Challenges and Opportunities for Automotive Composites

Materials Technologies

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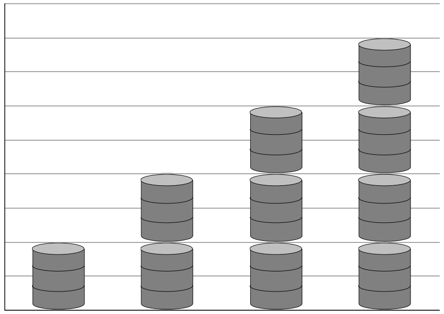
Outline

- The Automotive Lightweighting Imperative
- The Candidates (with emphases on composites)
- Thoughts on the Future

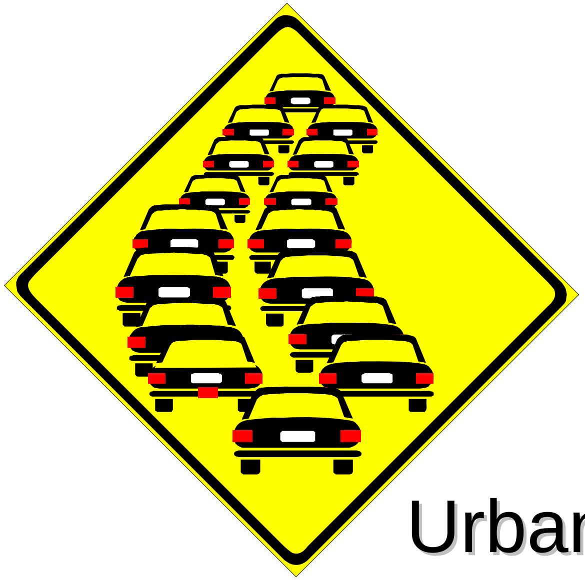
Bottom Line

- Despite the recent prices of fuel, the auto industry will not beat a path to the composites' door.
- Composites will have to earn a niche probably on bases of performance and safety.

The Challenges Facing Us…



Growing Petroleum Consumption

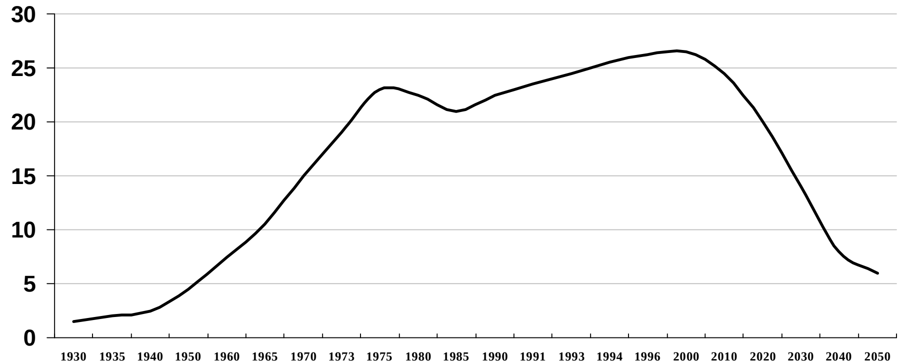


Urban Pollution

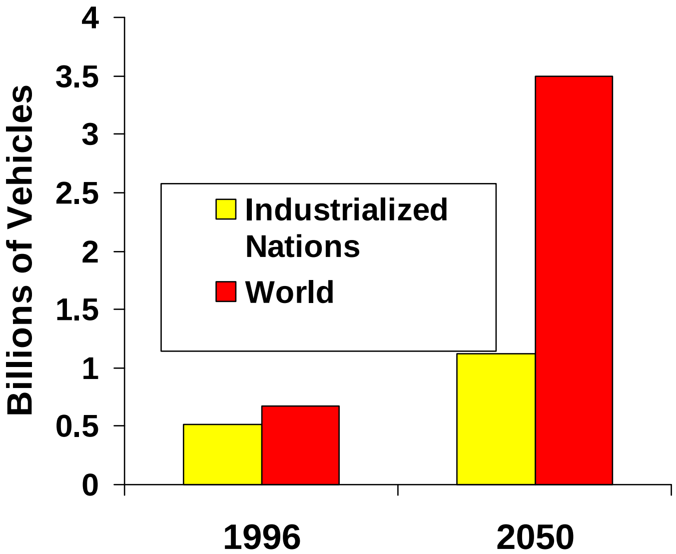
Global Climate Change

Can We Sustain Increasing Consumption?

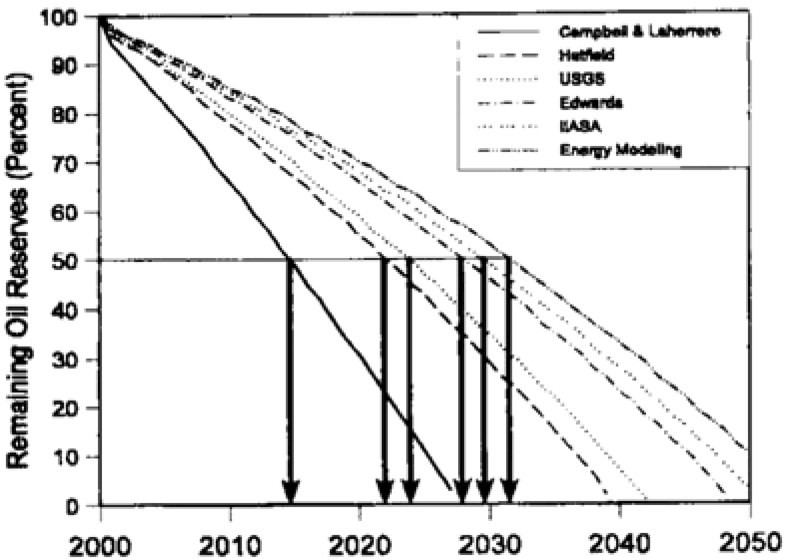
Annual World Oil Production (Billions of Barrels)



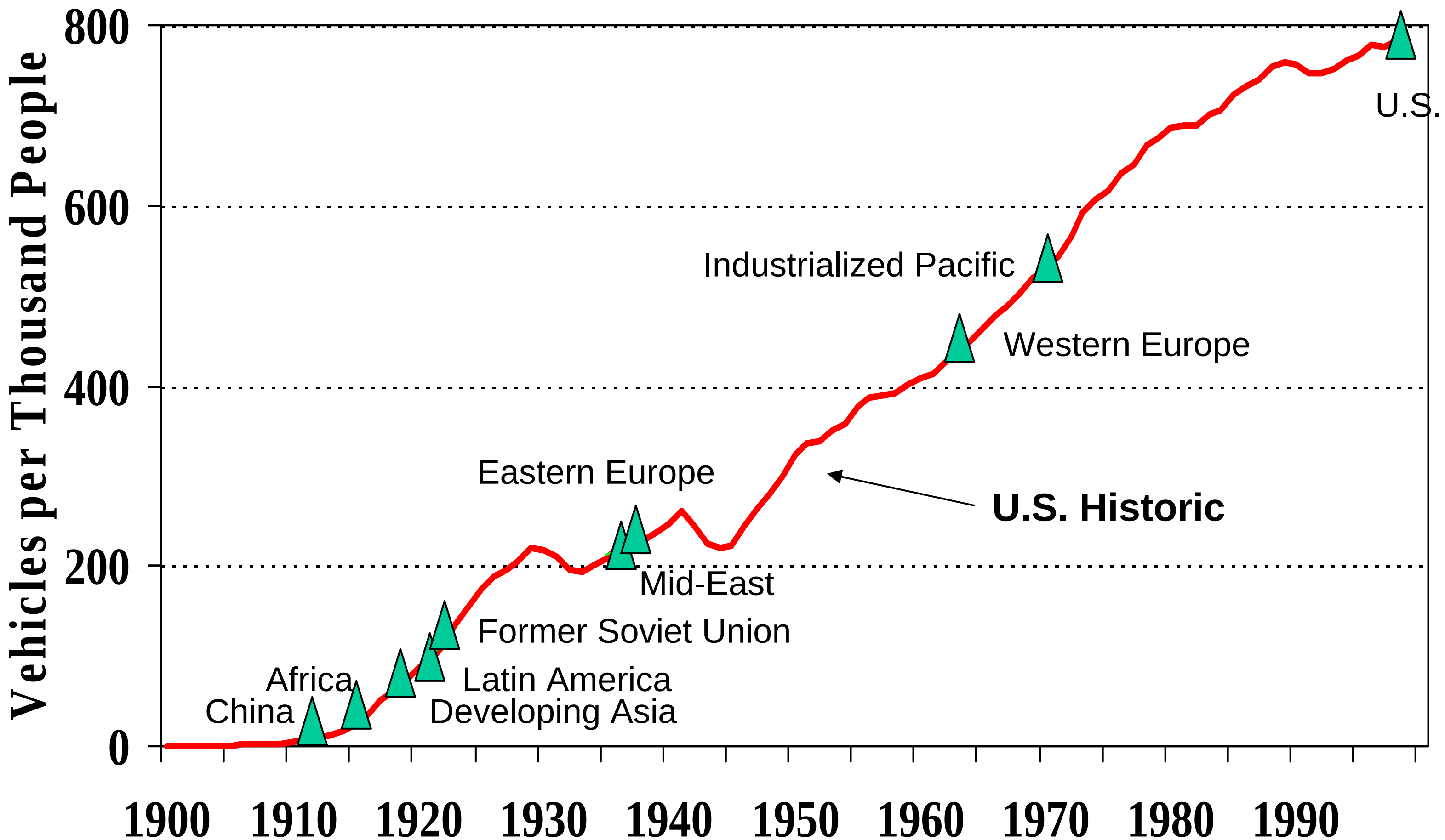
Projected Growth in Light-Duty Vehicle Registrations



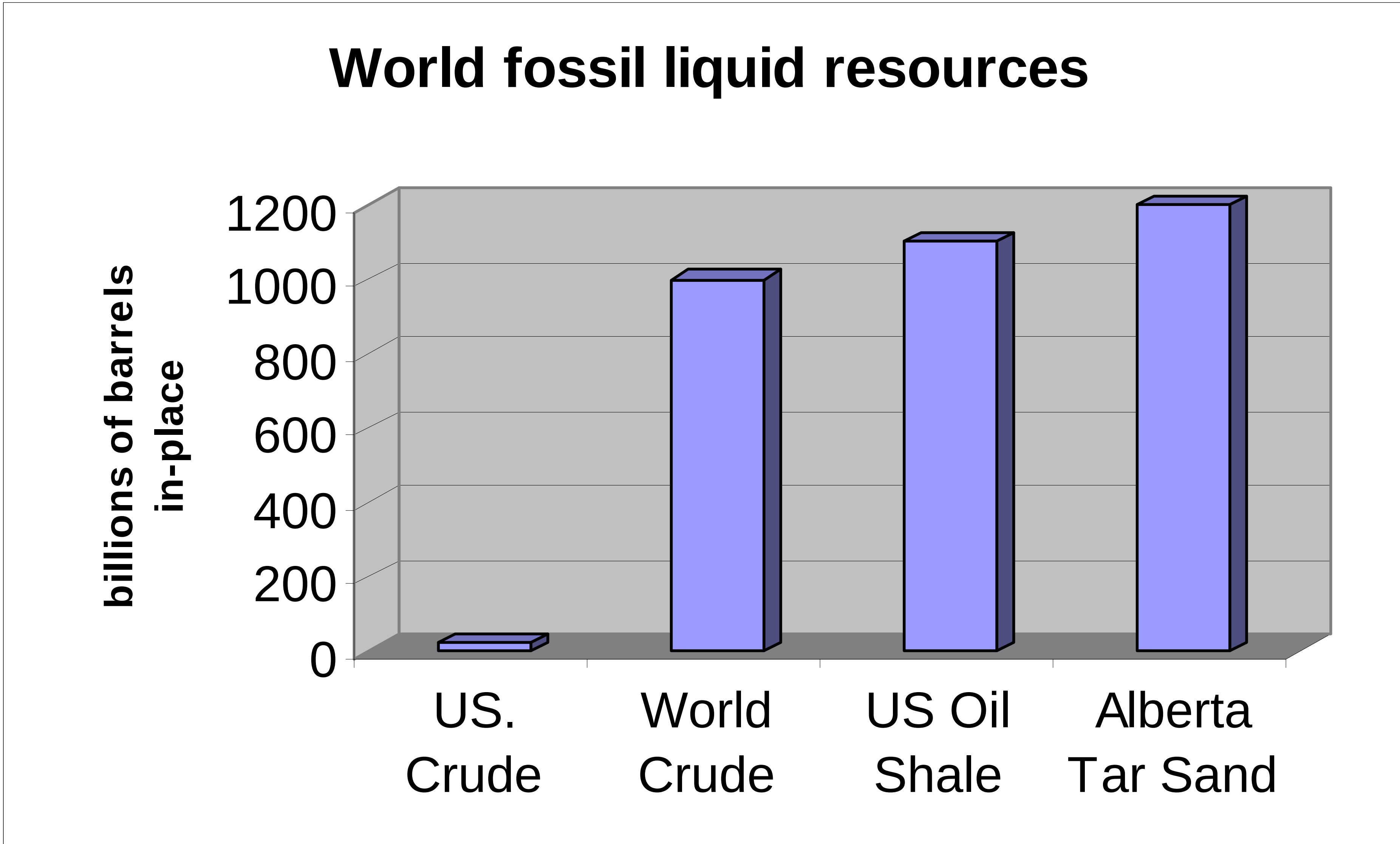
Estimates of Remaining Oil Reserves



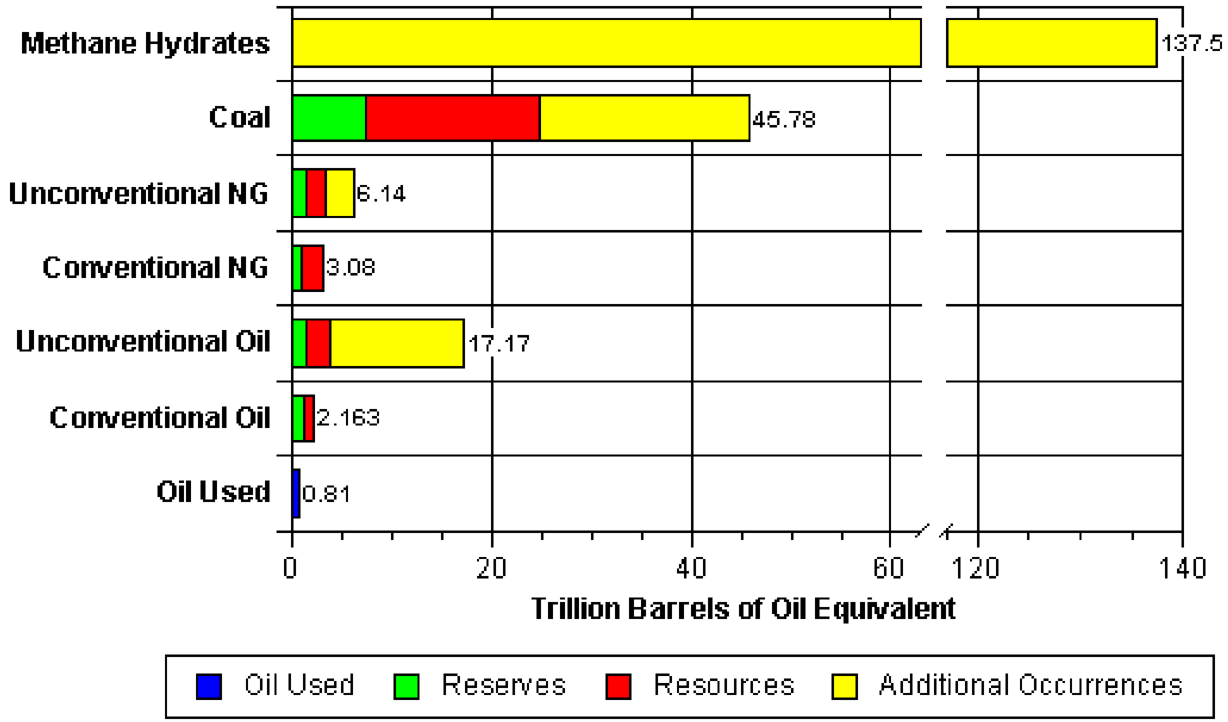
Global Growth in Transportation Is Accelerating the Demand for Oil



China, with 13 vehicles per 1000 people, is where the U.S. was in 1913


World fossil liquid resources
billions of barrels in-place
1200
1000
800
600
400
200
0
US. Crude
World Crude
US Oil Shale
Alberta Tar Sand

World Fossil Fuel Potential



Source: H. H. Rogner, "An Assessment of World Hydrocarbon Resources," Annual Review of Energy and Environment, 1997.

Renewable Resources are Adequate to Meet all Energy Needs

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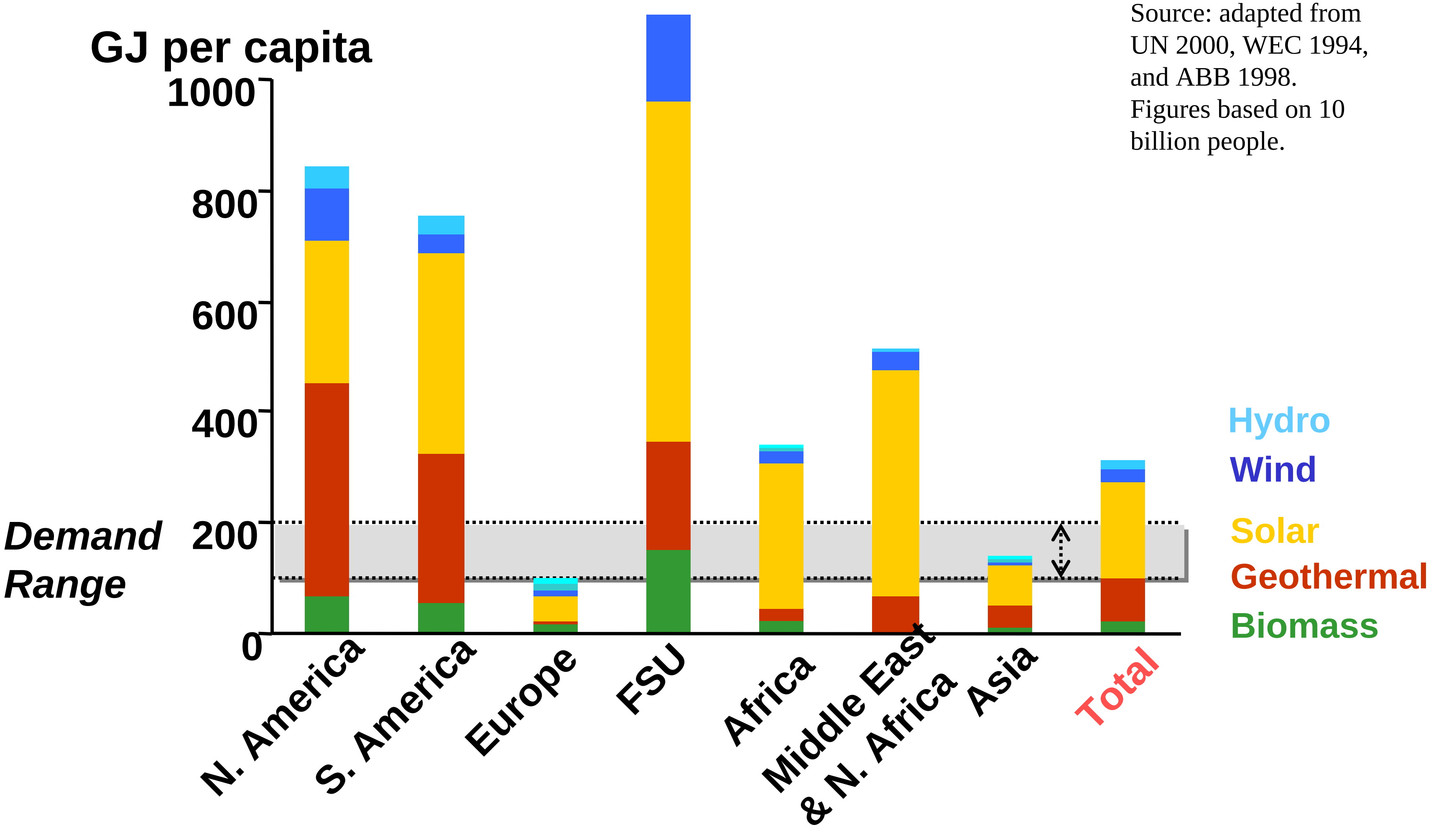
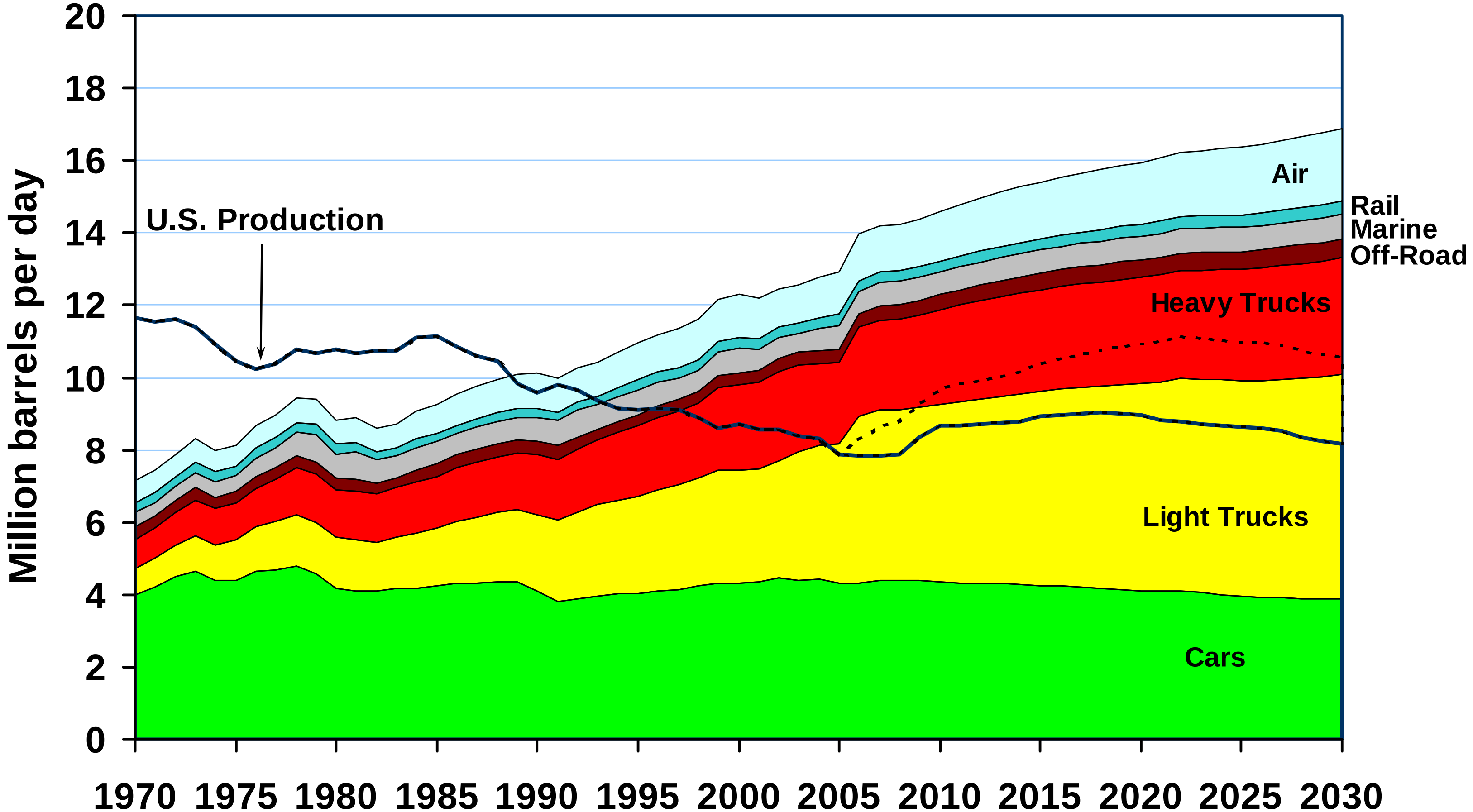
Source: adapted from UN 2000, WEC 1994, and ABB 1998. Figures based on 10 billion people.



U.S. Petroleum Production and Consumption, 1970-2030



Sources: *Transportation Energy Data Book: Edition 26* and projections from the *Annual Energy Outlook 2008*.

Notes:

• The U.S. Production has two lines after 2005. The solid line is conventional sources of petroleum. The dashed line adds in other inputs -- ethanol and liquids from coal. Historical petroleum production includes crude oil, natural gas plant liquids, refinery gains, and other inputs, which include liquids from gas, liquids from coal, and alcohols, ethers, petroleum product stock withdrawals, domestic sources of blending components, other hydrocarbons, and natural gas converted to liquid fuel.

•The sharp increase in values between 2005 and 2006 are the result of the data change from historical to projected values.

HISTORY

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- 1970 (to present) – In response to environmental movements of the 1960's, the Clean Air Acts established standards for criteria emissions (carbon monoxide, hydrocarbons, nitrogen and sulfur oxides, and particulates) from transportation vehicles and other sources.
- 1975 to 1986 - Energy Policy and Conservation Act of 1975 established Corporate Average Fuel Economy (CAFÉ) standards for light-duty vehicles. Raised in 2007 (2016 target).
- 1993-2002 – The Partnership for a New Generation of Vehicles (PNGV) between eight US government agencies and "Big Three" automakers, indicated that high-fuel efficiency (33 km/l) family autos are probably technically viable at a slight cost premium (15%?) through use of alternate power plants (mainly diesel-electric hybrids), advanced design and lightweighting, probably spurred automotive technology worldwide, and provided model for government-industry cooperation.

HISTORY - continued

- 2002 -- PNGV transitioned by President Bush to FreedomCAR with more emphases on fuel-cell vehicles, all varieties of light-duty vehicles ("CAR" stands for Cooperative Automotive Research, not "car") and limited to USCAR and DOE.

  -- Twenty-First Century Truck (21CT) Initiative also formed aimed at heavy-duty vehicles.

- 2002-2008 – President Bush rejects Kyoto Treaty on economic bases but pledges large R&D efforts to provide technological solutions to climate change (e.g., *U.S. Climate Change Strategy*, 2/14/07; G-8 announcement, 5/31/07; speech, 4/16/08).

- 2003 – FreedomCAR expanded to include the Hydrogen Fuels Initiative, becomes FreedomCAR and Fuels Initiative, to **explore** technologies for producing and delivering hydrogen for transportation and other uses (the "hydrogen economy"). Energy-supply industry joins. International Partnership for the Hydrogen Economy formed.

Key Drivers and Technology Enablers

Externalities

Product

Annual Model Change
Design Is King

"Safety" Focus

"Oil Shock"

"Hyper" Global Competition

"Personalized Design and Performance" Customer Experience

Fuel Economy Drives Weight Reduction
Lightweight Material Use Intensifies

1950 — 1960 — 1970 — 1980 — 1990 — 2000

~300,000 Units/Models

Increasing Automation

50,000-100,000 Units/Models

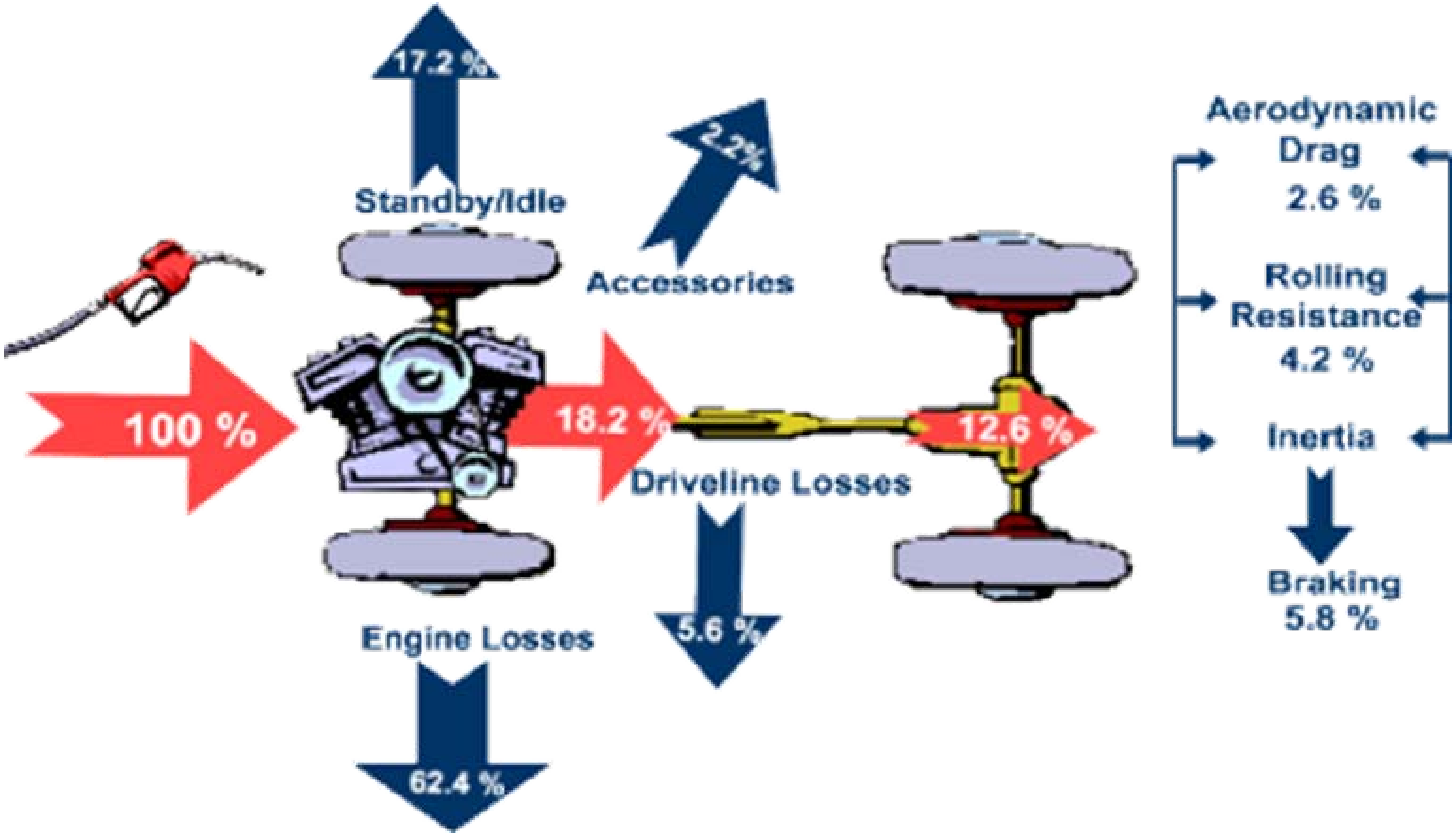
Plant

Robots

Lean Mfg.

CAD
CAM
CAE

Technology Enablers



Source: http://www.fueleconomy.gov

Effects of Automotive Lightweighting

- 6-8% (with mass compounding) increase in fuel economy for every 10% drop in weight, everything else the same

or

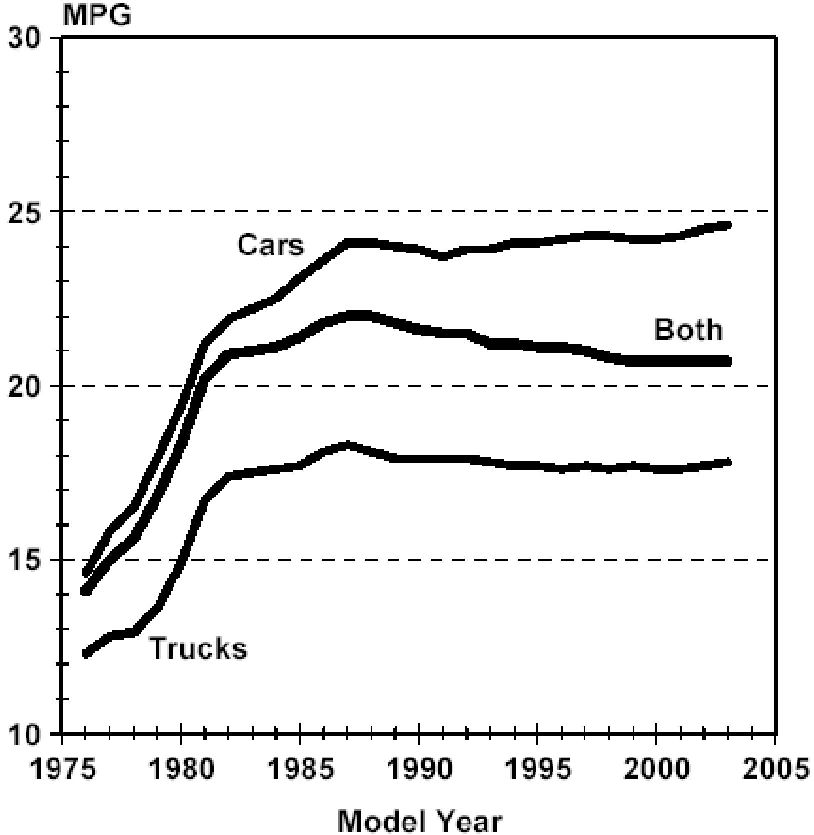
- Offset the increased weight and cost per unit of power of alternative powertrains (hybrids, fuel cells) with respect to conventional powertrains (*Alice in Wonderland* syndrome)

Drivers for Lightweighting

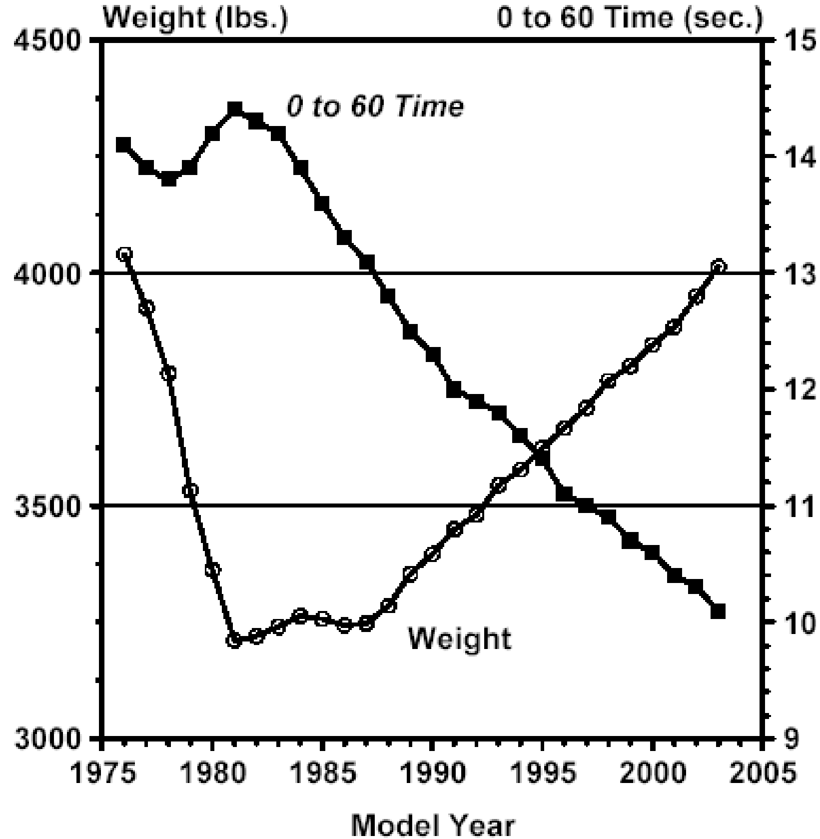
- Performance
- Increasing "customer value" while staying within Corporate Average Fuel Economy (CAFÉ) limits (offset)
- Potential of **<u>sustained</u>**, high (?) prices of fuel.
- The hybrids and hydrogen-fueled fuel-cell vehicles.

Light-Duty Vehicle Trends

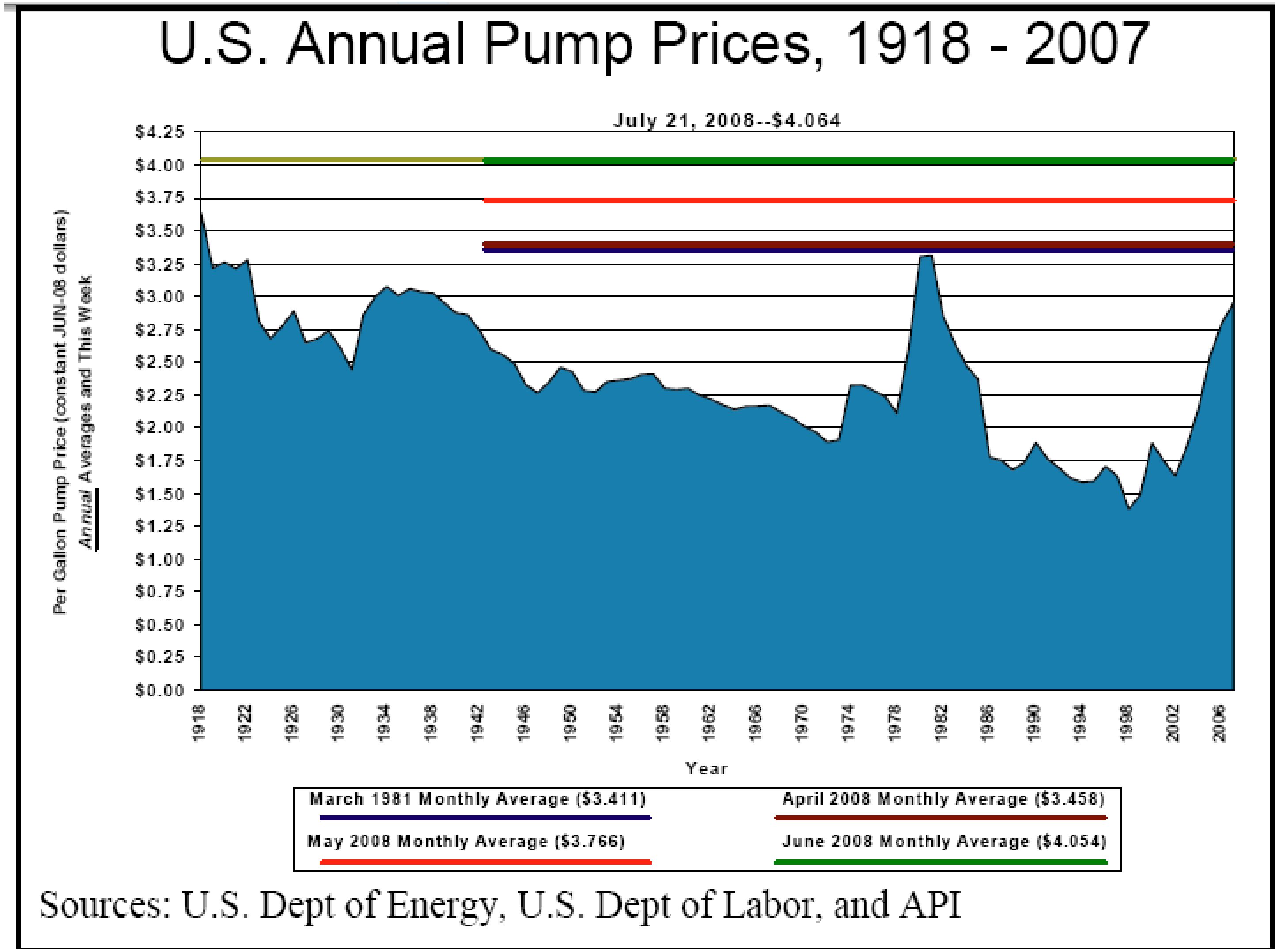
Adjusted Fuel Economy by Model Year
(Three-Year Moving Average)



Weight and Performance by Model Year
(Three Year Moving Average)



Source: *Light Duty Automotive Technology and Fuel Economy Trends: 1975 through 2004*, U.S. Environmental Protection Agency, April 2004.



Source: Retrieved from the American Petroleum Institute web site on July 29, 2008
http://www.api.org/aboutoilgas/gasoline/upload/PumpPriceUpdate.pdf

Oil and Substitute Costs

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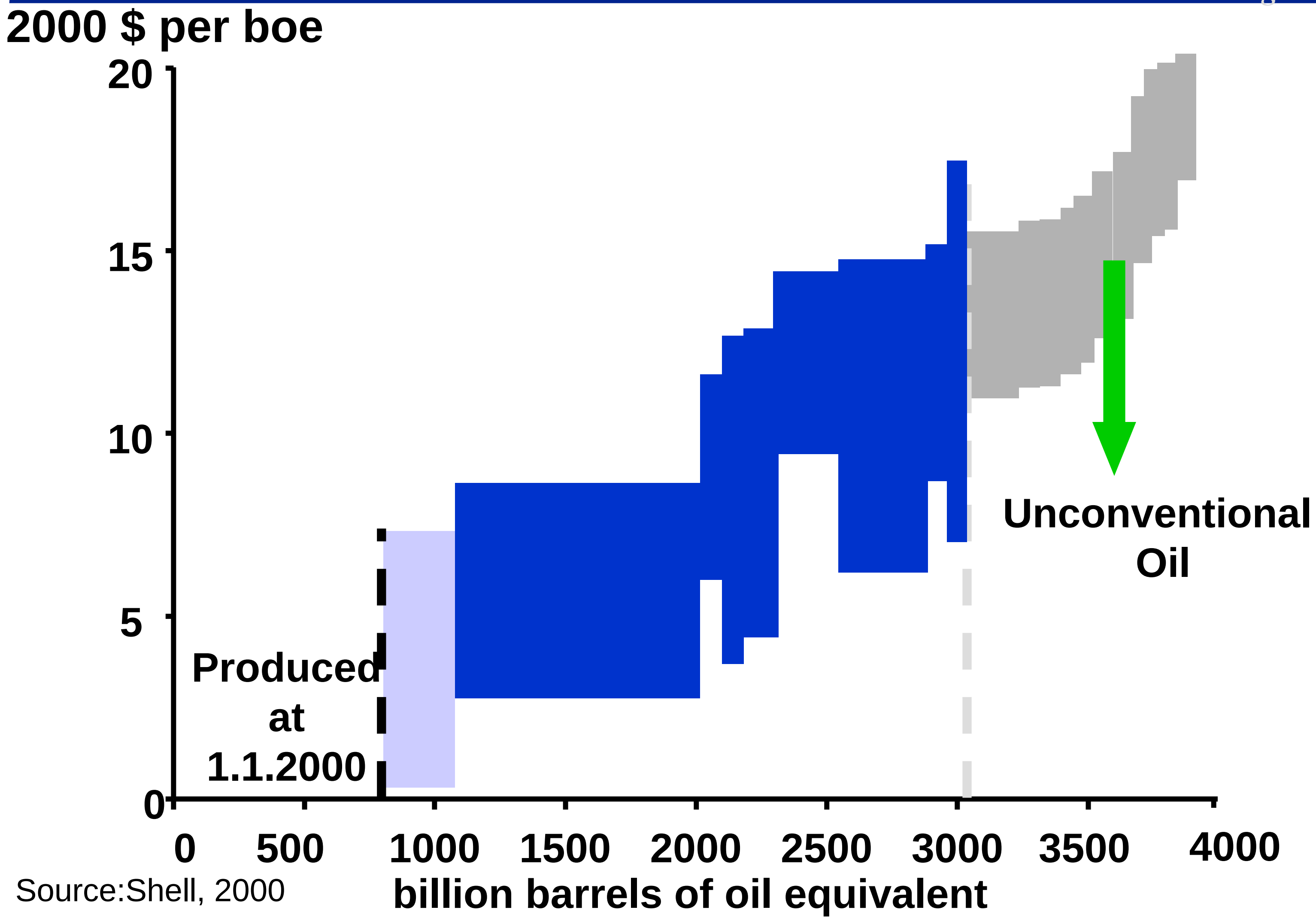
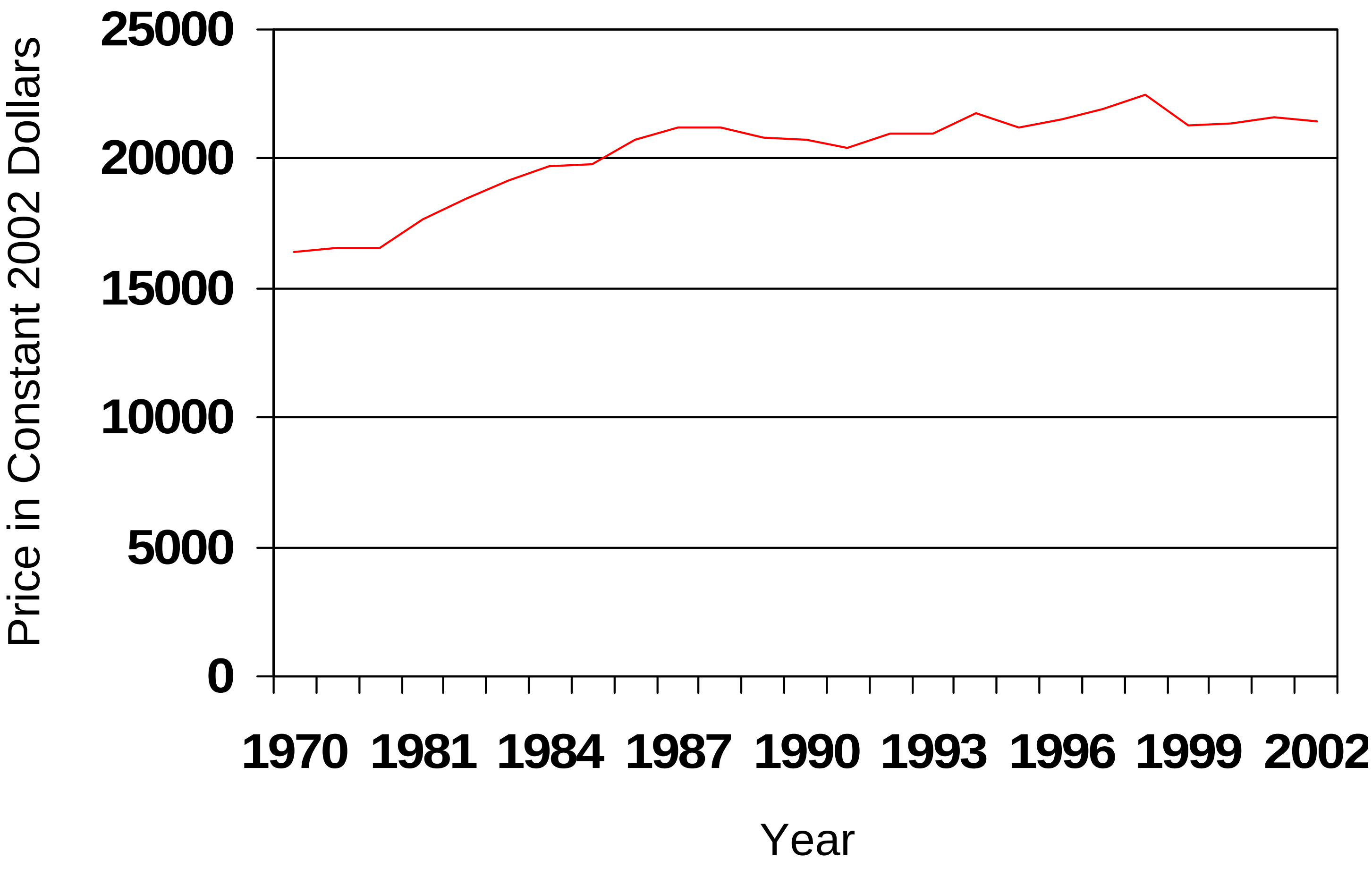


Source:Shell, 2000

Average Price of a New Car, 1970-2002



Barriers to Lightweighting

- Historically low prices of fuel.
- Higher costs of lightweighting materials.
- Lack of familiarity with them.
- Sunk capital in metal-forming technologies.
- Lack of large automotive composites and magnesium industries
- Preferences for large vehicles.
- Perceptions of safety.
- Recycling (plastics).
- Alternative fuels such as non-conventional petroleum, biofuels and electricity.
- Alternative propulsion systems such as hybrids and fuel cells.

Challenge

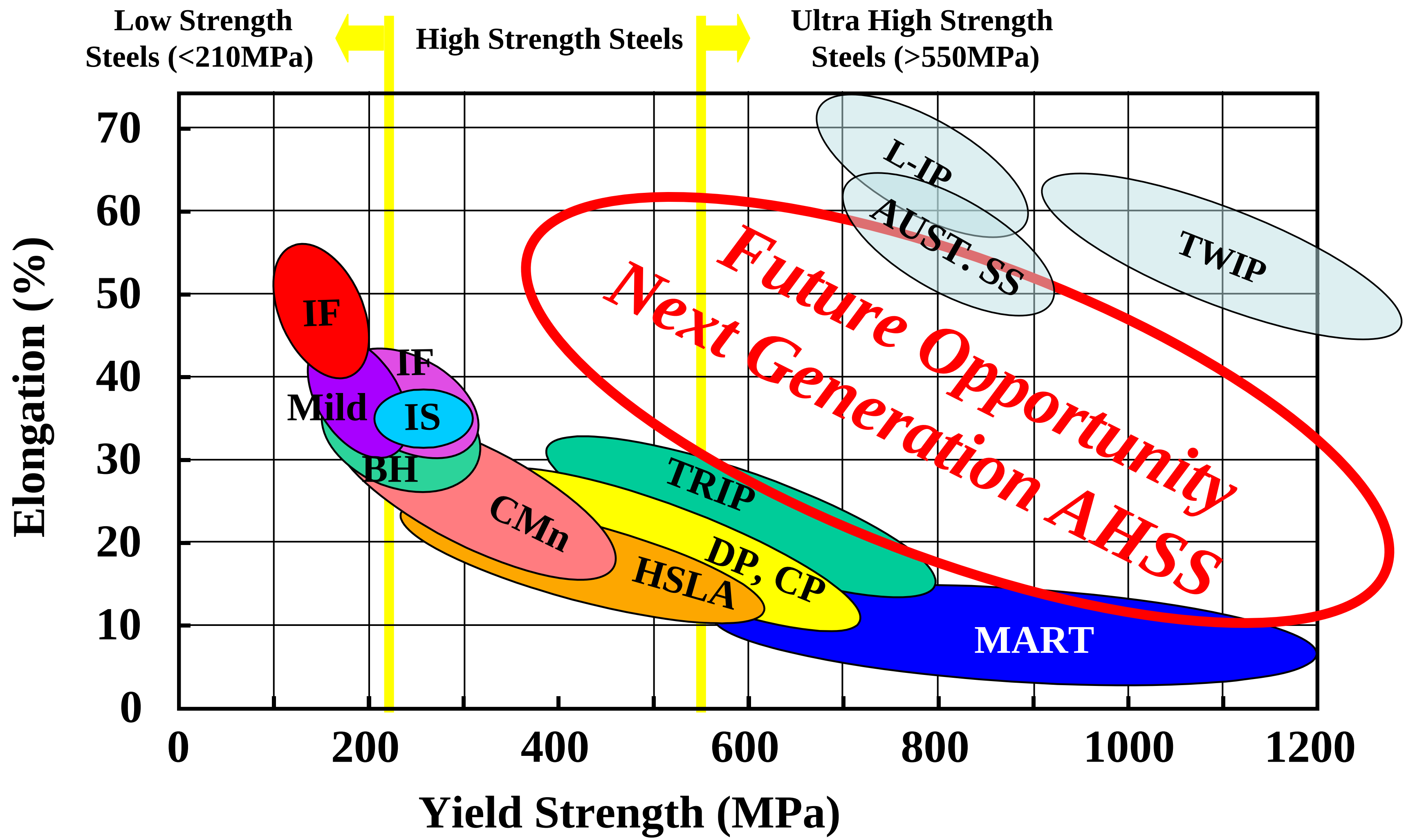
- “Steel is for cars, aluminum is for airplanes, and plastics are for toys”
  - – Francois Castaing, Chief Engineer, Chrysler Corporation, 1995

Weight Savings and Costs for Automotive Lightweighting Materials

Lightweight Material	*Material Replaced*	*Mass Reduction (%)*	*Relative Cost (per part)**
High Strength Steel	Mild Steel	10 (25?)	1 (<?)
Aluminum (AI)	Steel, Cast Iron	40 - 60	1.3 - 2
Magnesium	Steel or Cast Iron	60 - 75	1.5 - 2.5
Magnesium	Aluminum	25 - 35	1 - 1.5
Glass FRP Composites	Steel	25 - 35	1 - 1.5
Carbon FRP Composites	Steel	50 - 60	2 - 10+
Al Matrix Composites	Steel or Cast Iron	50 - 65	1.5 - 3+
Titanium	Alloy Steel	40 - 55	1.5 - 10+
Stainless Steel	Carbon Steel	20 - 45	1.2 - 1.7

•***Includes both materials and manufacturing.***

Ref: *William F. Powers, Advanced Materials and Processes, May 2000, pages 38 – 41.*



Low Strength Steels (<210MPa)
High Strength Steels
Ultra High Strength Steels (>550MPa)
Elongation (%)
Yield Strength (MPa)
0
10
20
30
40
50
60
70
0
200
400
600
800
1000
1200
IF
IF
Mild
IS
BH
CMn
HSLA
TRIP
DP, CP
MART
L-IP
AUST. SS
TWIP
Future Opportunity
Next Generation AHSS

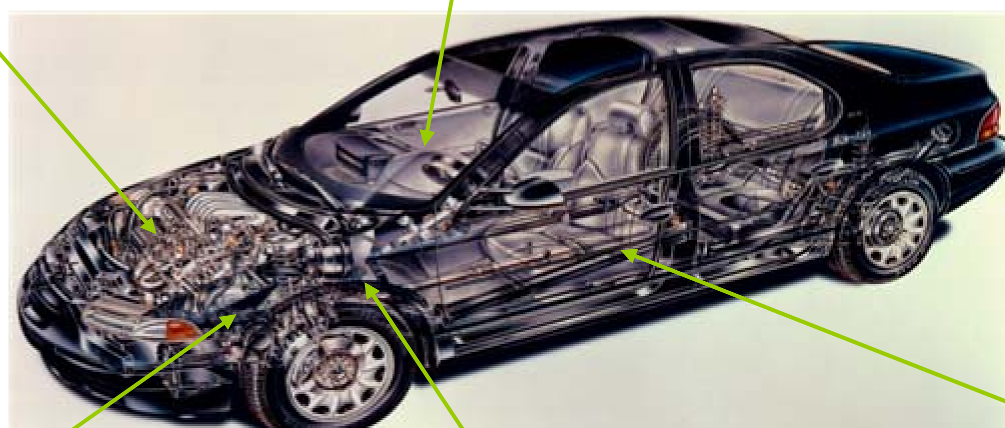
Automotive Aluminum Applications and Product Forms

Aluminum Powertrain Castings

•A319, A356, A380

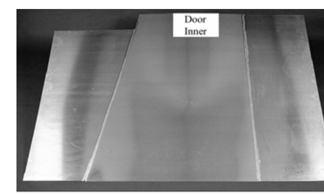
Aluminum Condenser and Radiators

•AA1200, AA3005

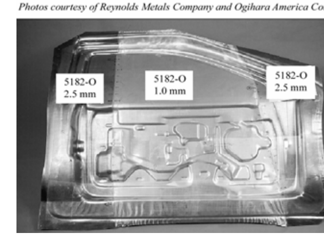


Aluminum Closures and Inner Body parts

•AA5052, 5454, 5754



Photos courtesy of Reynolds Metals Company and Ogihara America Corp.



35% weight reduction / reduction in part count

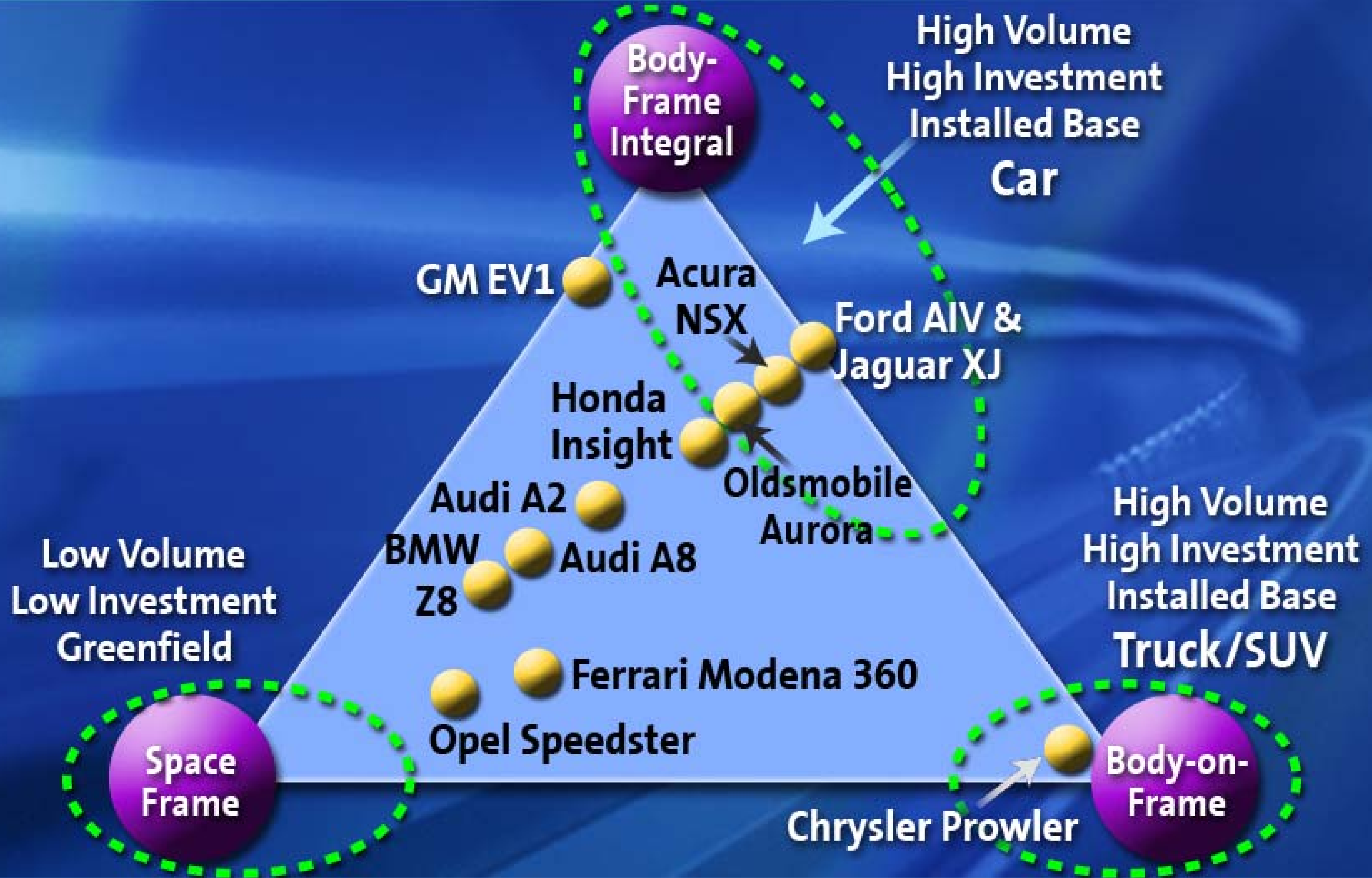
Aluminum Outer Body Panels and Closures

•AA 6009, 6111, 6022

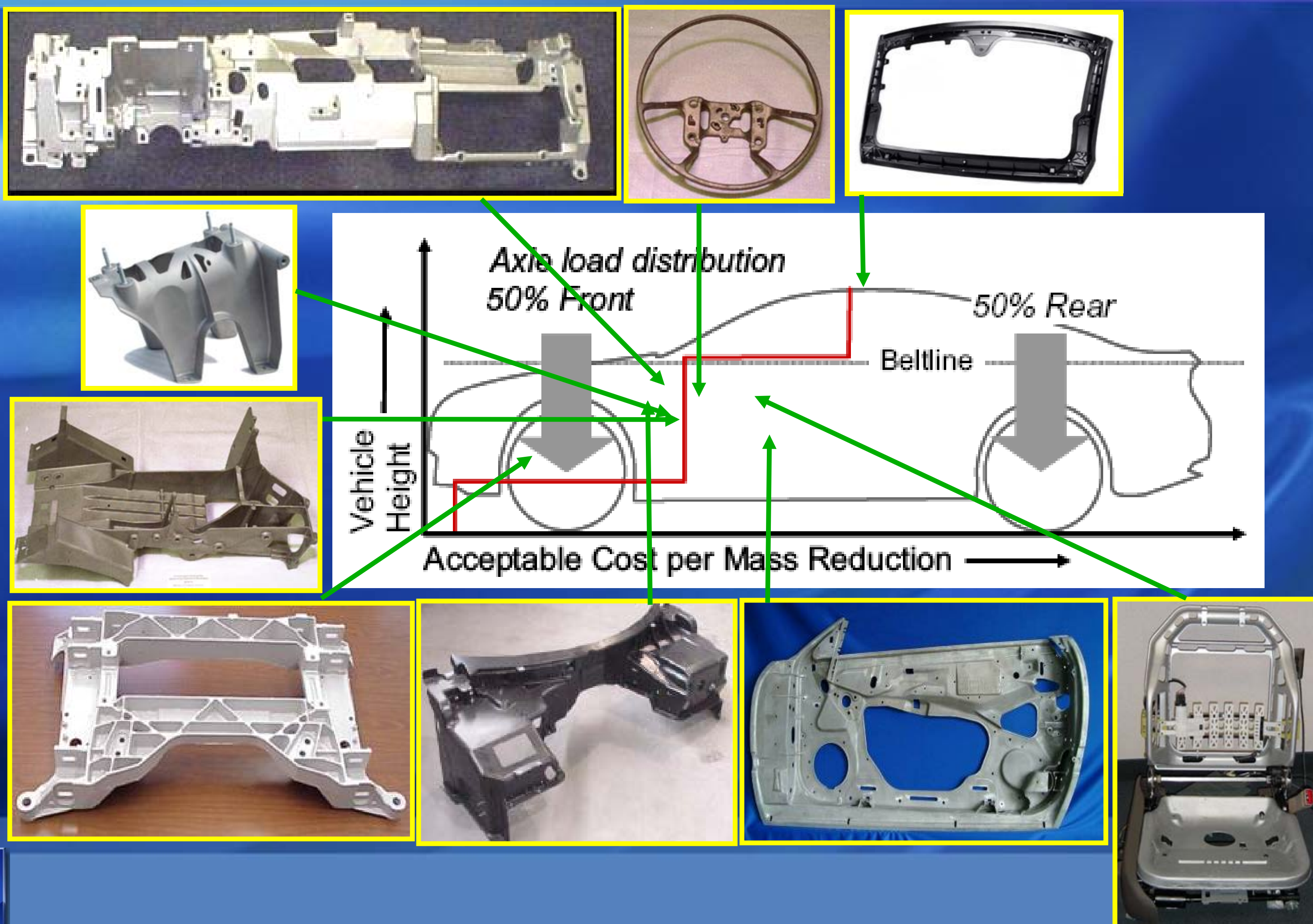
Aluminum Body Components – Extrusions

•AA 6061

Aluminum Intensive Vehicles



Mg opportunities: Lightweight “Up & Front”



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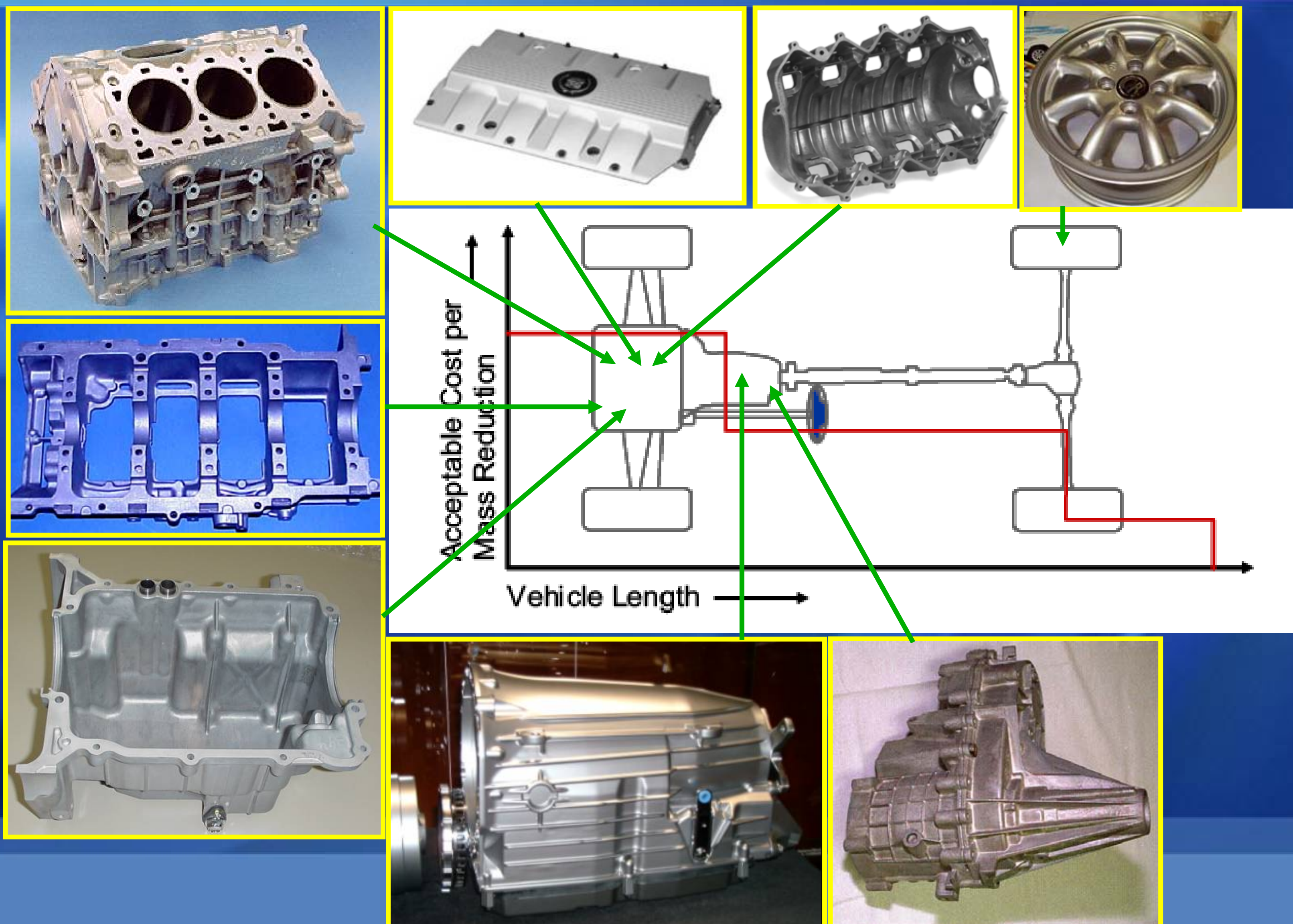


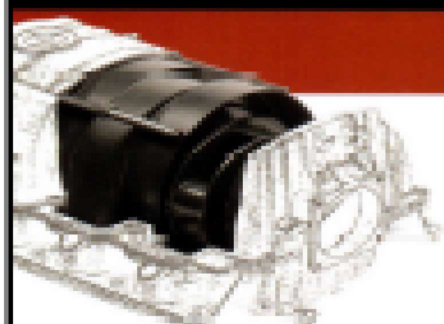
SUPPLEMENT TO:

2ND EDITION

AUTOMOTIVE COMPOSITES

A DESIGN AND MANUFACTURING GUIDE

MILESTONES



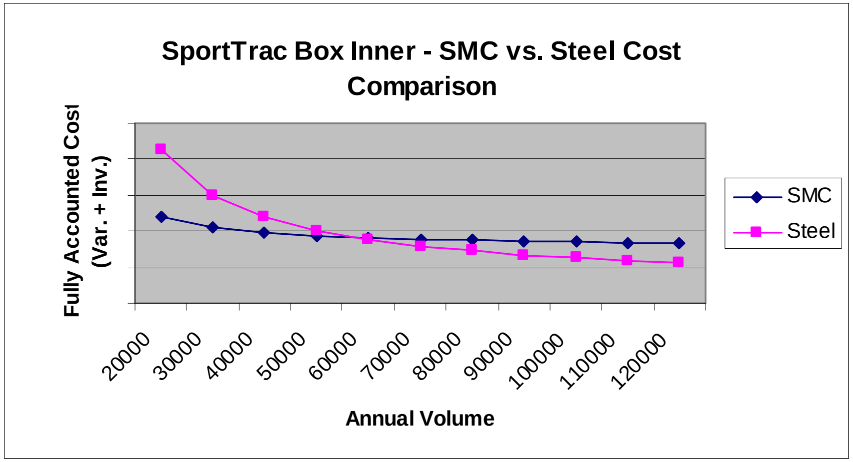
ROAD READY: Composites are proven materials — from bumper to Class A body, chassis to powertrain — as illustrated by nearly 70 years of FRP automotive applications.

Advantages of Composites in the Automotive Industry

- Weight: Reduction of 20%-40+% (versus steel)
- Styling flexibility: Deep draw panels not possible stamped in metal
- Tool Investment: 40%-60% save in part tooling vs steel
- Part Consolidation: Reduced assembly costs and time
- Customer Satisfaction: Resistance to corrosion, scratches, dents, and improvement in damping and NVH
- Safety: Highest specific energy absorption of all major structural materials

Case Study -Composite Pickup Boxes

Ford SportTrac (70K), Toyota Tacoma (170K), Honda Ridgeline (100K)



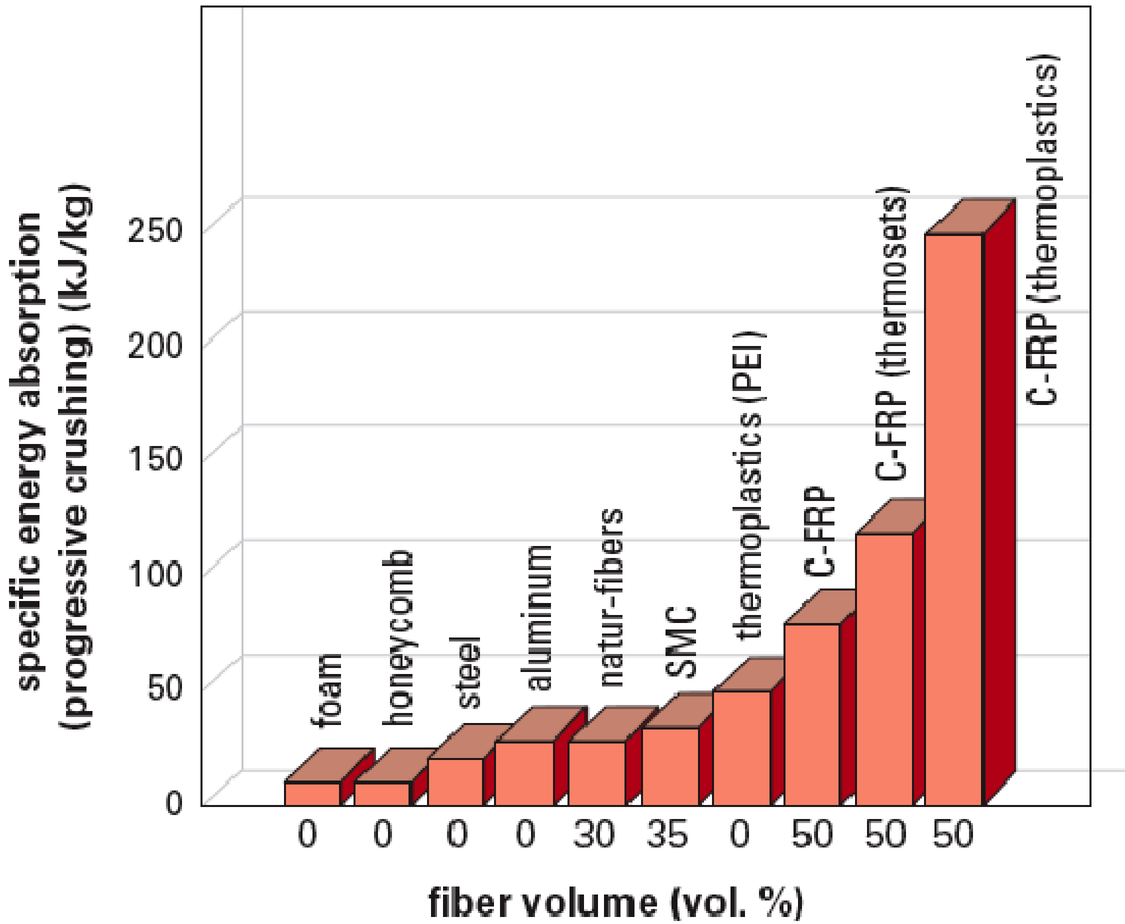
Customer Advantages

- Improved scratch and dent resistance
- Features and functionality (e.g. power points, storage, etc.)
- Improved entry/egress
- Tie down/rack systems (improved methods to secure cargo)

OEM Advantages

- Total program cost savings (x-over 70K)
- 4X capital investment reduction
- Design and styling flexibility
- Part integration, reducing assembly and tooling costs
- 25% weight savings over steel
- Ease of prototyping

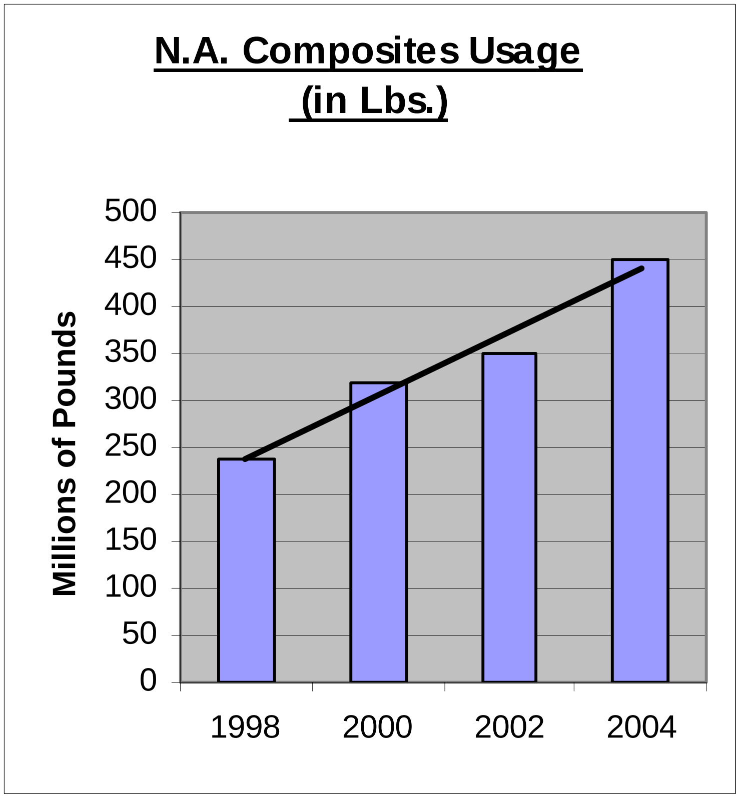
Figure 15: Advanced composites' remarkable crash energy absorption
Carbon-fiber reinforced polymer (C-FRP) crush cones and similar structures can absorb ~120 kJ/kg if made with a thermoset resin like epoxy, or ~250 with a thermoplastic, vs. ~20 for steel.[309] Crush properties can also be optimized by mixing carbon with other fibers.

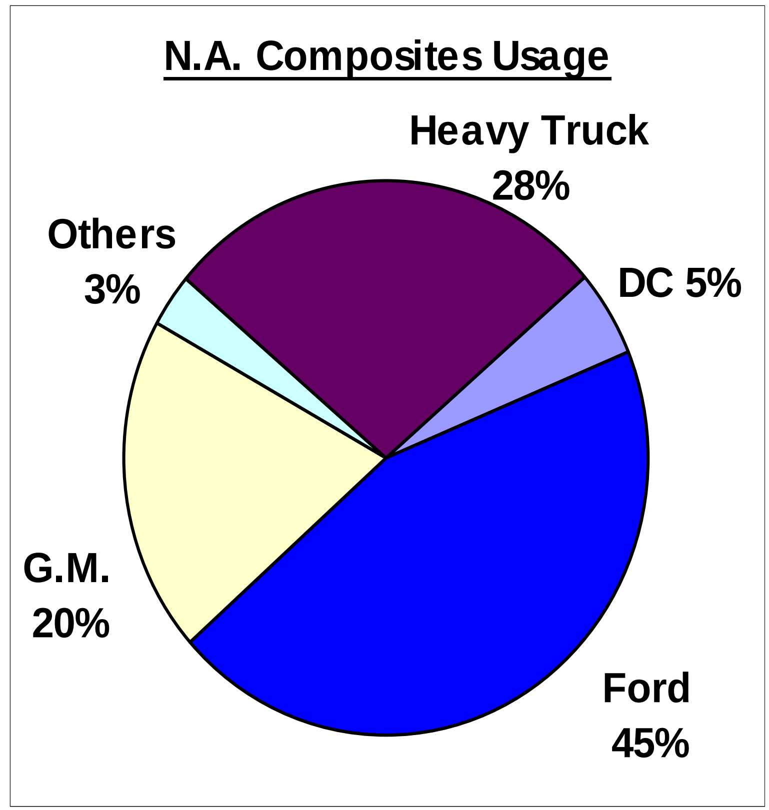


Source: Herrman, Mohrdeck, & Bjekovic 2002, p. 17.

Composites in the Automotive Industry

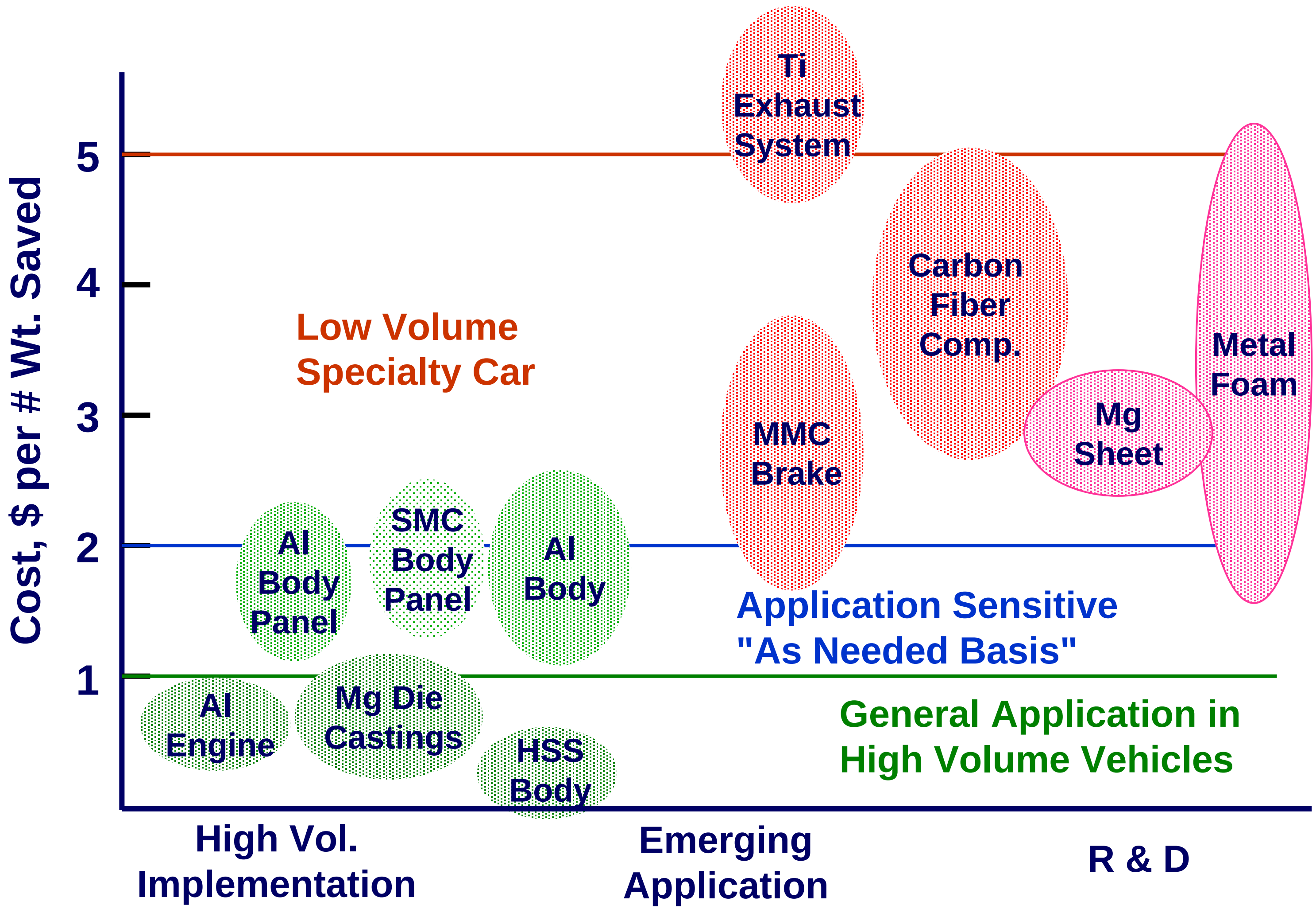
(Distribution of NA Usage)





Data from the Automotive Composites Alliance

Lightweight Automotive Materials - Market Penetration vs. Cost



Trends in Automotive Composites

• Glass-fiber-reinforced polymer-matrix composites (PMCs) will compete for "as-needed applications" with Al and Mg for high-volume models (> 50-100K per annum).

- Natural fibers may challenge glass fibers.

• Carbon-fiber-reinforced PMCs will find limited use in high-end, low-volume models (<50K per annum).

• Advent of lower (than aerospace) cost and performance carbon fiber could open a new era for composites in high-volume applications.

Aston Martin Vanquish

Carbon fiber composite transmission tunnel, braided A-pillar, front end crash structure (400-800 units/year)

Ford GT

Carbon fiber composite rear deck lid and seat (4500 units total)

2006 Z06 Corvette

Carbon fiber fenders, wheel house, and floorpan (7000 units/year)

2006 Dodge Viper

Carbon fiber LH/RH fender/sill supports, LH/RH door inner reinforcements, windshield surround reinforcement (2000 units/year)

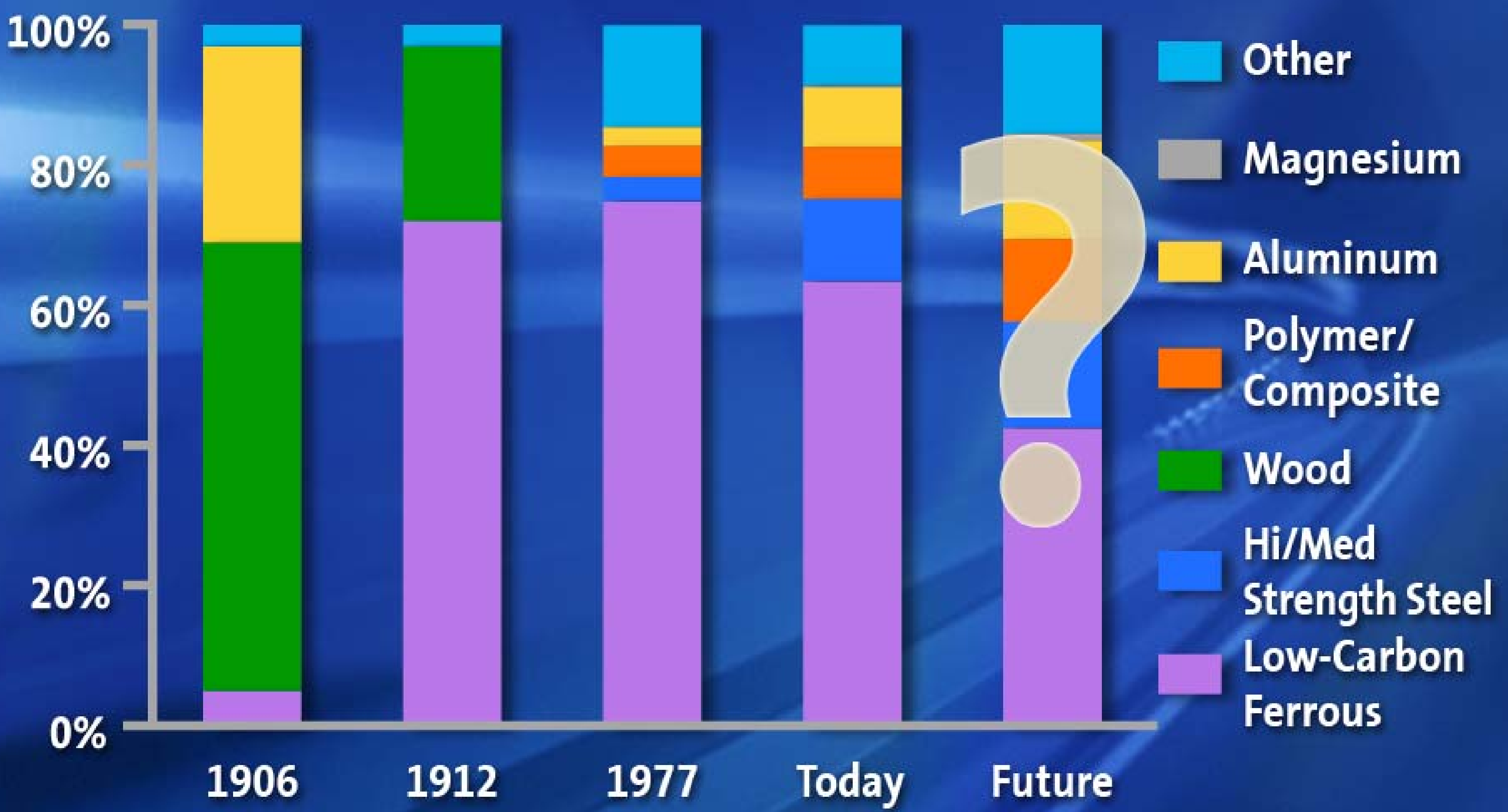
BMW M3 CSL

Carbon fiber roof (3000 units/year)

2005 Mercedes Benz SLR McLaren

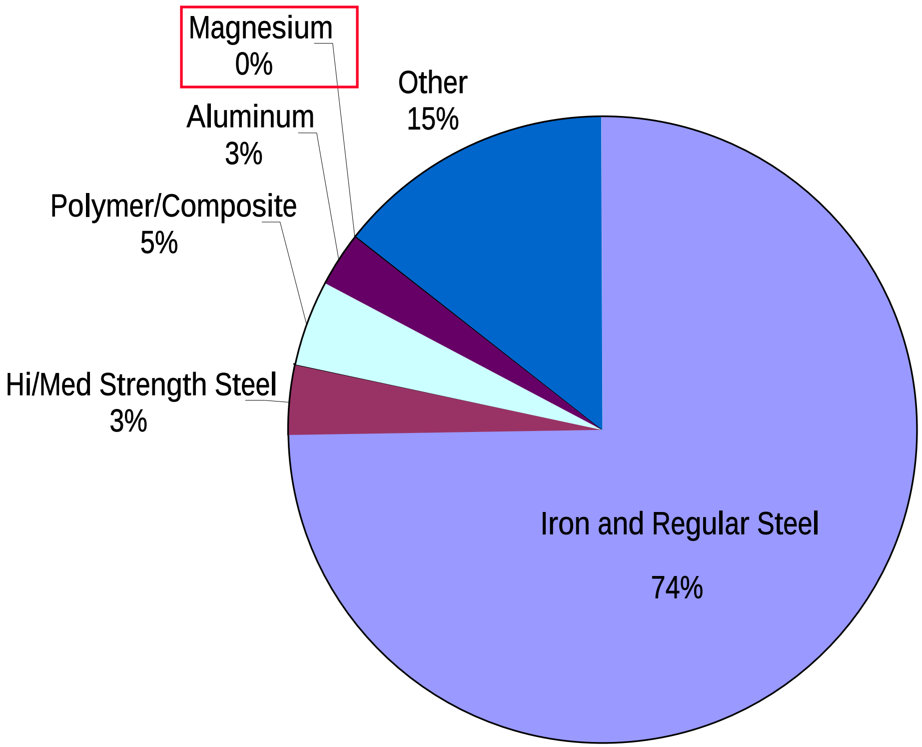
Carbon fiber intensive vehicle (500 units/year)

Materials in a Typical NA Vehicle

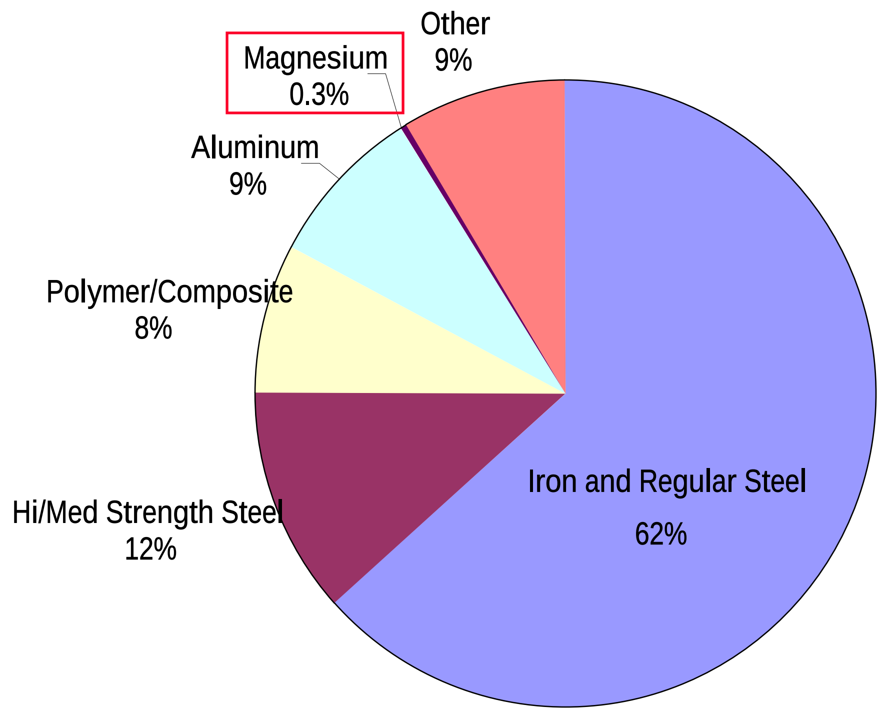


Materials in a Typical Family Vehicle

1977 Model Year

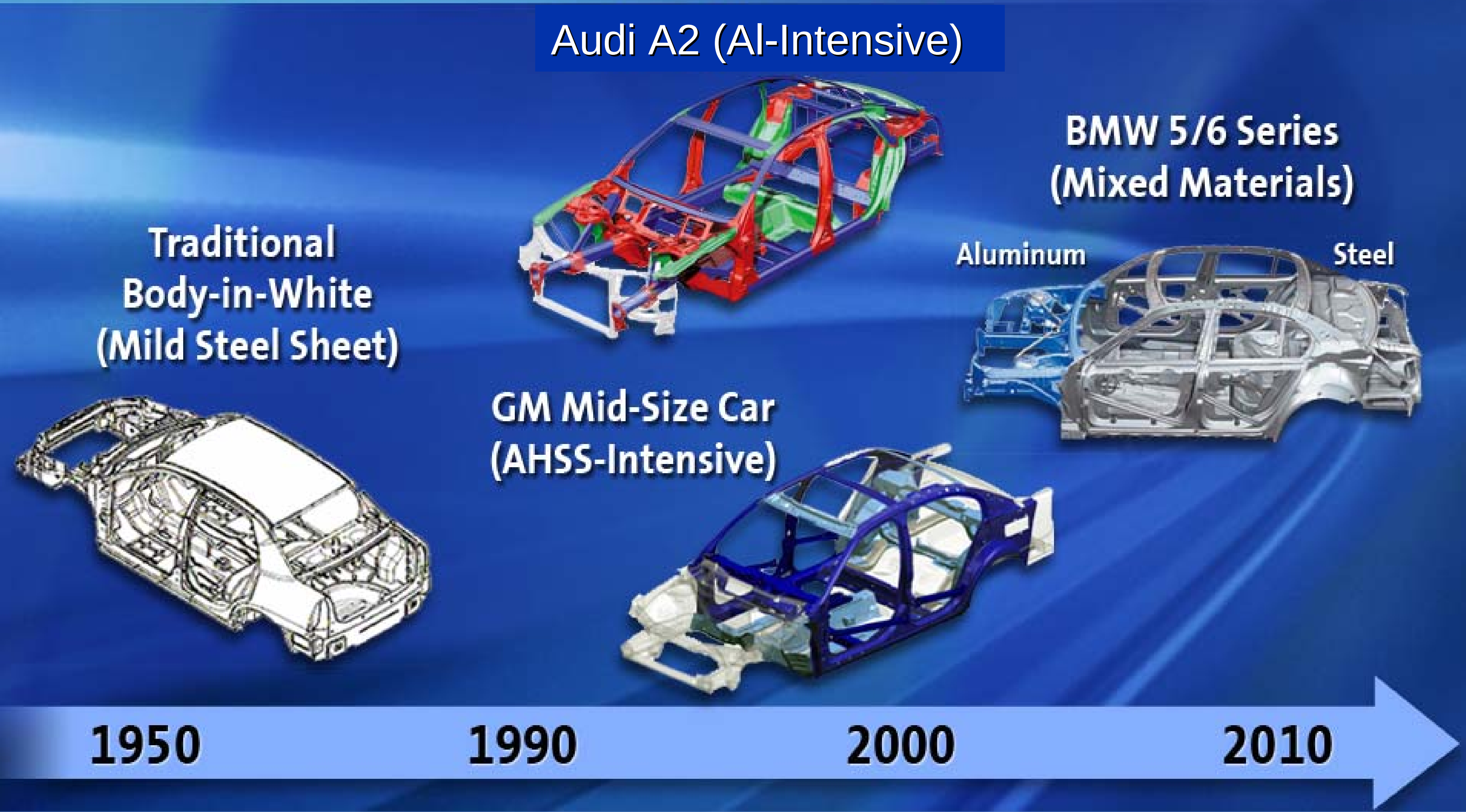


2004 Model Year



(Source: American Metal Market)

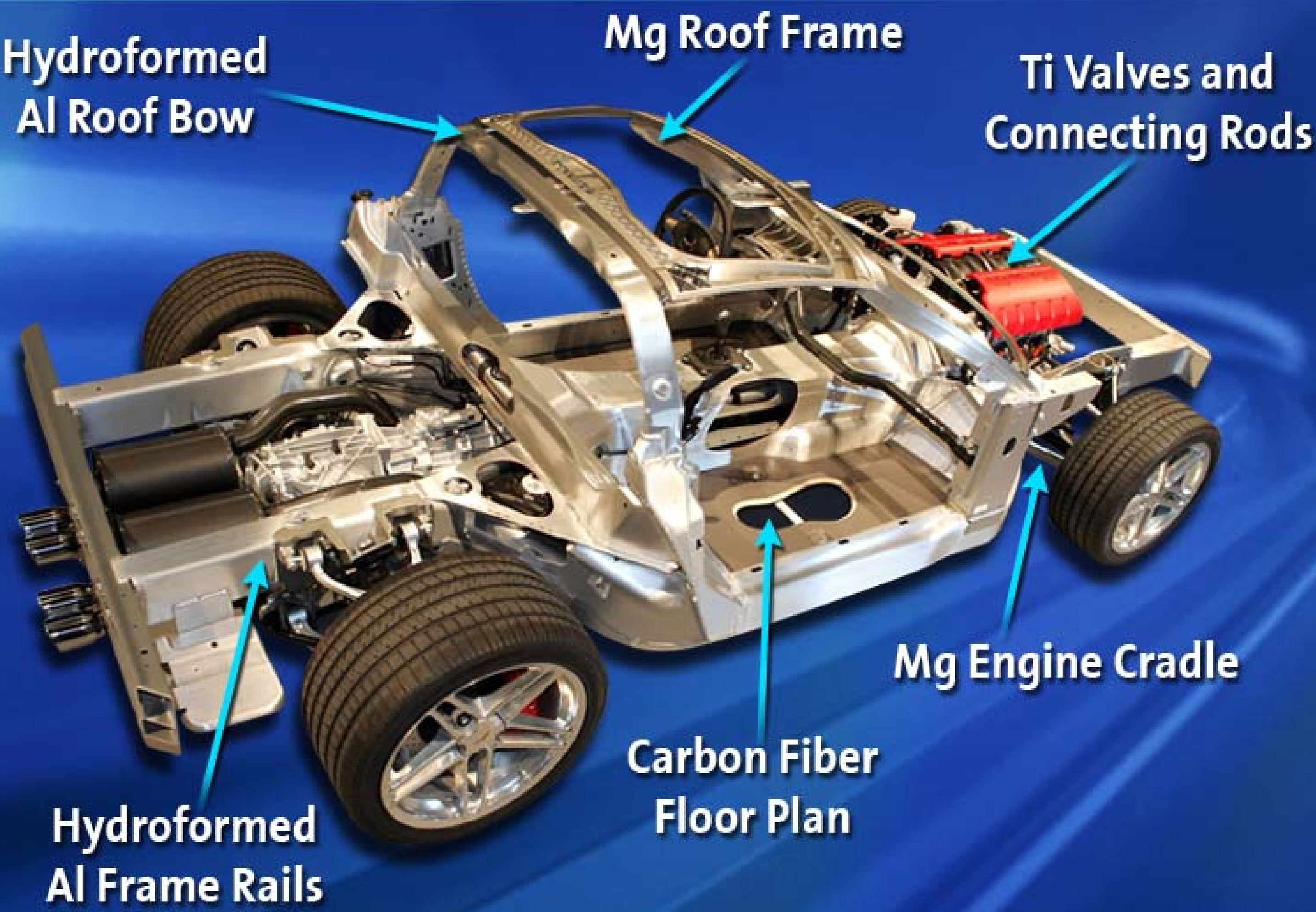
Body Structure



GM

R&D CENTER

2006 Chevrolet Corvette Z06



Material Use in Some PNGV Concept Vehicles

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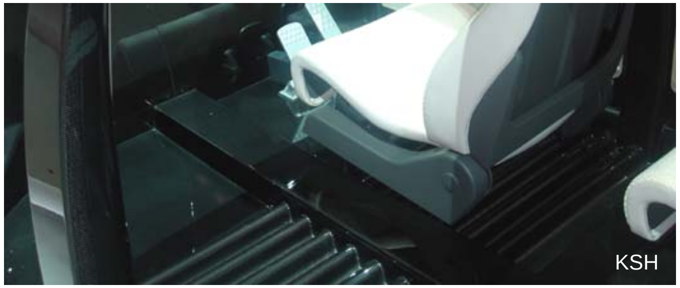
Table 3. Material Use in PNGV Vehicles (lbs.)			
Material	**1994 Base Vehicle**	**P2000**	**ESX2**
Plastics	223	270	485
Aluminum	206	733	450
Magnesium	6	86	122
Titanium	0	11	40
Ferrous	2168	490	528
Rubber	138.5	123	148
Glass	96.5	36	70
Lexan	0	30	20
Glass fiber	19	0	60
Carbon Fiber	0	8	24
Lithium	0	30	30
Other	391	193	273
Total Weight	3248	2010	2250

Source: Ducker 1998

Holistic Vehicle Efficiency Approach

- Combined synergistic technologies
  - Body and chassis of lightweight materials
  - Small flex-fuel engine in a hybrid system
  - Advanced batteries and/or capacitors
- Toyota 1/X Concept (Prius mock-up)
  - 33% weight
  - 50% fuel consumption
  - ‘Plausible’ application of carbon fiber reinforced plastic (CFRP)
    - *Benefit from Lexus LF-A sports car development and Toray’s increased production for the aircraft industry*
  - 500 cc engine (could be) adapted from available (hybrid) motorcycle technology
  - Plug-in hybrid with Li-ion battery



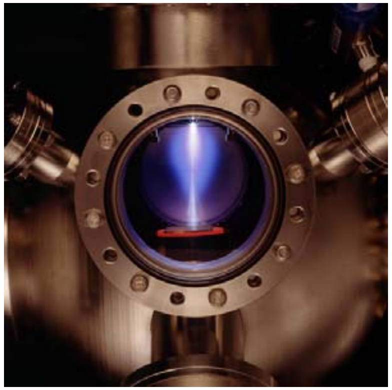
Future

(… barring some major shifts in politics or economics)

- Steel will predominate for high volume (numbers) models.
- Mg, Al and plastics will compete.
- The lighter weight materials like Mg and carbon-fiber composites will find extensive use in lower-volume niche vehicles mainly for performance reasons.
- The ultimate factors on adoption will likely be economic and political.

(most predictions of the future turn out to be wrong.)

http://www.eere.energy.gov



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