**	**59**	**69**
Wiring	n.a.	28	25	28
Battery	n.a.	14	8	14
Remainder - alternator, starter, speakers, etc.	n.a.	27	26	27
Total Vehicle (kg)	**1523**	**1559**	**1195**	**1301**

Memo:

Curb Weights

2002 Taurus 1523 kg

2013 Fusion 1559 kg

Mach-I Design 1195 kg

Mach-I Build 1301 kg

2014 Focus 1345 kg
4-door SE Automatic

2014 Fiesta 1195 kg
4-door Automatic

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MMLV Concept

364 kg mass reduction from 2013 Fusion (23.3%)

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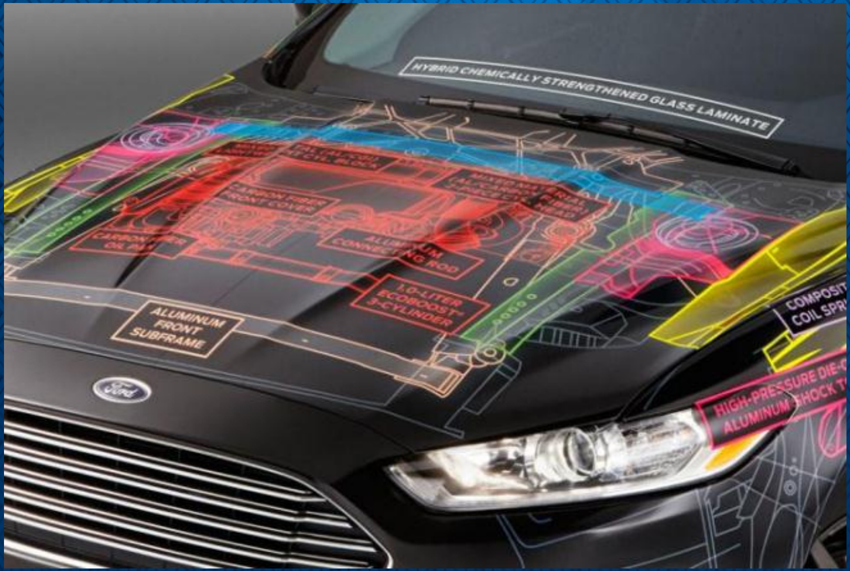
Body Exterior
- Aluminum Sheet

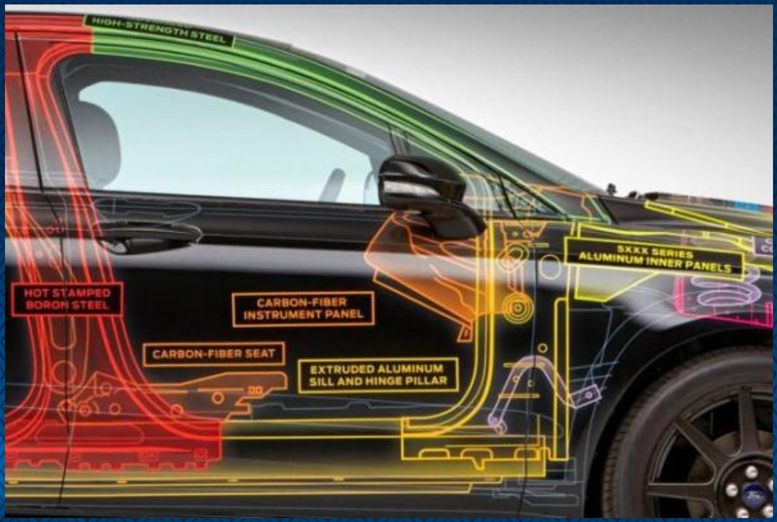
BIW Structure
- Vacuum Die Cast Aluminum
- AHSS plus Aluminum Sheet & Extrusions

Chassis
- Aluminum Subframes
- Hollow Steel, Glass+Epoxy Springs
- Aluminum Thermal Sprayed Brake Rotors

Bumpers
- Aluminum Extrusions

Glazing
- Chemically Toughened Hybrid Laminated Glass
- Polycarbonate with hardcoat for scratch resistance





Closures

Aluminum, Magnesium and Press Hardened Steel

Tires

Tall, Narrow Tires

Carbon Fiber and Aluminum Wheels

Interior

Carbon Fiber Seats

Carbon Fiber Instrument Panel Beam

Foamed Plastic ducts and trim panels

Powertrain

Cast Aluminum Block with PM Steel inserts

Carbon Fiber – Front Cover, Oil Pan, cam Carrier

Magnesium – Valve Body

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MMLV Concept

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Multi-Material Lightweight Vehicle
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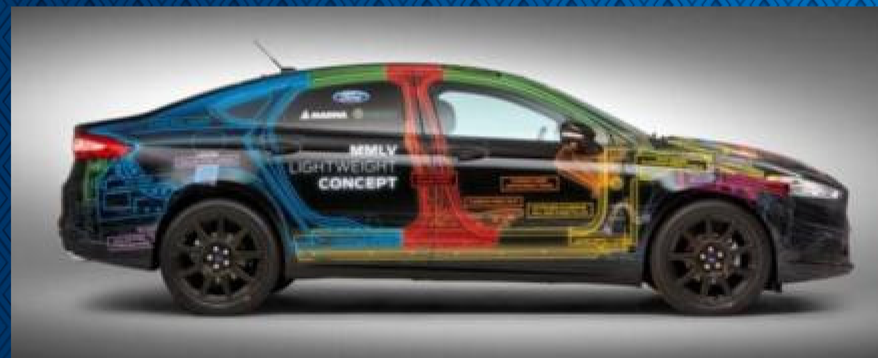


Body & Closures

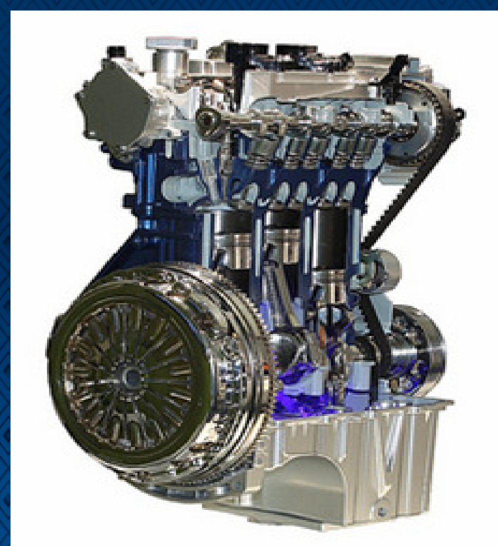
- BIW (24% 76kg)
- Major Panels (40%, 55kg)
- Bumpers (31%, 12kg)
- Toughened Laminated Glass Windshield and Drop Door Glass (37%,10.6kg)
- Polycarbonate Backlite (35%, 3.3kg)
- Tape-On Door Secondary Seals (31%, 1.2kg)
- Aluminum Hinges (42%, 1.5kg)
- NVH Sound Package (improve performance, weight neutral)

1.0 Engine (Fox)

- Aluminum Block (48%, 11.8kg)
- Aluminum Con-Rods (40%, 0.68 kg)
- CF/PA Oil Pan (30%, 1.2kg)
- CF/PA Front Cover (30%, 1.0 kg)
- CF/Al Cam Carrier (20%, 1.3 kg)

Transmission (6-spd Automatic)

- Al Pump Cover (59%,2 kg)
- Al/Steel FSW Clutch Hub (60%, 0.4kg)
- Mg Valve Body (35%, 1.0kg)



Interiors

- CF Seats (25%,2.2kg)
- CF IP (22%, 3.75kg)
- Chemically Foamed Plastics (20%, 2.3kg)

Electrical

- Li-Ion Starter Battery (30%, 4.5kg)

Chassis/Tires/Wheels

- Subframes (48%, 27kg)
- TS Aluminum Front Rotors (38%,6.75kg)
- TS Aluminum Rear Rotors (36%, 3.8kg)
- GF Composite Front Spring (57%, 6.4kg)
- Hollow Steel Rear Springs (37%, 6.4kg)
- Front Sta-bar Hollow Steel (39%, 1.7kg)
- Rear Sta-bar Hollow Steel (59%, 2.79kg)
- CF Wheels 19 x 5 (30%, 18.0 kg)
- Tires 155/70R19 (30%, 14.4 kg)

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Body-in-White (BIW) and Closures

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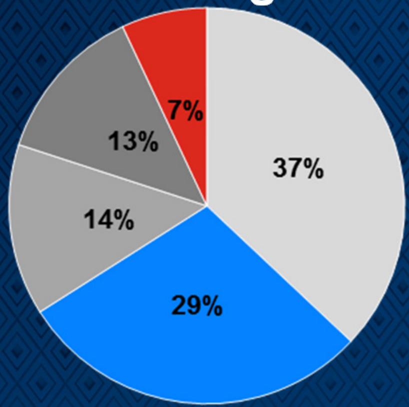
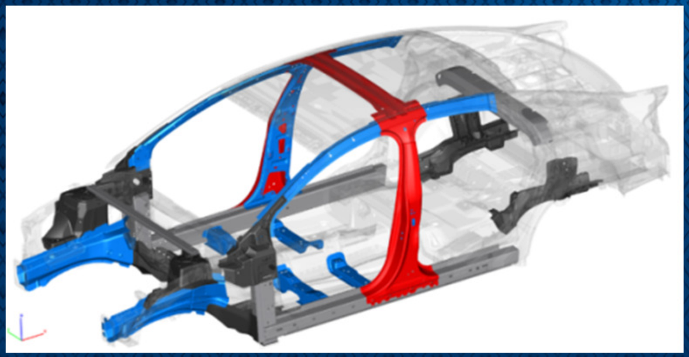
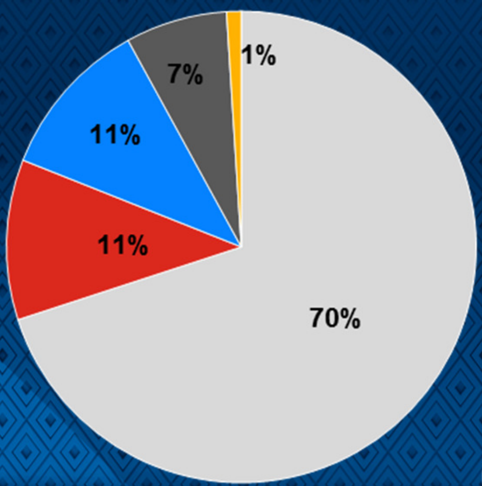
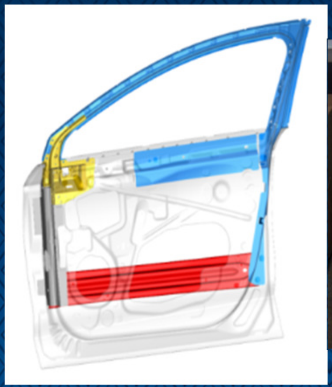
BIW 76.7 kg mass reduction from baseline (23.5%)

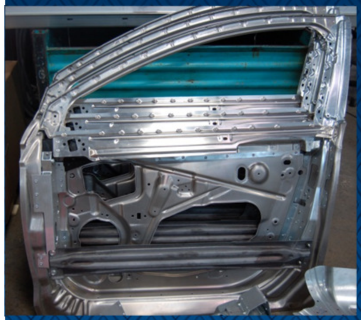


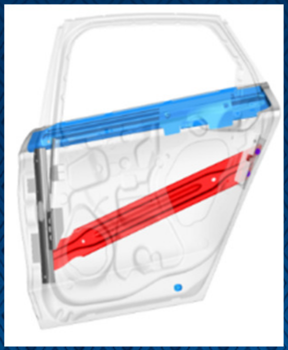


- ALUMINUM SHEET
- ALUMINUM CASTING
- STEEL AHSS
- STEEL HOT STAMPING
- ALUMINUM EXTRUSION
- MAGNESIUM CASTING









CLOSURES 29.0 kg mass reduction from baseline (29.7%)

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Bumper Structures and Subframes

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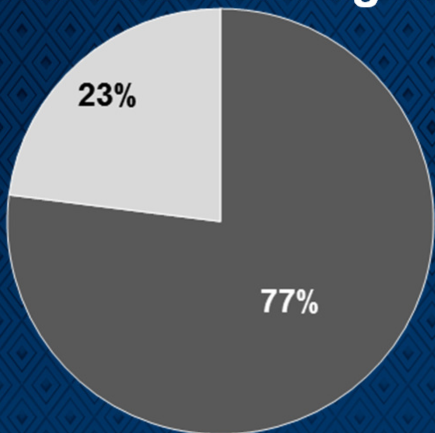
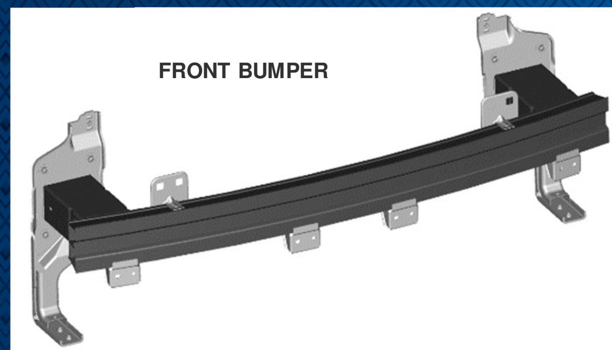
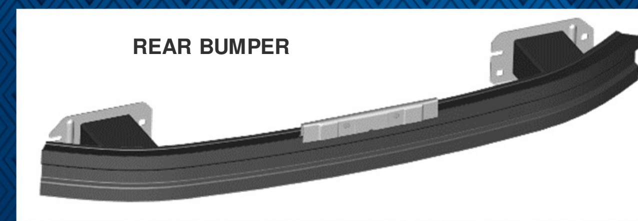
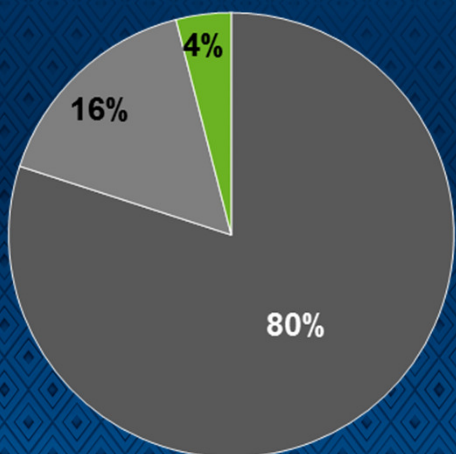
BUMPERS 11.4 kg mass reduction from baseline (30.9%)

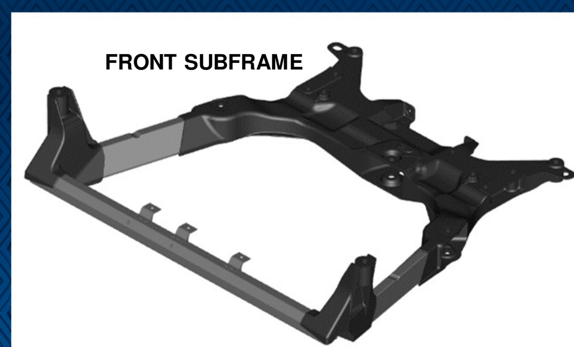


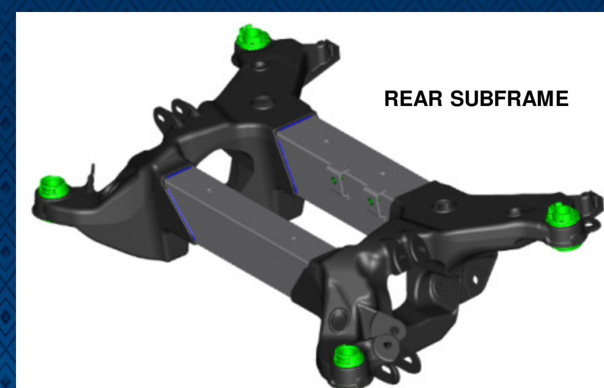




ALUMINUM CASTINGS · ALUMINUM EXTRUSION · ALUMINUM SHEET · OTHER (bushings …. etc.)







SUBFRAMES 27 kg mass reduction from baseline (47.4%)

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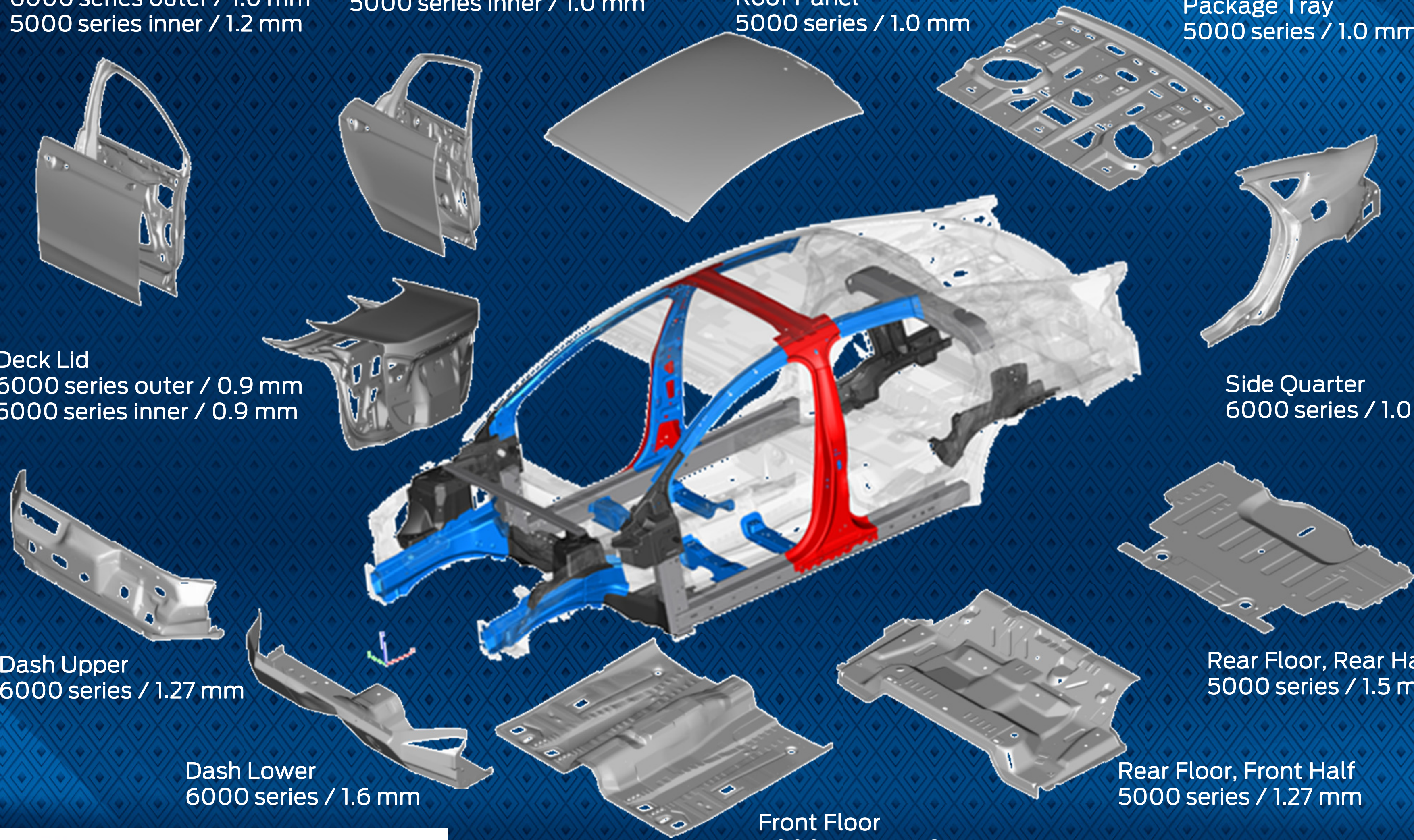
Major Body Panels

55.4 kg mass reduction from baseline (40%)



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Body Structure Joining

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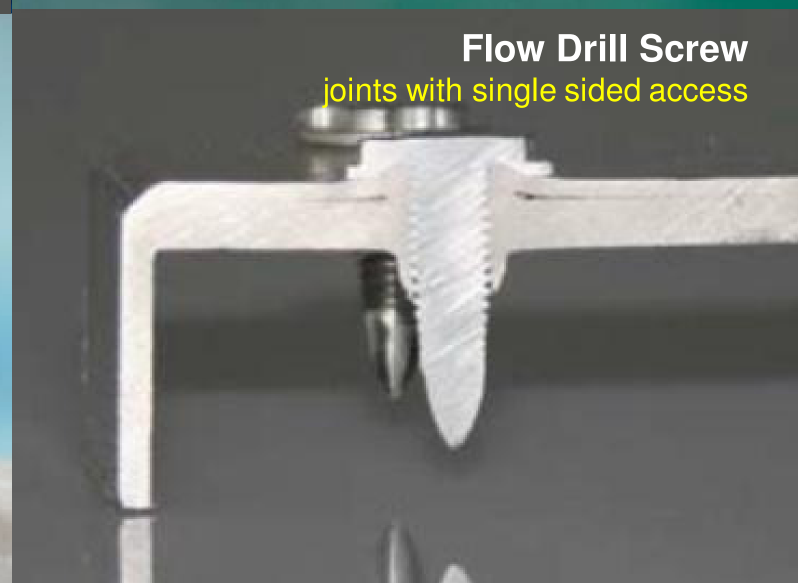
Adhesive Application
at all joints to resist galvanic corrosion between dissimilar materials and to increase durability life.

Self-Pierce Rivet (SPR)
at most joints, Al-Steel or Al-Al

RivTak™ Technology
joints with single sided access

Flow Drill Screw
joints with single sided access



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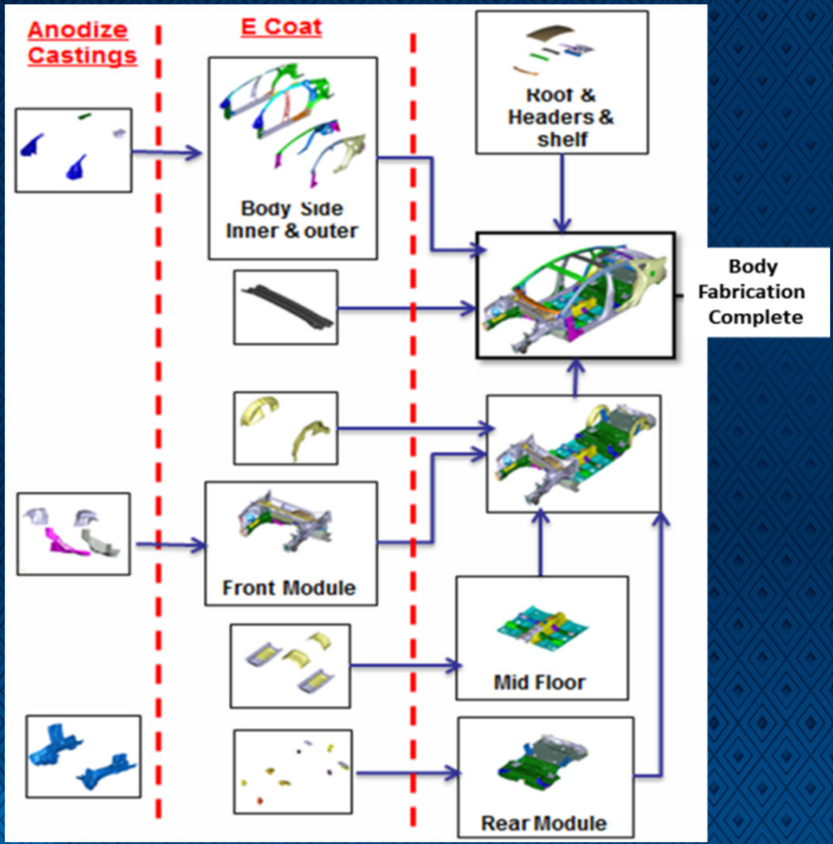
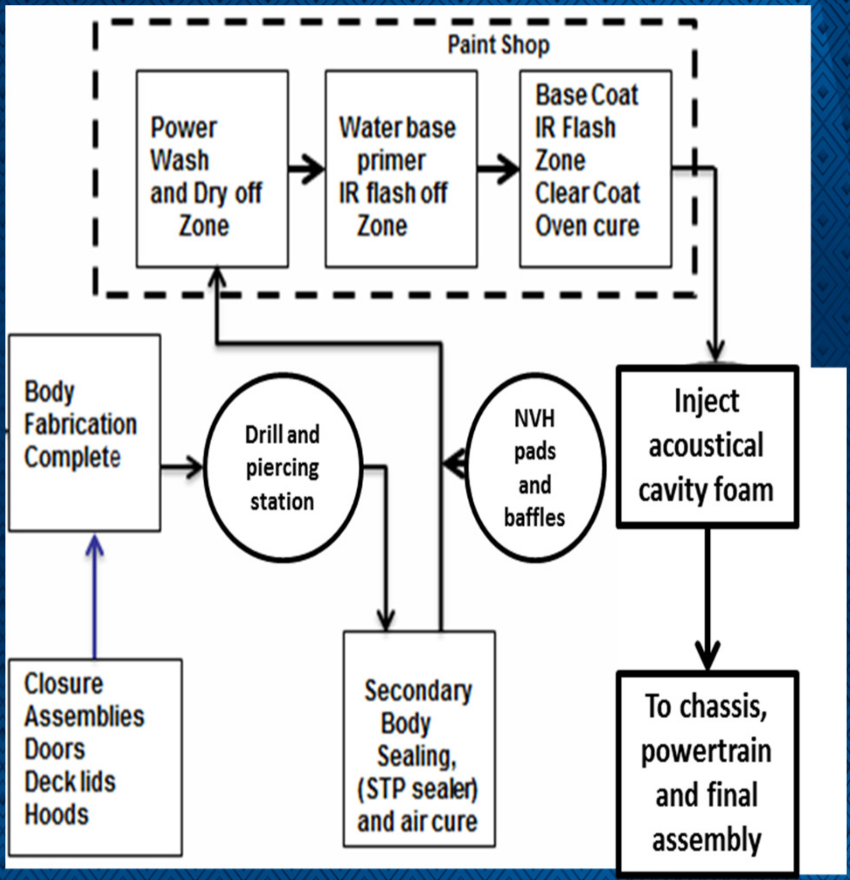
Two Corrosion Strategies

1. Alternative Strategy
Anodize castings, E-coat selected parts and subassemblies, then assembly (no full E-coat)



2. **Traditional Strategy**
without anodized castings, production pretreatment and full dip tank E-coat



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Powertrain & Suspension

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Powertrain – 73 kg mass reduction

- **1.0 liter I3 GDTi vs 1.6 liter I4 GTDI**
  - Aluminum block with PM Steel Bulkhead Inserts
  - Forged Aluminum connecting rods
  - CFRP Front Cover, Oil Pan and Cam Carrier
- **6-speed Automatic Transmission**
  - Magnesium Valve Body
  - Multi Material Clutch Hub

Suspension – 70 kg mass reduction

- Tall, Narrow Tires 155/70R19
- Wheels 19"x5", carbon fiber composite
- Delete Spare Tire/Wheel
- Al Brake Rotors, thermal spray coated
- Coil Springs
  - Glass-Epoxy Composite
  - Hollow micro alloy steel, shot peening
- Stabilizer Bars - front and rear
  - Hollow high strength steel, internal and external shot peening

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Interior & Glazing

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Interior & Climate Control
45 kg mass reduction

- Front & Rear Seats
  - Carbon fiber structures – injection molded 40% CF
- Instrument Panel Beam
  - carbon fiber with integrated HVAC ducts – injection molded 40% CF
- Air Ducts
  - Chemically foamed plastics

Glazing - 12 kg mass reduction

- Backlite
  - Polycarbonate with hardcoat for UV protection and Scratch Resistance
- **Windshield and Movable Glazing**
  - Hybrid chemically toughened laminate

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MMLV Vehicle Testing

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1. Buck Testing
Torsion, Bending, Door Slam

2. Durability Testing
- MPG & square edge chuck hole

3. Corrosion-Alternative
- Localized e-coat, Corrosion Test

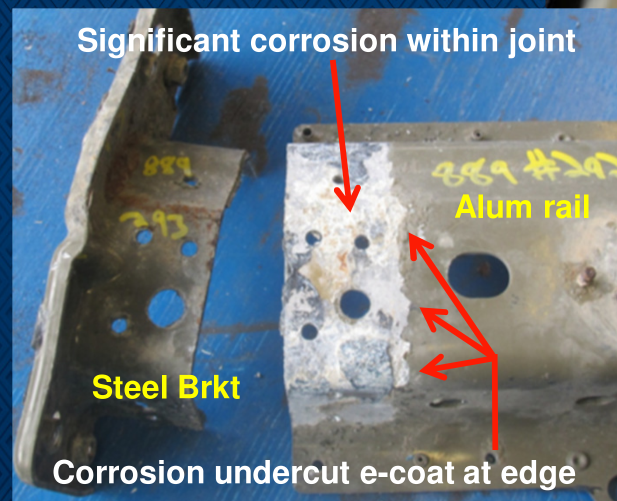
4. Corrosion Traditional
- 100% e-coat, Corrosion Test

5. Safety-A Testing
- IIHS ODB 40% offset, 40 mph

6. Safety-B Testing
- NCAP 35 mph rigid wall

7. NVH + Drives Testing
- Wind tunnel, Ride & Handling

Hollow steel rear stabilizer bar at 90% of durability



Corrosion at steel to aluminum joint

IIHS ODB is a 40% frontal offset impact test at 40mph

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Durability Results

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The Durability vehicle completed rough road durability testing representing 150,000 miles of severe customer usage with only these seven minor issues.

NO Body structure or Chassis structure durability issues!

PT mounting bracket

Shock tower

Inner hinge pillar

Rear shelf area

Front subframe & Control arm

Issues List:

1. Rear stabilizer bar bracket bolt cracked at 85%.
   (this production part had been repeatedly removed and re-attached during the build)
2. Rear hollow steel stabilizer bar cracked at ~90%.
   (this was expected since the chosen bar size was under capacity)
3. Front aluminum thermally sprayed brake rotor had coating degrade at ~90%.
4. Left front door chemically toughened laminated glass cracked at ~95%.
5. Left rear door chemically toughened laminated glass cracked at ~95%.
6. Left front lower ball joint softened ~95%.
   (this production part saw higher loads due to the thin wheels)
7. Left rear door chemically toughened laminated glass cracked at 100%.

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Corrosion Results

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Results: Both the *alternative* and *traditional* corrosion mitigation strategies produced acceptable results in accelerated corrosion testing at Ford's Proving Grounds.

Lessons Learned:

- Additional seam sealer applied to bi-metallic joints improves corrosion protection.
- Aluminum castings showed little evidence of corrosion products, however, anodizing the castings before assembly further reduces chances of corrosion.
- Magnesium castings need both surface treatment, such as a ceramic coating, AND must be protected from water ingress.
- Hardware selection requires careful material and surface specification.

Seam sealer improves performance

Al castings

Mg castings, same surface, different sealer

Hardware selection issue

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Safety Result

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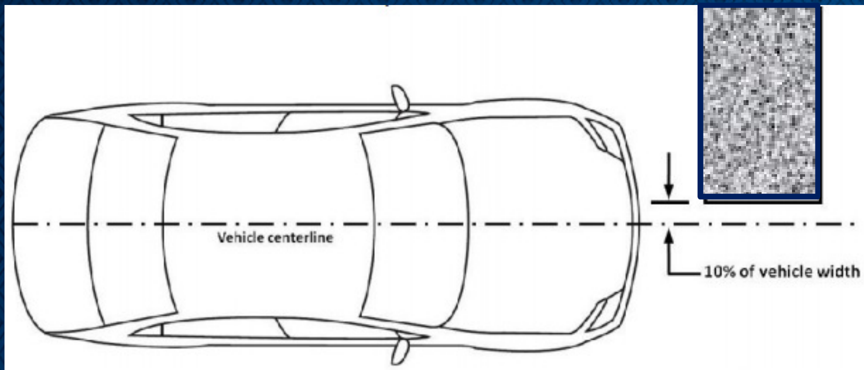
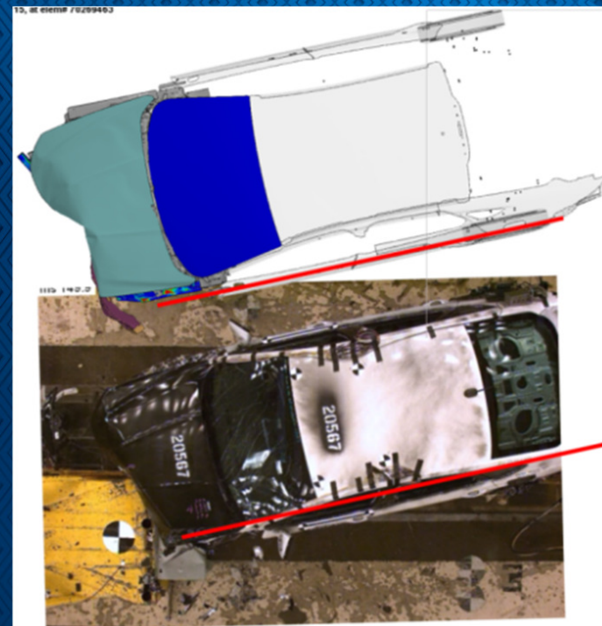


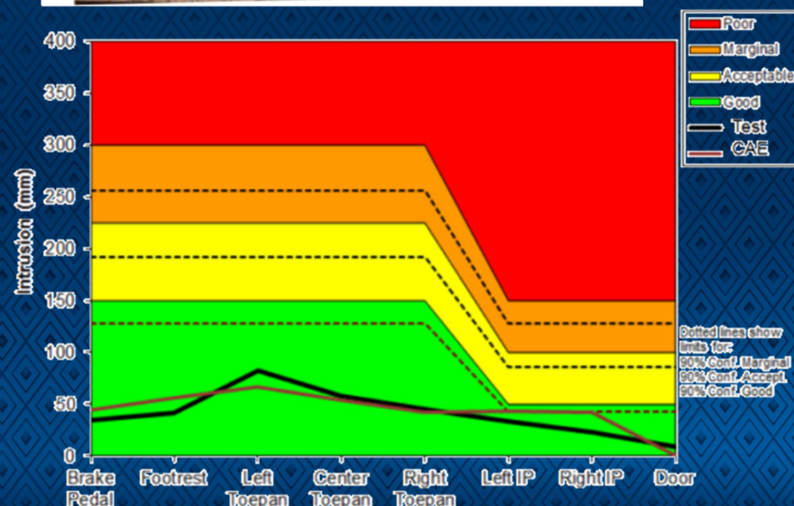


CAE Predictions are in good agreement with Test Results

Occupant Space Intrusion

- Offset Deformable Barrier
- 40 mph vehicle impact speed
- Dimensional Analysis of several cabin points after the impact
  - Floor Pan
  - Instrument Panel
  - A-Pillar

“Good" IIHS Structure Rating



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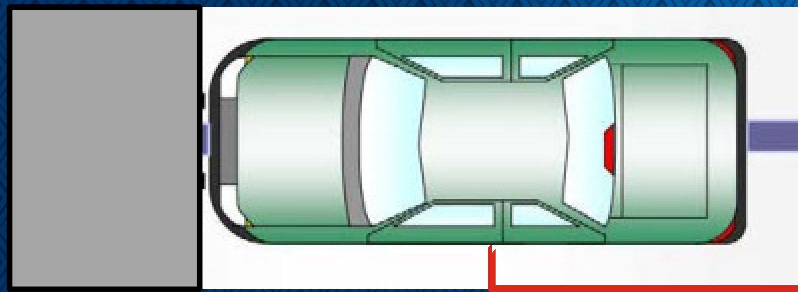
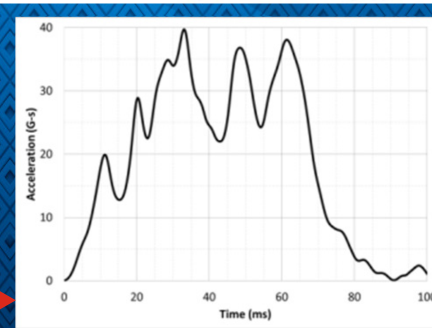
NCAP Safety Result

- Rigid Barrier
- 35 mph





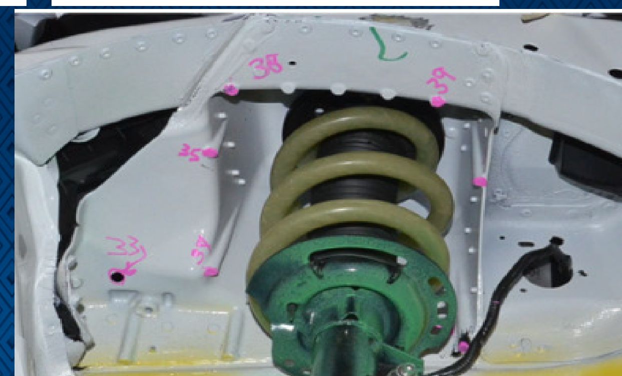
Extruded Aluminum Front Bumper and Crush Can

Laminated Chemically Toughened Windshield

Composite wheel

Subframe – Extrude Aluminum Portion

Anti-roll Mount



Composite Coil Spring

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Noise Assessment

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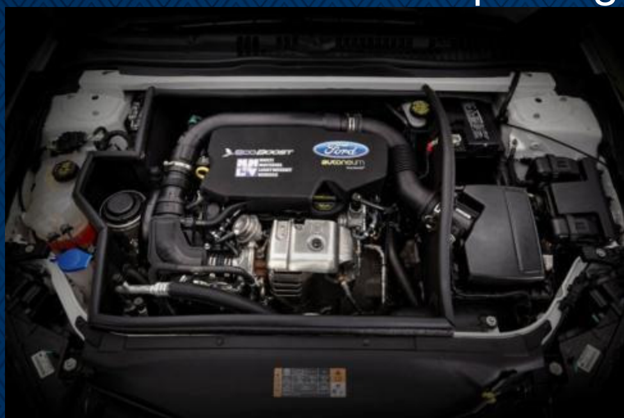
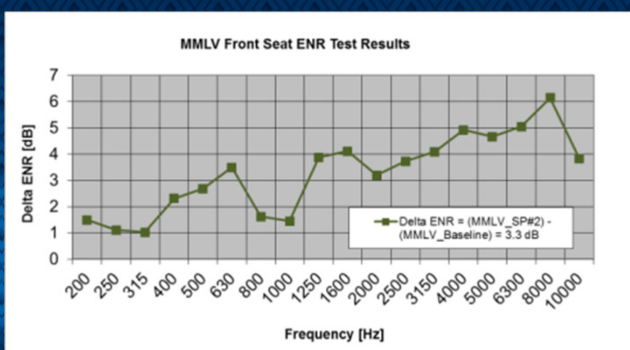
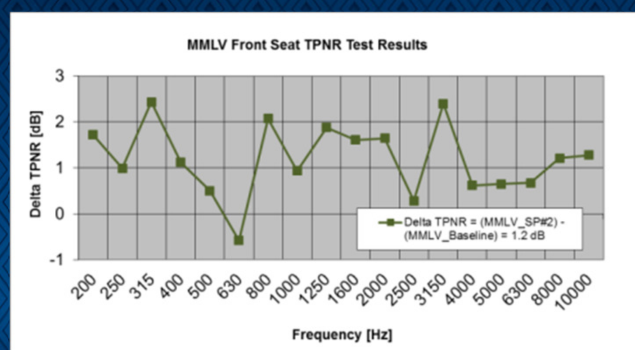
Vehicle NVH Test Results:

- Engine Noise Reduction (ENR) improved by 3.3 dB
- Tire Patch Noise Reduction (TPNR) improved by 1.2 dB
- Asphalt Road Noise at 50 mph degraded by 1.7 dB
- Wind Noise at 80 mph degraded by 0.9 Sones

Overall, approximately equivalent to Fusion







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Life Cycle Assessment

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Life Cycle Assessment (LCA)

- LCA - Per ISO 14044 & CSA G2014 Guidance with third party review
- Performed by outside consultant:
  Lindita Bushi, PhD. Eng. in Life Cycle Assessment, Toronto, ON, Canada

Summary

The MMLV concept is superior to the 2013 Fusion, both built and driven for 250,000 km in North America, in terms of total Global Warming Potential and Total Primary Energy.

The *cradle-to-grave total net savings* of the MMLV relative to the cradle-to-grave LCA of the 2013 Fusion, resulted in calculated environmental benefits of:

Global Warming Potential (kg CO2 eq) (16%),
Total Primary Energy (MJ) (16%)

note: 2013 Fusion at 28 mpg combined, Mach-I at 34 mpg combined


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THANKS… Questions?

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Thanks to the US-DOE,
Magna, Ford and our Suppliers

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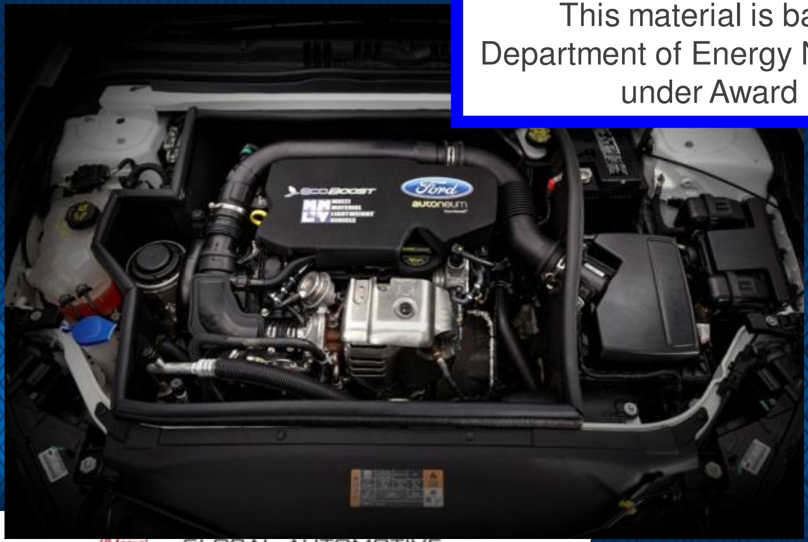

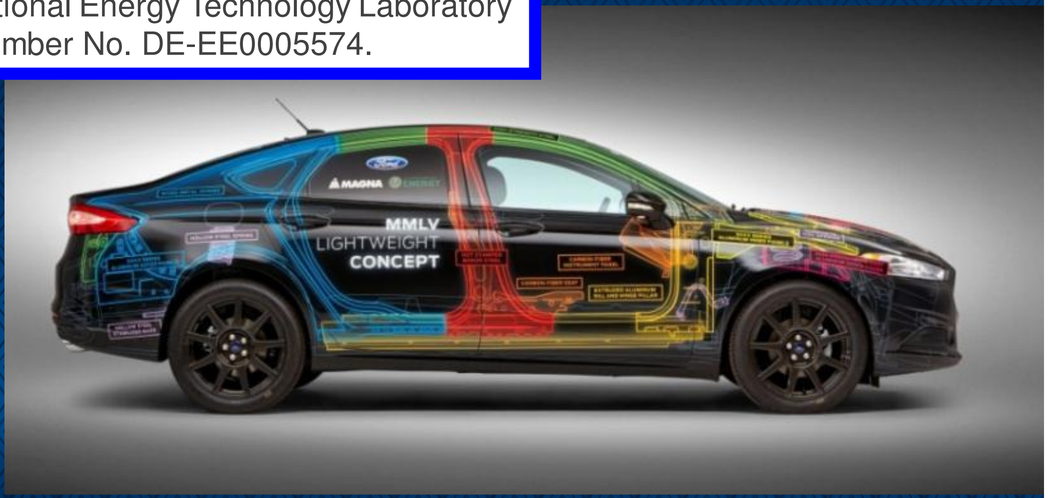

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