FreedomCAR Automotive Lightweighting Materials

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(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

Can We Sustain Increasing Consumption?

Annual World Oil Production (Billions of Barrels)

Projected Growth in Light-Duty Vehicle Registrations

Estimates of Remaining Oil Reserves
China, with 13 vehicles per 1000 people, is where the U.S. was in 1913.
World Fossil Fuel Potential

World fossil liquid resources

Billions of barrels in-place

<table>
<thead>
<tr>
<th>Category</th>
<th>Billions of Barrels</th>
</tr>
</thead>
<tbody>
<tr>
<td>US. Crude</td>
<td>0</td>
</tr>
<tr>
<td>World Crude</td>
<td>1000</td>
</tr>
<tr>
<td>US Oil Shale</td>
<td>1200</td>
</tr>
<tr>
<td>Alberta Tar Sand</td>
<td>1300</td>
</tr>
</tbody>
</table>
Materials Technologies

billion barrels of oil equivalent

Source: Shell, 2000

Unconventional Oil

Produced at 1.1.2000

Oil and Substitute Costs

2000 $ per boe

Source: Shell, 2000
Renewable Resources are Adequate to Meet all Energy Needs

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.
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)

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.


• 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.
• 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.
Materials Technologies

I. Technology Development Phase
II. Initial Market Penetration Phase
III. Infrastructure Investment Phase
IV. Fully Developed Market and Infrastructure Phase

Timeline

Phase I
- RD&D
- Commercialization Decision

Phase II
- Transition to the Marketplace

Phase III
- Expansion of Markets and Infrastructure

Phase IV
- Realization of the Hydrogen Economy

Timeline:

- 2000
- 2010
- 2020
- 2030
- 2040
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)
<table>
<thead>
<tr>
<th>Materials Technologies</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Efficiency</strong></td>
</tr>
<tr>
<td>Fuel Cell System</td>
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<tr>
<td>Hydrogen Fuel/Storage/Infrastructure</td>
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<tr>
<td>Electric Propulsion</td>
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<tr>
<td>Electric Energy Storage</td>
</tr>
<tr>
<td>Materials</td>
</tr>
<tr>
<td>Engine Powertrain System**</td>
</tr>
</tbody>
</table>

* Cost references based on CY2001 dollar values
** Meets or exceeds emissions standards.
Materials in a Typical Family Vehicle

1977 Model Year
- Iron and Regular Steel: 74%
- Hi/Med Strength Steel: 3%
- Polymer/Composite: 5%
- Aluminum: 3%
- Magnesium: 0%
- Other: 15%

2004 Model Year
- Iron and Regular Steel: 62%
- Hi/Med Strength Steel: 12%
- Polymer/Composite: 8%
- Aluminum: 9%
- Magnesium: 0.3%
- Other: 9%

(Source: American Metal Market)
## Weight Savings and Costs for Automotive Lightweighting Materials

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

*Includes both materials and manufacturing.

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


- **Casting**
  - Al
  - Mg
- **Wrought**
  - Al
  - AHSS
  - Mg
- **Fiber-Reinforced Polymer-Matrix Composites Processing**
  - Glass-fiber-reinforced
  - Carbon-fiber-reinforced
- **Low-Cost Carbon Fiber**

(FP1)
<table>
<thead>
<tr>
<th>Year</th>
<th>Metal Production</th>
<th>Joining</th>
<th>Nondestructive Testing</th>
<th>Crashworthiness (FP1)</th>
<th>Recycling</th>
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<tr>
<td>1990</td>
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<td>1995</td>
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<td>2005</td>
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<tr>
<td>2010</td>
<td></td>
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</tbody>
</table>
ALM Historical Timeline – Minor Materials


Metal-Matrix Composites

Titanium

Steel

Glazing (Glass)

ULSAB
FreedomCAR Automotive Lightweighting Materials Highlights

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

- Programmable 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”
Bringing you a prosperous future where energy is clean, abundant, reliable, and affordable
Back-up Slides
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**

- Composites: 44%
- Steel: 17%
- Aluminum: 11%
- Magnesium: 9%
- Titanium: 3%
- Recycling: 7%
- HQ & Taxes: 9%

**DOE Funds + Industrial In-Kind**

- Composites: 37%
- Steel: 19%
- Aluminum: 14%
- Magnesium: 11%
- Titanium: 10%
- Recycling: 7%
- HQ & Taxes: 2%

## Table 3. Material Use in PNGV Vehicles (lbs.)

<table>
<thead>
<tr>
<th>Material</th>
<th>1994 Base Vehicle</th>
<th>P2000</th>
<th>ESX2</th>
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<tbody>
<tr>
<td>Plastics</td>
<td>223</td>
<td>270</td>
<td>485</td>
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<tr>
<td>Aluminum</td>
<td>206</td>
<td>733</td>
<td>450</td>
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<tr>
<td>Magnesium</td>
<td>6</td>
<td>86</td>
<td>122</td>
</tr>
<tr>
<td>Titanium</td>
<td>0</td>
<td>11</td>
<td>40</td>
</tr>
<tr>
<td>Ferrous</td>
<td>2168</td>
<td>490</td>
<td>528</td>
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<tr>
<td>Rubber</td>
<td>138.5</td>
<td>123</td>
<td>148</td>
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<tr>
<td>Glass</td>
<td>96.5</td>
<td>36</td>
<td>70</td>
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<tr>
<td>Lexan</td>
<td>0</td>
<td>30</td>
<td>20</td>
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<tr>
<td>Glass fiber</td>
<td>19</td>
<td>0</td>
<td>60</td>
</tr>
<tr>
<td>Carbon Fiber</td>
<td>0</td>
<td>8</td>
<td>24</td>
</tr>
<tr>
<td>Lithium</td>
<td>0</td>
<td>30</td>
<td>30</td>
</tr>
<tr>
<td>Other</td>
<td>391</td>
<td>193</td>
<td>273</td>
</tr>
<tr>
<td><strong>Total Weight</strong></td>
<td><strong>3248</strong></td>
<td><strong>2010</strong></td>
<td><strong>2250</strong></td>
</tr>
</tbody>
</table>

*Source: Ducker 1998*
Design & Product Optimization for Cast for Cast Light Metals

Cooperative Resources

USAMP
ORNL
SNL
LLNL
DOE
AFS
WMT&R
Entelechy
Geo. Tech.

Technology for Rapid Application of Light Metal Structural Castings

Customers: OEM’s and Suppliers

32 Suppliers & Big 3

USAMP Project
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.

Component Weight Reduction

58% Savings
20% Savings

USAMP Project
Property Influence

Reduced material property variation combined with an increasing mean leads to ......

Material Properties

- YS
- UTS
- Ductility
- Fat. Str.

= Lower Cost & Weight
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

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