Efficiency Technology Advancements

John German, ICCT

July 9, 2014

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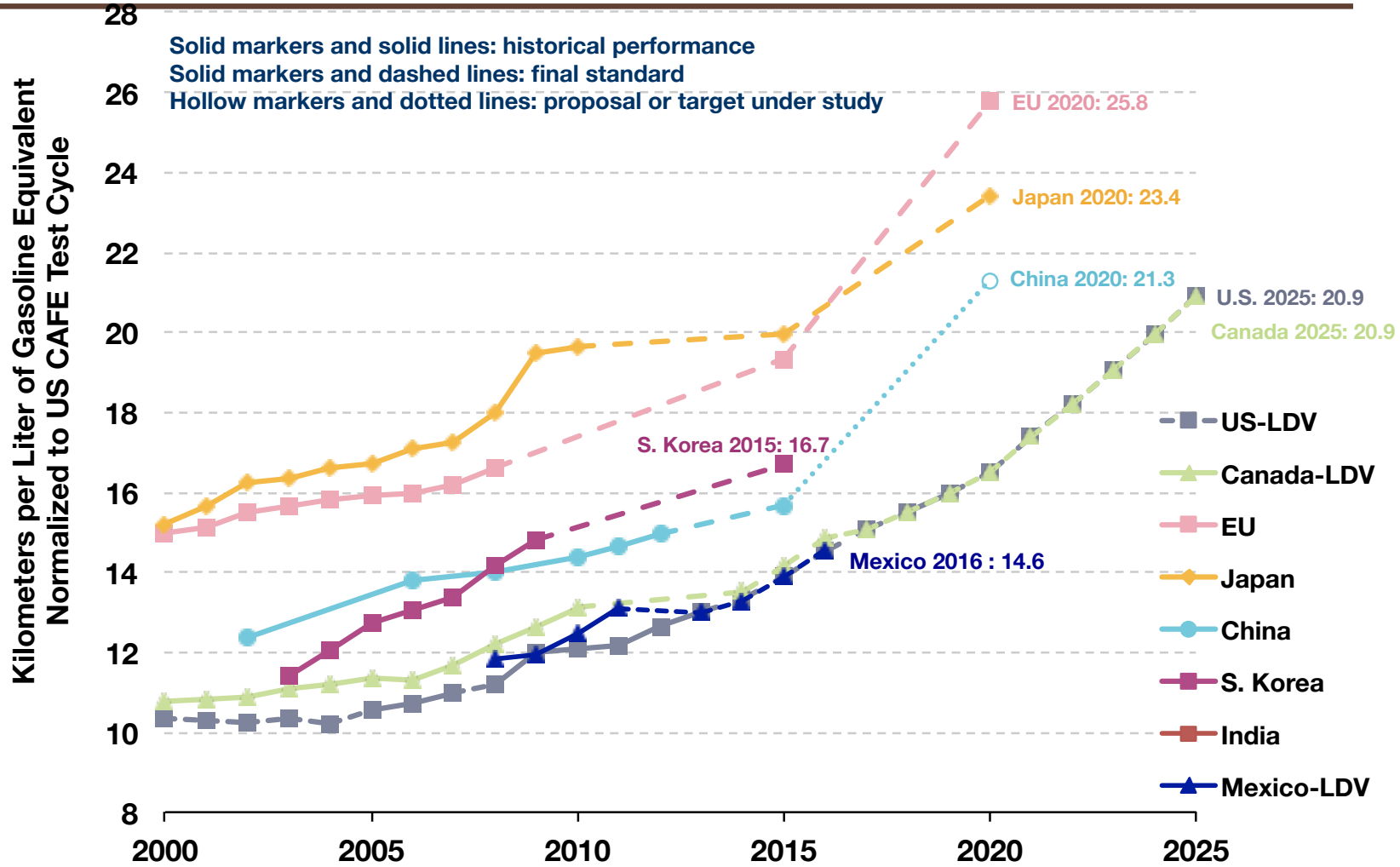
Passenger Car Fuel Economy Standards Globally



[1] China's target reflects gasoline vehicles only. The target may be higher after new energy vehicles are considered.
[2] US, Canada, and Mexico light-duty vehicles include light-commercial vehicles.
[3] Mexico does not include early action credits for MYs 2012 and 2013 but does include full application of other credits.

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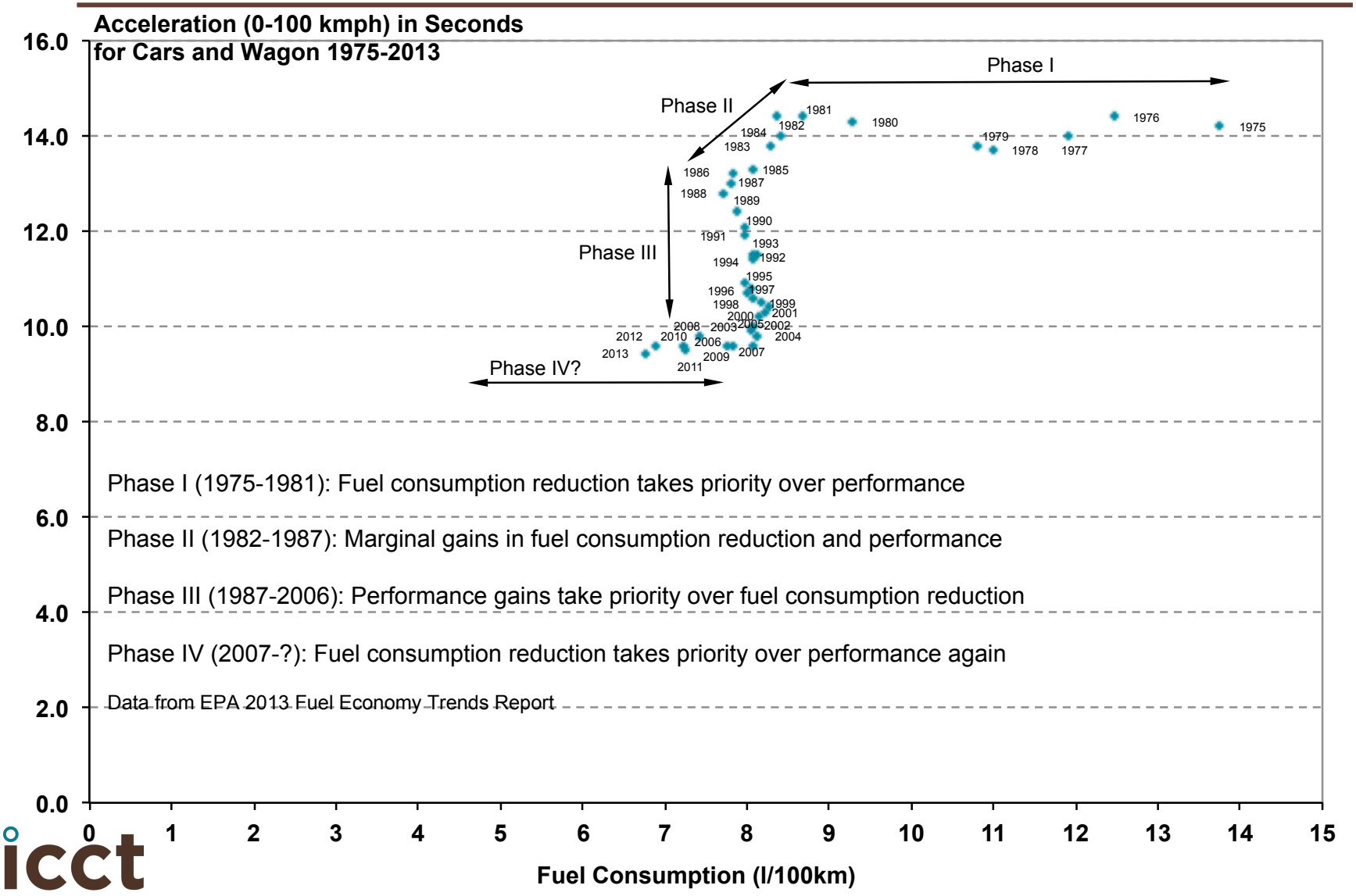
Role of Fuel Economy Standards in Managing Performance – Fuel Consumption Tradeoff: US Example



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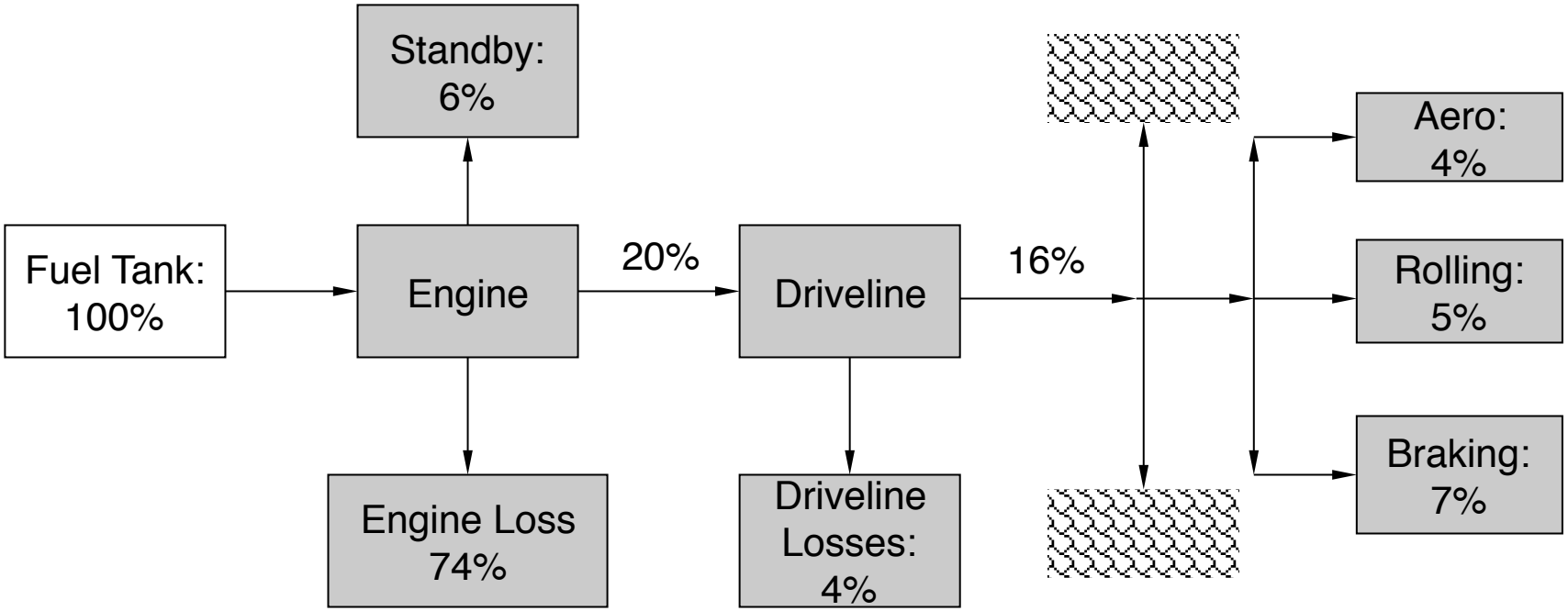
Technology Deployment Spurred by Fuel Economy Standards

Opportunities for Vehicle Efficiency Improvements



» Matt Kromer

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Urban Drive Cycle, 2005 2.5L Toyota Camry

The Real Technology Breakthrough

Computers

- Computer design, computer simulations, and on-vehicle computer controls are revolutionizing vehicles and powertrains
- Especially important for lightweight materials
  - Optimize hundreds of parts – size and material
  - Capture secondary weight – and cost – reductions
- The high losses in the internal combustion engine are an opportunity for improvement
- Also reducing size and cost of hybrid system

A broad suite of cost-effective technology packages are available to meet upcoming efficiency standards

- Assessment of US 2012-2025 standards indicates the standards can be met with:
  - Gasoline direct injection (GDI)
  - Turbocharged/downsized engines
  - Advanced transmissions (6-speed/8-speed automatic or dual-clutch transmissions and high efficiency gear box)
  - Vehicle mass reduction
  - Lower tire rolling resistance
  - Improved aerodynamics
  - Friction reduction
  - More efficient vehicle accessories
  - Engine start-stop systems
  - …..
  - …..
  - …..
  - Some increased hybrids, EVs, PHEVs

- No penetration of diesels or hybrid vehicles necessary to meet US 2016 standards.

EPA/NHTSA project that MY2025 vehicles will be 90% advanced gasoline, 9% hybrids, and 1% EV/PHEVs

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Accelerating Technology Introduction in the U.S. is driven by Fuel Economy Regulation

	GDI	Turbo	VVT	6 speed	7+ speed	CVT	Hybrid
2004	-	4%	43.7%	5%	0.4%	2%	1%
2005	-	2%	49.4%	6%	0.4%	3%	2%
2006	-	3%	58.2%	12%	2%	3%	2%
2007	-	4%	63.3%	16%	2%	10%	3%
2008	3%	4%	62.7%	19%	3%	11%	3%
2009	4%	4%	79.1%	19%	3%	11%	3%
2010	9%	4%	91.8%	33%	3%	14%	5%
2011	18%	8%	94.9%	54%	5%	12%	3%
2012	28%	10%	97.7%	58%	6%	15%	5%
2013	38%	16%	98.0%	61%	8%	17%	6%

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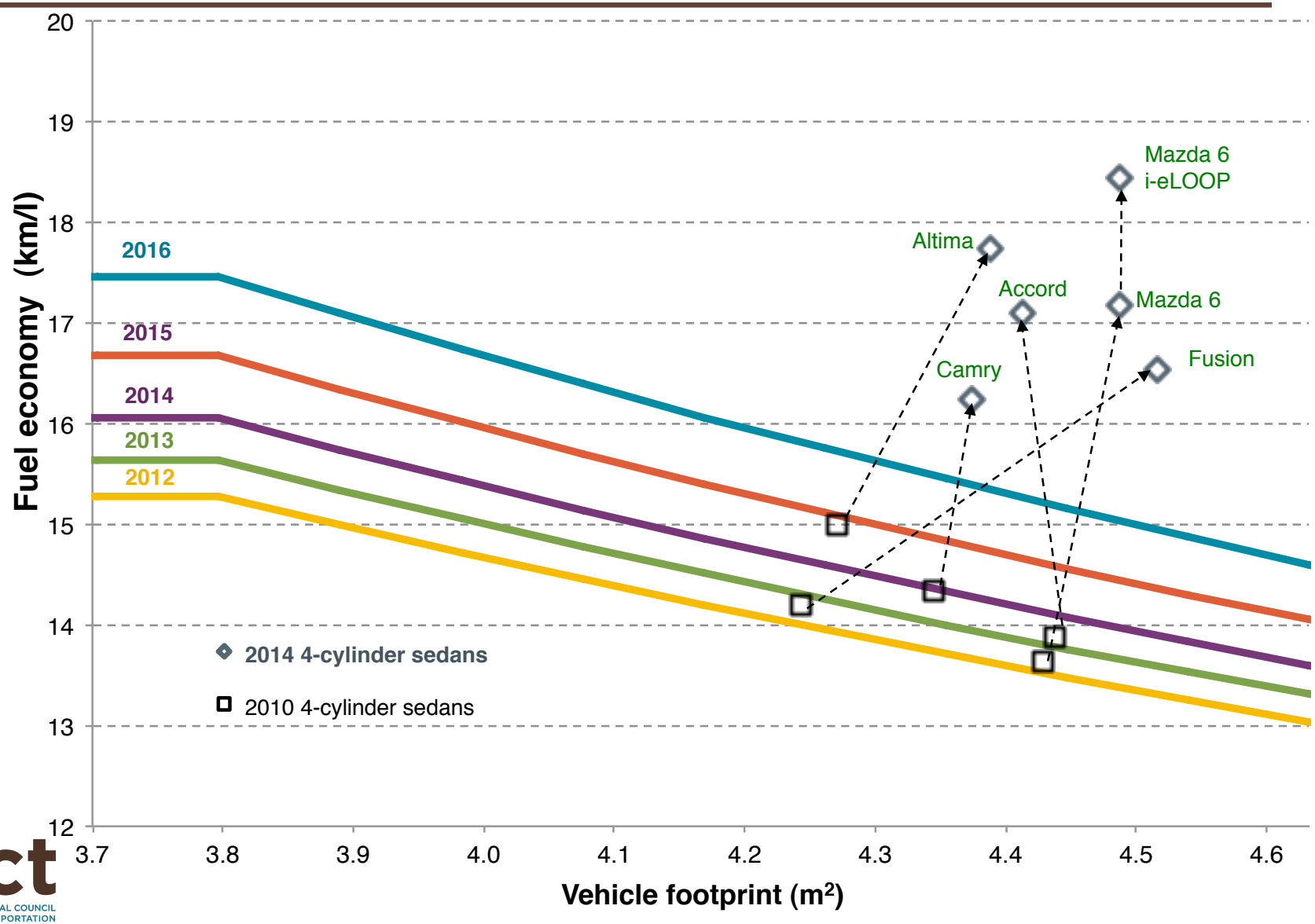
Source: 2013 EPA Fuel Economy Trends Report – **Cars only**
GDI: Gasoline Direct Injection
CVT: Continuously Variable Transmission
VVT: Variable Valve Timing

Example of Technology Upgrade: High-Selling Passenger Cars 2010 to 2014



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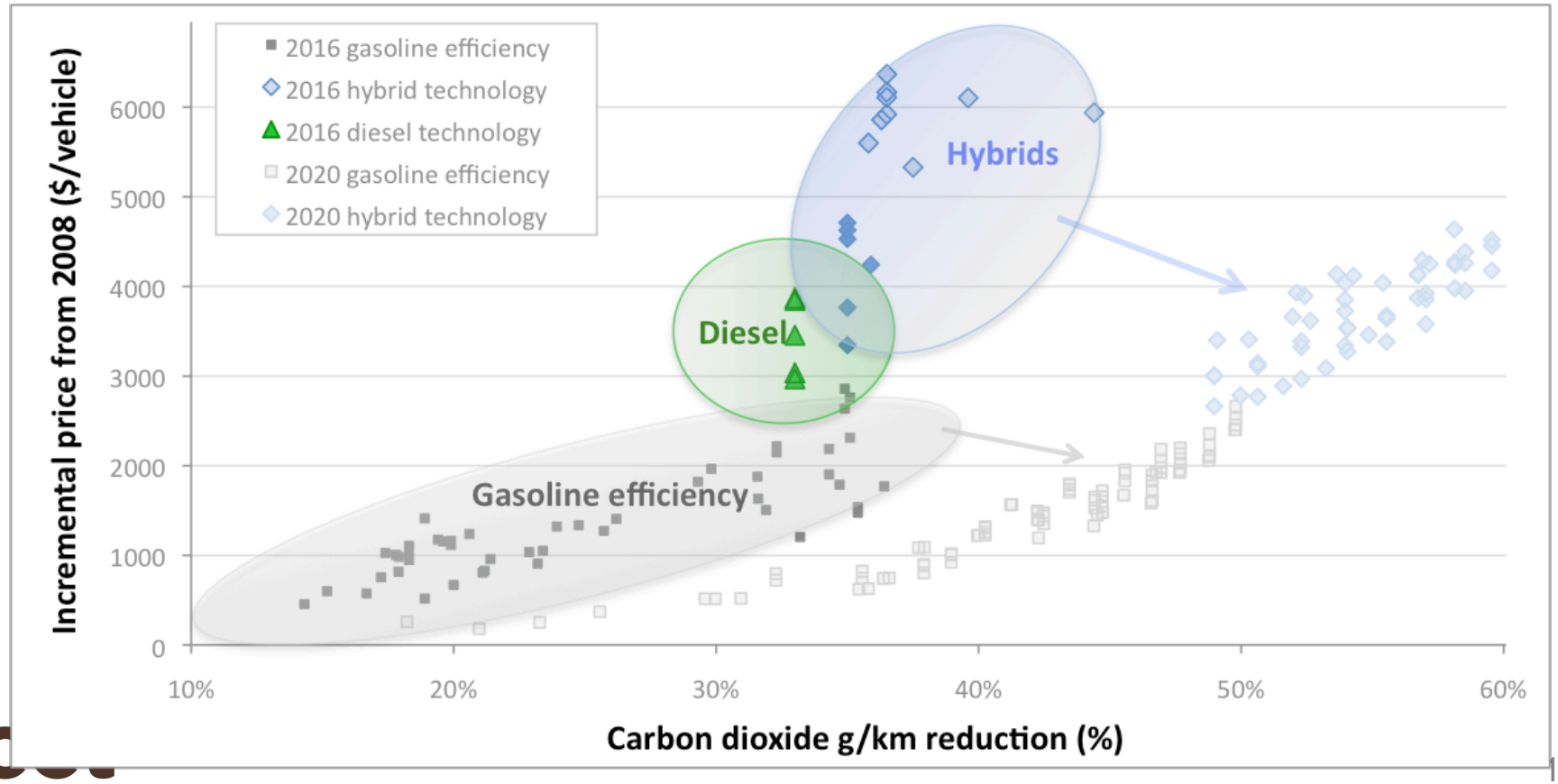
Technology Costs Dropping Rapidly

Technology availability increases - and its costs decrease - over time

- Incremental vehicle costs and percent improvements versus MY2008 baseline
- Data from EPA/NHTSA 2012-2016 rulemaking and EPA/NHTSA/CARB *TAR* for 2020



Examples of new/future Technologies

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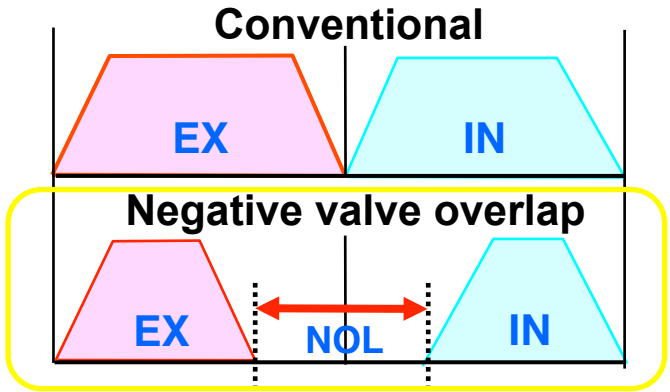
Next-generation Gasoline Engines

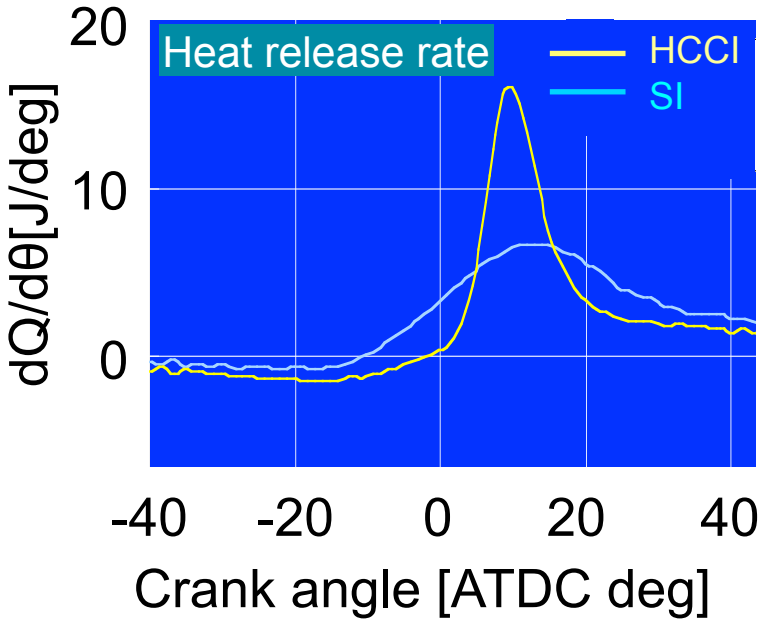
Fiat MultiAir
Digital Valve Actuation



HCCI Engine

Improvement in fuel economy: **30%**

Honda Prototype Engine Base
(Electro-magnetic valve)



Requires increasing the self-ignition region

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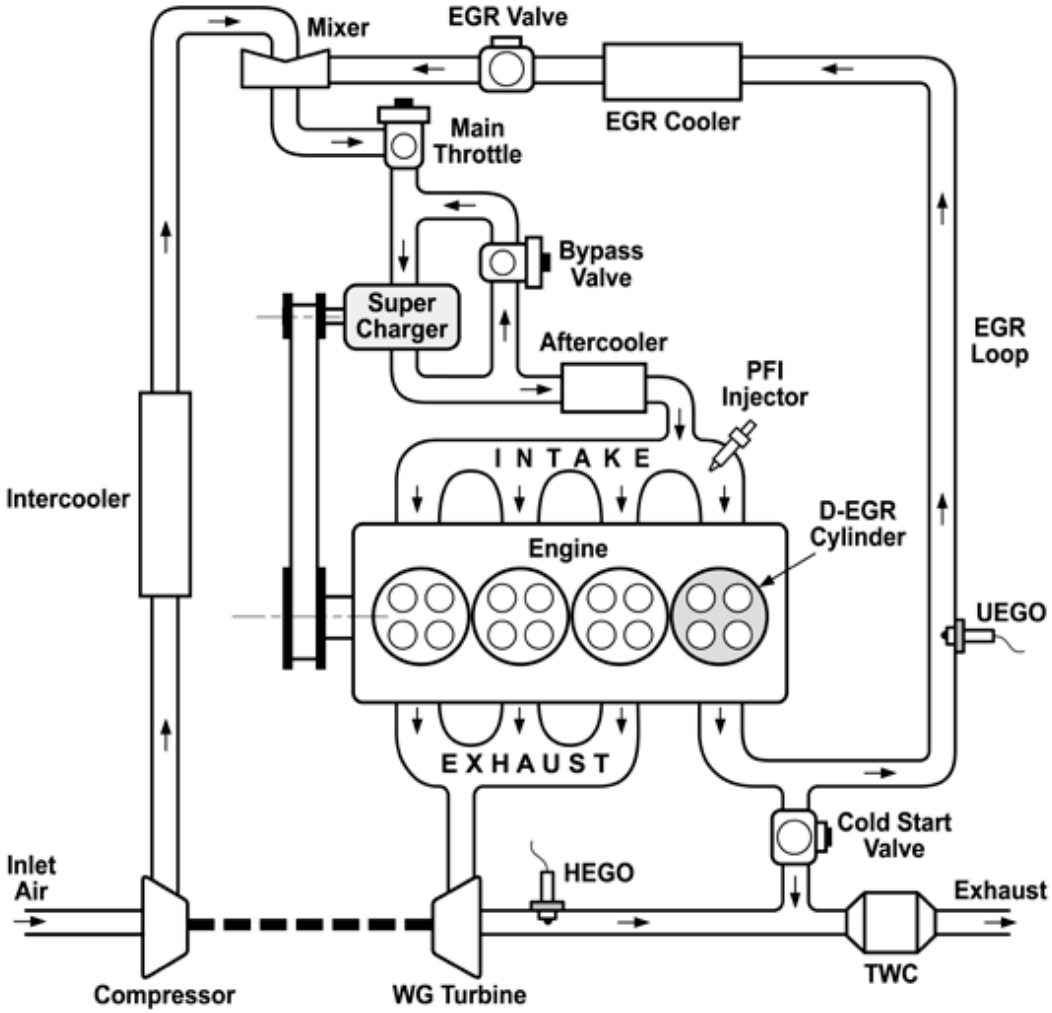
Turbo Dedicated EGR Engines

- Highly dilute, low temperature combustion
- ~1% H_2 by volume in the intake
- Advanced ignition systems required
- ~40% brake thermal efficiency (similar to diesel)
- PSA 2018 introduction



Christopher Chadwell, Dr. Terry Alger, Raphael Gukelberger, Jacob Zuehl – Southwest Research Institute, A DEMONSTRATION OF DEDICATED-EGR ON A 2.0 L GDI ENGINE, SAE 2014-01-1190

Lightweight Materials: Costs are dropping rapidly

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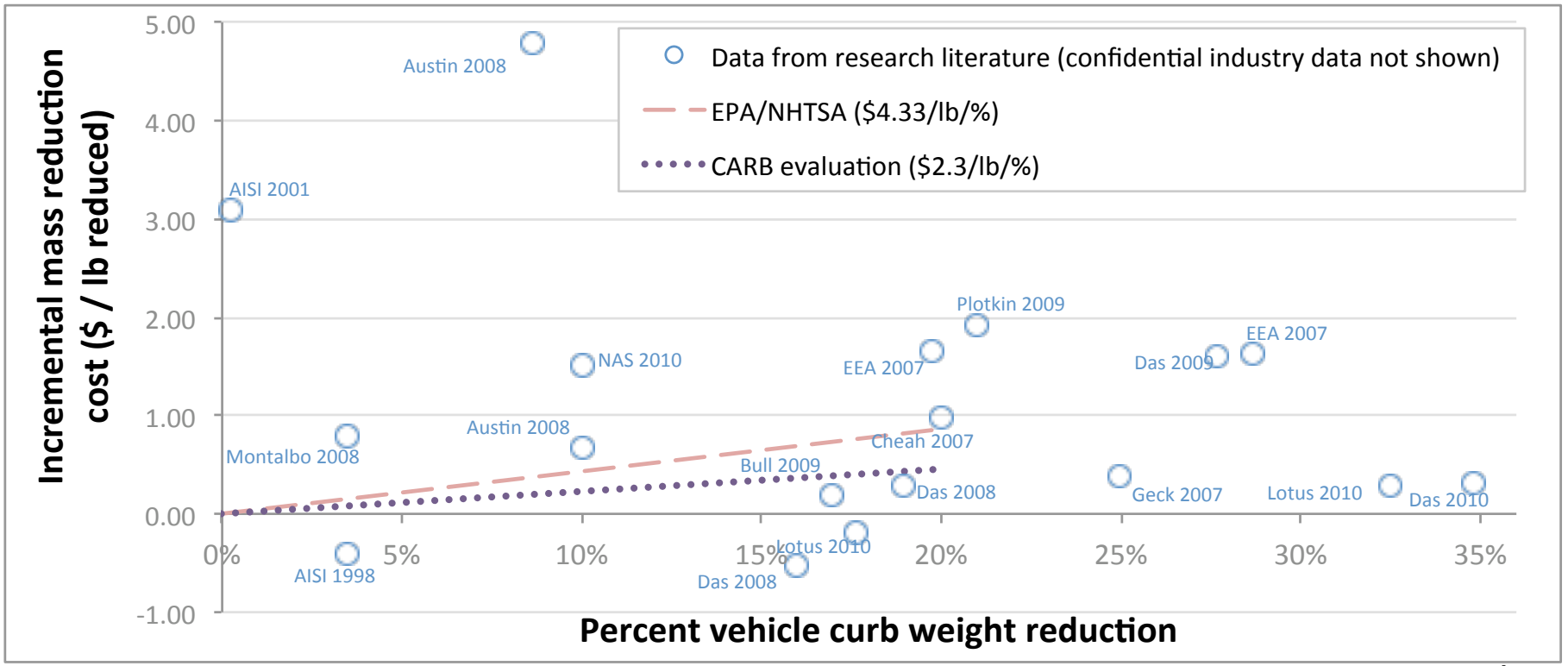
Vehicle Lightweight Research in 2017-25 Rule

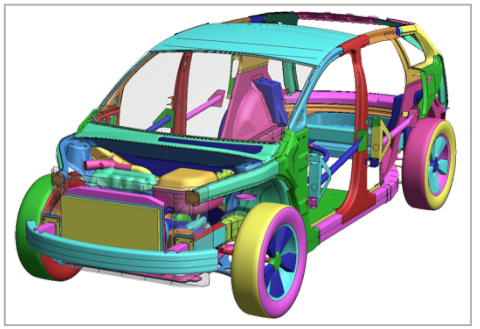
- Technical assessments on mass-reduction involve major studies by national US laboratories, OEM steel suppliers, OEMs with universities
  - Each data point represents a different material/design approach to mass reduction
  - Studies vary in technical rigor, transparency, comprehensiveness, crashworthiness validation
  - EPA projected average vehicle mass would decrease by 7% by 2025

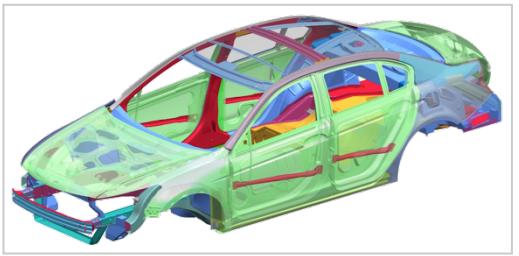


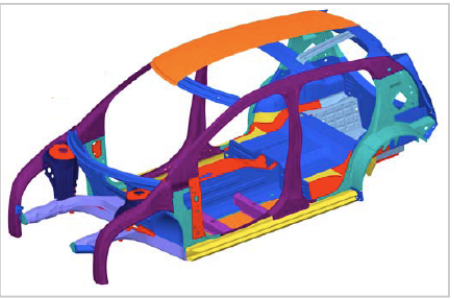
Major New Mass-Reduction Work

- Lotus Engineering (CARB) – Toyota Venza
  - Continuation of 2010 study (-33% mass Toyota Venza)
  - Cost-effective 18-32% mass reduction at < $0/vehicle
  - Includes crashworthiness safety (NHTSA FMVSS) validation
- FEV (US EPA) – Toyota Venza
  - Technical assessment of -18% mass at < $0/vehicle
  - Includes crashworthiness safety (NHTSA FMVSS) validation and detailed tear-down cost assessments
- EDAG / Electricore (NHTSA) – Honda Accord
  - Technical assessment of -22% mass at $319/vehicle
  - Includes crashworthiness safety (NHTSA FMVSS) validation
- EDAG WorldAutoSteel "Future Steel Vehicle"
  - 12-18% mass reduction, no additional cost, with only using steels
- George Washington University (NHTSA) – Chevy Silverado
  - 19% mass reduction with advanced plastics, composites

    http://www.nhtsa.gov/DOT/NHTSA/NVS/Crashworthiness/Plastics/811692.pdf







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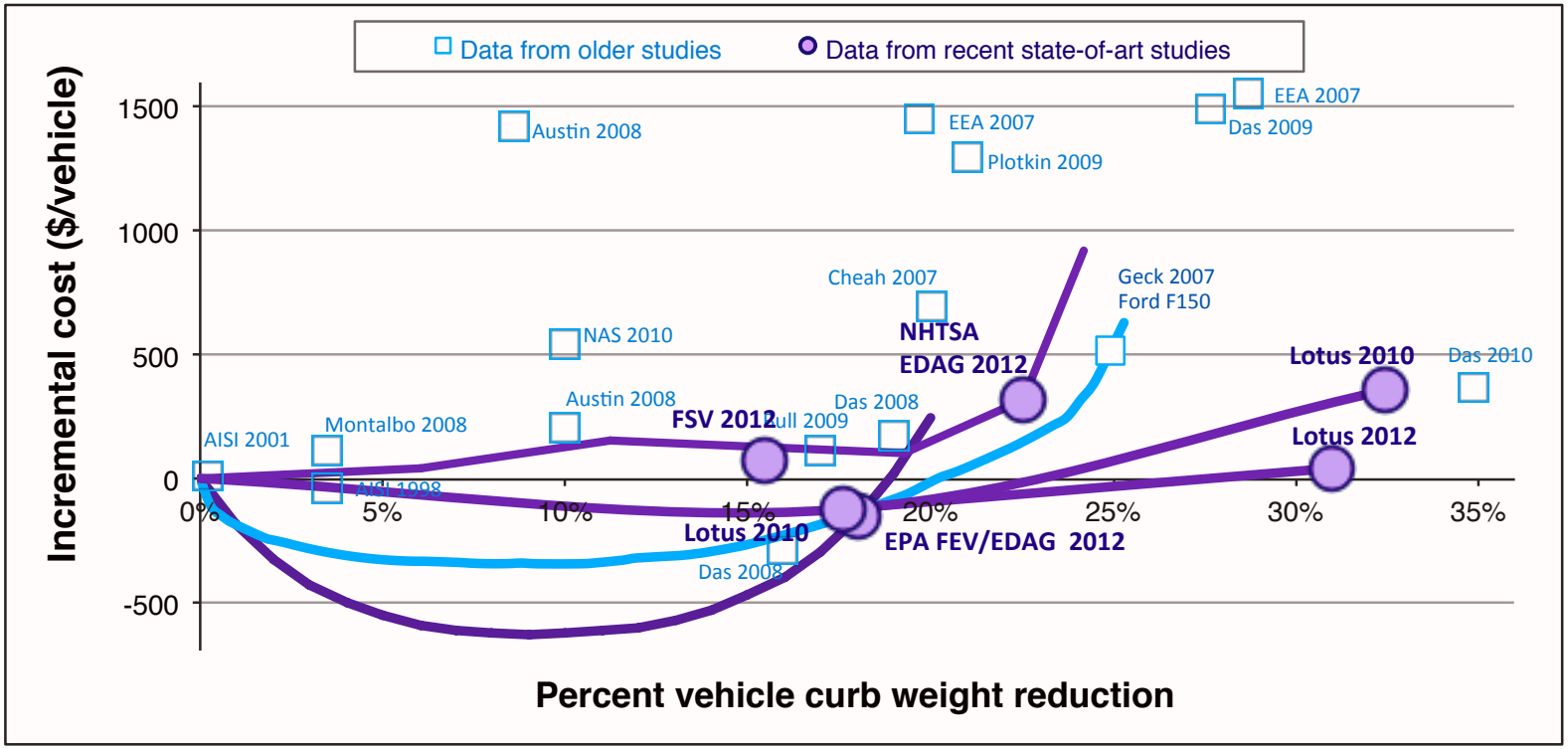
Vehicle lightweighting is highly cost-effective

- Major new state-of-the-art studies examine advanced materials, parts integration, system-level holistic vehicle redesign
  - High lightweighting potential, crashworthy designs, and diverse highly cost-effective approaches
  - EDAG, FEV, Lotus, and FSV lightweighting cost results are shown below



Weight Reduction in 2015 Ford F150

Vanguard of a truly radical transformation in how vehicles are designed and built

The largest selling vehicle in the US

Weight reduction:
318 kg, 14%

Engine downsize:
3.5L to 2.7L

First use of aluminum body in high volume production vehicle

95% of body– Aluminum
77% of frame– HSS

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Source: http://www.ford.com/trucks/f150/2015/

Examples of vehicles in production

Vehicle make	Model year	Weight reduction (kg)*	Weight reduction (%)*	Designed market
Ford F150	2015	318	14%	US
Acura MDX	2014	111	5%	US
GM Cadillac CTS	2014	111	6%	US
Peugeot 308 SW Blue Hdi	2014	140	9%	EU
VW Golf TDI	2015	49	4%	EU
Audi Q7	2014	363	15%	US, EU
BMW i3 EV	2014	249	17%	US, EU
Land Rover Range Rover	2014	350	14%	US, EU
Porsche Cayenne	2012	181	8%	US, EU
Audi A8	2014	145	7%	US, EU
Audi A3	2014	80	6%	US, EU
Nissan Leaf	2012	80	5%	US, EU
Lamborghini Huracan	2015	78	5%	US, EU
Audi TT 3rd gen 2.0 TDI	2015	50	4%	US, EU

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* The weight of new models are compared to its predecessors, except for BMW i3 EV, which is compared to the conventional steel structure.

Technology Tear-Down: Robust and Transparent Cost Estimates

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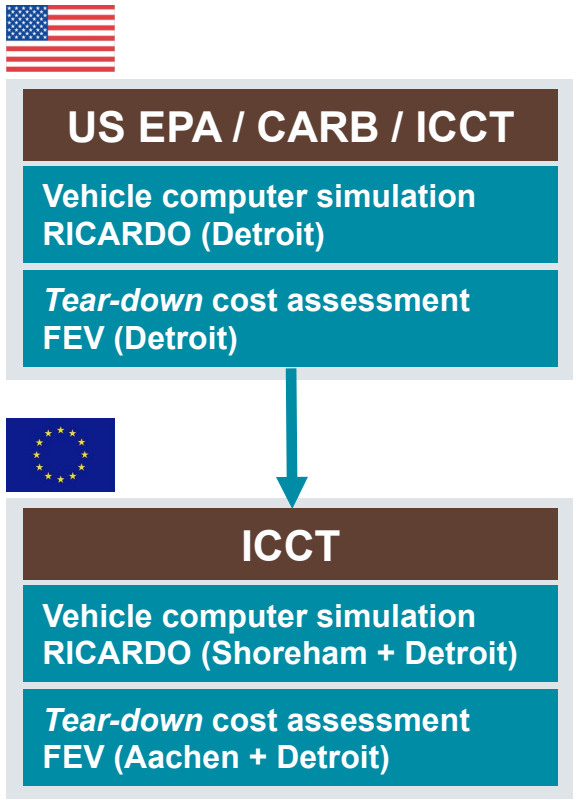
Significantly improved method to assess CO_2 reduction potential and costs of technologies.



Significantly improved method to assess CO_2 reduction potential and costs of technologies.

US EPA / CARB / ICCT

Vehicle computer simulation
RICARDO (Detroit)

Tear-down cost assessment
FEV (Detroit)

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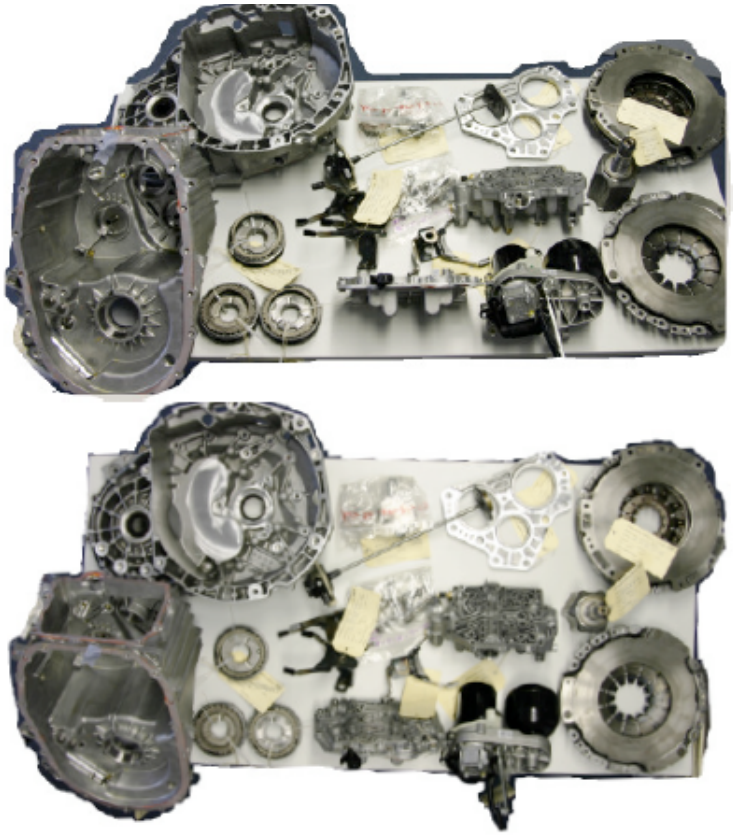
Vehicle computer simulation
RICARDO (Shoreham + Detroit)

Tear-down cost assessment
FEV (Aachen + Detroit)



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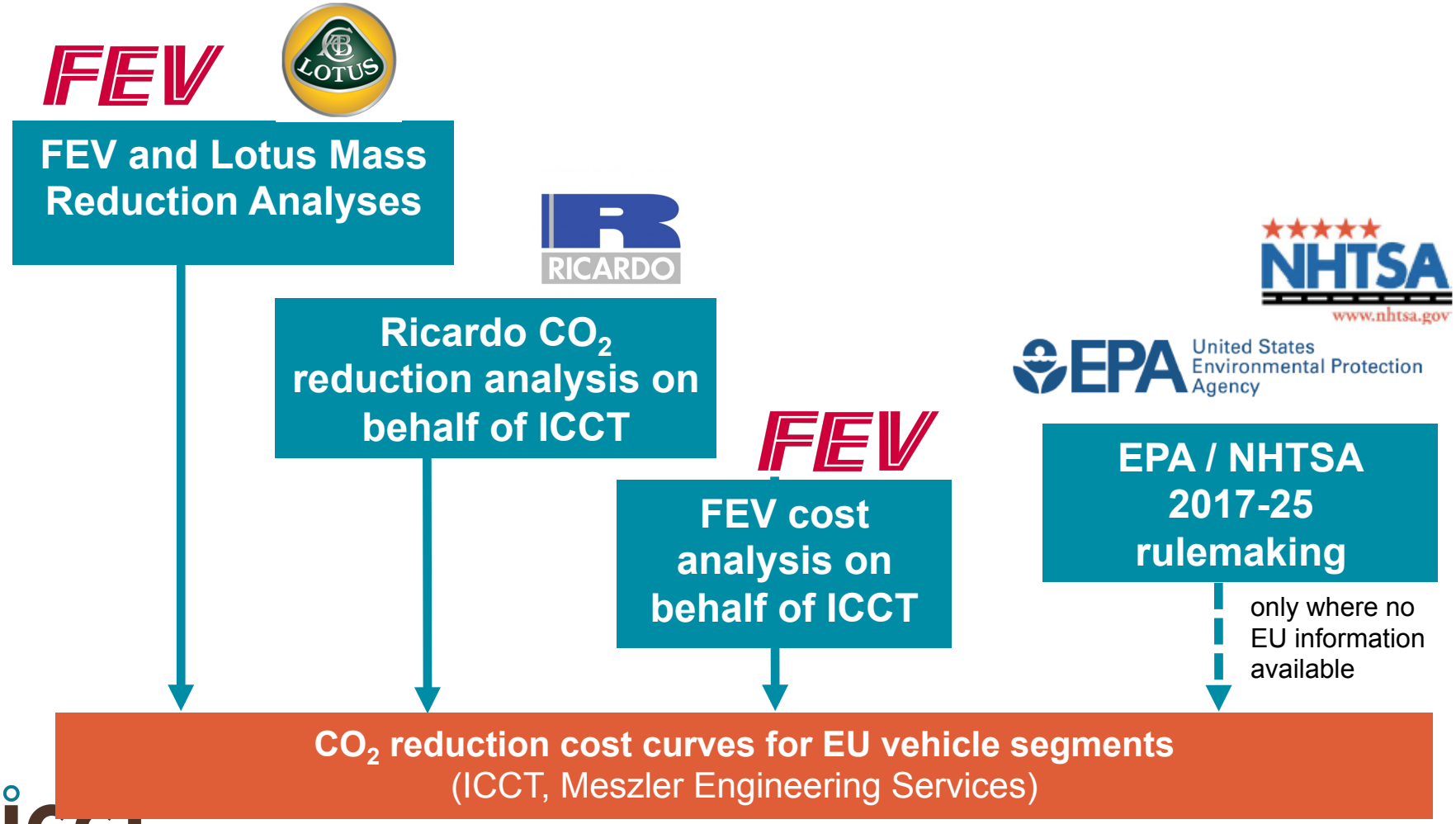
Methodology

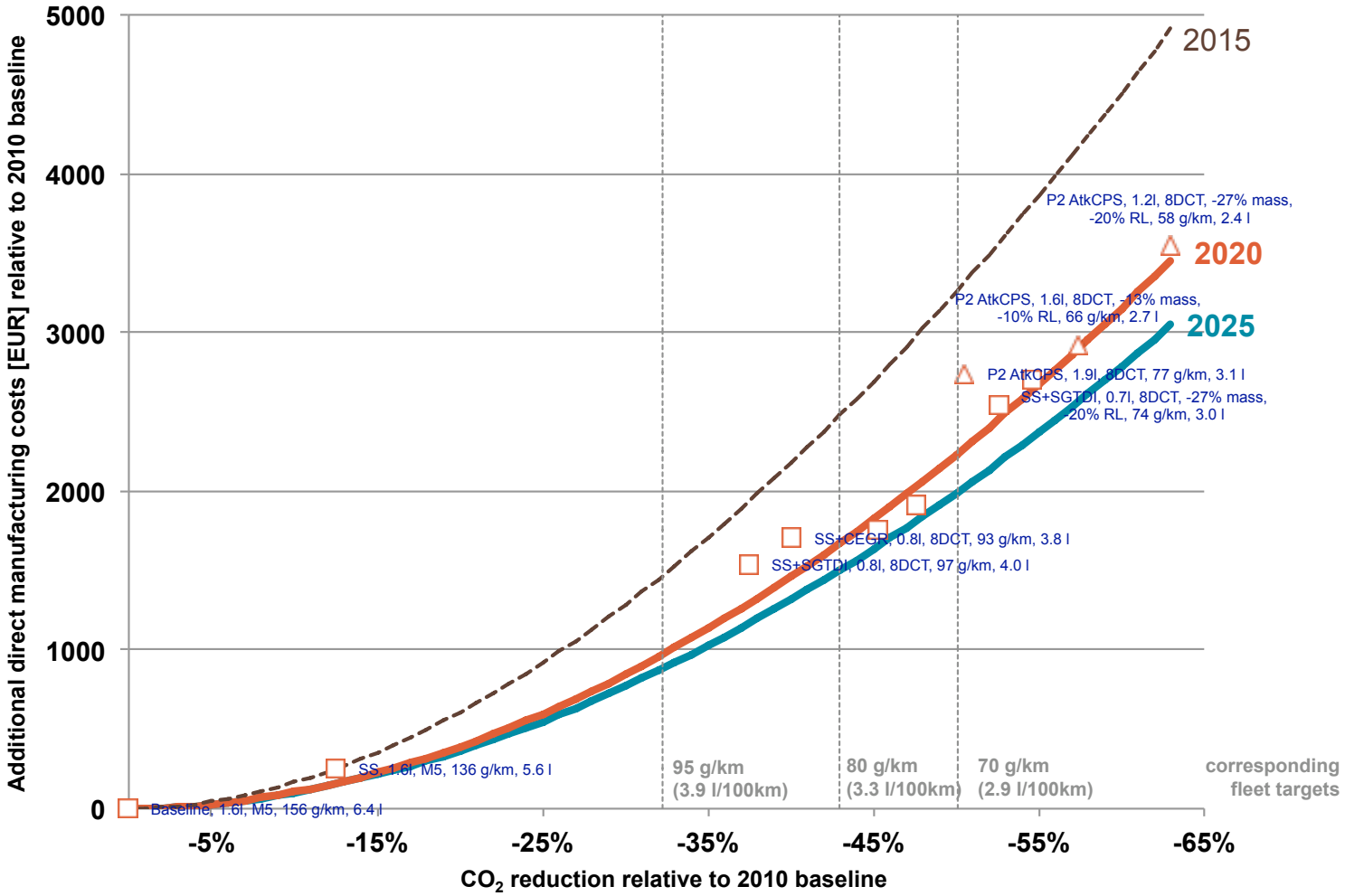
Data sources



Methodology

The Final Result

- C-segment gasoline



Comparison of Vehicles in US versus Mexico

High Altitude Impacts

- Fuel economy is BETTER at high altitude:
  - Air density is lower, decreasing aerodynamic drag and reducing pumping losses.
- There is a loss of power if the engine is naturally aspirated:
  - If a manufacturer **designs** the vehicle for high altitude, they will need to install a larger engine.
  - However, engines in Mexico are still smaller and have less power than engines in the US, making it easier for Mexican vehicles to meet the standards.
- Turbocharging will eliminate the power loss at high altitude - while preserving the pumping loss improvements:

  "All EcoBoost V-6 engines maintain peak torque capability at well over 5,000 feet above sea level, making EcoBoost-equipped vehicles ideal for high-altitude operation."
  http://media.ford.com/article_display.cfm?article_id=30651

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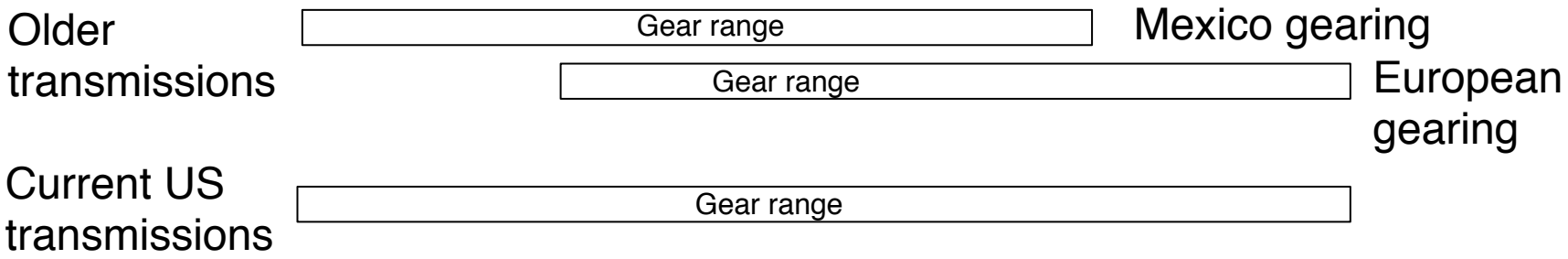
Wide-Range Transmission Gears

- Older 4- and 5-speed transmissions have a gear range of about 4.5 (ratio of shortest gear to tallest gear). It cannot cover all driving from highway cruising to high-altitude grades. Thus, some low-powered vehicles may need to have shorter gears for Mexico.
- Current 6+ speed transmissions have wider gear ranges, of 6.0 or more. This provides proper gearing for both highway cruising and high-altitude grades, without the need to change gearing.
- Also note that turbocharged engines do not lose performance at high-altitude, further reducing any need for shorter gears.



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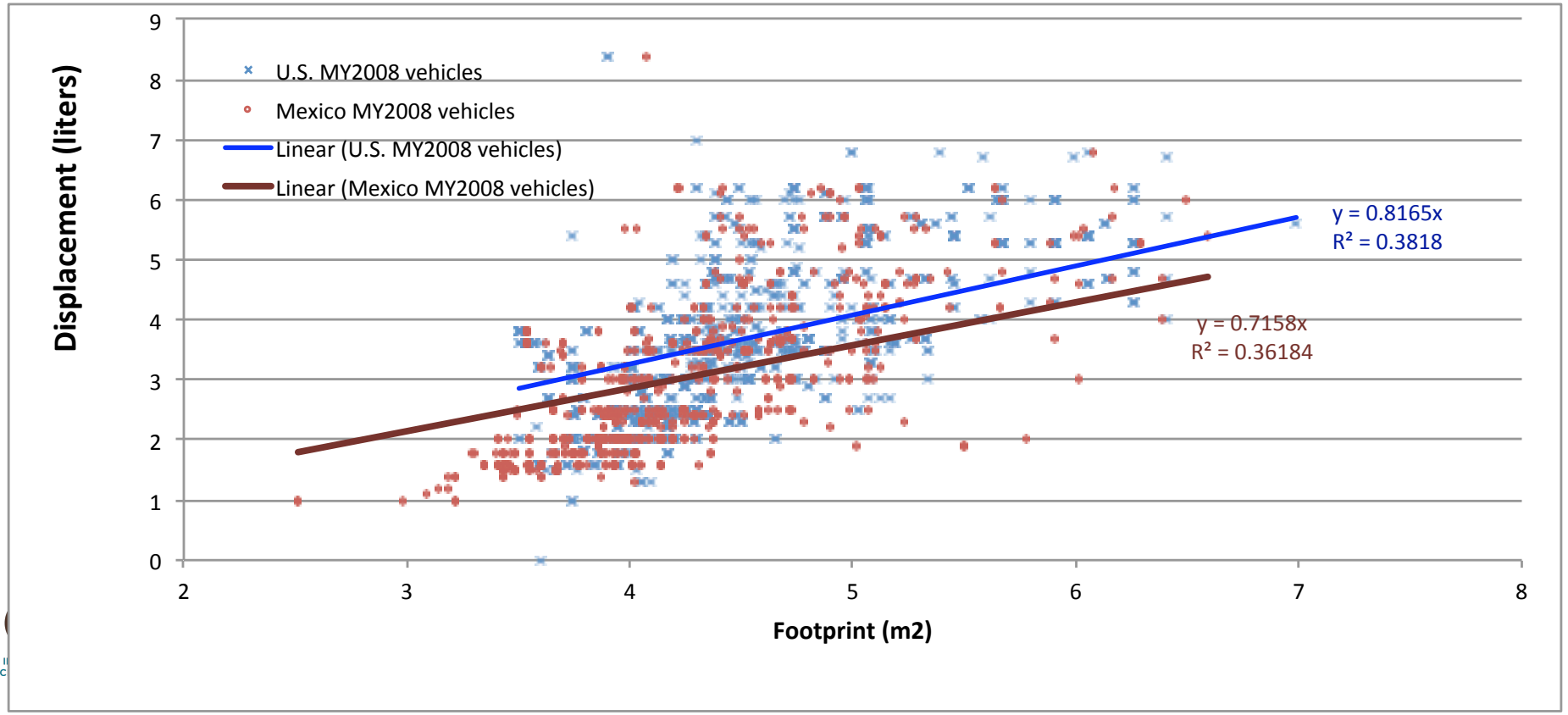
Displacement vs. Footprint: All Vehicles

- Regression of engine size versus vehicle footprint is 14% higher in the US than in Mexico
  - 2008 data for Mexico and the US, cars and light trucks combined

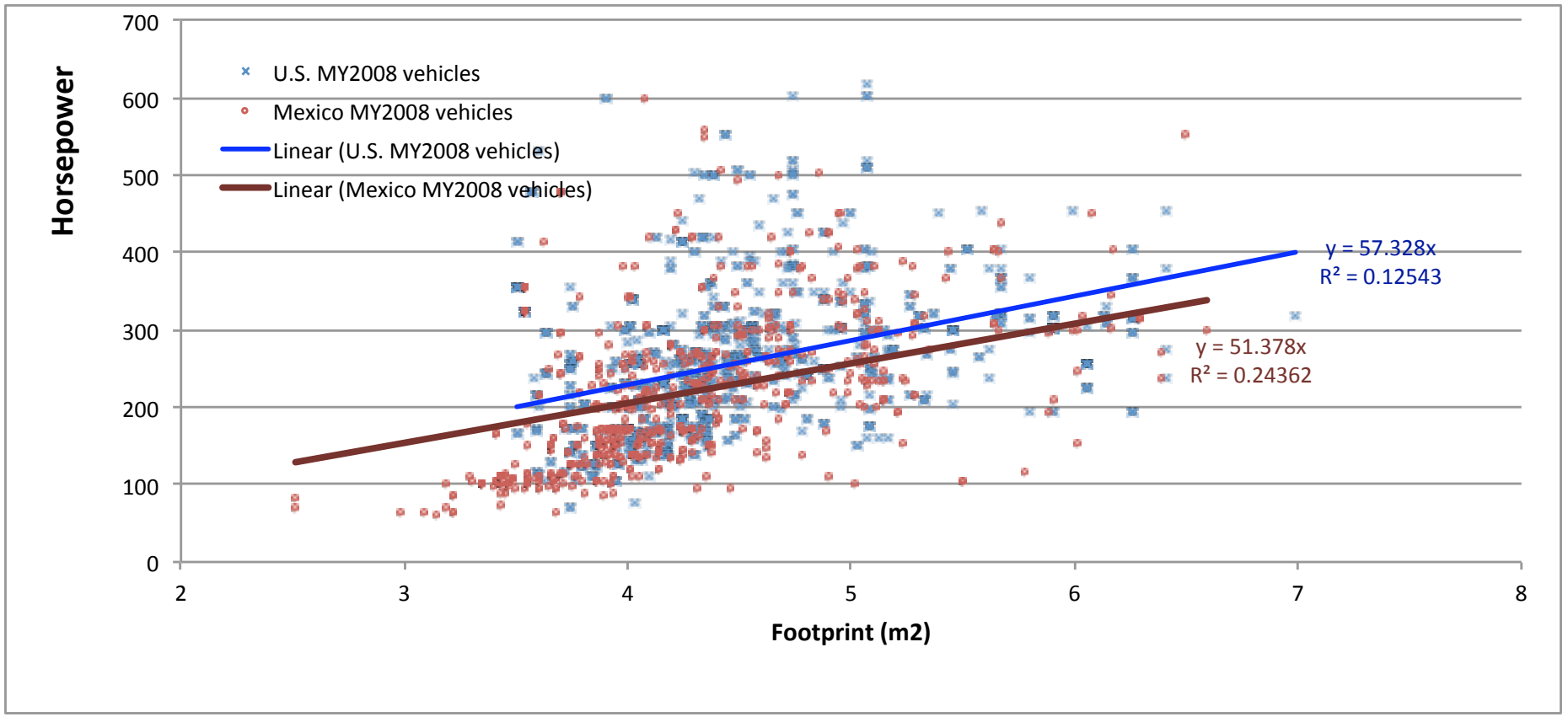
Displacement/kg - Mexico versus US vehicles - 2008 data			
	US	Mexico	Mexico vs US
Test weight (kg)	1875	1548	-17%
Engine size (liter)	3.3	2.4	-27%
Liters/kg	0.117	0.102	-13%



Power vs Footprint: All vehicles

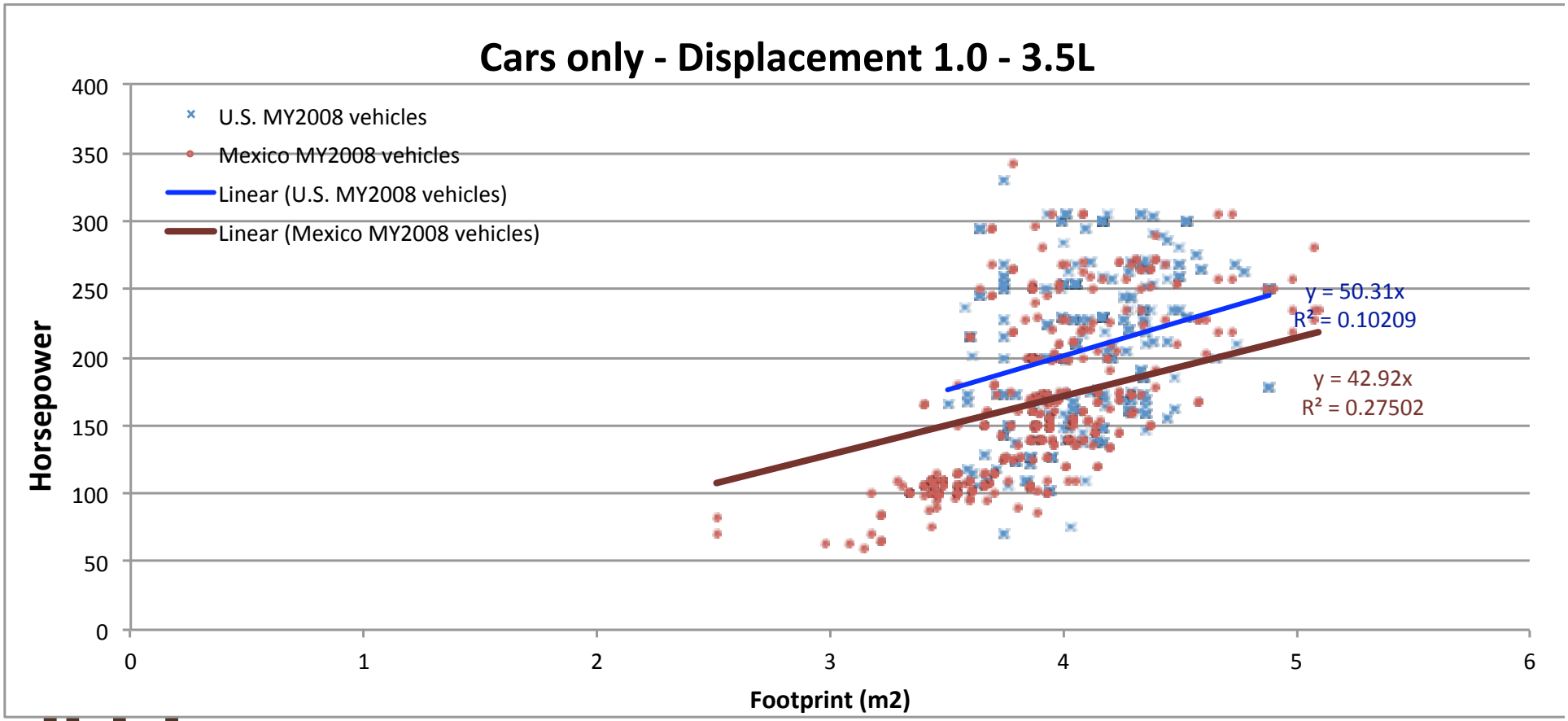
- Regression of engine power (hp) versus vehicle footprint is 12% higher in the US than in Mexico
  - 2008 data for Mexico and the US, cars and light trucks combined

HP/kg - Mexico versus US vehicles - 2008 data			
	US	Mexico	Mexico vs US
Test weight (kg)	1875	1548	-17%
Horsepower	220	157	-28%
HP/kg	0.117	0.102	-13%



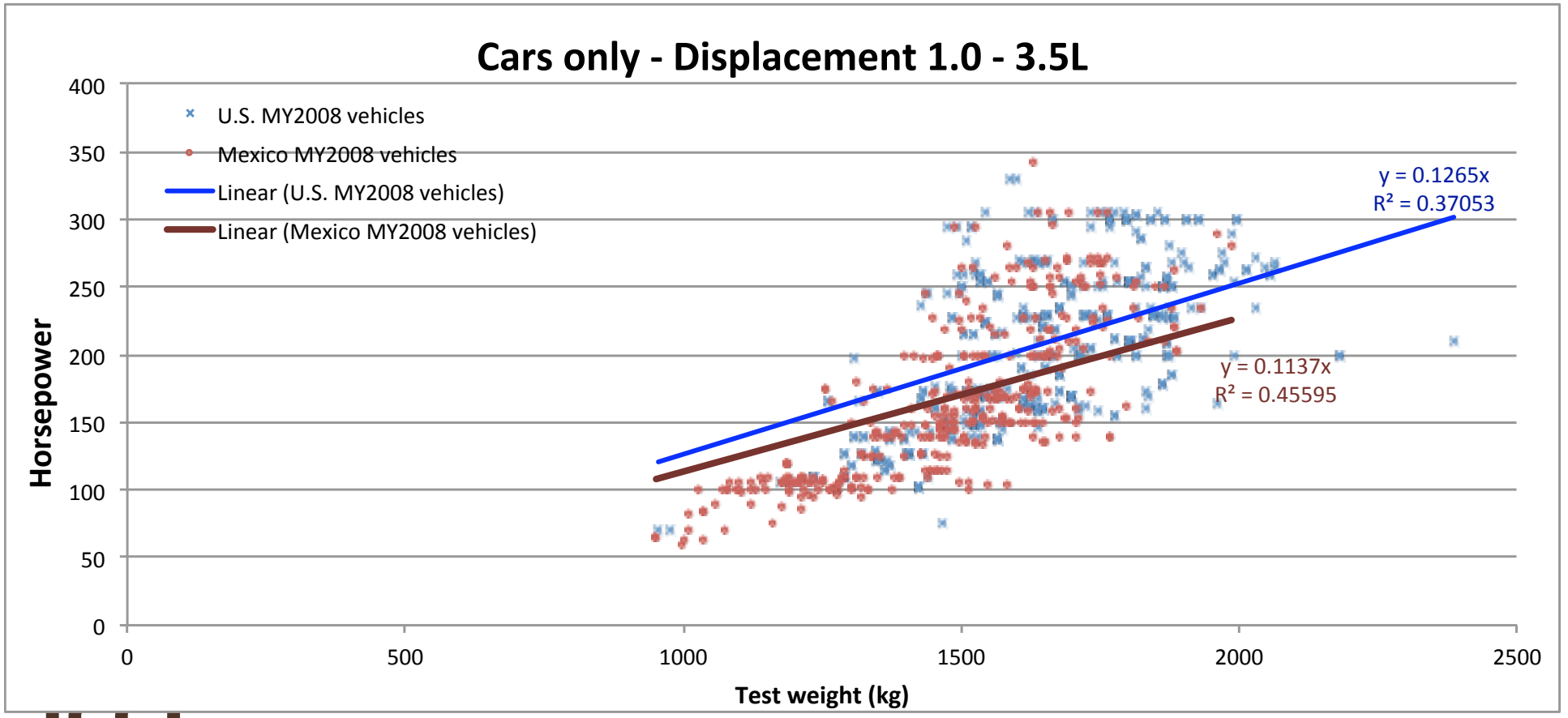
Cars 1.0L – 3.5L: Horsepower v Footprint

- Regression of HP versus vehicle footprint is 17% higher in the US
  - 2008 data for Mexico and the US



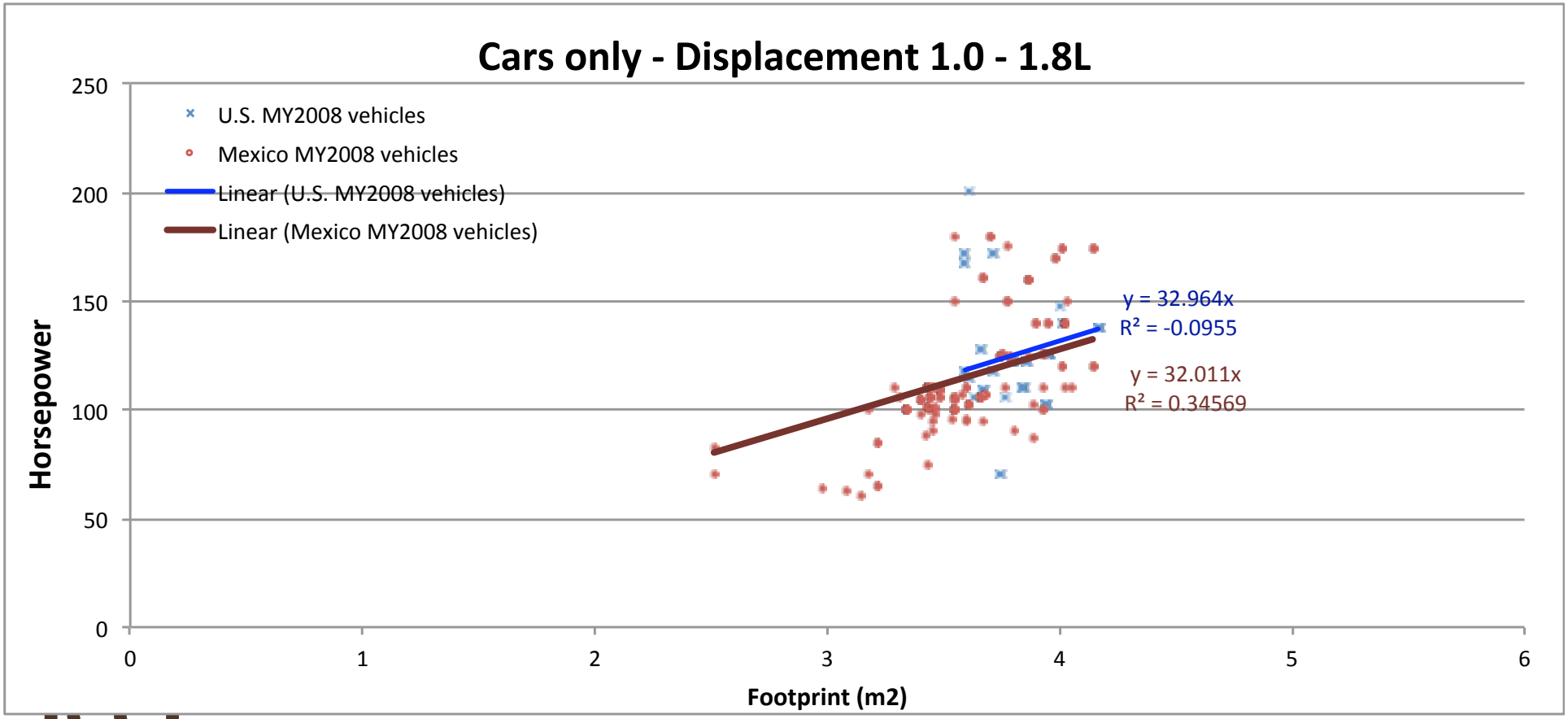
Cars 1.0L – 3.5L: Horsepower v Test Weight

- Regression of HP versus test weight is 11% higher in the US
  - 2008 data for Mexico and the US



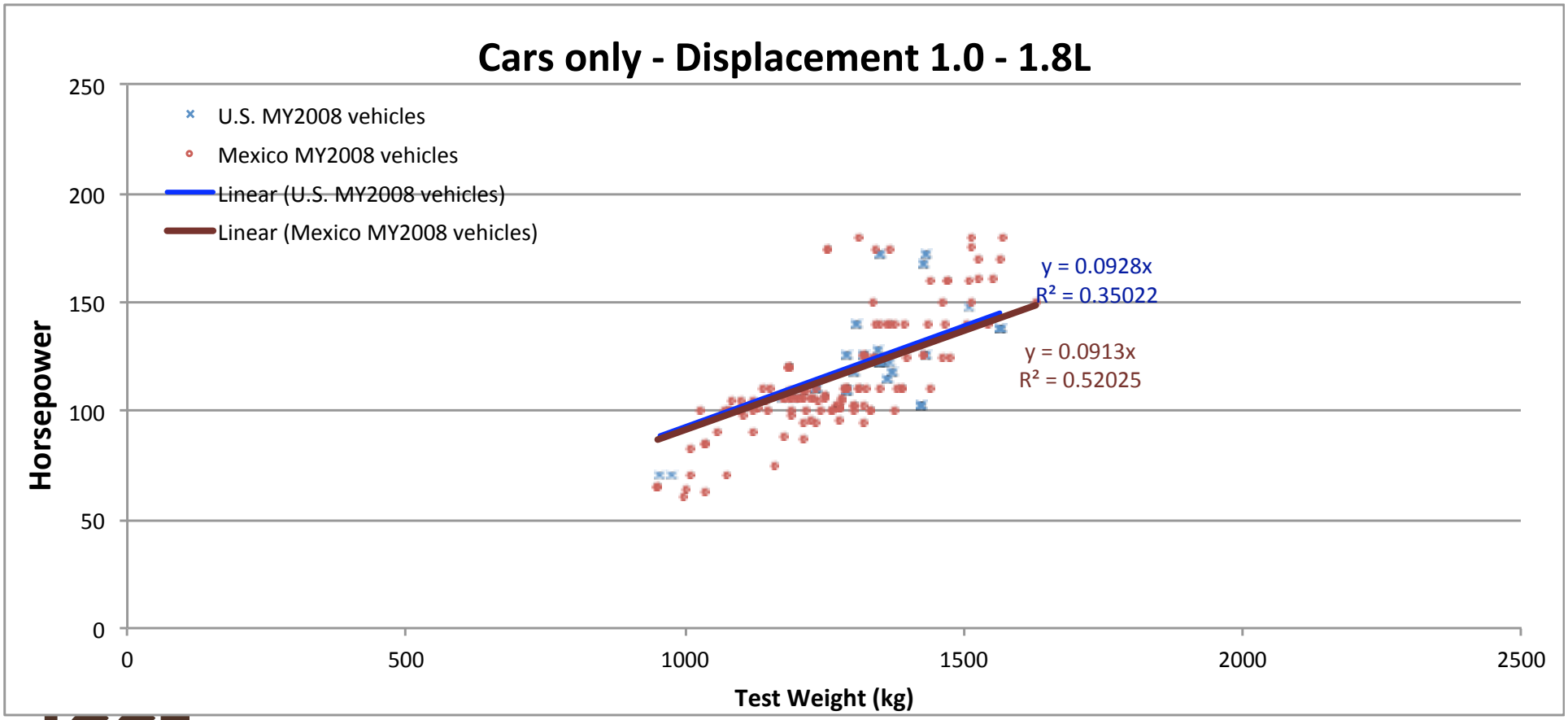
Cars 1.0L – 1.8L: Horsepower v Footprint

- Regression of HP versus vehicle footprint is 3% higher in the US
  - 2008 data for Mexico and the US



Cars 1.0L – 1.8L: Horsepower v Test Weight

- Regression of HP versus test weight is 2% higher in the US
  - 2008 data for Mexico and the US



Heavy-Duty Vehicle Fuel Economy Improvement Opportunities

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There are many opportunities to reduce fuel consumption of heavy vehicles (including buses).

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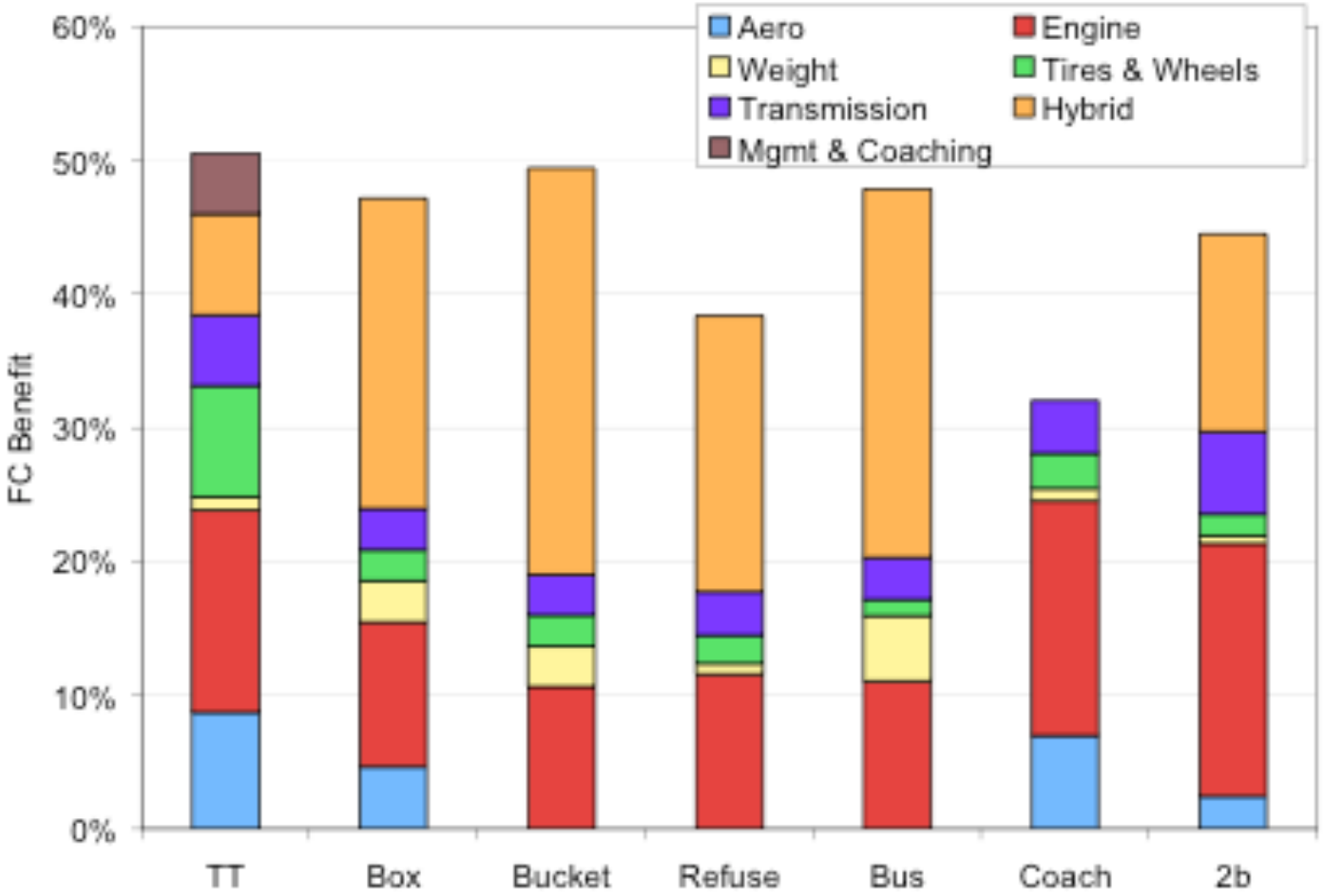
U.S. National Academy of Sciences (March 2010) found 35-50% improvement could be achieved in the 2015 to 2020 timeframe



National Academy of Sciences (2010) FIGURE S-1 Comparison of 2015-2020 New Vehicle Potential Fuel Savings Technology for Seven Vehicle Types: Tractor Trailer (TT), Class 3-6 Box (Box), Class 3-6 Bucket (Bucket), Class 8 Refuse (Refuse), Transit Bus (Bus), Motor Coach (Coach), and Class 2b Pickups and Vans (2b). Also, for each vehicle class, the fuel consumption benefit of the combined technology packages is calculated as follows: % FCpackage = 1 – (1 - %FCtech 1)(1 - %FCtech2)(1 - %FCtech N) where %FCtech x is the percent benefit of an individual technology. SOURCE: TIAX (2009) ES-4.

Conclusion

Summary

- Computer aided design and computer simulations are accelerating technology development.
  - Especially important for lightweight materials.
- Costs are rapidly decreasing.
- Altitude impacts are becoming less important, due to turbocharging and transmissions with a wider range of gears.
- Engines in Mexico are smaller and have less power than in the US, making it easier for them to meet the standards.

For more information…

- ICCT Passenger Vehicles website:
  http://www.theicct.org/passenger-vehicles
- Global Passenger Vehicle Standards Update:
  http://www.theicct.org/global-passenger-vehicle-standards-update
- US CAFE Standards:
  http://www.theicct.org/policies/us-cafe-standards
- EU LDV CO2 Regulation:
  http://www.theicct.org/policies/eu-light-duty-vehicle-co2-regulation
- Review and Comparative Analysis of Fiscal Policies to promote fuel economy:
- http://www.theicct.org/review-and-comparative-analysis-fiscal-policies
- CO_2 Standards:
  http://www.theicct.org/issues/co2-standards

Anup Bandivadekar
anup “at” theicct.org

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Thank You

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