Joseph A. Carpenter, Jr., U.S. Department of Energy
Edward Daniels, Argonne National Laboratory
Philip Sklad and C. David Warren, Oak Ridge National Laboratory
Mark Smith, Pacific Northwest National Laboratory

TMS Light Metals Division Luncheon
Walt Disney World
Orlando, Florida USA

February 28, 2007

(*In remembrance of Dr. Sidney Diamond of USDOE*)

# Outline

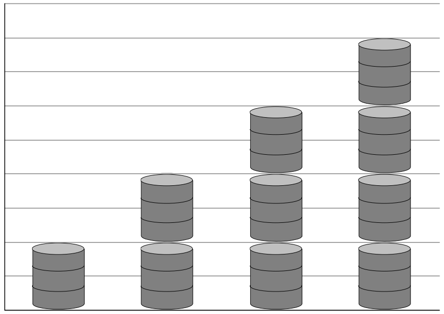


- The FreedomCAR and Fuels Initiative
  - History
  - Goals
- FreedomCAR-supported Body and Chassis Lightweighting Materials Thrusts
- Summary and Thoughts

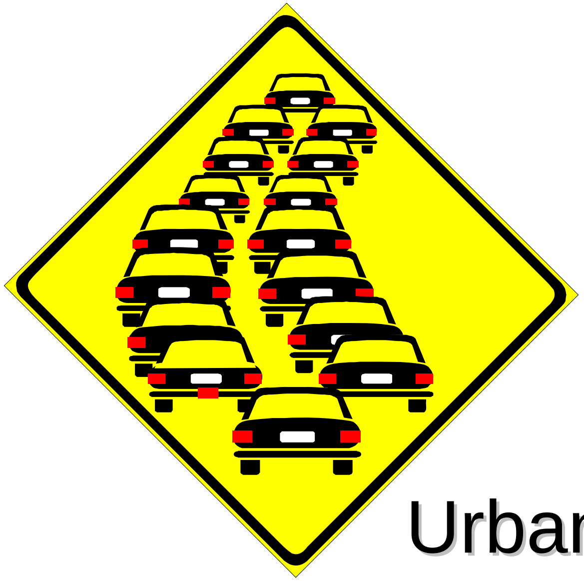
Based upon paper in *Proceedings of the International Auto Body Conference*, Novi, Michigan USA, September 19, 2006

# The Challenges Facing Us…





Growing Petroleum Consumption



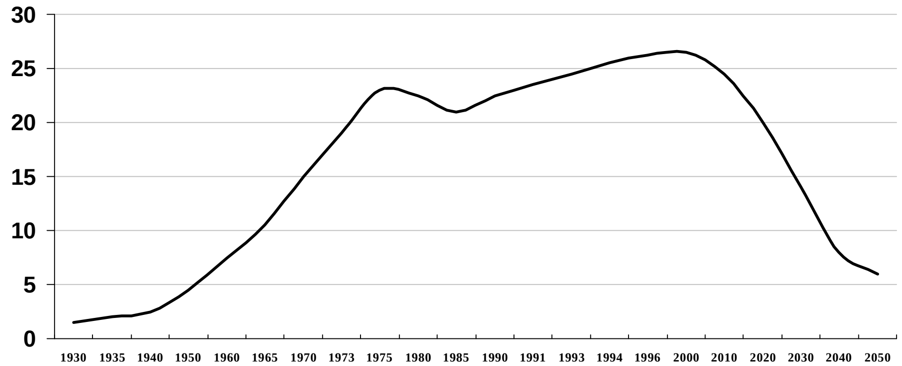
Urban Pollution

Global Climate Change

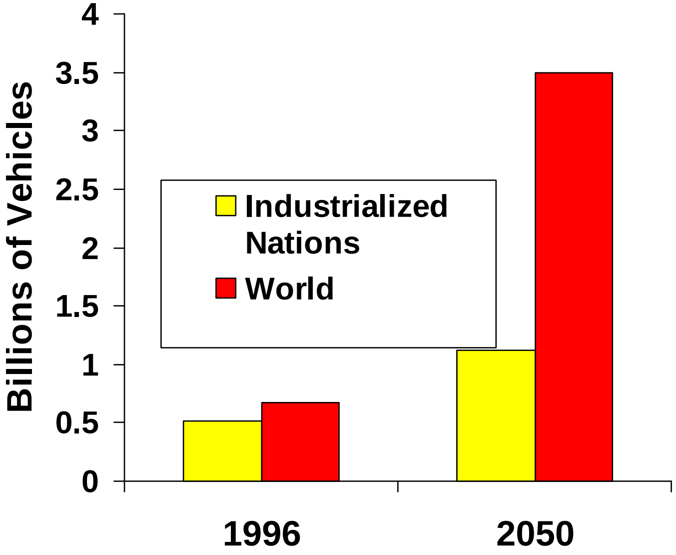
# Can We Sustain Increasing Consumption?



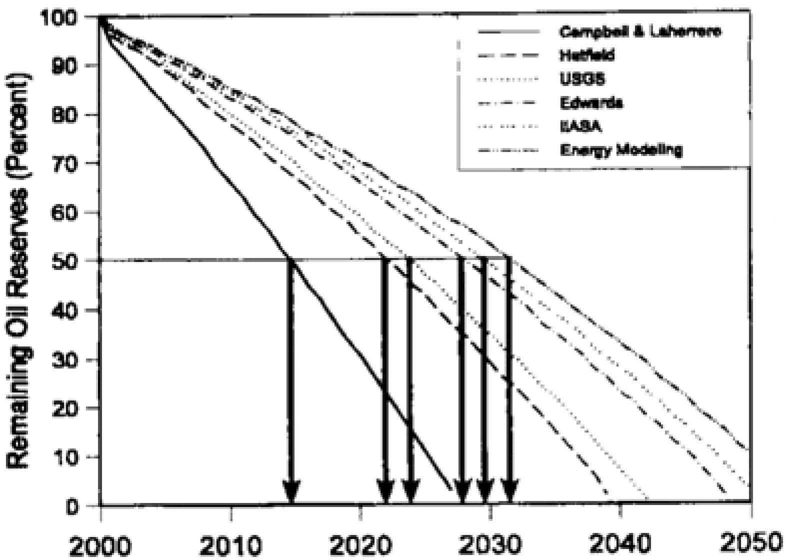
**Annual World Oil Production (Billions of Barrels)**




**Projected Growth in Light-Duty Vehicle Registrations**

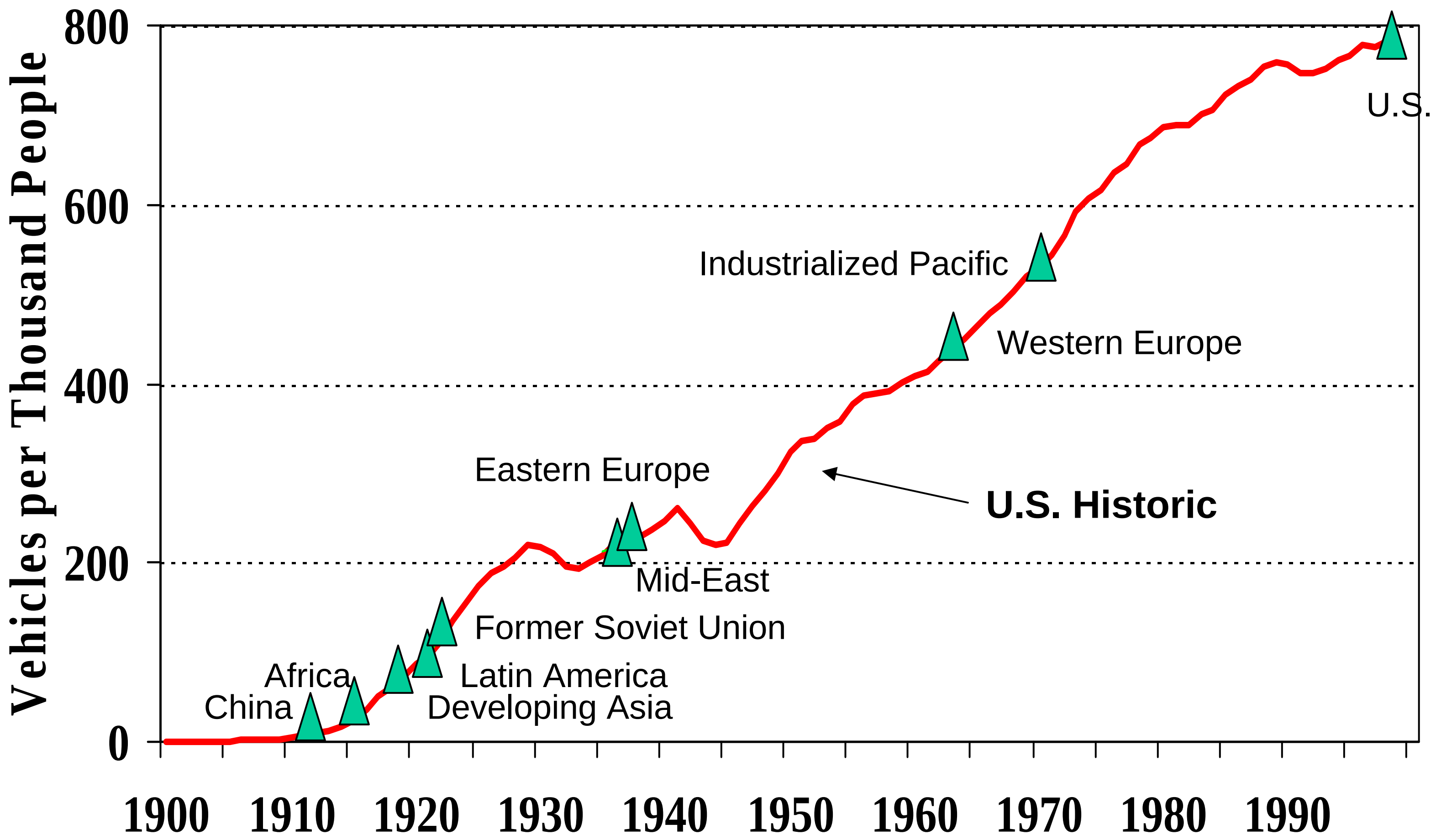



**Estimates of Remaining Oil Reserves**



U.S. Department of Energy
Energy Efficiency and Renewable Energy

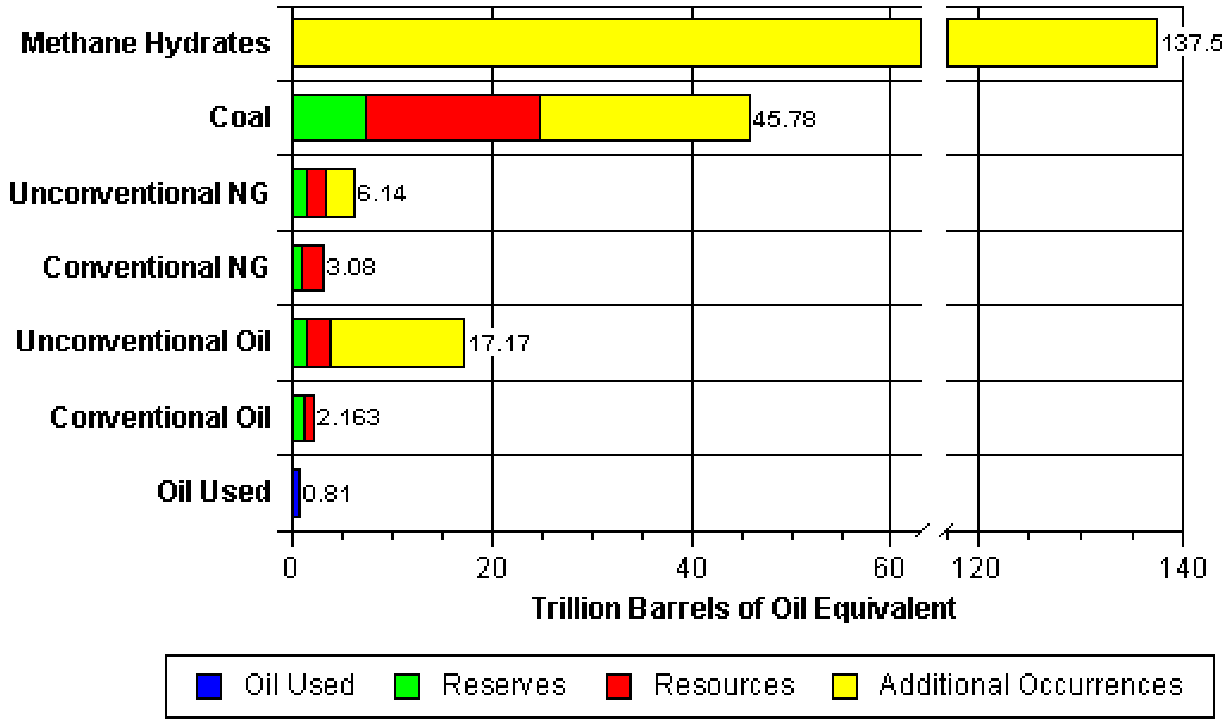
# Global Growth in Transportation Is Accelerating the Demand for Oil




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

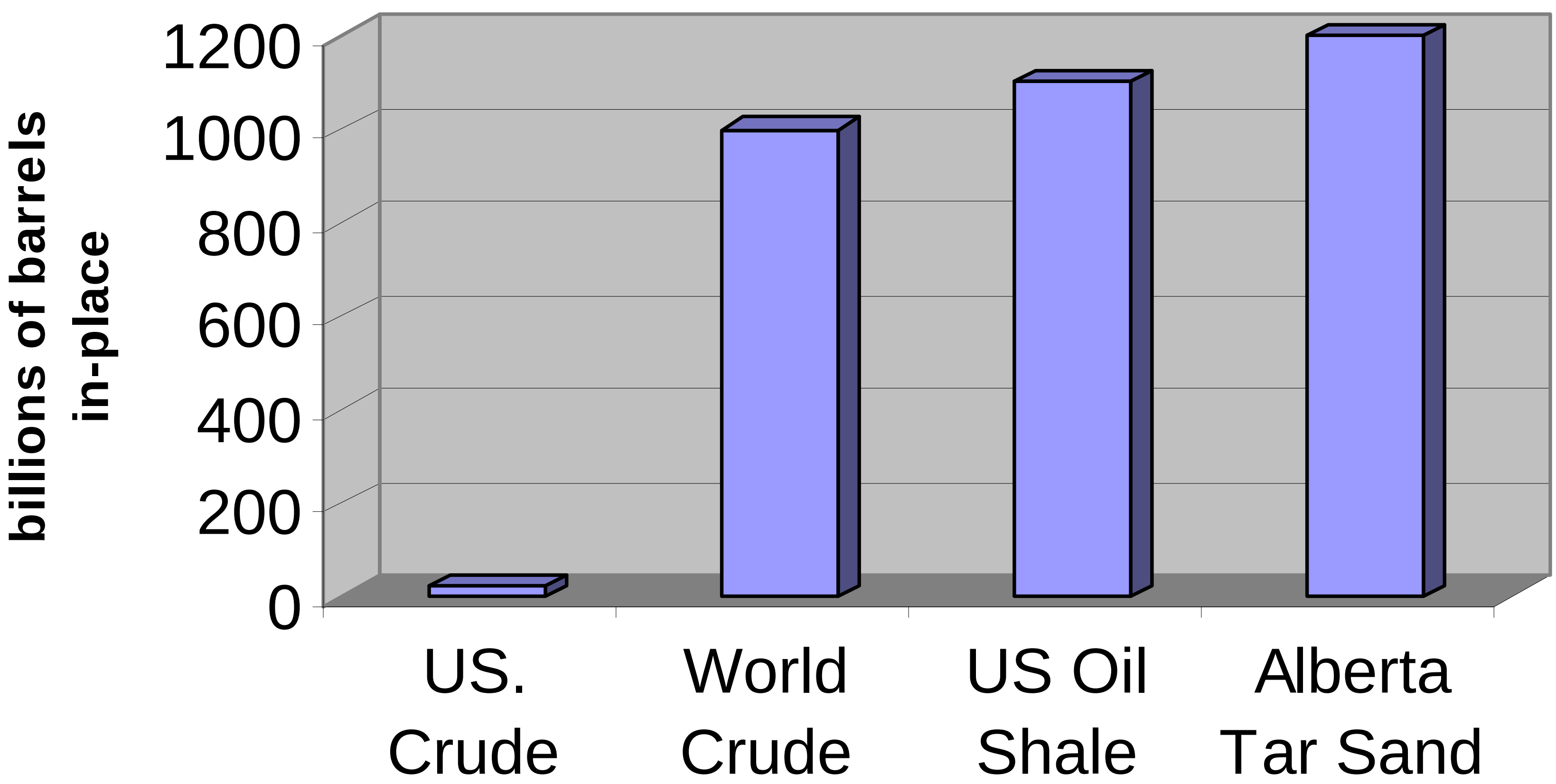
# World Fossil Fuel Potential

*Materials Technologies*



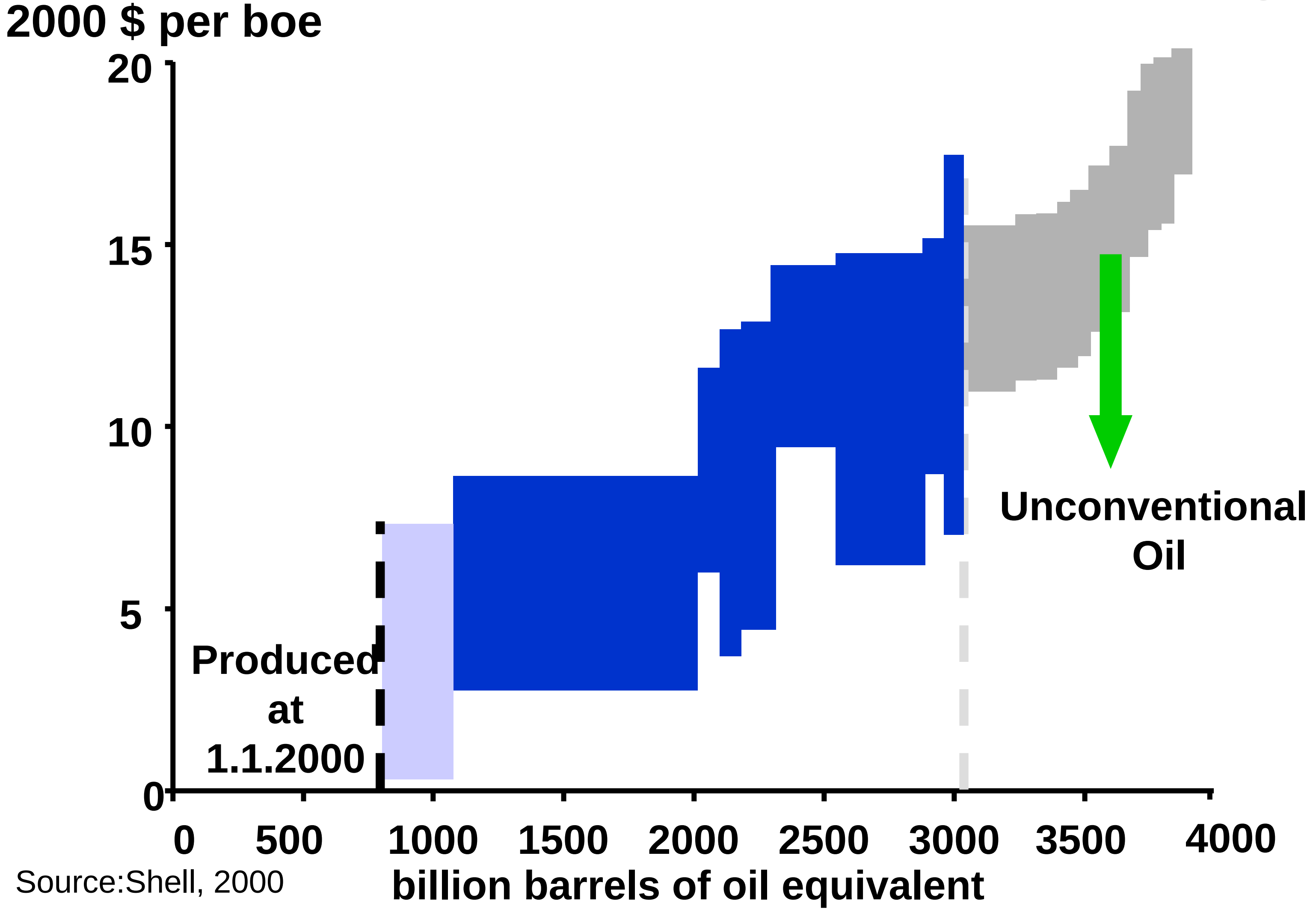

Source: H. H. Rogner, "An Assessment of World Hydrocarbon Resources," Annual Review of Energy and Environment, 1997.

# World fossil liquid resources



# Oil and Substitute Costs

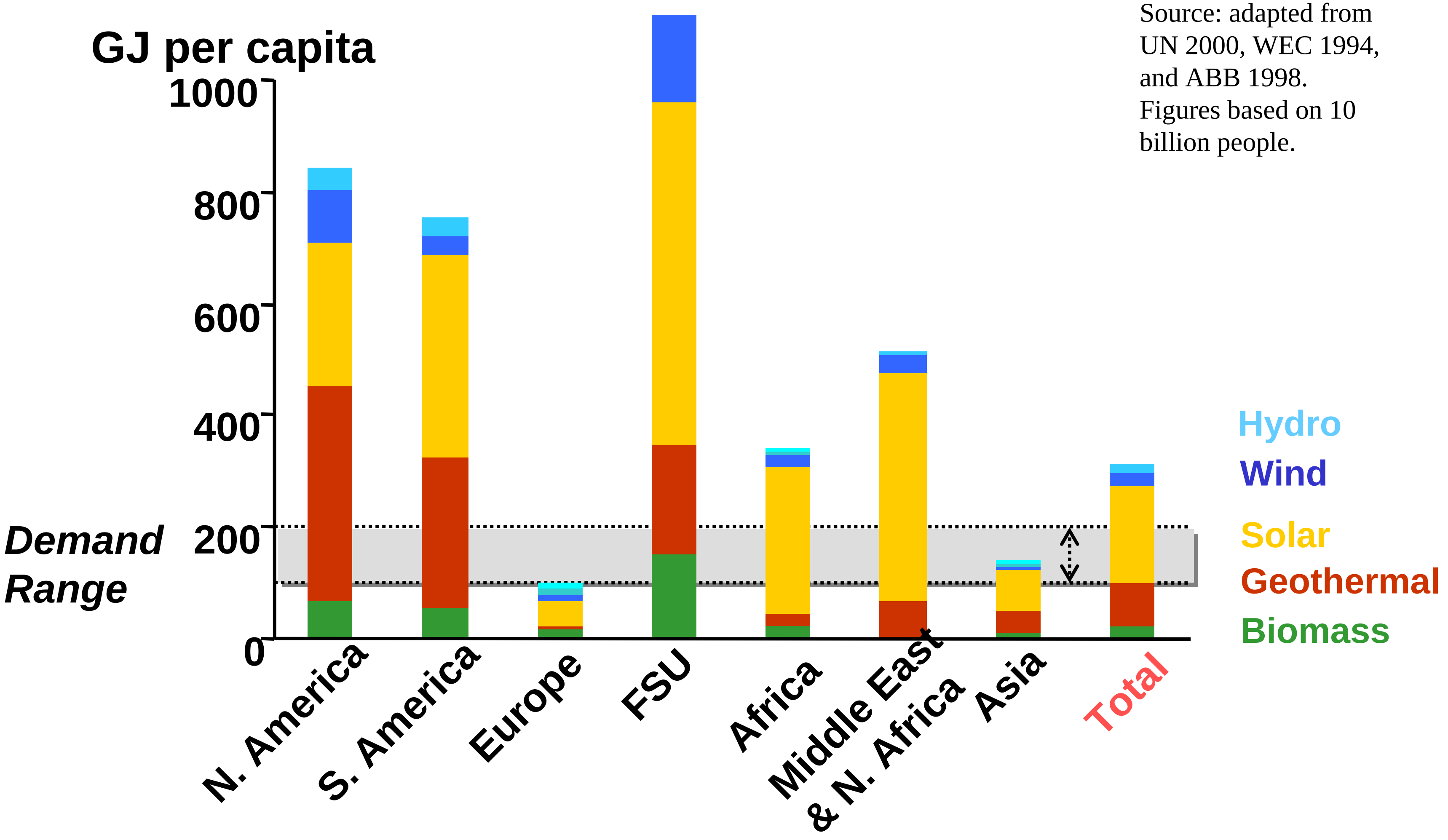
*Materials Technologies*




Source:Shell, 2000

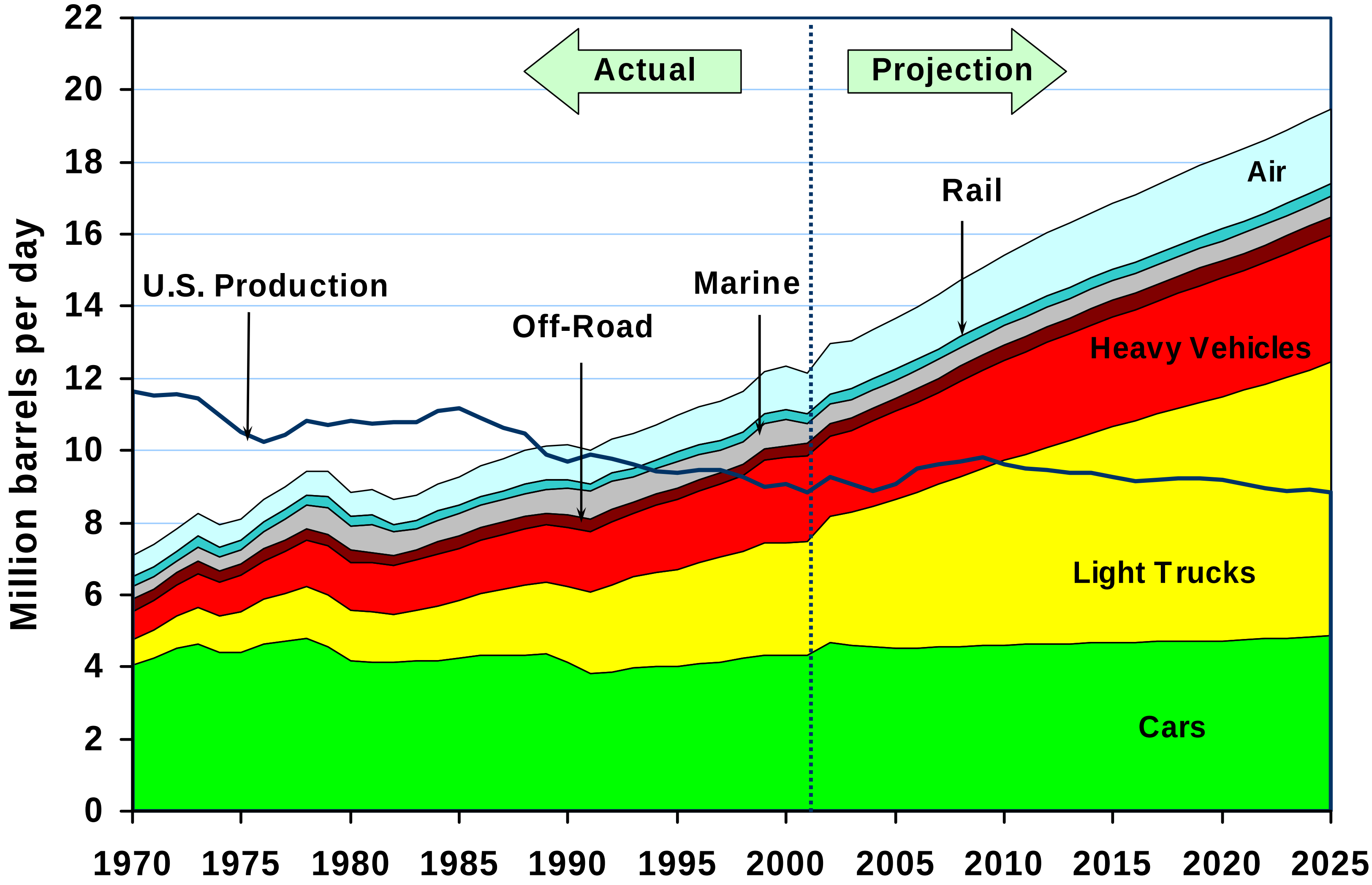
# Renewable Resources are Adequate to Meet all Energy Needs






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

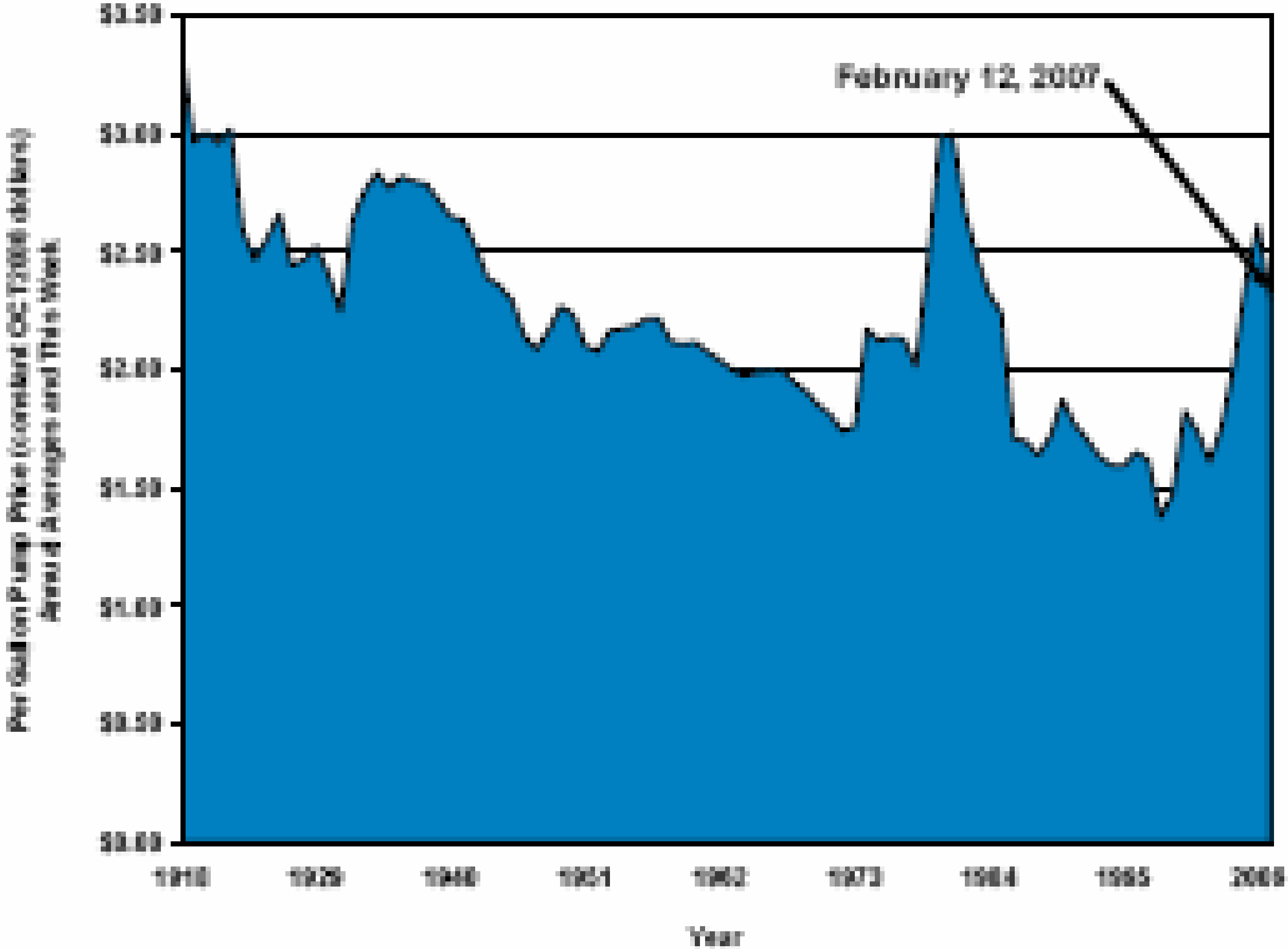
# USA Transportation Petroleum Use by Mode (1970-2025)
## 2003 Total = 13.42 mbpd




Note: Domestic production includes crude oil, natural gas plant liquids, refinery gain, and other inputs. This is consistent with EIA, MER, Table 3.2. Previous versions of this chart included crude oil and natural gas plant liquids only.

Source: Transportation Energy Data Book: Edition 24, ORNL-6973, and EIA Annual Energy Outlook 2005, Preliminary release, December 2004.

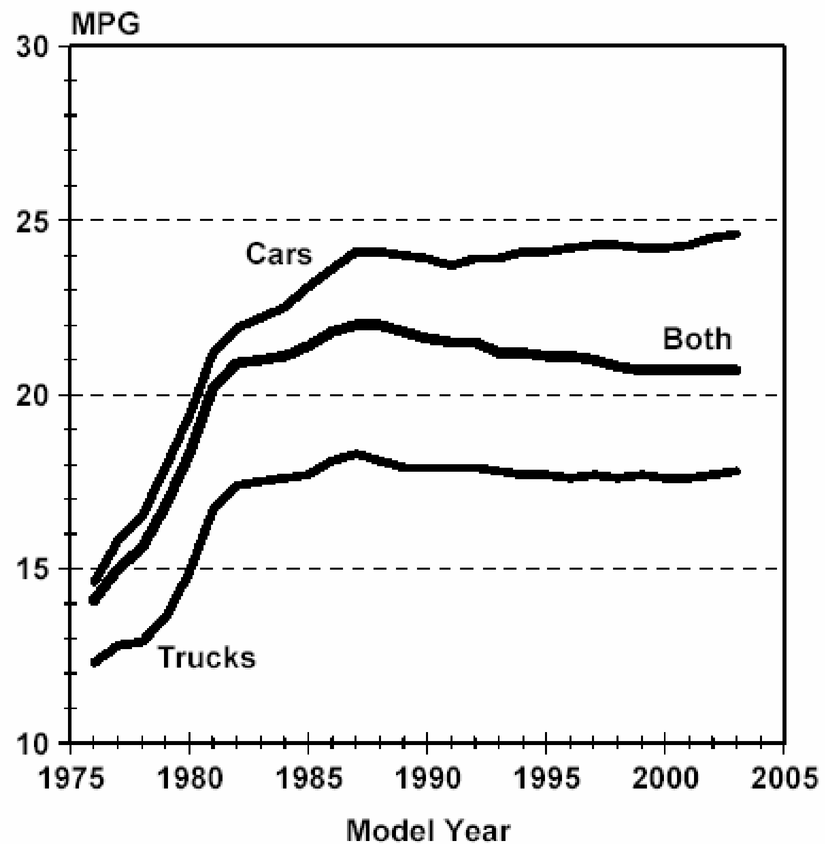
# U.S. Pump Prices, 1918 - 2007



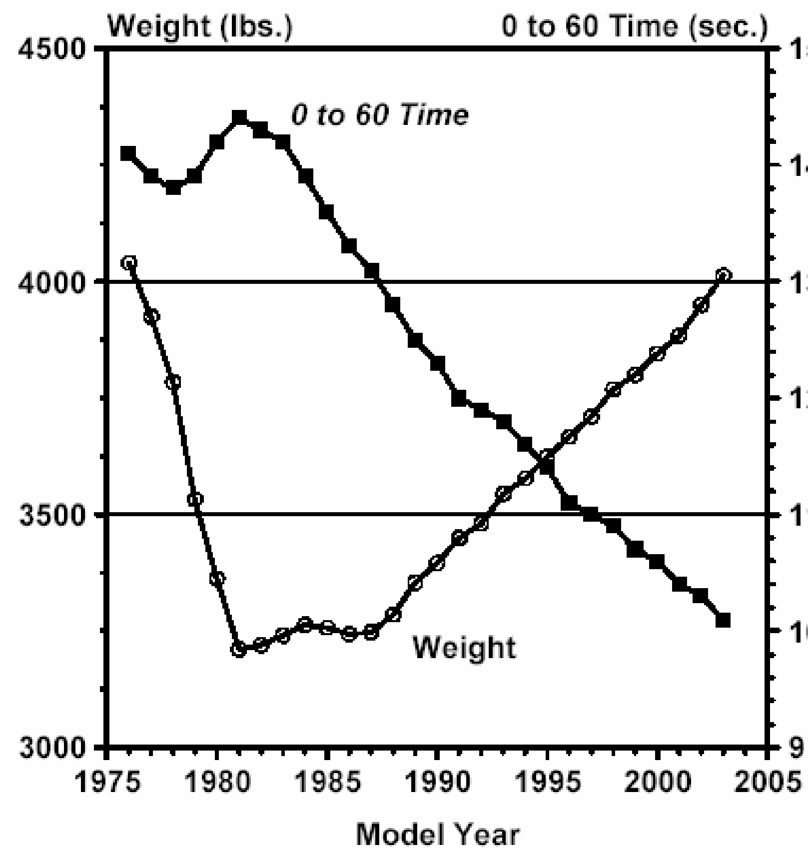

Sources: U.S. Dept of Energy, U.S. Dept of Labor, and API

# 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.

# HISTORY



- 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 (and to present) - Energy Policy and Conservation Act of 1975 established Corporate Average Fuel Economy (CAFÉ) standards for light-duty vehicles.
- 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.

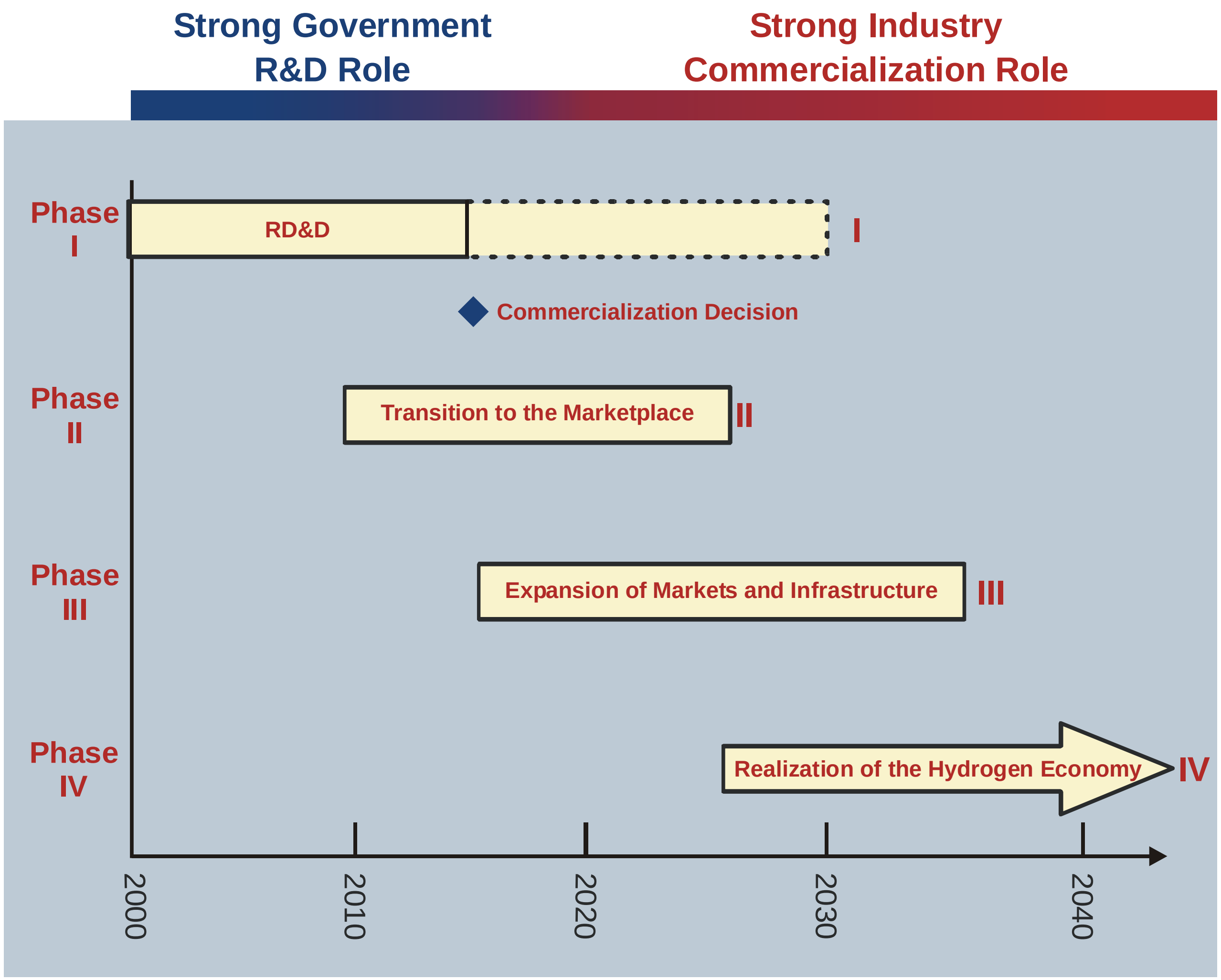
# HISTORY - continued



- 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.
- 2002-2007 – President Bush rejects Kyoto Treaty but pledges large research, development, demonstration and deployment (RDD&D) efforts to provide technological solutions to climate change (e.g., *U.S. Climate Change Strategy*, 2/14/07)
- 2003 – FreedomCAR expanded to include the Hydrogen Fuels Initiative, becomes FreedomCAR and Fuels Partnership, 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.

# Timeline






## Transitional Phases

I. Technology Development Phase

II. Initial Market Penetration Phase

III. Infrastructure Investment Phase

IV. Fully Developed Market and Infrastructure Phase

# FreedomCAR Strategic Approach

- Develop technologies to enable mass production of affordable hydrogen-powered fuel cell vehicles and assure the hydrogen infrastructure to support them

- Continue support for hybrid propulsion, advanced materials, and other technologies that can dramatically reduce oil consumption and environmental impacts in the nearer term

- Instead of single vehicle goals, develop technologies applicable across a wide range of passenger vehicles.

# Effect 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



- Potentially higher prices of fuel.
- The hydrogen-fueled fuel-cell vehicle.
- Increasing “customer value” while staying within Corporate Average Fuel Economy (CAFÉ) limits

# Barriers



- Historically low prices of fuel.
- Higher costs of lightweighting materials.
- Lack of familiarity with them.
- Preferences for large vehicles
- Perceptions of safety
- Recycling (plastics)

# FreedomCAR Technology Specific Goals

*Materials Technologies*

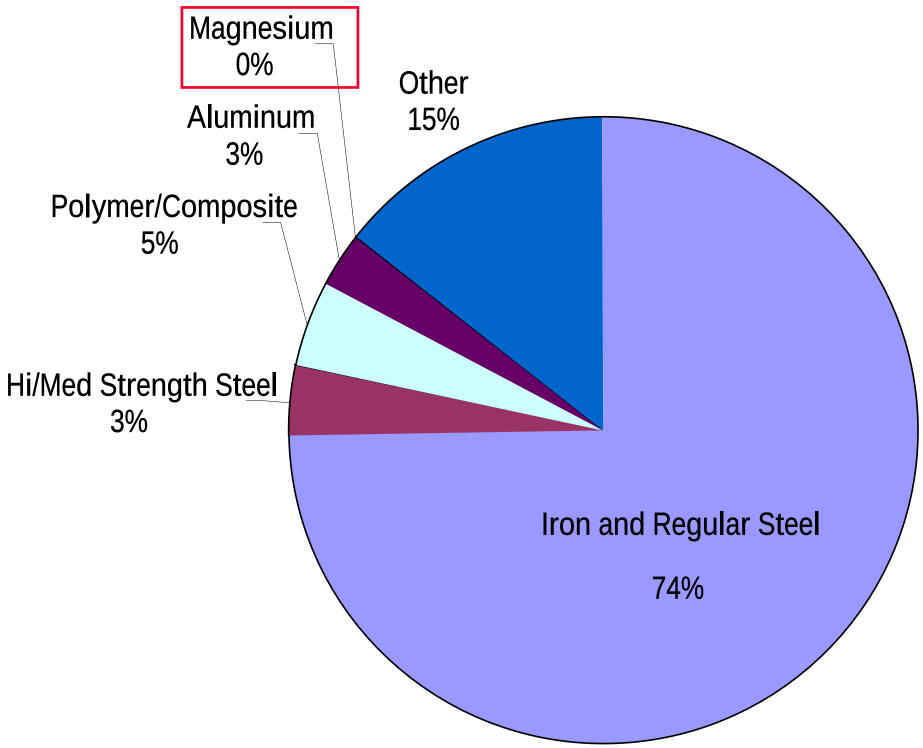
| | Efficiency | Power | Energy | Cost* | Life | Weight |
|---|---|---|---|---|---|---|
| **Fuel Cell System** | 60% (hydrogen)<br>45% (w/ reformer) | 325 W/kg<br>220 W/L | | $45/kW (2010)<br>$30kW (2015) | | |
| **Hydrogen Fuel/ Storage/ Infrastructure** | 70% well to pump | | 2 kW-h/kg<br>1.1 kW-h/L | $5/kW-h<br>$1.25/gal (gas equiv.) | | |
| **Electric Propulsion** | | $\geq$55 kW 18 s 30 kW cont. | | $12/kW peak | 15 years | |
| **Electric Energy Storage** | | 25 kW 18 s | 300 W-h | $20/kW | 15 years | |
| **Materials** | | | | Same | Same | 50% less |
| **Engine Powertrain System**** | 45% peak | | | $30/kW | 15 years | |

* Cost references based on CY2001 dollar values

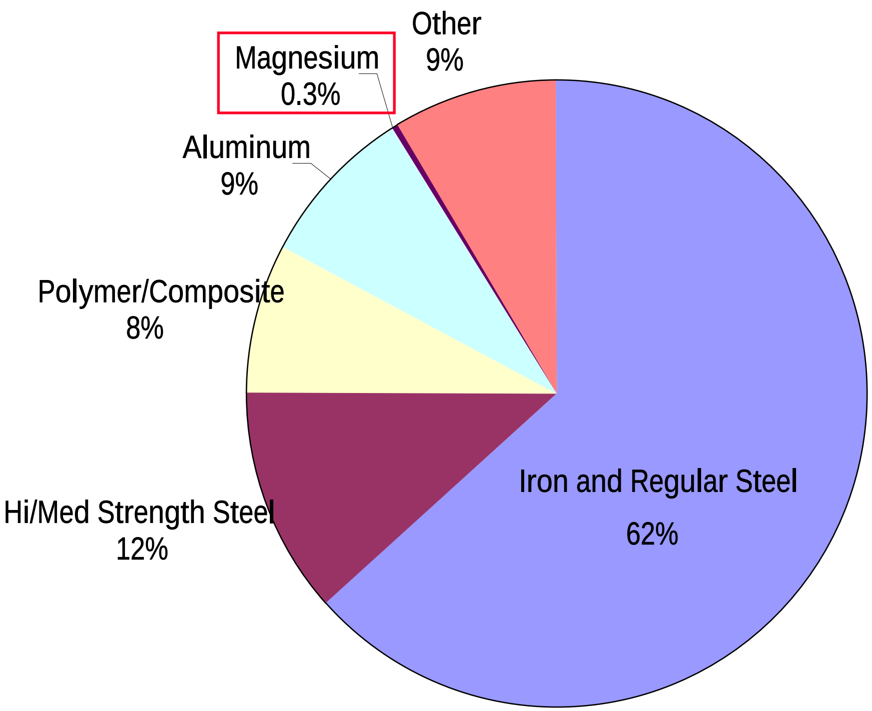
** Meets or exceeds emissions standards.

# *Materials in a Typical Family Vehicle*

1977 Model Year




2004 Model Year




*(Source: American Metal Market)*

# 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.*

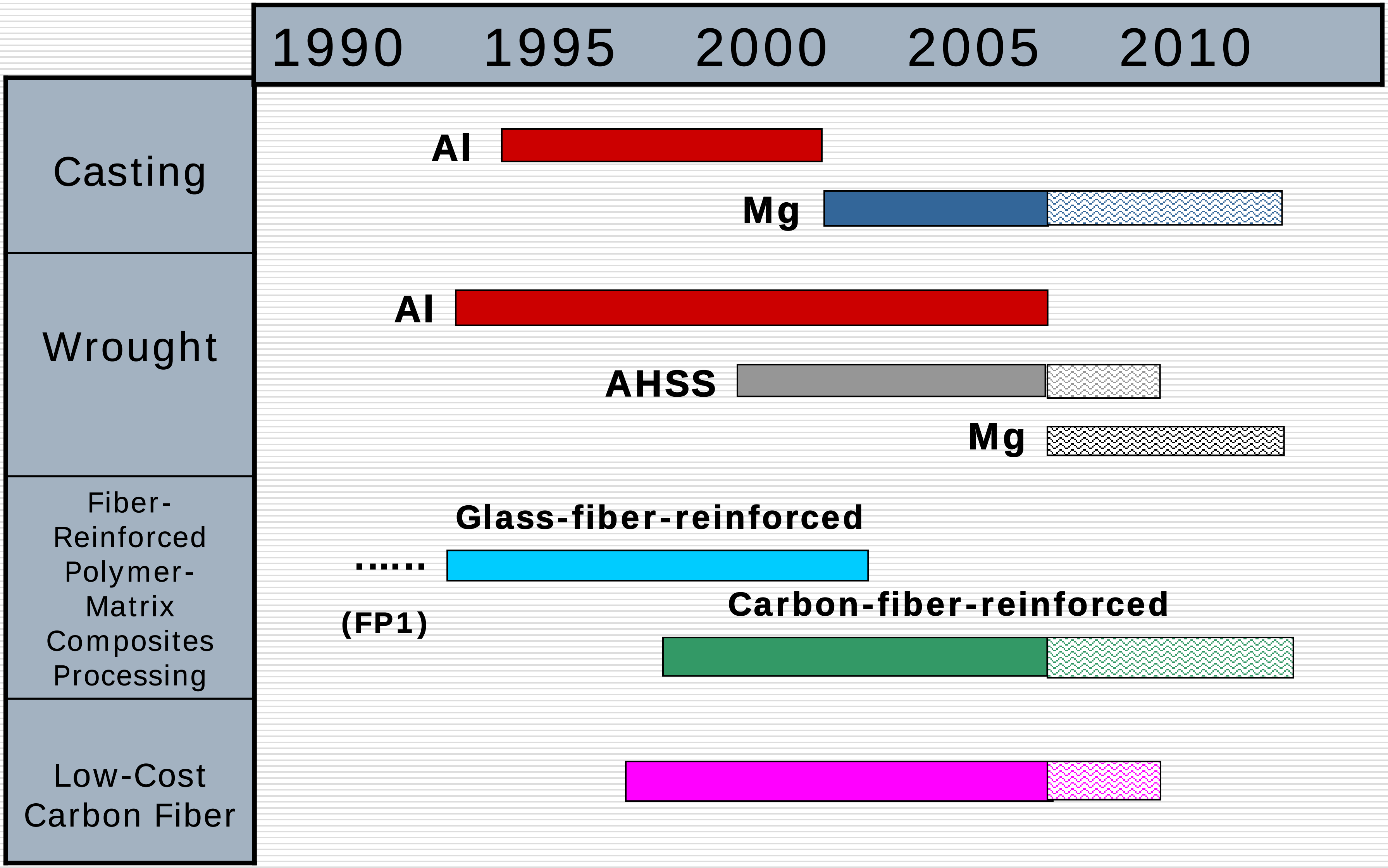
# Automotive Lightweighting Materials



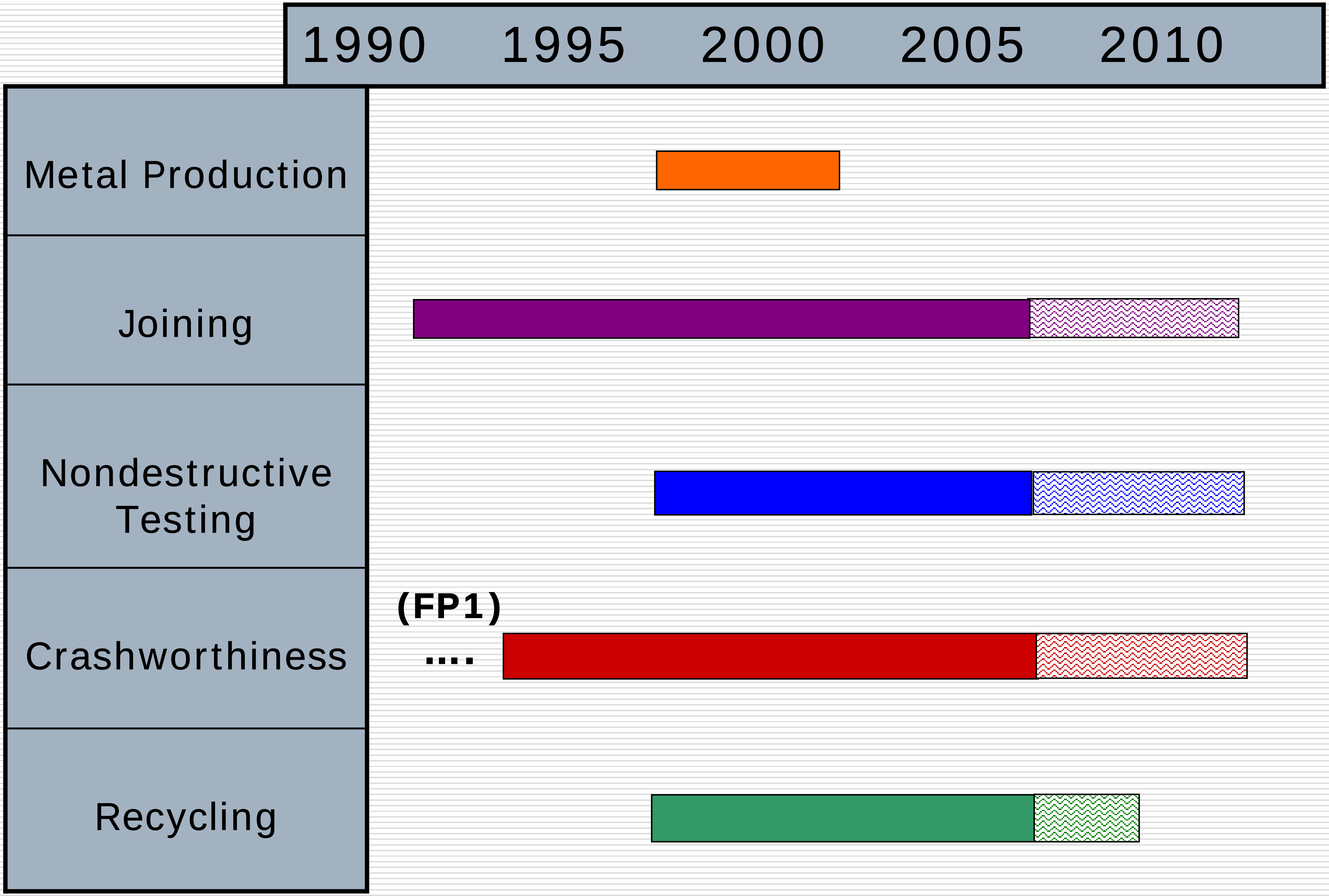
- Largest Focus Areas
  - Casting (Al and Mg)
  - Wrought (mainly Al and Mg sheet formation and fabrication)
  - Fiber-reinforced polymeric-matrix composites processing
  - Low(er)-cost carbon fiber production

- Smaller Focus Areas
  - Metal production (Al and Mg)
  - Metal(Al)-matrix composites
  - Ti metal production and fabrication
  - Steel
  - General manufacturing (joining and NDT)
  - Glazing (glass)
  - Crashworthiness
  - Recycling

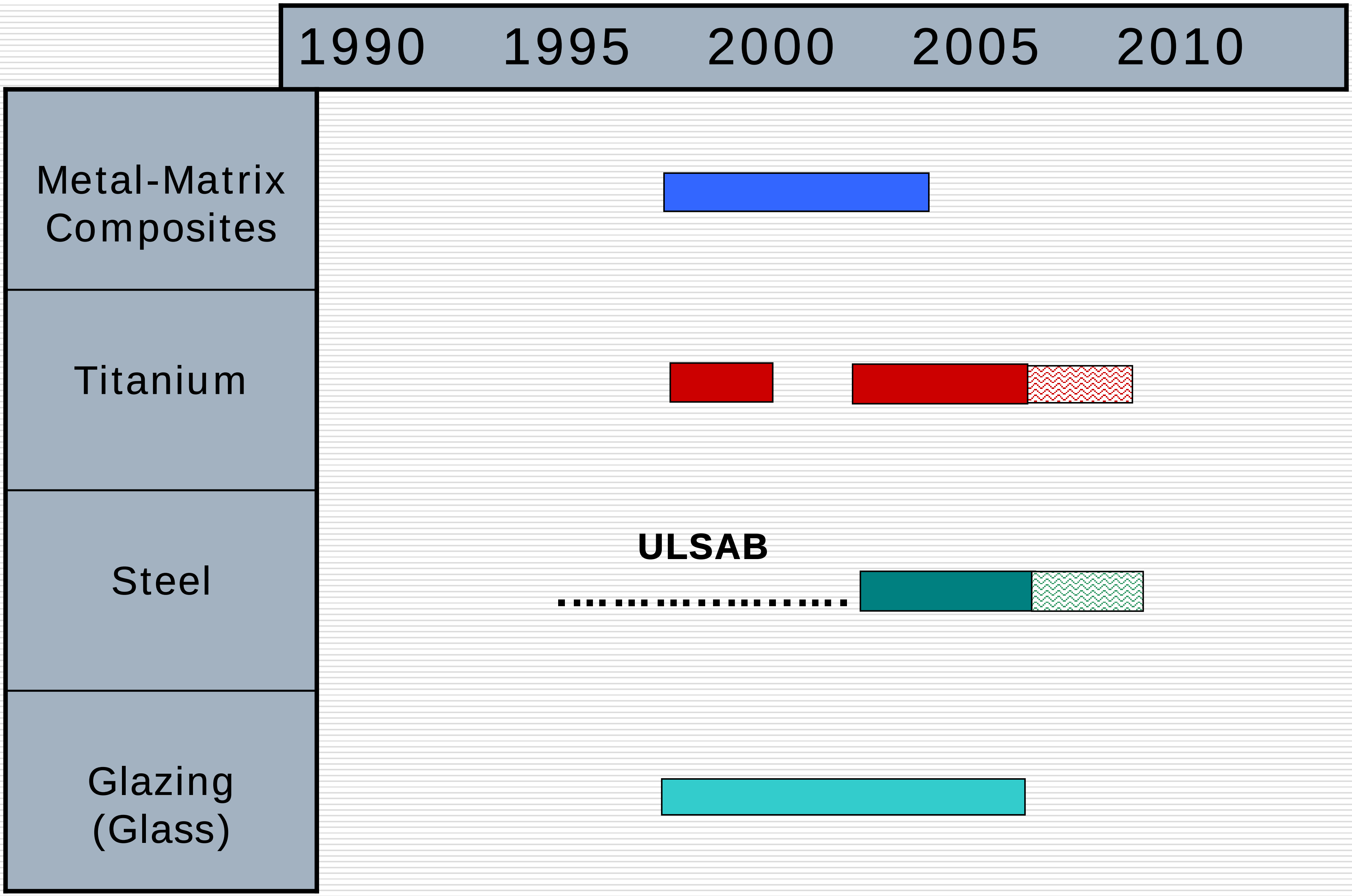
# ALM Historical Timeline – Main Efforts



# ALM Historical Timeline - General Manufacturing



# ALM Historical Timeline – Minor Materials



# FreedomCAR Automotive Lightweighting Materials Highlights



• Superplastic Forming of Aluminum (GM’s Quick Plastic Forming)

• Programmamble Powdered Preform Process (P4) for Automotive Composite Structures

• Initial Automotive Composites Durability Guidelines

• Optimization of Al Castings

• Mg Casting for Structural and Powertrain Applications

• Initial (?) Identification of Emerging Lower-Cost Ti Production Processes

# Summary and Thoughts



•FreedomCAR supports research, development, demonstration and deployment (RDD&D) to increase the energy efficiency of vehicles and the use of alternative fuels, especially hydrogen.

• Lightweighting is addressed by FreedomCAR to help minimize overall costs of vehicles, especially those powered by hydrogen-fueled fuel-cells.

• Such applied R&D is best done when the potential implementer(s) is(are) involved from the start.

• The ultimate implementation decisions are more apt to be based on economic and political factors than technical factors.

# Summary and Thoughts

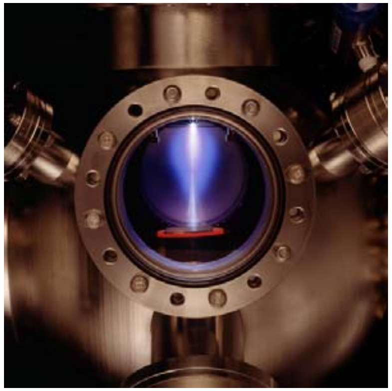


- Has the $200M + spent by FreedomCAR and PNGV on automotive lightweighting been worth it?
    - Commercial implementations and formal evaluations would indicate “yes.”
    - Too early to tell quantitatively?
    - At least we know the technical and costs parameter space better

- Qualitatively, the greatest value may have been in fostering government-industry collaborations.
    - Industry brought their “A Teams”

# http://www.eere.energy.gov

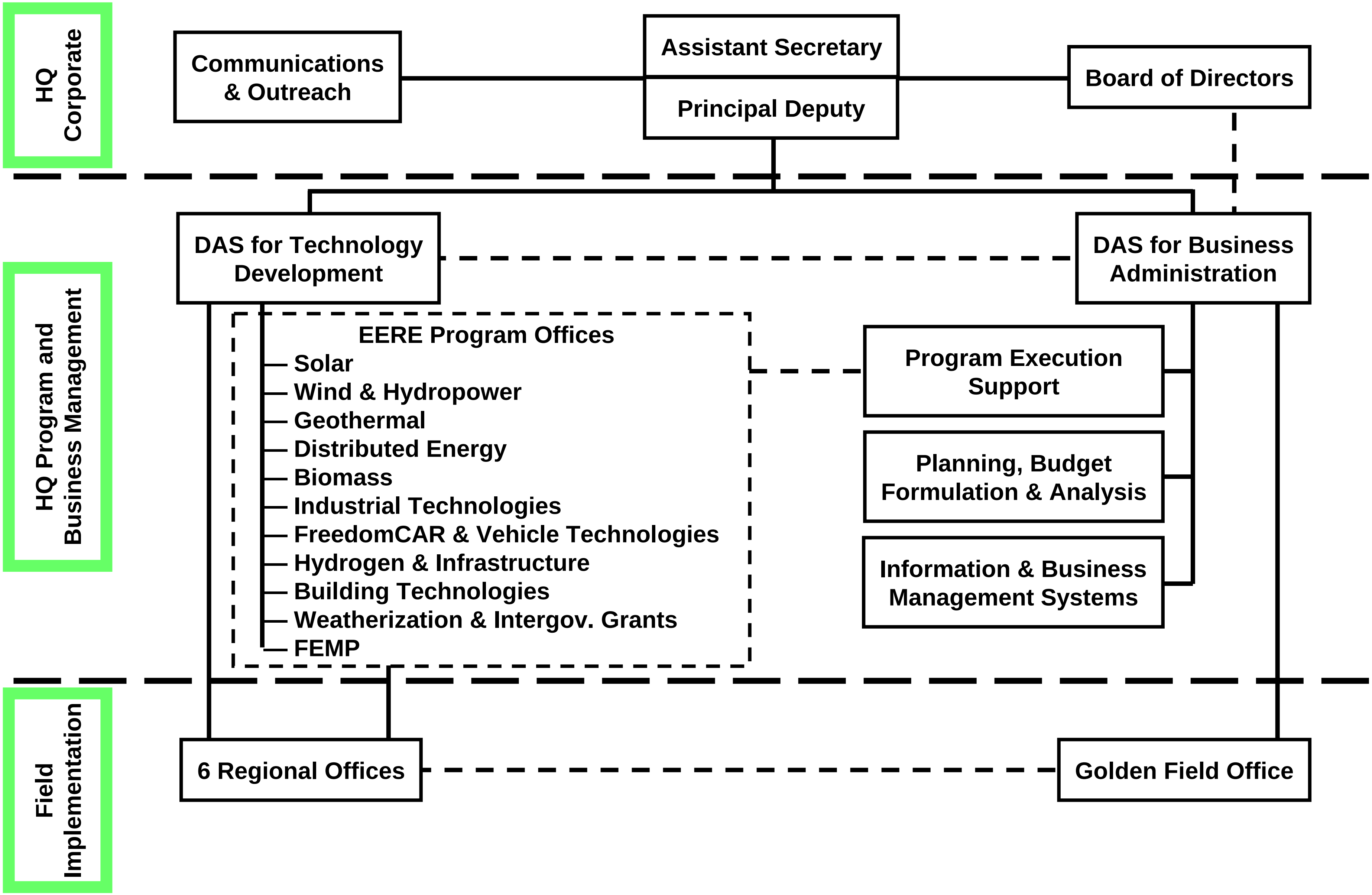




***Bringing you a prosperous future where energy is clean, abundant, reliable, and affordable***

# *Back-up Slides*

# EERE Organization



# Vehicle Materials Technologies

## Propulsion Materials

### Automotive PMs
Ro Sullivan

- Electric Drive System Materials (4)
- Combustion System Materials (8)

### Heavy Vehicle Propulsion Materials
Dr. James Eberhardt

- Fuel Systems Materials (1)
- Exhaust Aftertreatment System (8)
- Handling, Hot Section, & Structural Components (5)
- Testing and Materials (4)
- Innovative Materials (7)
- Engine Materials (16)

## Lightweight Materials

### Automotive Lightweighting Materials
Dr. Joe Carpenter

- Low Cost Carbon Fiber Production (7)
- Carbon Fiber Composites Processing (1)
- Composite Enabling (4)
- Crashworthiness (2)
- Joining (2)
- Casting (4)
- Sheet & Extrusion Fabrication (1)
- Steel (3)
- Recycling (5)
- Miscellaneous (3)
- Management, Planning & Assessments (3)
- Non-Destructive Evaluation (3)
- USAMP Cooperative Agreement (30)

### High Strength Weight Reduction
Dr. James Eberhardt

- Application of Innovative Materials (8)
- Lightweight Vehicle Structures (7)
- Materials Development (10)
- Processing Techniques (5)
- Enabling Technologies (19)

### High Temperature Materials Laboratory

Dr. James Eberhardt

(number of agreements)

# Materials Portfolio Funding

## DOE Automotive Lightweighting Materials - Operation

**Shared Materials R&D Philosophy**

**Direct-funded Research**

**Materials Tech Team**

National Labs
Universities
Contractors

**USAMP/DOE Cooperative Agreement**

**USAMP – Steering Committee**

- **Automotive Metals Division (AMD)**
- **Automotive Composites Consortium (ACC)**
- **Auto/Steel Partnership (A/SP)**

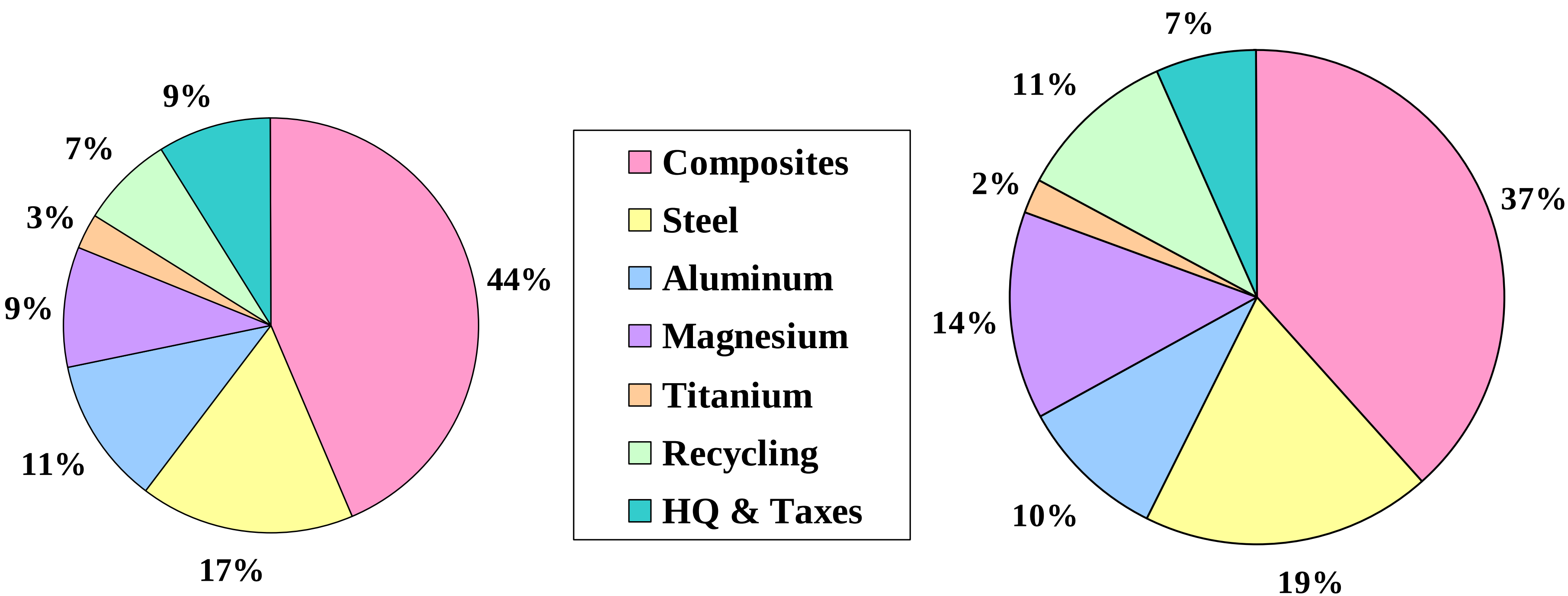
[teams of OEM’s, Suppliers, Universities]

**ALM Program**
**DOE Investment (Approx $19 M.)**

| | | |
|---|---|---|
| **Direct Funded Projects Approx $12 M** | **USAMP Cooperative Agreement Approx.$7 M.** | **OEM and Supplier In kind Approx. $7 M** |

**Equal Match**

# Budget Distribution by Technical Area




DOE Funds

DOE Funds + Industrial In-Kind

# Material Use in Some PNGV Concept Vehicles

*Materials Technologies*

| 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

# Design & Product Optimization for Cast for Cast Light Metals

## Cooperative Resources

USAMP

ORNL

AFS

SNL

WMT&R

Technology for Rapid Application of Light Metal Structural Castings

Customers: OEM's and Suppliers

LLNL

Entelechy

DOE

Geo. Tech.

32 Suppliers & Big 3

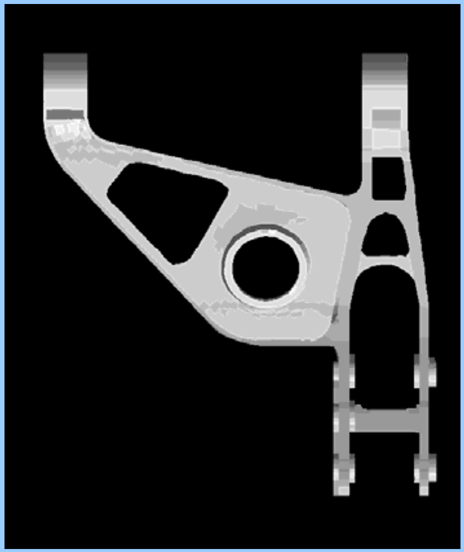
# Design & Product Optimization for Cast for Cast Light Metals

## Material & Technology

**Using New Technology to Further Reduce Component Weight**

Original - Nodular Iron
16 lbs.

Conversion to Cast
Aluminum 6.7 lbs.



Application of Simulation
Tool 5.4 lbs..

58% Savings

20% Savings

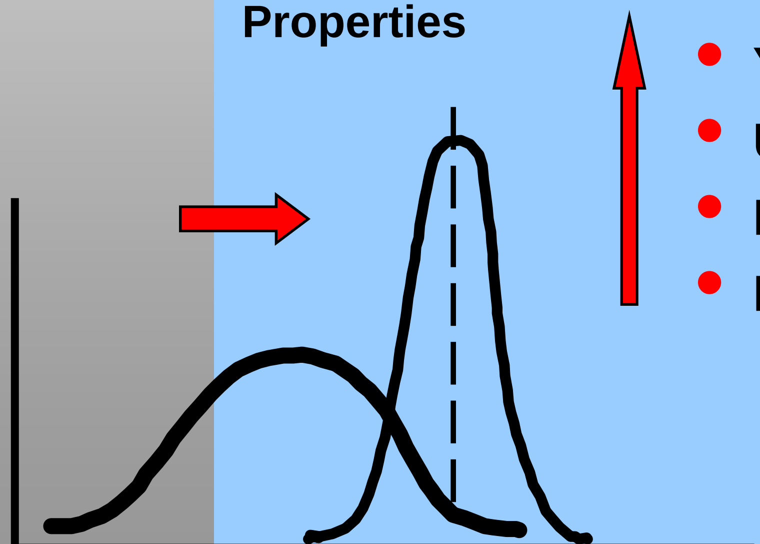
**Component Weight Reduction**

# Design & Product Optimization for Cast for Cast Light Metals

## Property Influence

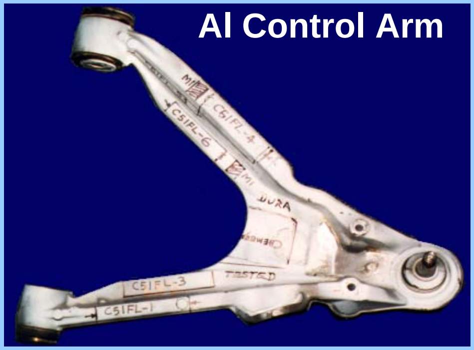
Reduced material property variation combined with an increasing mean leads to …… = Lower Cost & Weight

Material Properties

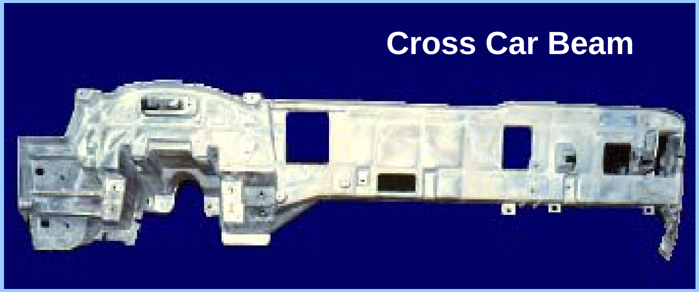


- YS
- UTS
- Ductility
- Fat.Str.

mean



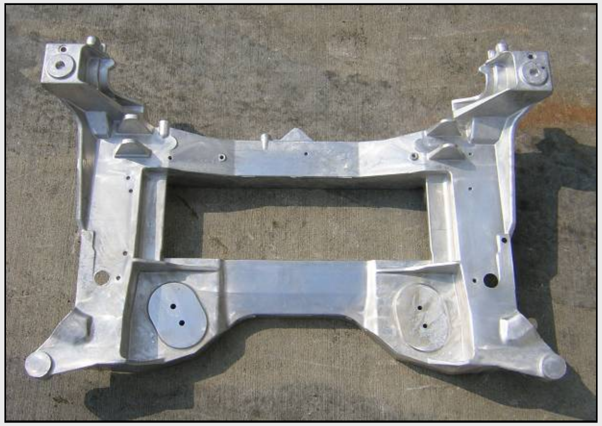




## Mg Cradle on 2006 Corvette Z06

**Benefits:**

- Mass Reduction: Mass savings of 5.6 kg (34%)
  - Mass Delta: 16.4 kg (Al) to 10.8 kg (Mg)
- Improved vehicle performance
- Avoidance of $1000/car gas guzzler tax
- Very high visibility



# Focal Project II - Glass Fiber

*Vehicle Systems*

MATERIALS | JOINING | ENERGY MANAGEMENT | PROCESSING


**Compared to Steel Baseline**

25% lighter | Greater Durability

Equal cost | Equal Safety

1 part every 4 min achieved

50 lb lighter - 15 lb lighter tailgate

No painting necessary

Impact and Corrosion Resistant

Tailgate Load Capacity 1000lb vs 600lb steel