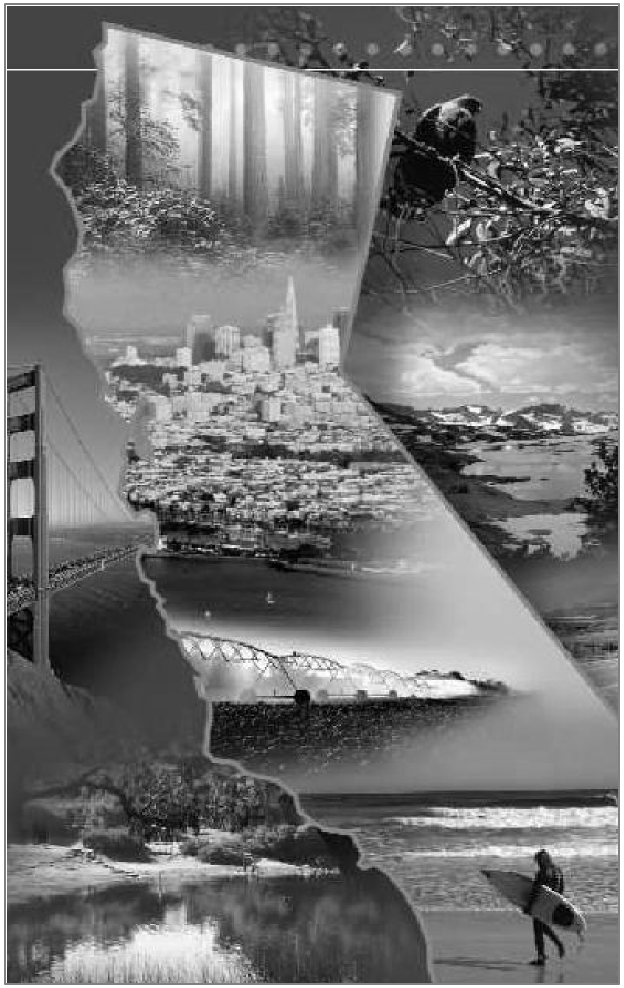
Survey of vehicle mass-reduction technology trends and prospects



Nic Lutsey
El Monte, California
May 18th, 2010

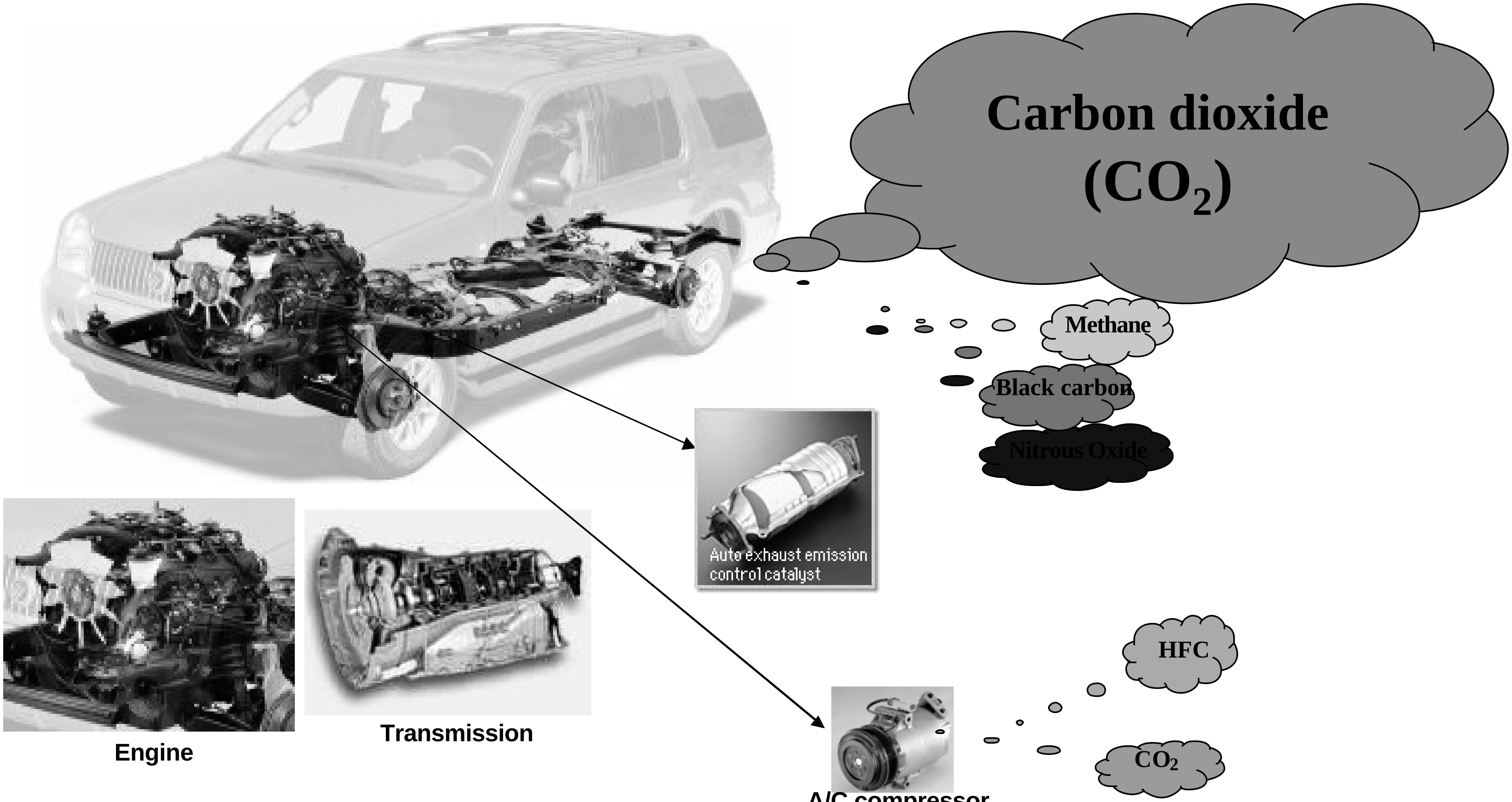
Outline

- Introduction: CO_2 reduction technologies
- Vehicle mass-reduction technology
  - Mass-reduction techniques
    - Background, advanced materials, components, designs
  - Potential for future designs
    - Prototypes, concepts
- Objective
  - Highlight emerging mass-reduction technology trends
  - Examine the technology potential for the 2025 timeframe

This a presentation based on the following report:

Lutsey, N., 2010. *Review of technical literature and trends related to automobile mass-reduction technology*. Institute of Transportation Studies, University of California, Davis, UCD-ITS-RR-10-10. http://pubs.its.ucdavis.edu/publication_detail.php?id=1390

Vehicle GHG emissions



GHG-Reduction Technologies

- There are many promising CO_2-reduction technologies for vehicles
- Vehicle design and electric-drive technologies could be increasingly critical

Area	Technology or mechanism for CO_2 reduction		Potential CO_2 reduction *	U.S. adoption in 2008 fleet #
		Variable valve timing or lift	2-8%	53%
		Cylinder deactivation	3-6%	6%
		Turbocharging	2-5%	2%
	Engine	Gasoline direct injection	8-15%	4%
		Compression ignition diesel	15-40%	0.1%
Powertrain		Digital valve actuation	5-10%	0%
		Homogeneous charge compress. ignition	15-20%	0%
		6+ speed	3-5%	21%
	Transmission	Continuously variable	4-6%	8%
		Dual-clutch, automated manual	4-8%	1%
	Aerodynamics		5-8%	-
	Tire rolling resistance		2-8%	-
	More efficient auxiliaries (steering, air conditioning)		2-10%	-
Vehicle	**Mass-reduction**	**Advanced material component**	**5-10%**	-
		Integrated vehicle design	**10-20%**	-
	Hybrid systems	Stop-start mild hybrid	5-10%	<1%
		Full hybrid electric system	20-50%	2%
	Electric-drive	Plug-in capable electric vehicles	30-75%	0%
		Fuel cell vehicles	30-75%	0%

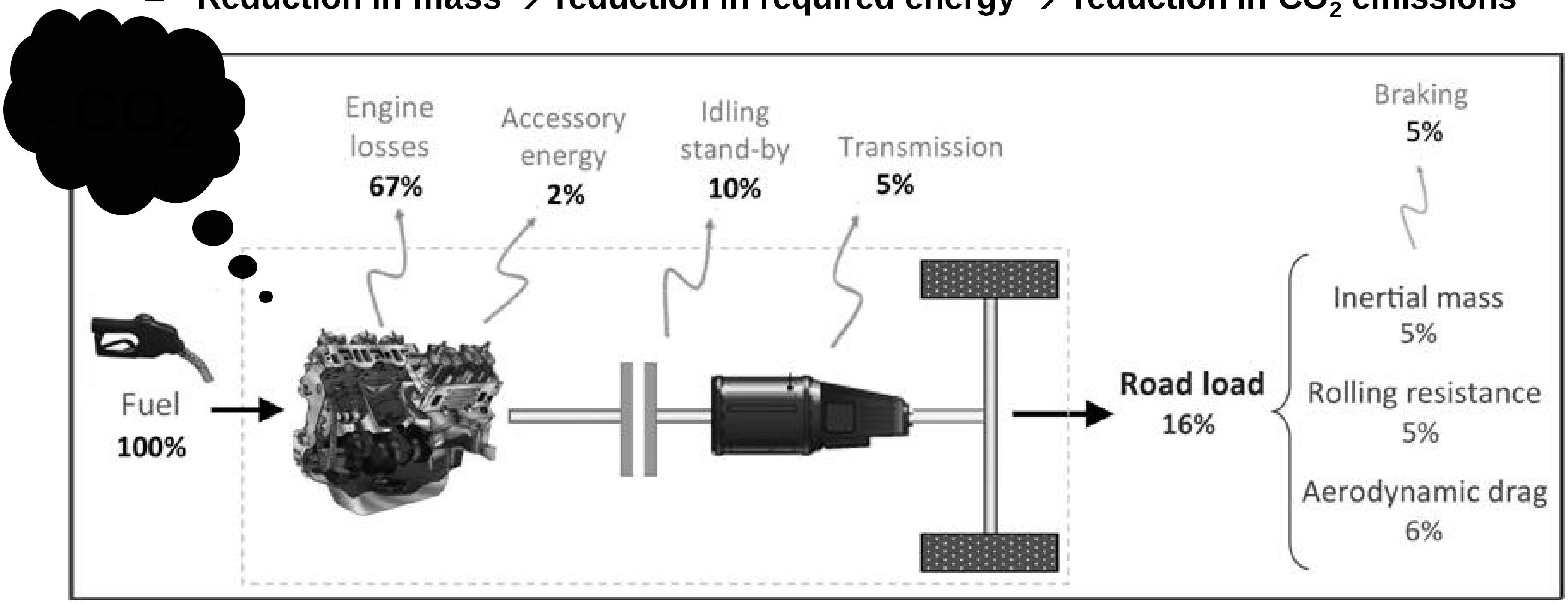
Critical nearer term CO_2 reduction technologies (Variable valve timing or lift through More efficient auxiliaries)

Critical medium and long-term CO_2 reduction technologies (Aerodynamics through Fuel cell vehicles)

**** Many technologies can be combined, but percents are not strictly additive; Estimations are based on primarily on US EPA/NHTSA, 2010; # From US EPA, 2009 "Trends" report***

Background: Mass and CO_2 emissions

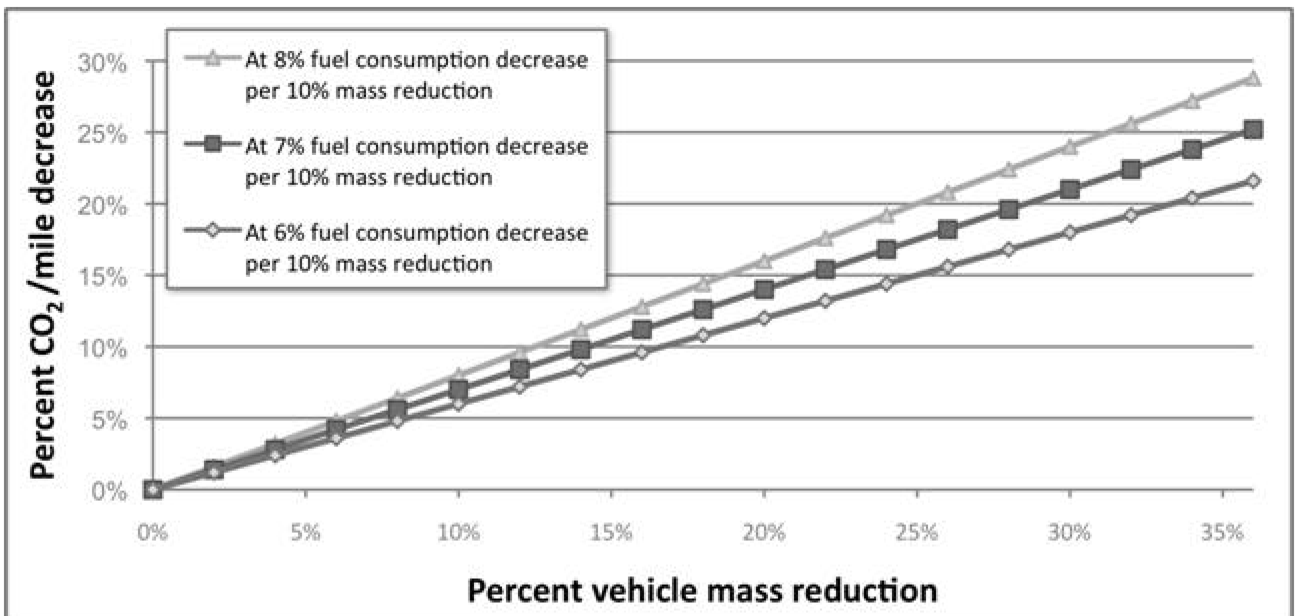
- **Vehicle mass is fundamental part of vehicle CO_2 emissions**
  - **Efficiency is the ability of a powertrain to convert energy into vehicle propulsion**
  - **The ultimate vehicle "road load" is tied directly to the vehicle mass**
  - **Reduction in mass → reduction in required energy → reduction in CO_2 emissions**



Approximately based on U.S. city and highway drive cycles (Kromer and Heywood, 2008); in addition to inertial mass and rolling resistance hill-climbing is also directly linked to vehicle mass, percent vehicle energy use and loss vary greatly according to vehicle technology and drive cycle.

Background: Mass and CO_2 emissions

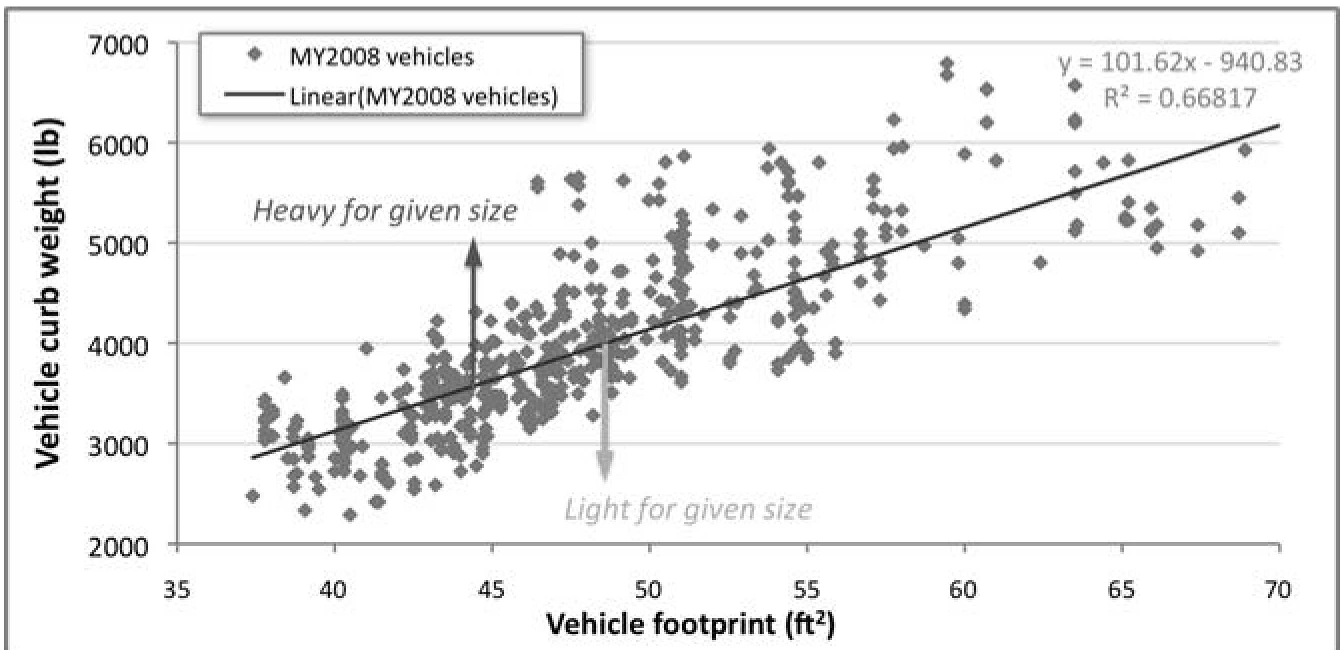
- **Mass has a large effect on vehicle CO_2 emissions**
  - **With vehicle mass-reduction technology, CO_2 emissions are decreased due to reduced vehicle road loads (i.e., inertial acceleration, rolling resistance, grade)**
  - **For constant performance, 20% mass-reduction → ~12-16% CO_2/mi decrease**



Sources: Casadei and Broda, 2008; Bandivadekar et al, 2008; FKA, 2007; Pagerit, et al, 2006. Effects differ by drive cycle (greater effect in city/urban, lesser effect in highway conditions)

Use of Mass-Reduction Technology

- **<u>Today's vehicles</u> use different amounts of mass-reduction technology**
  - **For a given size and functionality, some models are heavy (by over 40%)**
  - **Models with more mass-reduction technology can by 20-25% lighter (for a given size)**
  - **Some automakers use far more mass-reduction technology across all their models**



Among the distinguishing underlying factors on relative vehicle weight are the use of advanced materials (e.g., high-strength steels, aluminum) and mass-optimized designs

Mass-Reduction: Automaker Plans

- **Major efforts to reduce vehicle mass <u>are underway</u>**

Company	Quote, statement, or commitment
Ford	• From 2011 to 2020: "Full implementation of known technology… weight reduction of 250-750 lbs" • "The use of advanced materials such as magnesium, aluminum and ultra high-strength boron steel offers automakers structural strength at a reduced weight to help improve fuel economy and meet safety and durability requirements
Toyota	• 10-30% weight reduction for small to mid-size vehicles
Volkswagen	• "Automotive light weight solutions are necessary more than ever to reduce CO_2 emissions " • "Multi-Material Concepts promise cost effective light weight solutions "
GM	• "We… are likely to use more lightweight materials in the future" • "One trend is clear - vehicles will consist of a more balanced use of many materials in the future, incorporating more lightweight materials such as nanocomposites and aluminum and magnesium."
Mazda	• Reduce each model by 220 lb by 2015; another 220 lb by 2020
Nissan	• Average 15% weight reduction by 2015 • "We are… expanding the use of aluminum and other lightweight materials, and reducing vehicle weight by rationalizing vehicle body structure
BMW	• "Lightweight construction is a core aspect for sustainable mobility improving both fuel consumption and CO_2 emissions"
Renault	• "To meet commitments on CO_2 emission levels, it is important that we stabilize vehicle weight as from now, and then start bringing it down."

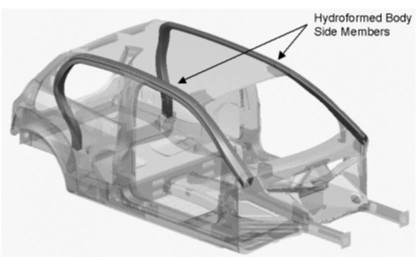
Use of Mass-Reduction Technology

- **One example: the 2011 Porsche Cayenne**
  - **The model year 2011 offers a 10% weight reduction from mass-reduction technology**
  - **550-lb reduction (with 154 lb of added amenities) → 396 lb net reduction**
    - **And actually slightly *larger* size than 2010; also Porsche's first hybrid offering**

Source: Stahl, A., 2010. "2011 Porsche Cayenne breaks cover in Germany." http://www.insideline.com/porsche/cayenne/2011/2011-porsche-cayenne-breaks-cover-in-germany.html. January 8. Accessed April 7

Vehicle Mass and Body Mass

- **The <u>vehicle body</u> or "body-in-white"**
  - **Core structure and frame of the vehicle; roughly one-quarter of vehicle mass**
  - **Fundamental to the core structure and integrity of the vehicle**
  - **Often the critical part of the vehicle that is designed in mass-reduction concepts**



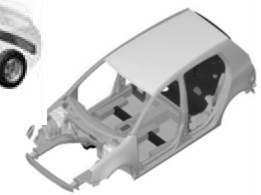
System	Major components in system
Body-in-white	Passenger compartment frame, cross and side beams, roof structure, front-end structure, underbody floor structure, panels
Powertrain	Engine, transmission, exhaust system, fuel tank
Chassis	Chassis, suspension, tires, wheels, steering, brakes
Interior	Seats, instrument panel, insulation, trim, airbags
Closures	Front and rear doors, hood, lift gate
Miscellaneous	Electrical, lighting, thermal, windows, glazing

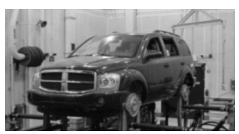
Vehicle Body Mass Reduction

- <u>Major reductions</u> from production vehicles, prototypes, design concepts
  - Many designs with 20%, 30%, 40%+ reduction of vehicle body mass





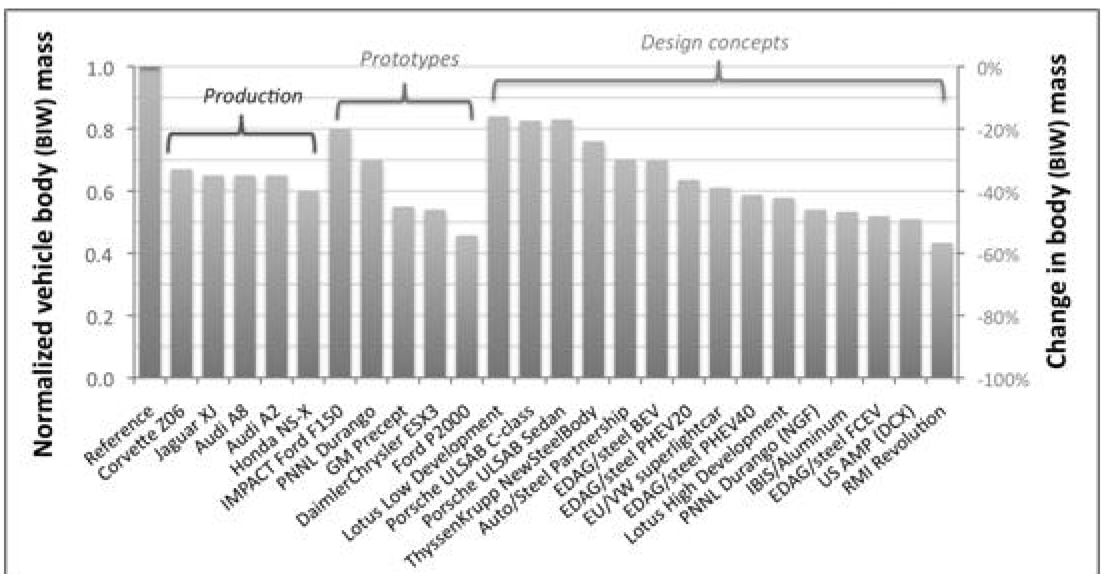






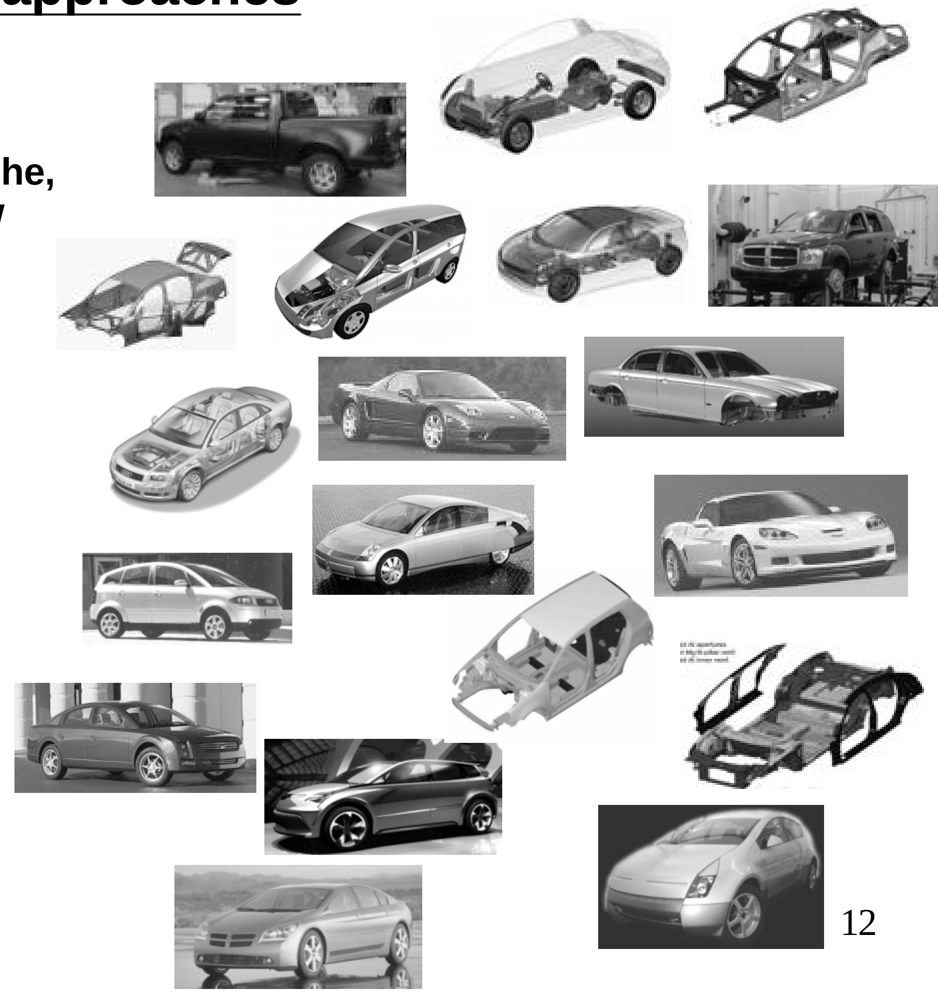




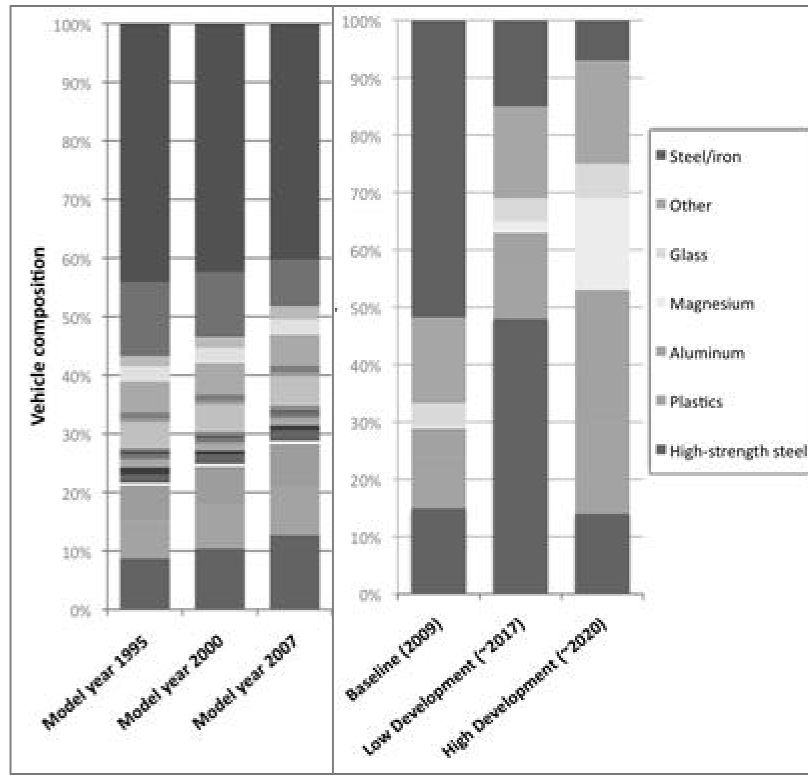
Vehicle Mass Reduction: Strategies

- **Major reductions from <u>different approaches</u>**
  - **Steel-intensive design**
    - **15-40% reduction**
    - **Many OEMs, ThyssenKrupp, Porsche, Auto/Steel, EDAG, Ford, Lotus, VW**
  - **Aluminum-intensive design**
    - **30-45% reduction**
    - **Audi, GM, Honda, Jaguar, Ford**
  - **Multi-material design**
    - **30-50% reduction**
    - **VW/Superlight car, Lotus, DCX**
  - **Carbon-intensive design**
    - **40-60% reduction**
    - **Dodge, RMI**



Vehicle Mass Reduction: Materials

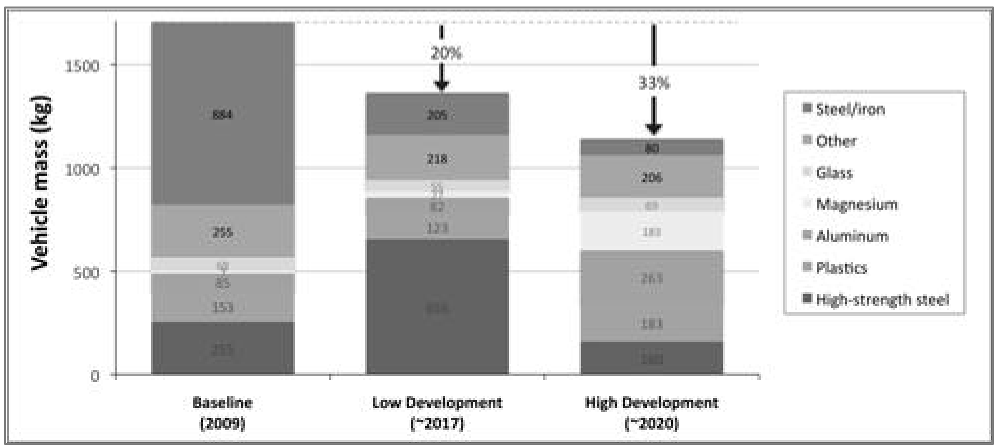
- **<u>Material composition</u>: a continuation of past trends**
  - **From 1995 to 2007**
    - **Magnesium: +100%**
    - **Aluminum: +22%**
    - **Plastics/composites: +25%**
    - **High-strength steels: +45%**
  - **Lotus baseline to Low Development**
    - **Magnesium: 3x**
    - **High-strength steels: 1.6x**
  - **Lotus baseline to High Development**
    - **Magnesium: 26x**
    - **Aluminum: 2x**
    - **Plastics/composites: +20%**



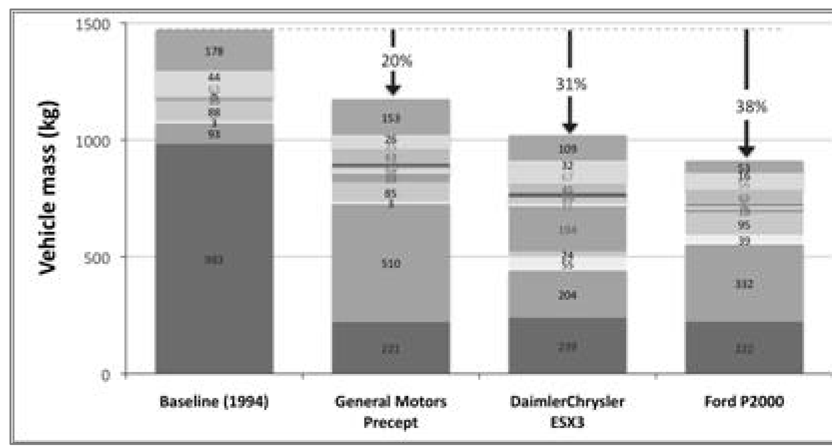



Overall Vehicle Mass Reduction

- **Materials and designs can offer promising vehicle mass reduction**
  - **Lotus (2010) designs use some similar techniques, materials of the PNGV (~2000) models**
  - **Both show range of approaches with 20-33%+ vehicle mass reduction**
  - **But now many new low-cost techniques are proven in existing vehicles**



Lotus Engineering (2010) mass-reduction study



Partnership for a New Generation Vehicles (PNGV) program





Sources: *Lotus, 2010. An Assessment of Mass Reduction Opportunities for a 2017-2020 Model Year Vehicle Program. March.*
Schexnaydor et al, 2001. Environmental Evaluation of New Generation Vehicles and Vehicle Components.

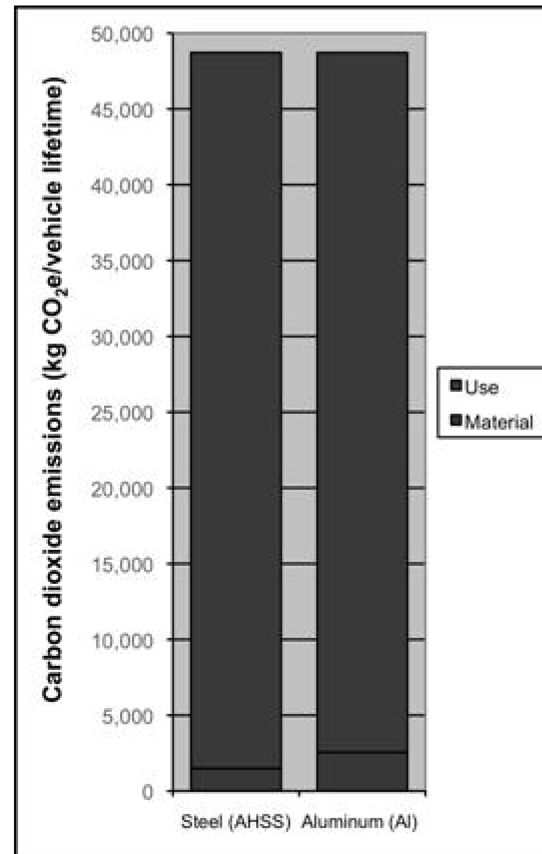
Mass-Reduction: Costs

- **Some of the mass-reduction projects also estimate costs**
  - **Near-term incremental approaches - up to 20% - have minimal costs**
  - **More advanced technologies (~30% mass reduction) could have more substantial vehicle manufacturing cost increases.**

Automaker	Findings related to vehicle costs of mass-reduction technology
Ford F150 "IMPACT"	• 19% mass reduction at zero net cost • 25% mass reduction at $500 increase in variable vehicle cost
ThyssenKrupp "New Steel Body"	• 24% body mass reduction at 2% manufacturing cost increase
IBIS aluminum	• 40%+ body mass reduction for $500-600 cost increase (aluminum body) • 17% vehicle mass reduction for $100-200 vehicle cost increase
Volkswagen-led "Super Light Car"	• 22% body mass reduction "multi-material, economic" at <5 €/kg • 39% body mass reduction "multi-material, advanced" at <10 €/kg
Lotus "Low Development"	• 20% vehicle mass decrease causes 2% decrease in cost (~$300/vehicle)
Lotus "High Development"	• 33% vehicle mass decrease causes 3% increase in cost (~$500/vehicle)

Mass-Reduction: Upstream CO_2

- **Some materials have larger upstream energy and CO_2 impacts**
  - **The vast majority of vehicle's CO_2 emissions are due their use of energy during driving**
    - **But manufacturing, end-of-life stages differ by material**
    - **And more efficient vehicles put increased proportion of energy/CO_2 impacts upstream**
  - **Materials, like aluminum and magnesium, are used on many mass-reduction designs and warrant further consideration of upstream impacts**

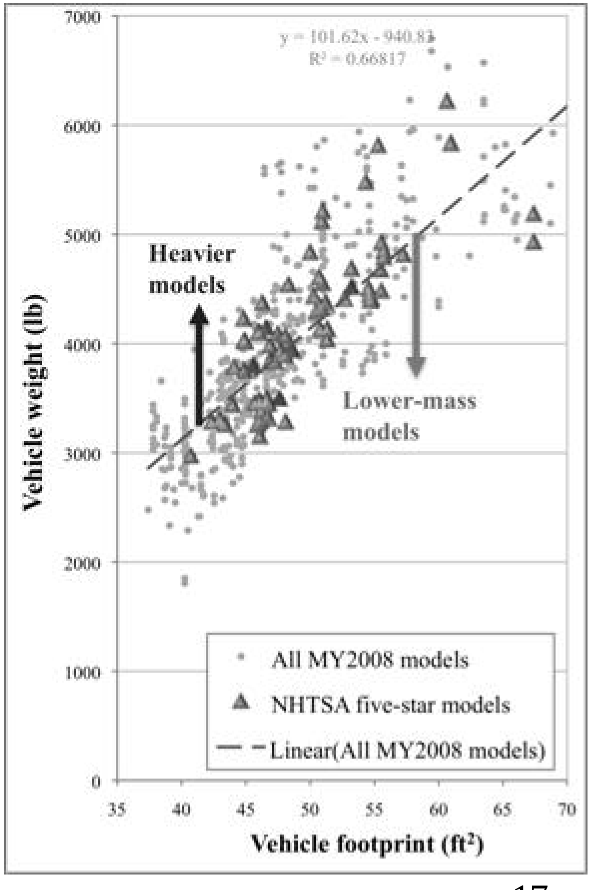


Source:
WorldAutoSteel, 2007. http://www.worldautosteel.org/Environment/Life-Cycle-Assessment/Automotive-Material.aspx

Mass-Reduction: Safety

- **Issues of safety is commonly raised with mass-reduction**
  - **From U.S. EPA and NHTSA:**

    “ …the likely deleterious safety effects of the MYs 2012-2016 standards may be much lower than originally estimated. They may be close to zero, or possibly beneficial if mass reduction is carefully undertaken in the future ”
  - **No known impacts from mass-reduced components (aluminum engine, carbon fiber roof, aluminum doors)**
  - **Many of the above projects found no compromises.**
  - **The recent studies (Lotus, Super Light Car, Future Steel Vehicle) continue to investigate structure, crashworthiness**
  - **Many Five-Star safety rated vehicles are no heavier for a given size than others**
    - **Half of them have lower mass than industry average**



Sources: *U.S. EPA and NHTSA. Final rule for MY2012-2016 CO2 and fuel economy standards.*
NHTSA 5-star safety ratings (frontal, side driver, side rear), model year 2008 (www.safercar.gov)

Conclusions

- Mass-reduction technology is a core efficiency technology
  - It has been, is being, and will continue to be deployed by automakers
- There is a variety of known approaches for mass-reduction
  - High-strength steel, aluminum, multi-material designs will all be prominent
  - Many off-the-shelf options for use of advanced materials, components
    - Deploying best-in-class options for components throughout the vehicle
    - Up to 20% mass reduction, minimal costs, near-term ~2015 availability
  - Many emerging concepts are available
    - New manufacturing techniques, greater use of advanced designs
    - Up to ~30-35% mass reduction, additional costs, mid-term ~2020 availability
- Areas for further study
  - Full manufacturer costs, crashworthiness, upstream CO_2 impacts, manufacturing phase-in, inclusion with electric-drive technologies.

Vehicle Mass Reduction: Conclusions

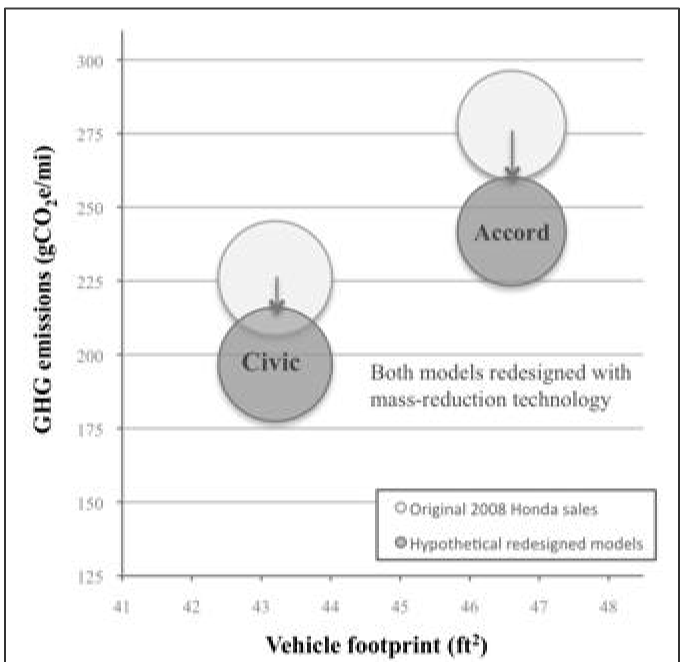
- **Acknowledgement**
  - **Study done under contract for California Air Resources Board**

- **See publication for documentation**
  - **Lutsey, N., 2010. *Review of technical literature and trends related to automobile mass-reduction technology*. Institute of Transportation Studies, University of California, Davis. UCD-ITS-RR-10-10. http://pubs.its.ucdavis.edu/publication_detail.php?id=1390**

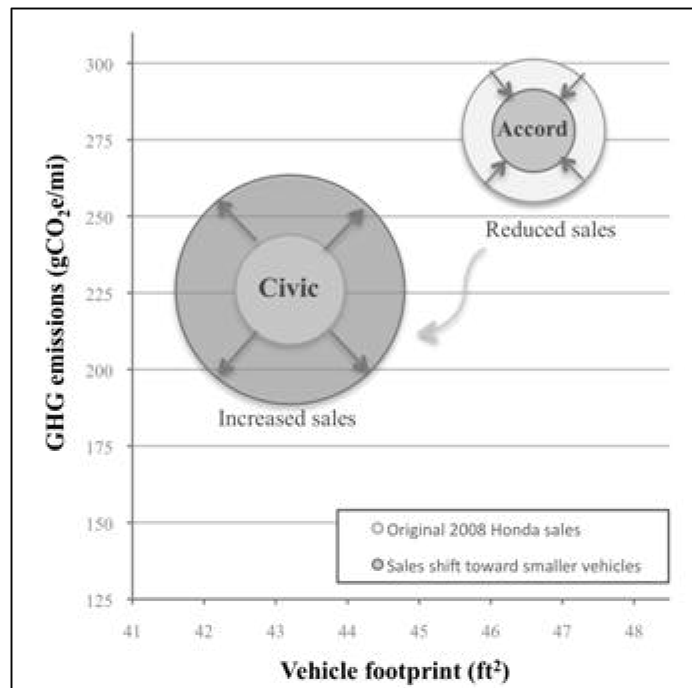
Mass-Reduction Technology
(and what it is not)

- **Vehicle mass-reduction technology is not "downsizing"**

  + ***Mass-reduction technology*: the redesign of vehicle models with advanced materials and designs for reduced mass (without compromise in vehicle space, utility)**



  – ***Downsizing*: referred to generally as a shifts in the fleet toward smaller vehicles**



Hybrid Technology: GHG Reduction

- **Hybrid vehicle models commercialized in U.S.**
  - **Span vehicles: compacts, sedans, crossovers, large SUVs, pickups**
  - **Average 33% CO_2/mi reduction, 50% mpg increase vs. similar non-hybrids**
  - **Hybrids also put an upward pressures on vehicle mass (~9%)**