ALUMINUM IN TRANSPORTATION

THE ALUMINUM ASSOCIATION, INC.

Automotive Aluminum: Continued Gains in Fuel Economy

Doug Richman

Kaiser Aluminum

August 12, 2010

About The Aluminum Association's Aluminum Transportation Group (ATG)

ALCAN

KAISER ALUMINUM

ALUMINUM IN TRANSPORTATION

THE ALUMINUM ASSOCIATION, INC.

ALCOA

ADITYA BIRLA NOVELIS

ALUMINUM PRECISION PRODUCTS

sapa:

www.aluminumintransportation.org

Aluminum Facts

13
Al
26.98

- **Aluminum - most abundant metal**
- **<u>75%</u> of all aluminum produced since 1888 is <u>still in use</u>**
- **Recycled aluminum uses <u>5%</u> of the energy required to produce primary aluminum**
- **<u>95+%</u> of Automotive aluminum is recycled**

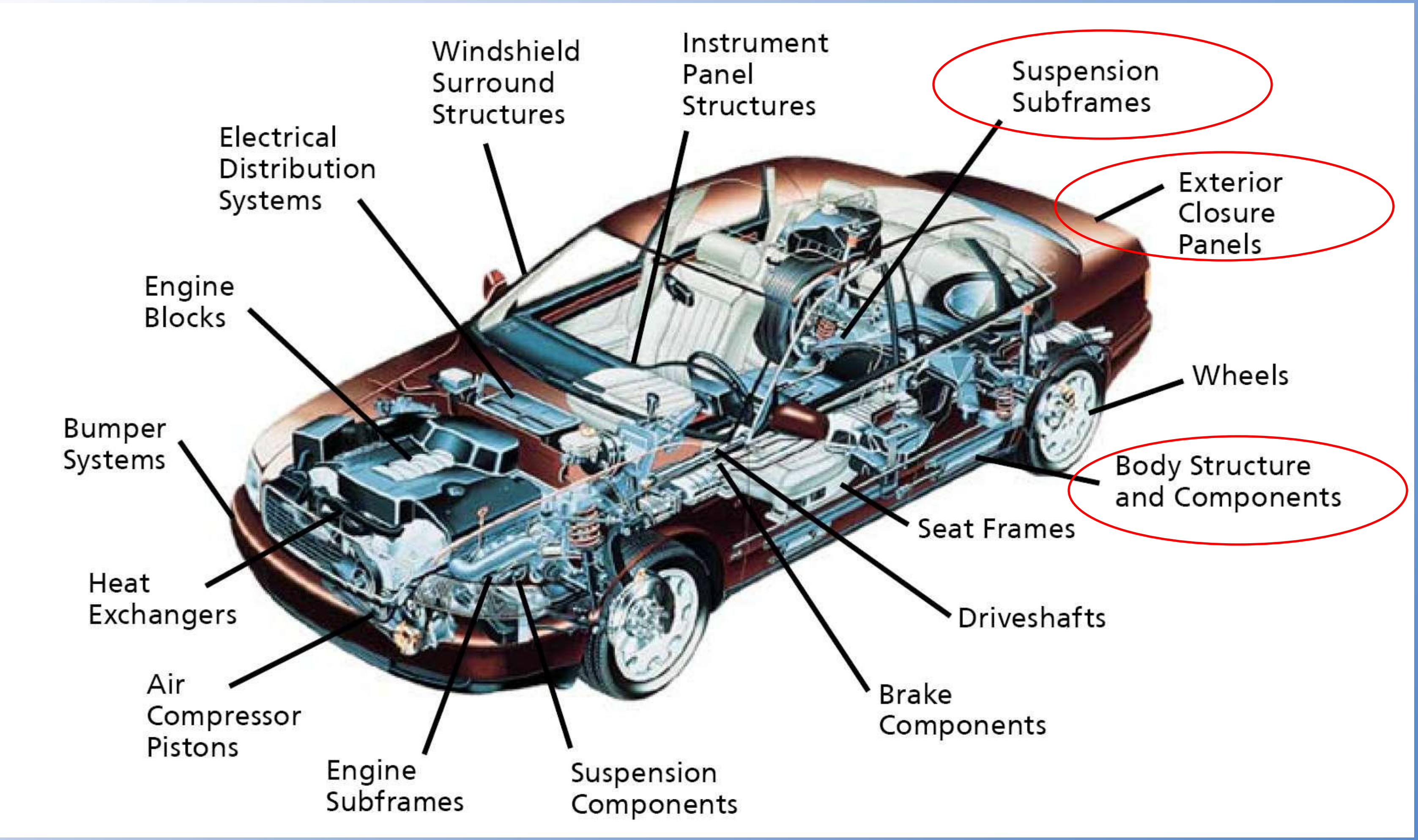
Outline

- Auto Aluminum Today
  - Demand Drivers
- Weight, Fuel Efficiency, Cost
  - SI / CI
  - Hybrid
  - Electric (EV, HEV)
- Weight and Life Cycle – Energy, CO_2
- Auto Aluminum Forecast

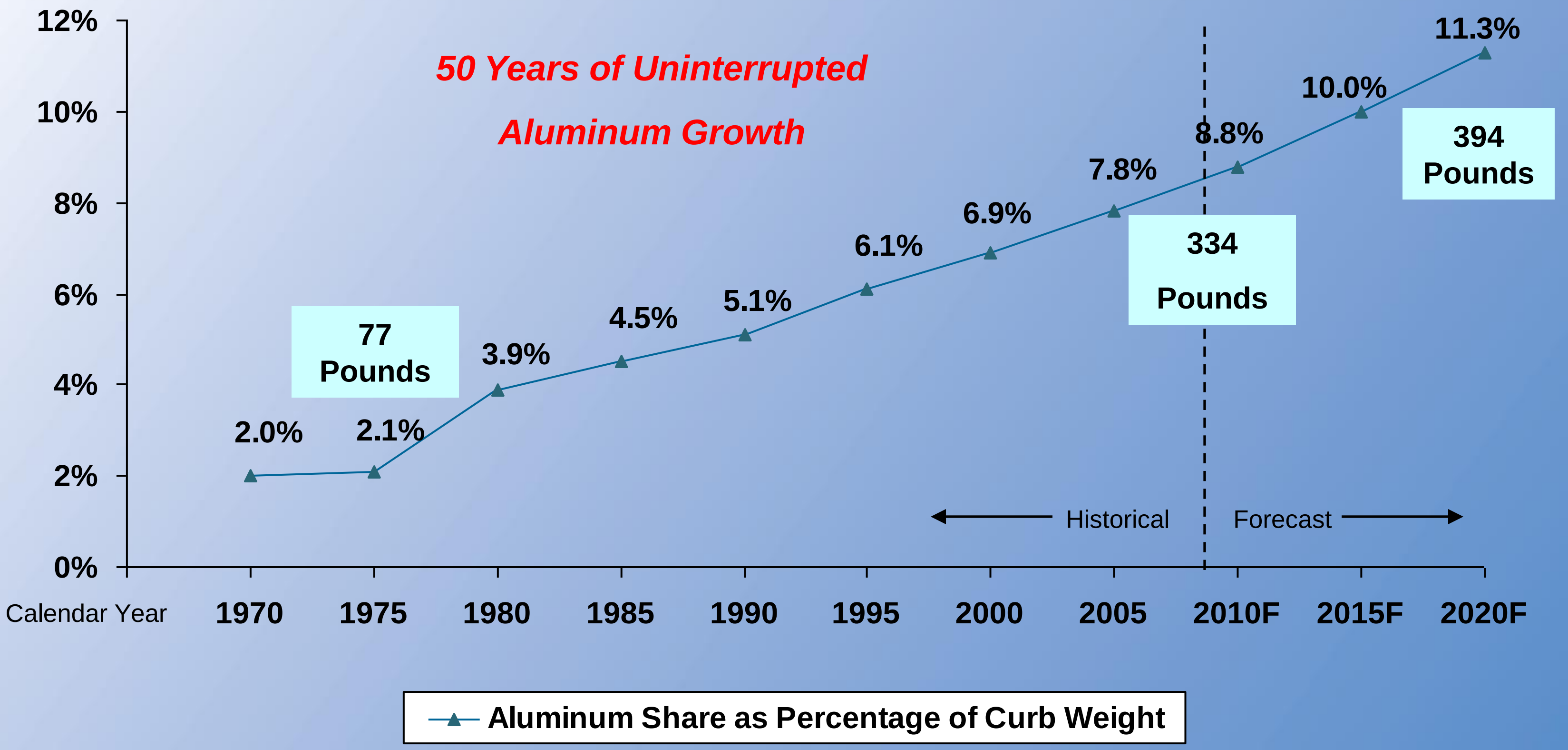
Auto Aluminum Demand Drivers

- Not a new automotive material
- Weight reduction
  - Fuel Economy (CAFE)
  - Performance
- Inhibitors
  - Cost / Benefit (vs. steel)

Aluminum Use in Light Duty Vehicles



Auto Aluminum Content – Percent of Curb Weight (North America)



DUCKER worldwide

Partial List of High Aluminum Content Vehicles [(1)]

Euopean Union Aluminum Content		N. American Aluminum Content		Japan Aluminum Content	
Over 500 lbs.	**400 to 500 lbs.**	**Over 500 lbs.**	**400 to 500 lbs.**	**Over 500 lbs.**	**400 to 500 lbs.**
Audi A6	Rover Defender	Altima	Chrysler 300	Nissan Cima/Q45	Subaru Legacy
Audi A7/Q7	Range Rover	Maxima	Charger	Nissan Fuga/M45M36	Nissan Stagea
Audi A8	Renault Espace	Lincoln LS	Magnum	Nissan Skyline/G35	Nissan Fairady Z
Audi TT	Renault Vel Satis	Navigator	Ford F150	Toyota Celsior	Toyota Majesta
Audi LeMans	Citron C6	Expedition	Explorer	Toyota Soarer	Toyota Aristo
Bentley Continental	Volvo V70	Corvette	Ford GT	Toyota Crown	Honda S2000
BMW 5 Series	Volvo S60	Cadillac CTS	Mustang	Toyota Mark X	Dahatsu Copen
BMW 6 Series	Volvo S80	Cadillac STS	Legacy/Outback	Honda Legend	Honda Insight
BMW 7 Series	Porsche 911	Cadillac DTS	New Escalade	Acura RL	
Rolls royce Phantom	Porsche Boxster	Cadillac XLR	New Suburban	Mazda RX8	
Mercedes C Class	Porsche Cayenne	Pacifica	New Yukon		
Mercedes E Class	Opel Signum	BMW Z4	New Tahoe		
Mercedes S Class	Opel Vectra		Subaru Tribeca		
Mercedes CLK	Saab 9-3		Lincoln Town Car		
Mercedes SL Roadster	Saab 9--5		Ford 500		
Mercedes Maybach			Ford Freestyle		
Jacuar XJ 350					
Jaguar XK 150					
VW Phaeton					
Ferrari F430					
Various Aston Martin					
Various Lamborghini					

80+ Vehicles

[(1)] **400+ lbs.**

2009 OEM Analysis

2009 DODGE CHARGER- E Segment Unibody

- <u>413 Pounds</u> of finished aluminum
- <u>10.9%</u> of overall weight is aluminum
- Aluminum:
  - Driveline
  - Hood, suspension arms, knuckles

2009 NISSAN ALTIMA- D Segment Unibody

- <u>409 Pounds</u> of finished aluminum
- <u>13%</u> of overall weight is aluminum
- Aluminum:
  - Driveline
  - Hood, suspension arms, knuckles

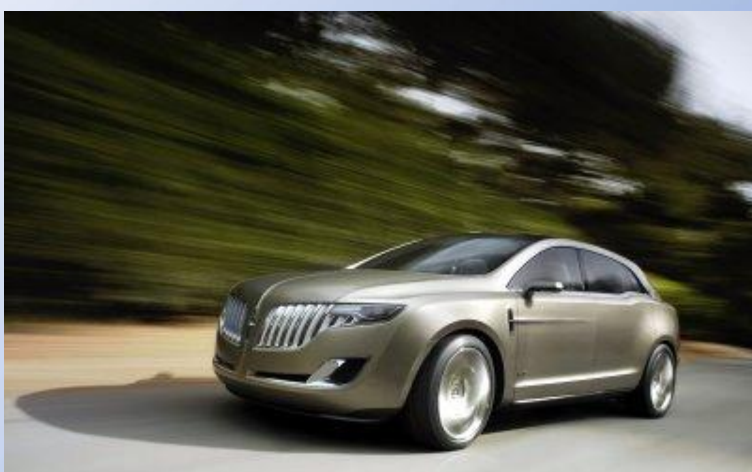
2009 OEM Analysis

2009 HONDA CIVIC- C Segment Unibody

- **310 Pounds** of finished aluminum
- **11.5%** of overall weight is aluminum
- Aluminum:

  Driveline

  Bumper beams, knuckles



2010 LINCOLN MKT (2009 PRODUCTION) E Segment Unibody

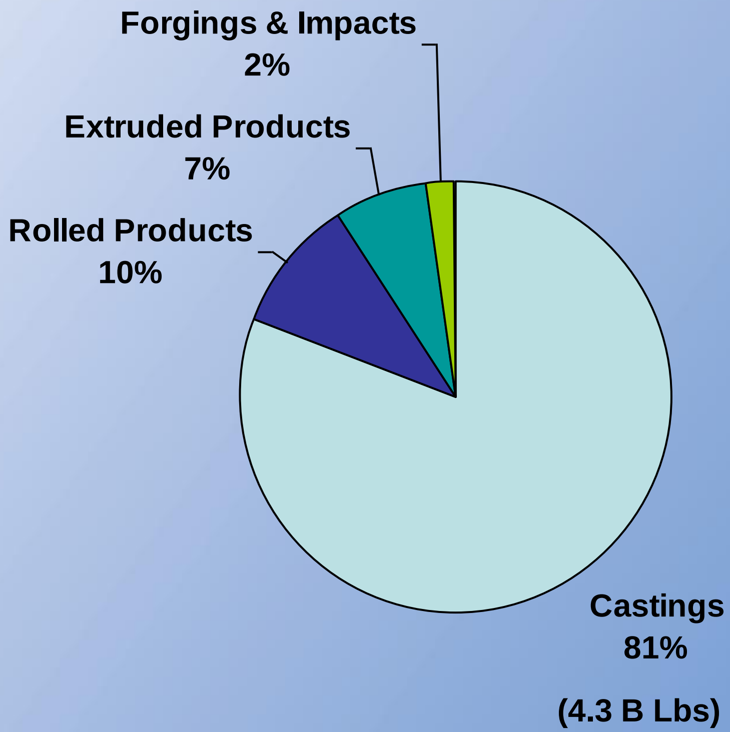
- **431 Pounds** of finished aluminum
- **10.6%** of overall weight is aluminum
- Aluminum:

  Driveline

  Hood, suspension arms, knuckles

Transportation Shipments by Product

Transportation Shipments by Product



The Aluminum Association

Total = 6.3 B Lbs

Weight Reduction

vs.

Fuel Economy

Impact of Vehicle Weight Reduction on Fuel Economy for Various Vehicle Architectures

Prepared for: The Aluminum Association, Inc.

By: Anrico Casadei and Richard Broda

Project FB769

RD.07/71602.2

Technical Approval: __Reviewed by [Frederic Jacquelin]________________

Date: ____________________ **(20-Dec-2007)**

Study Objectives

- Quantify impact of vehicle weight reduction
  - Fuel economy
  - Performance
- Quantify impact of engine downsizing
  - Maintain vehicle performance level
- Evaluate weight reduction with engine types
  - Gasoline (SI)
  - Diesel (CI)

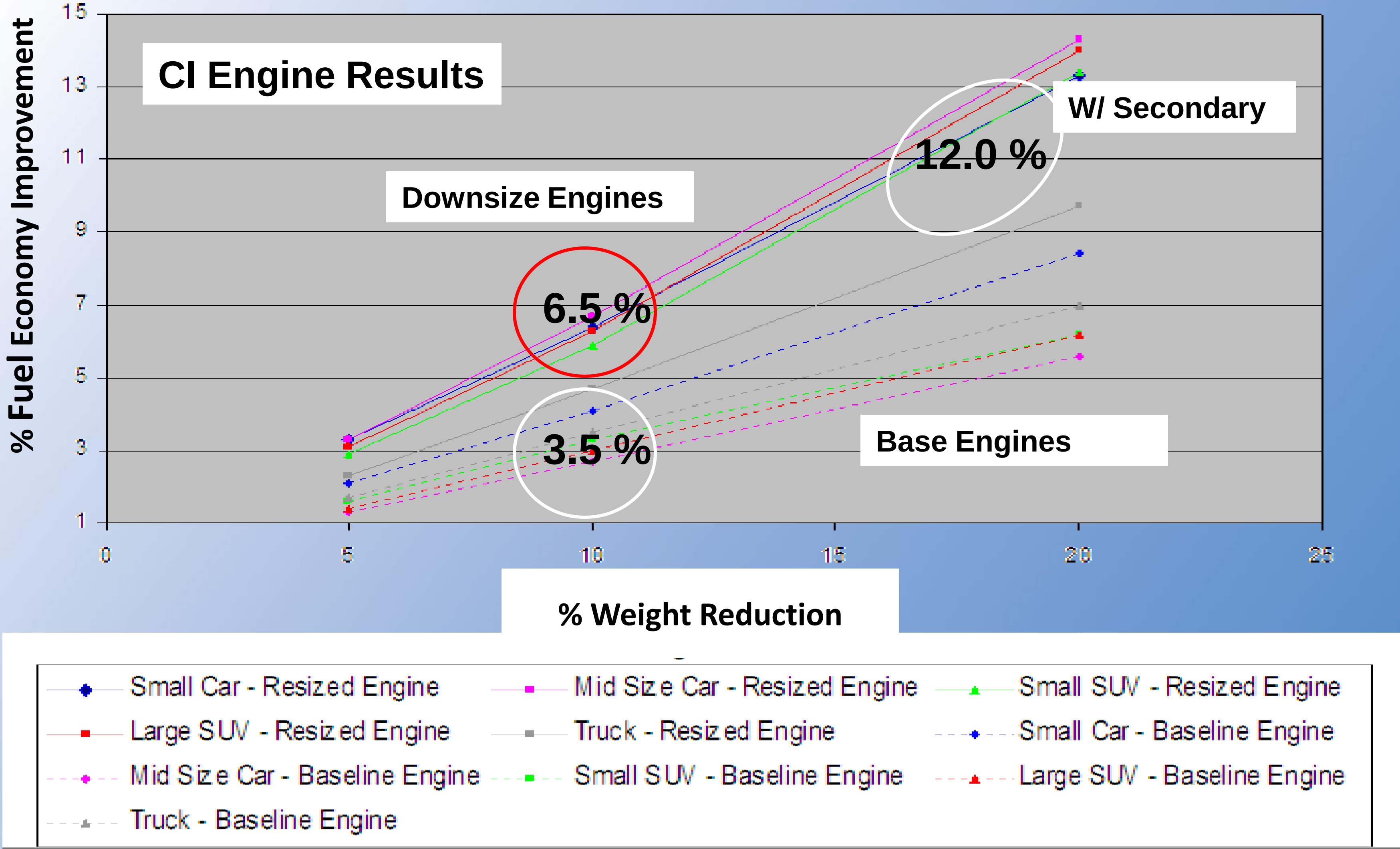
Vehicle Selection

- Vehicle Classes
  - Range of vehicle weights and engines
  - passenger and light-duty truck
- Comparator Vehicle
  - Small Car / Mini Cooper
  - Mid-Size Car / Ford Fusion
  - Small SUV / Saturn Vue
  - Large SUV / Ford Explorer
  - Truck / Toyota Tundra

Vehicle Simulations

- Vehicle fuel economy (MPG)
  - EPA FTP75 (City)
  - EPA HWFET (Highway)
  - ECE (European)
  - Steady State: 30, 45, 60 and 75 MPH
- Vehicle performance (sec.)
  - 0 – 10 MPH
  - 0 – 60 MPH
  - 30 – 50 MPH
  - 50 – 70 MPH
- Each vehicle:
  - Baseline
  - Base engine: <u>weight reduced by 5%, 10% and 20%</u>
  - Reduced weight <u>and</u> engine downsized to match the baseline vehicle performance

Weight Reduction vs. Fuel Economy



Weight Reduction vs. Fuel Economy

	Fuel Economy Improvement / 10% Weight Reduction (EPA Combined Drive Cycle)			
	Passenger Vehicle		Truck	
	Base Engine	Downsized Engine	Base Engine	Downsized Engine
Gasoline	3.3%	6.5%	3.5%	4.7%
Diesel	3.9%	6.3%	3.6%	4.6%

Fuel economy impact of weight reduction

- **Similar for gasoline and diesel vehicles**

Truck engines

- **Downsized to a lesser degree – maintain loaded performance**
- **Vehicles rated to tow a trailer benefit the least**

FD807 – Electric Vehicle Component Sizing vs. Vehicle Structural Weight Report

13 - May - 2009

Fred Jacquelin – Section Leader

RD.09/17995.3

PEV/PHEV Study Criteria

- **Vehicles –**

  <u>Small car</u> – BMW Mini

  <u>Small SUV</u> – Saturn Vue

- **Performance**

  Range: **<u>40 / 80 miles</u>**

  Acceleration: **<u>10 sec</u>. 0-60 MPH, <u>FTP75</u>**

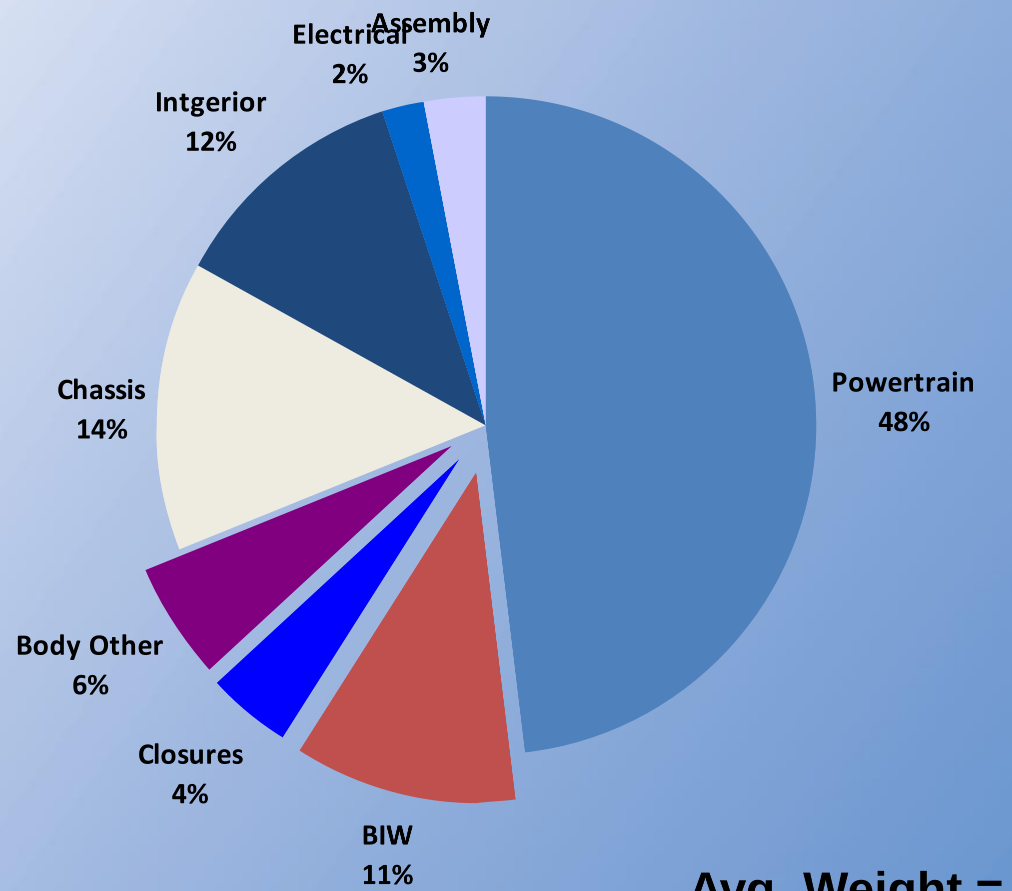
  Top speed: **<u>100 MPH</u>**

***Note*: <u>PHEV, operates on batteries only</u>, carries mass of ICE engine and associated "support systems"**

Simulation Assumptions

- **Rolling and Aero Resistance – Baseline Vehicles**
  - **No secondary loads – steering, HVAC, etc.**
  - **No additional structure to support battery (51 – 209 Kg)**
- **Battery – Lithium-Ion, Sized for Range**
  - **SOC 0.9-0.25, 115 W-h/kg, 155 W-h/l**
- **Motor - Sized For Performance**
  - **(FTP75, 0-60 time)**
  - **top speed**
  - **3.05 kW/kg motor power density**
- **Regenerative Braking @1000N, Throttle = 0**
- **Final Drive Ratio - Fixed**

Weight Distribution of a Mid-Sized "Aluminum" Car



Avg. Weight = 1270 Kg

Vehicle Weight Analysis
Small Car

Base (Steel)		**1,304 Kg**
- Powertrain system	(571) Kg	
+ Hybrid charging	348	
+ e Powertrain	124	
	(99)	
HEV (Steel)		**1,205 Kg**
- Hybrid charging	(348)	
- Structure design (PT)	(52)	
- Light Weighting (AIV)	(147) *(12%)*	
- e Powertrain	(36)	
	(583)	
EV Light Weight (Al)		**622 Kg**

Vehicle Weight Analysis
Small Car

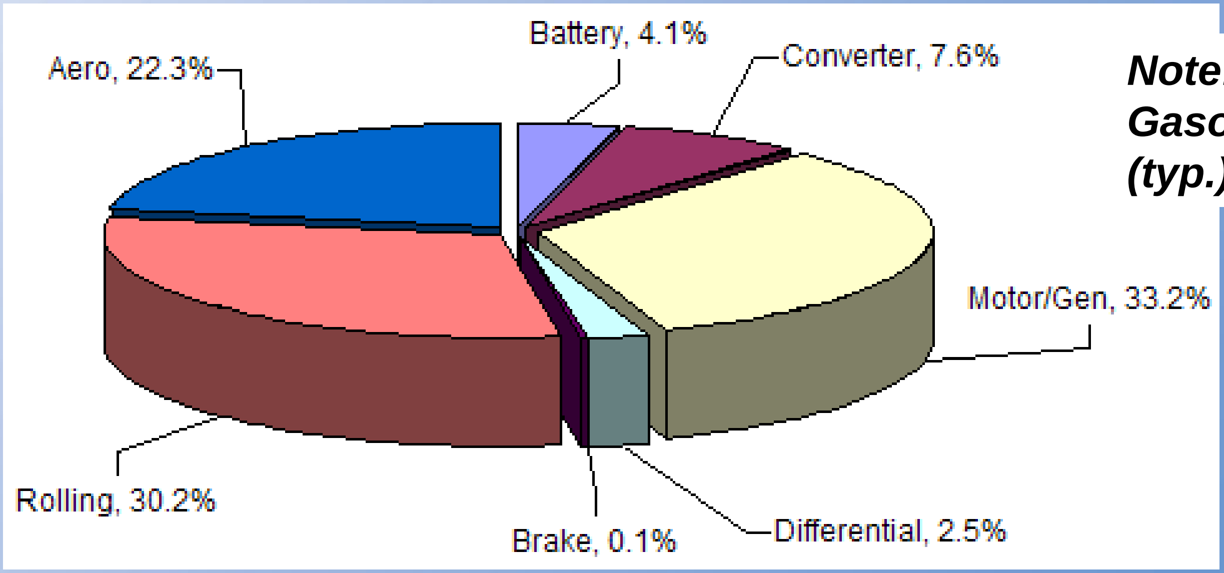
EV Weight Reduction with Aluminum :

BIW		96 KG reduction
Closures		28
Chassis		23
	Total	147 KG *

* 19% of EV (622 Kg) final weight !

Small Car – Energy Usage

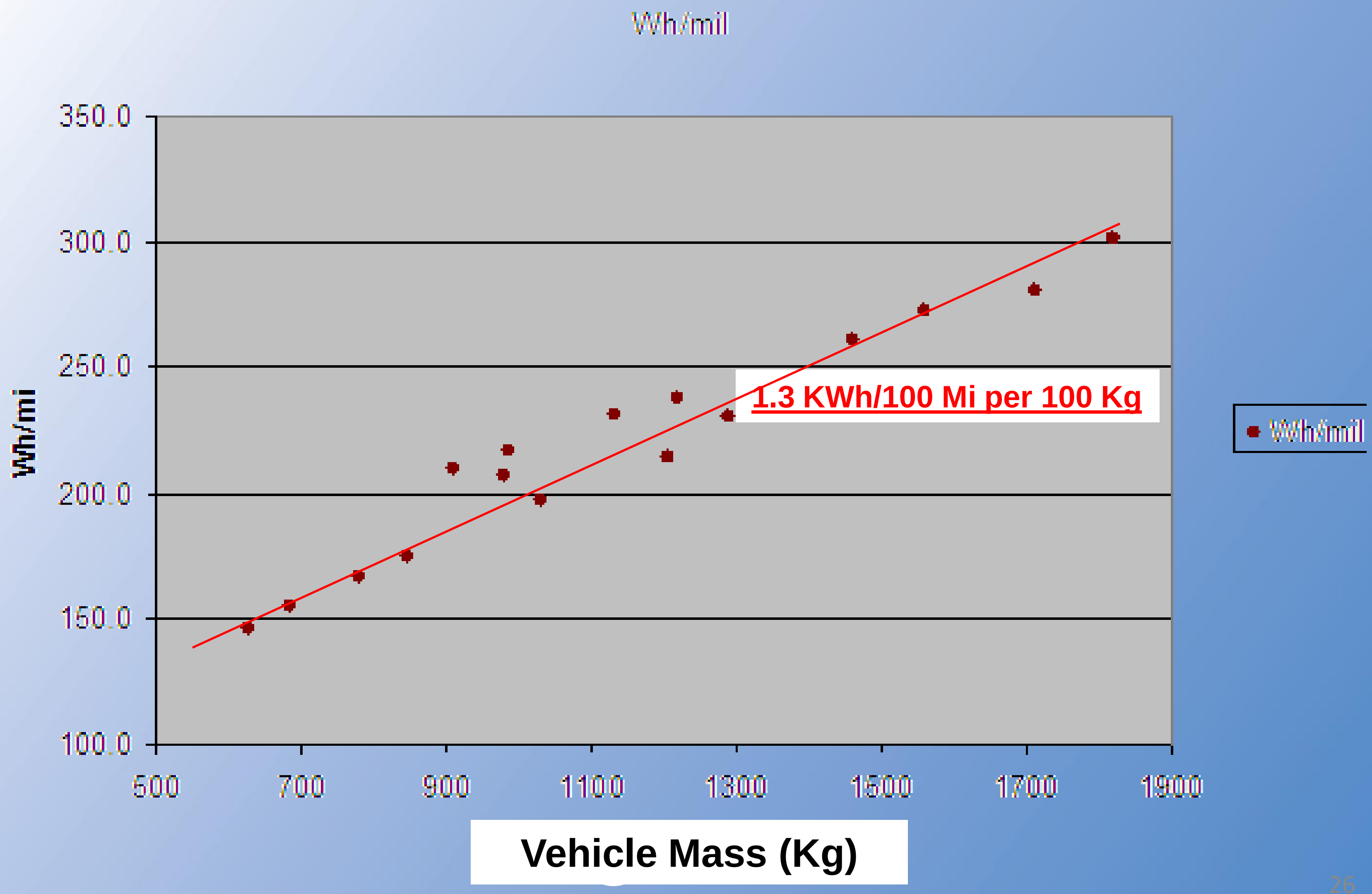
PHEV (Fe): 1205 kg
[Regen = 20.9%]



Note: Gasoline: (typ.) >60%

Schedule (FTP75)

EV Mass vs. Energy Consumption



PEV (PHEV) Study Findings

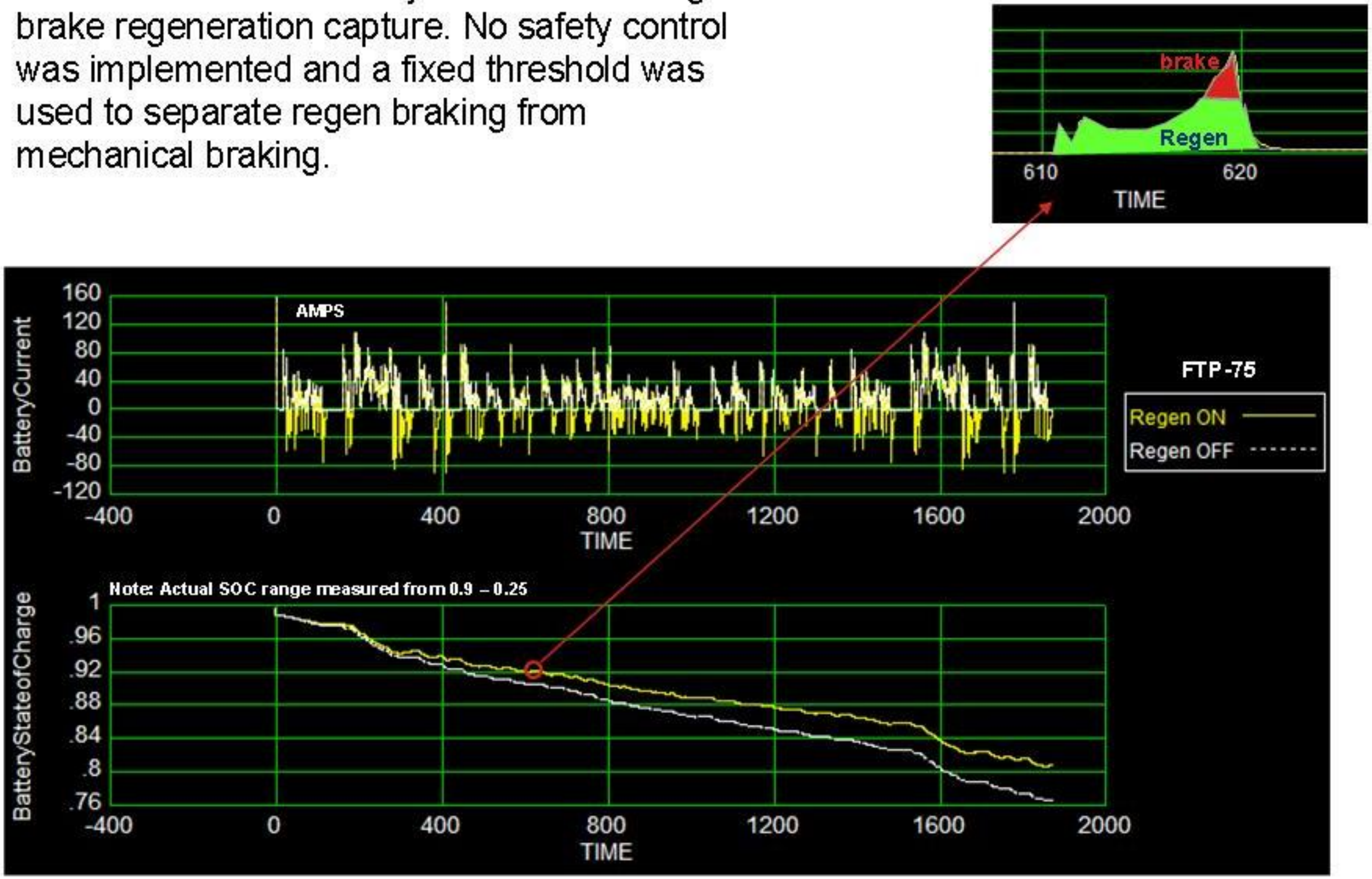
- **10% Mass Reduction: 4 – 6% reduction in battery size**
- **Low Mass Aluminum Structure Achieves**
  - Weight reduction potential: **147 Kg** (**19%)**
    - Reduce battery cost: **$ 900 – $ 1,950** (@ $750/KWh)
    - Expected aluminum structure cost premium : $ 630
    - **Net cost savings = $775**
  - Reduced energy consumption: **1.3 KWh / 100 Mi per 100 Kg**

Regenerative Braking PEV/PHEV

- Impact of regenerative braking
- Effect of weight reduction on benefit

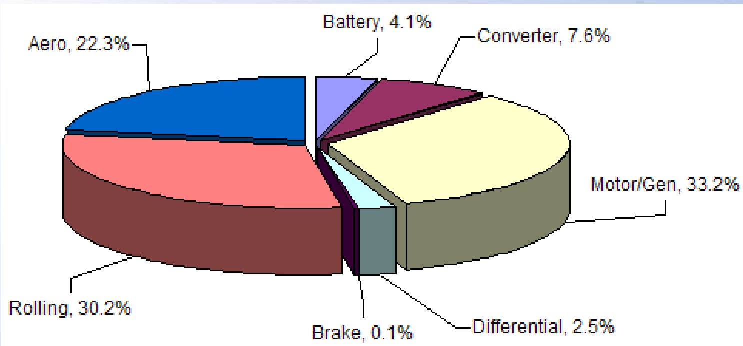
Regenerative Braking Small Car

The EV motor and battery size allow for large brake regeneration capture. No safety control was implemented and a fixed threshold was used to separate regen braking from mechanical braking.

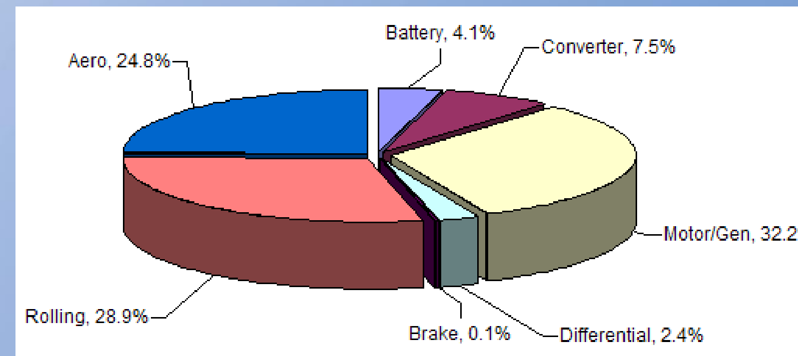


Small Car – Energy Usage

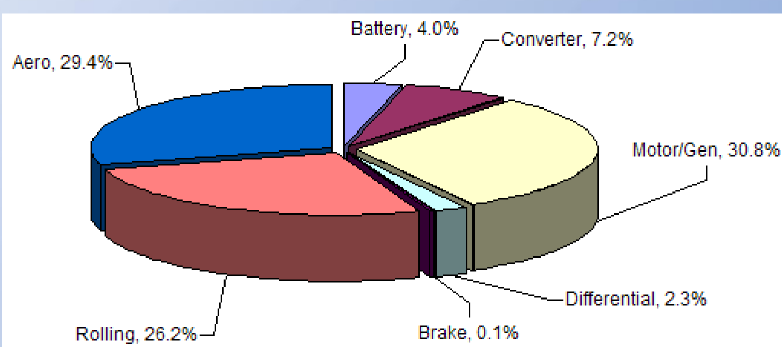
PHEV (Fe): 1205 kg
[Regen = 20.9%]



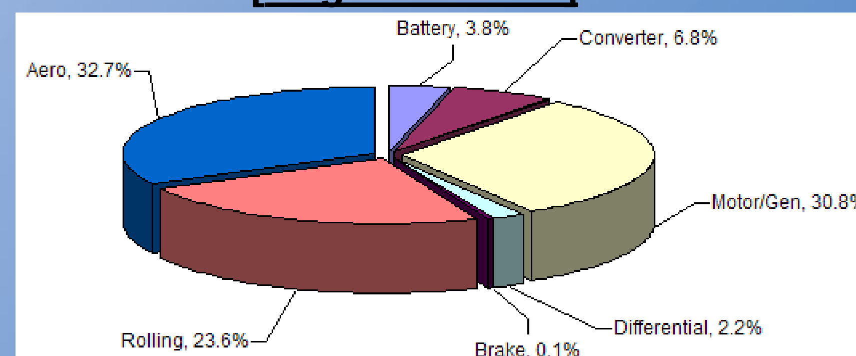
PHEV (Al): 1031 kg
[Regen = 20%]



PEV (Fe): 781 kg
[Regen = 18.1%]



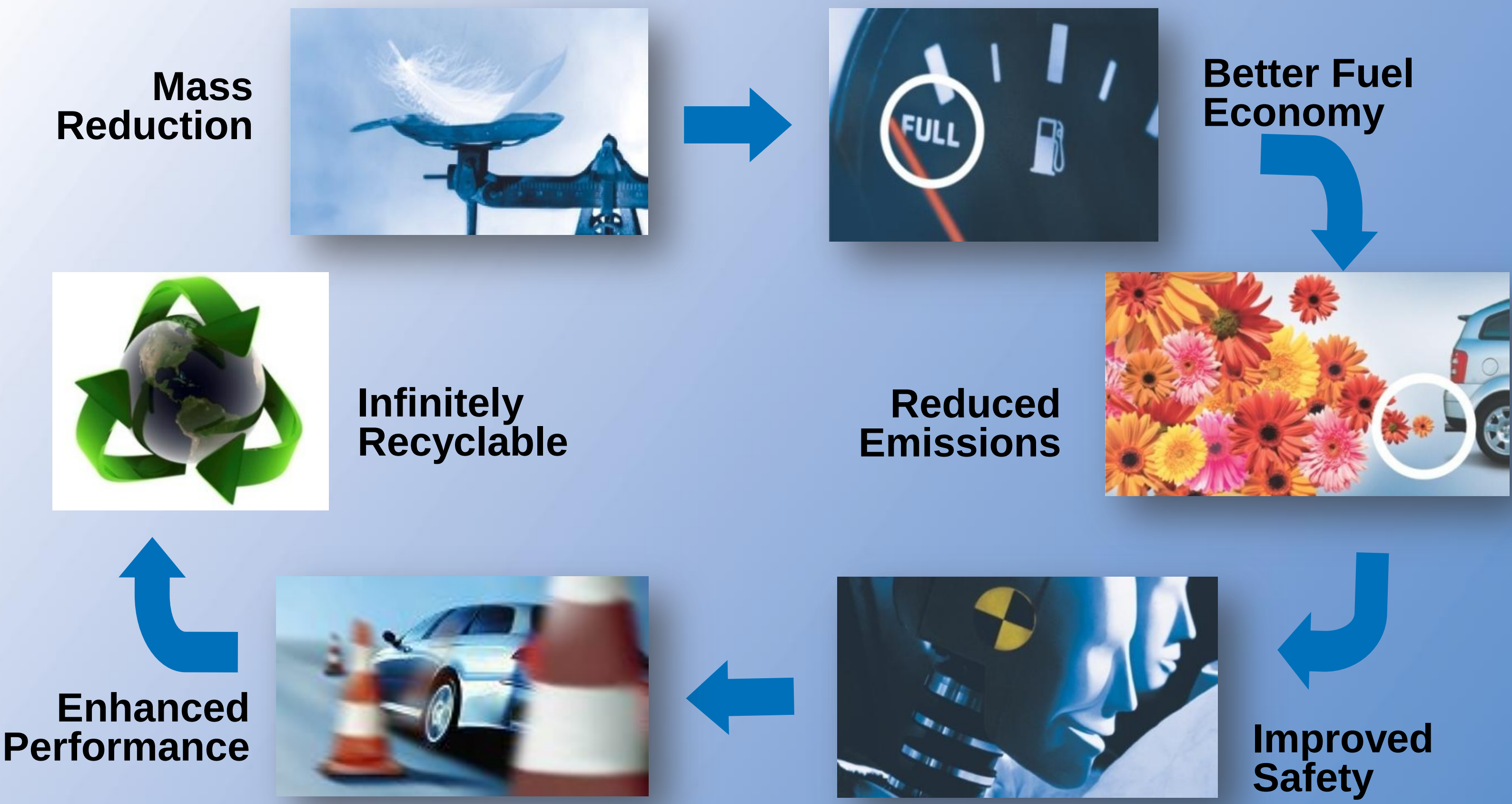
PEV (Al): 627 kg
[Regen = 15.6%]



PEV (PHEV) Study Findings

- **Regenerative Braking**
  - Recycles 15 – 20% of FTP75 drive cycle energy
  - Impact (%) essentially independent of vehicles mass

Automotive Aluminum Life Cycle

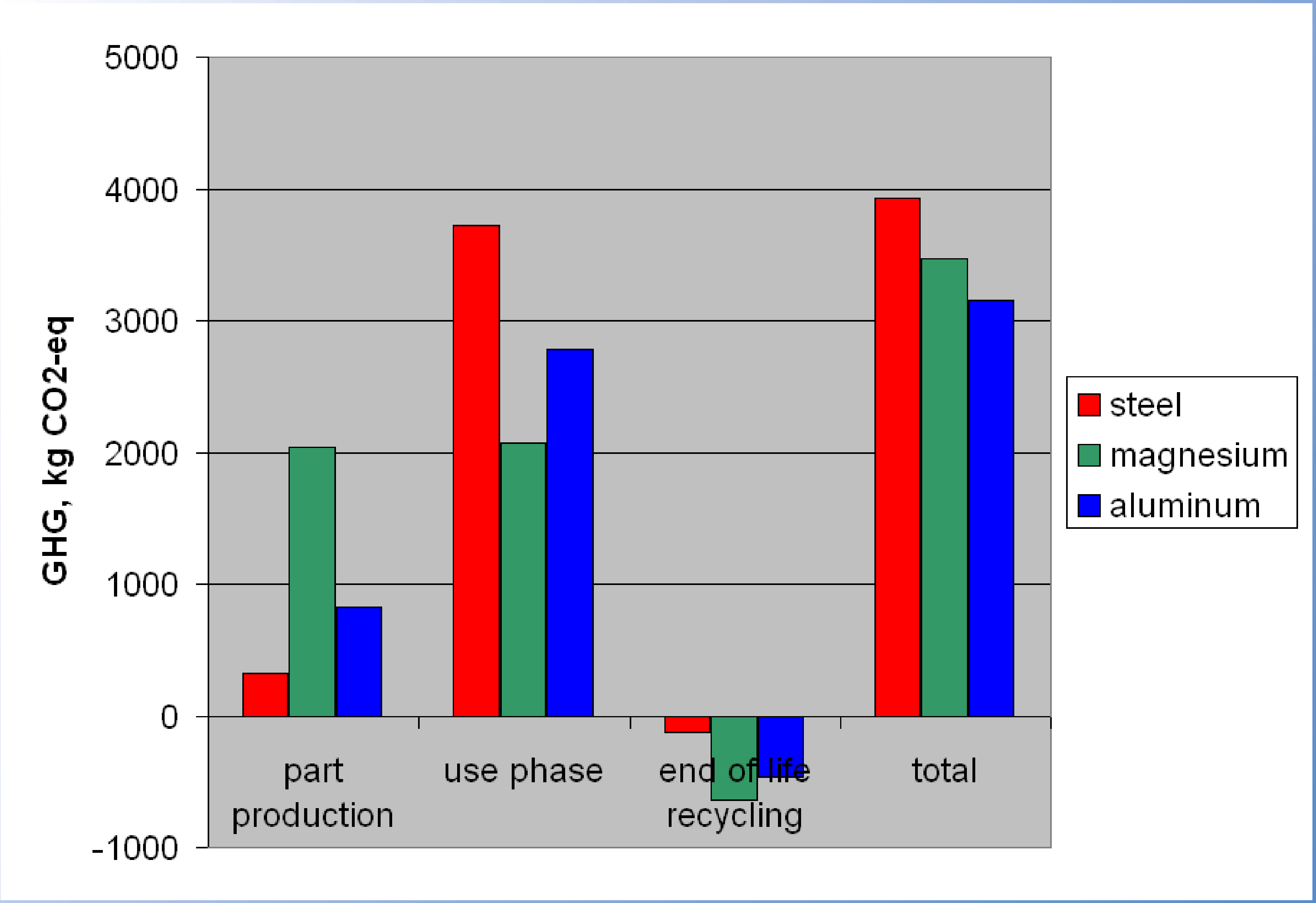


Comparative Life Cycle Assessment

- **Life cycle analysis (LCA) study conducted by the "Magnesium Front End Research and Development"**
  - Sponsorship: Canada, China and U.S.
  - Environmental performance of:
    - 2007 Cadillac CTS front end – **steel** design
    - new **magnesium** and **aluminum** designs
- **Environmental impacts**
  - Total energy
  - Greenhouse gases emissions
  - Air pollutants

Source: SAE 2010-01-0275, Magnesium Front End Research and Development Project

Less Life Cycle Emissions

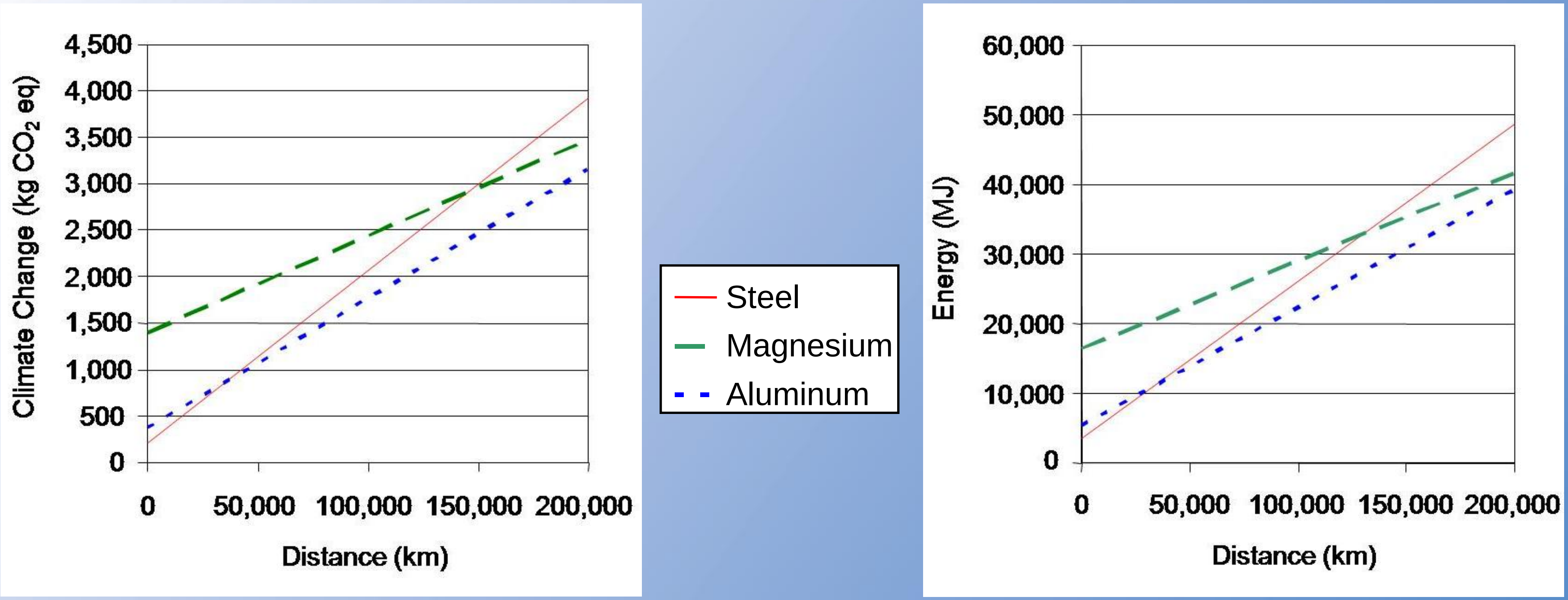


Source: Magnesium Front End Research and Development Project

Emissions Over Vehicle Lifetime

Lifetime Emissions Output

Lifetime Energy Consumed



Source: Magnesium Front End Research and Development Project

Life Cycle Study

- Use Phase dominates Life Cycle (Energy / Emissions)
  - Weight reduction
- Energy Consumption / Emissions
  - Magnesium 15% savings
  - Aluminum 20% savings
- Aluminum – "Best lifetime performance for overall energy use and greenhouse gas emissions"

To purchase a full copy of the study (SAE 2010-01-0275), visit the World Congress Technical Papers Store on the SAE website at: www.sae.org

For additional life cycle data on aluminum in transport go the Aluminum Automotive Industry website http://transport.world-aluminium.org/facts/life-cycle-data/

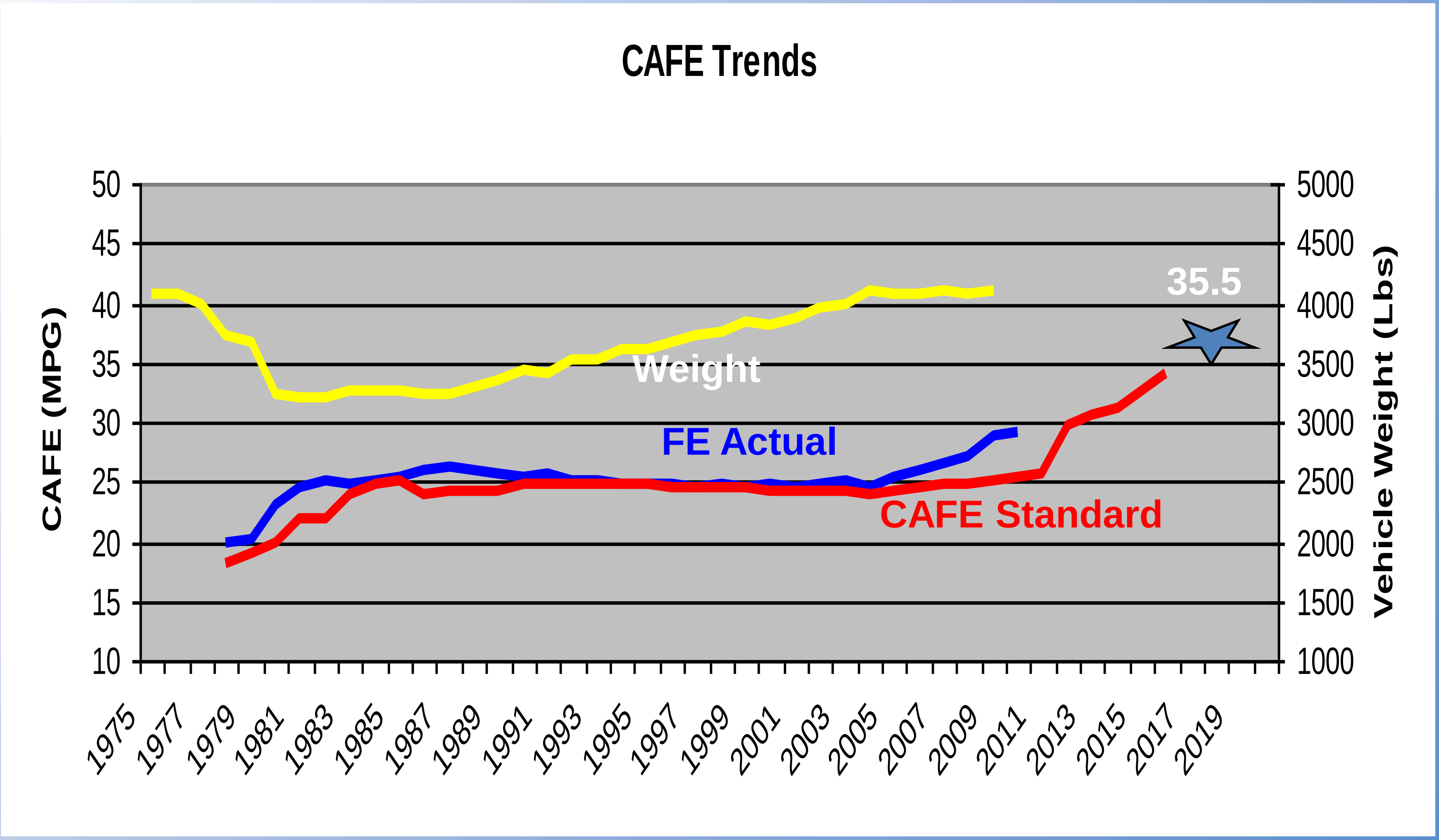
Automotive Aluminum Forecast

The Value Proposition

Auto Fuel Economy Objectives 2010-2020

- Achieve reasonable return on investment
- **CAFE: +10 MPG (+40%)**
- Continuous Improvement
  - Vehicle utility – size, range, performance
  - Safety
  - Reliability
  - Customer satisfaction
  - **Affordability**
  - Emissions
- Constraints
  - Engineering resources
  - Product life cycle (8 – 10 years)
  - Manufacturing resources
  - Investment capital

Fuel Economy History



FE Technology Assessment (2010)

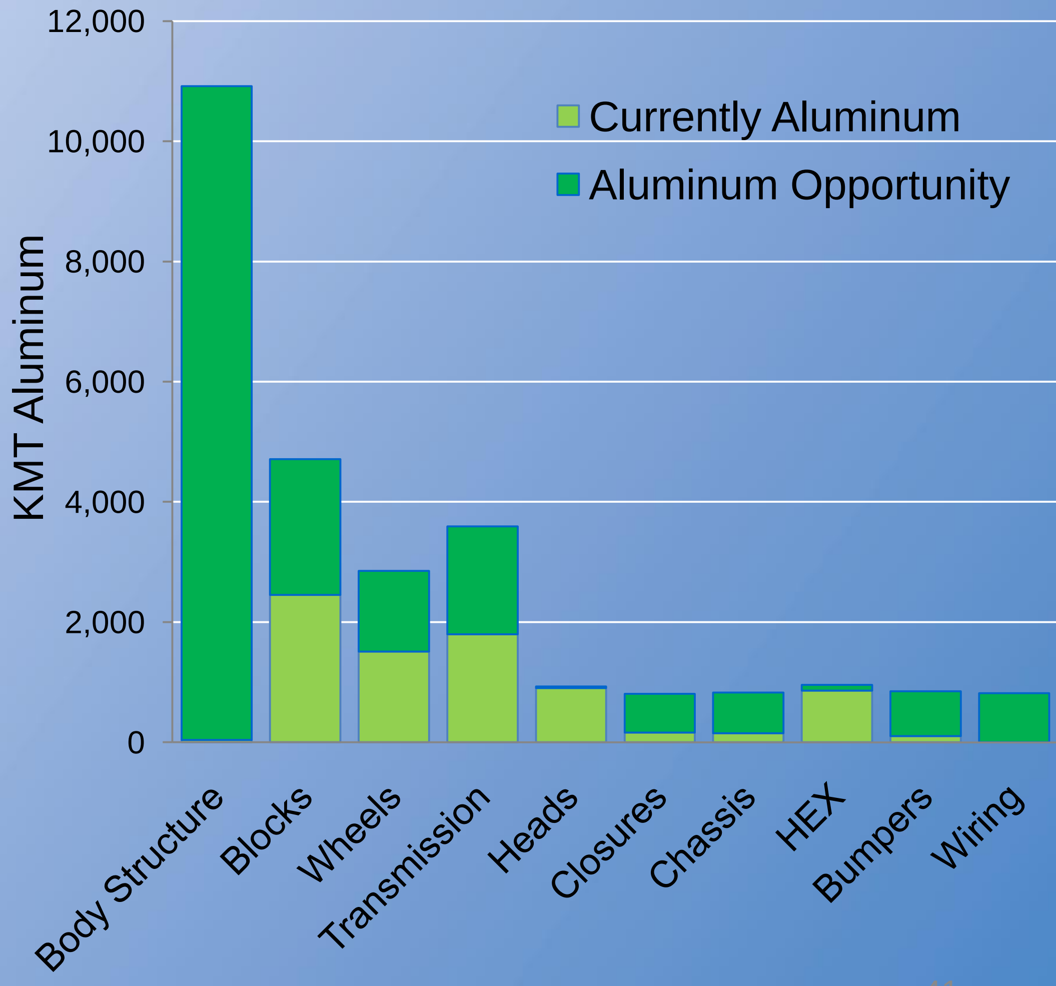
(National Academy of Science - July 2010)

Technology	FE Imp.	Cost ($/ Veh.)	$ / % FE Imp.
Engine			
Conv. Eng Improvements	7 %	$ 700	$ 100
Conv. Downsize, Turbo	5 %	$ 650 - 950	$ 160
Diesel Engine	25 %	$ 3,000 - 4,500	$ 170
Gas Electric Hybrid	35 %	$ 4,500 – 6,500	$ 160
Electric Hybrid (Plug-in)	???	$13,000 – 23,000	
Electric	???	NA	
Fuel Cell	NA	NA	
Vehicle			
Weight reduction (10%)	7 %	* $ 800-1,600	$ 170
Aero	2 %	$ 70	$ 50
Brakes	1 %	---	
Tires	2 %	$ 50	$ 25
Transmission	3 %	$ 30	$ 10
Accessories	2 %	$ 100	$ 50

* Cost estimate does not include savings from secondary component weight optimization

Body Holds the Largest Weight Reduction Opportunity

- Shift to aluminum saves 550 lbs direct and secondary weight
- 10% better fuel economy
- No compromise to safety
- No downsizing required
- Better performance
- Lower lifetime CO_2



Weight Reduction Potential with Aluminum

MID-SIZE CAR EXAMPLE

	Al Weight	Wt. Reduction	Cost Impact
BIW	320 Lbs	280 Lbs	$ 455
Closures	115 Lbs	70 Lbs	$ 150
Structures	45 Lbs	50 Lbs	$ 160
Total (Direct)	480 Lbs	380 Lbs	$ 765
Optimization (In-direct)	(50 Lbs)	170 Lbs	($ 665)
Net	430 Lbs	550 Lbs	$ 100

Multi material body:

AL Sheet	330 Lbs
Al Extrusion	60
Al Castings	30
Steel Sheet	50
HSLA Sheet	10

$ 0.18 Per Lb Weight Reduction

15% Weight Reduction

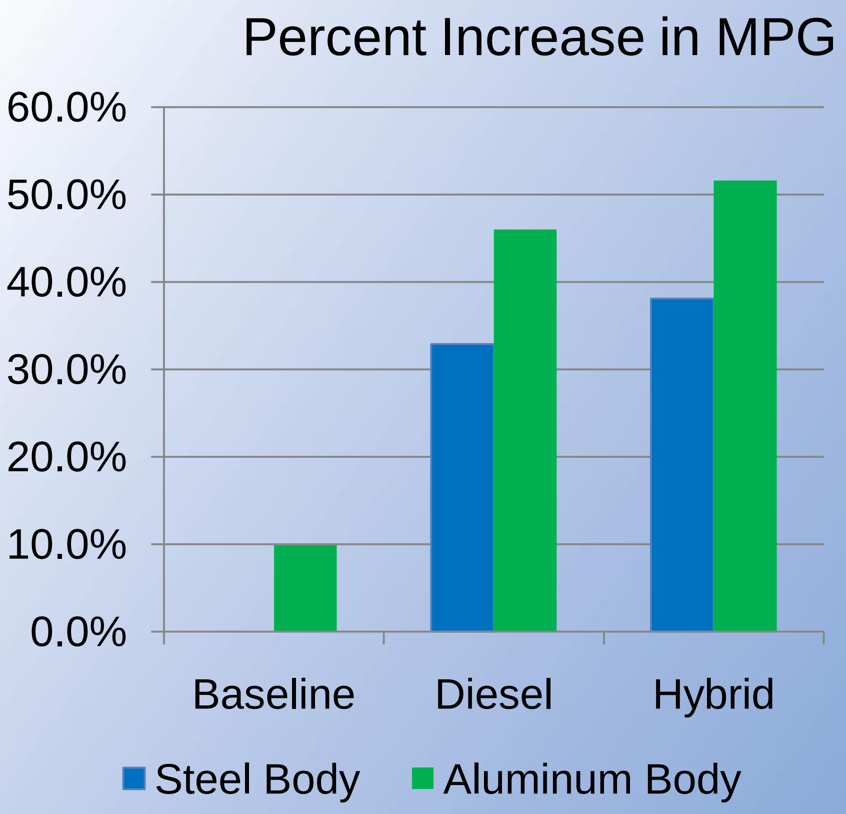
Cost Estimates Related to Mass

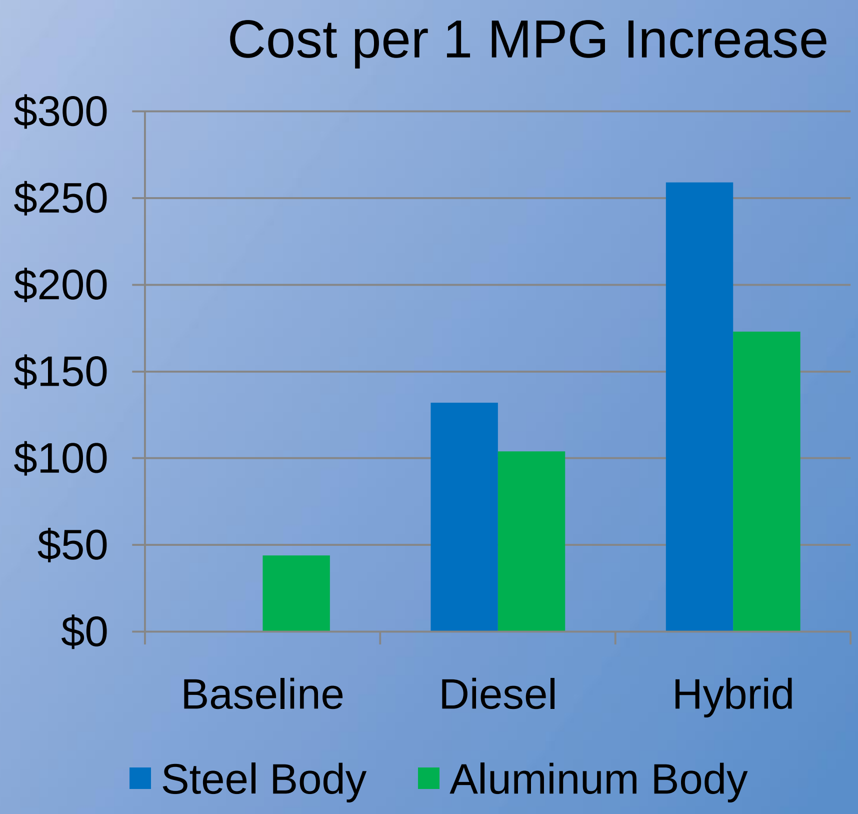
NHTSA

- NAS report - $1.50 per pound
- Sierra Research - $1.01 per pound (w/secondary)
- MIT - $1.36 per pound

Applying an ICM factor of 1.11 (low complexity technology), results in a compliance cost of $1.48 per pound. Based on current assumptions and recent studies, we've found costs ranging far below that average.

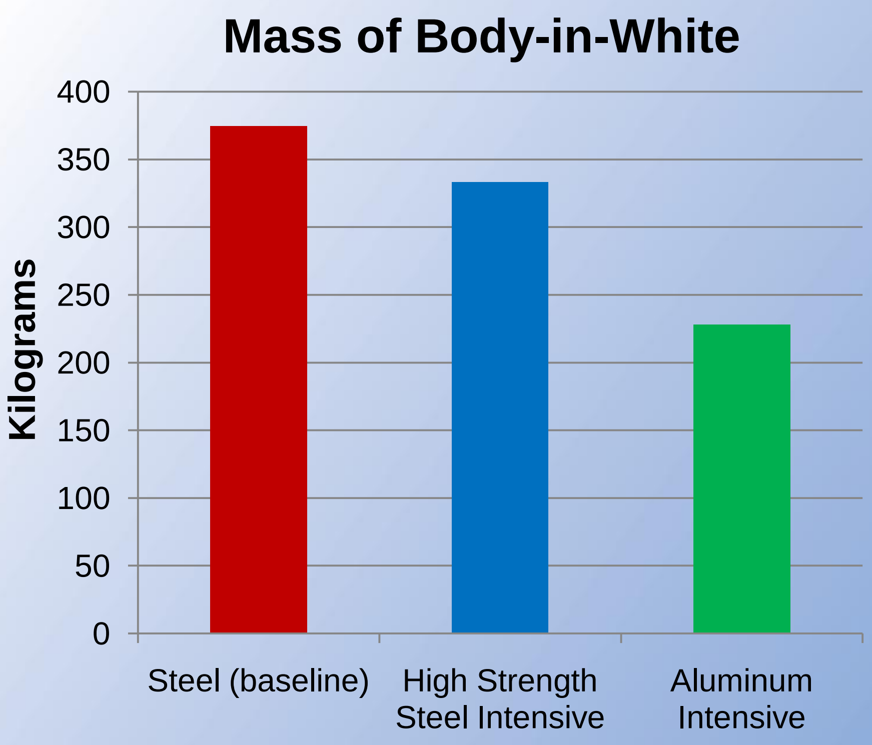
Down Weighting Creates Value for Alternative Powertrains



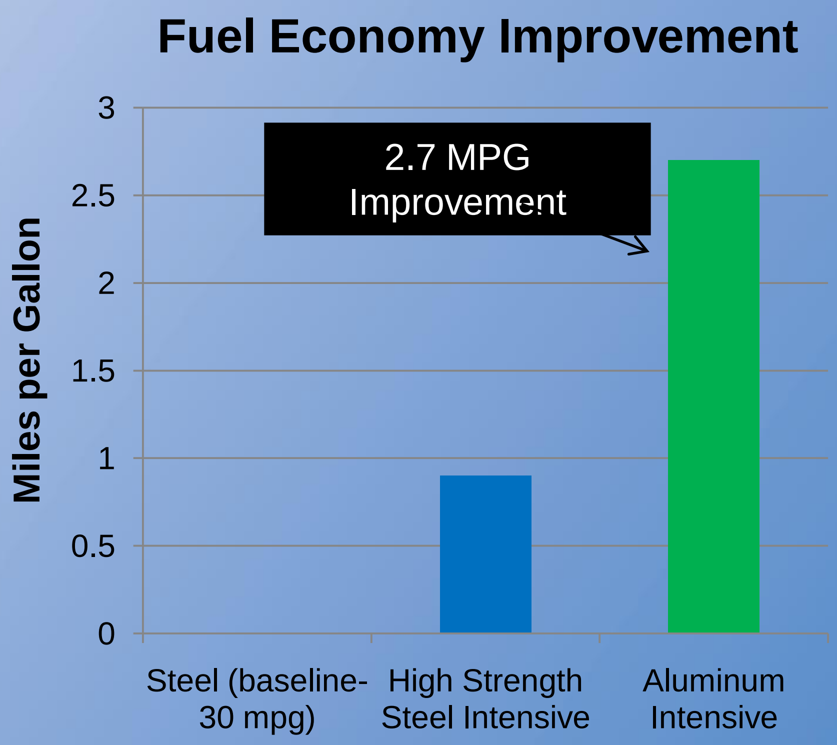


Source: IBIS Associates

Weight Savings Translate to Fuel Economy Improvement



Source: *ika - University of Aachen and the European Aluminium Association (EAA)*



Source: *Aluminum Association calculated based on ika mass reduction data; assumes 23% secondary weight savings*

40% (10 MPG) Fuel Economy Improvement by 2020

- No single dominant technology
- Aggressive application: <u>most know practical technologies</u>
- Technology estimate: <u>(% Improvement)</u>
  - Engine (Conventional, diesel, hybrid) 50 % (5 MPG)
  - Vehicle (Tires, Aero, Transmission, …) 25 % (2.5 MPG)
  - Weight (Aluminum, Magnesium, HSS) 25 % (2.5 MPG)
    - Vehicle downsizing 50 %
    - Component optimization 35 %
    - Full AIV (10+%) 15 %
- Aluminum 2020
  - 394 Lb Average (+60 Lbs) – realistic
    - sheet, extrusion, casting
    - <u>+1.0 MPG Fleet</u>

Automotive Weight Reduction Summary

- **One pound** of aluminum replaces **two pounds** of Fe /Steel
  - **Can allow additional indirect reduction up to 0.5 Lbs**
- **10%** vehicle weight reduction: **6.5%** fuel economy improvement
- Weight reduction **additive** to other fuel economy improvements
  - Including: Diesel, Hybrid, Electric, Aero, Tires, …
- Proven aluminum components can achieve **15% avg.** weight reduction
  - 10 % MPG improvement (2.7 MPG)
- Weight reduction with aluminum **cost competitive** with other fuel economy technologies