Ricardo's Report - *Simulation of CO_2 Reducing Vehicle Technologies*

Presentation to the
National Research Council
Committee on Fuel Economy of Light-Duty Vehicles
January 24, 2008

Background – Ricardo Work commissioned to support future Vehicle GHG Rulemaking

- Context for the Ricardo work
  - As part of the analytical support for a future regulatory action to address GHG emissions from vehicles, EPA initiated this Ricardo Study
  - April 2, 2007 - The Supreme Court ruled in Mass v. EPA that the EPA had the authority under the Clean Air Act to address greenhouse gas emissions from motor vehicles
  - May 14, 2007 - The President signed an executive order directing EPA and other Agencies - including DOE, USDA, DOT, to develop new regulatory requirements to reduce motor vehicle GHGs
  - See September 10, 2007 EPA Presentation to this Committee for additional background
- This Study was designed to complement other existing sources:
  - 2002 NAS study
  - 2004 NESCCAF/AVL Study
  - Recent technical literature, and critiques of these prior works
  - EPA vehicle certification data

The Ricardo Report is one element to support a GHG vehicle rule

Objectives of this Study

- EPA's desired outcomes from this study:
  - Provide a Peer-Reviewed source document that characterizes individual and combined vehicle technology efficiency improvement potentials
  - Use a robust, science-based "full vehicle simulation" analysis to characterize consequences of combining multiple technologies for efficiency gains (e.g., quantify synergistic effects)
  - Quantify how the individual technologies, and their combinations, provide different levels of vehicle efficiency improvement in different vehicle classes
  - Avoid duplication of earlier works
  - Provide a means to extract detailed technology characteristics that could be used for future analysis and modeling work
- Timeline constraining the work:
  - Scoping of Work defined in June, 2007
  - Report commissioned in July
  - Completed draft report at the end of October
  - Peer-review of draft final report in November
  - Final report completed in December

Study Scope - Primarily ICE & Transmission Technologies

- What is in this Study:
  - Report includes simulation of five vehicles representing different vehicle-classes and looks at 26 technology “packages”
  - Report shows that 25- 30% CO2 reduction (30-40% fuel economy) is possible across the range of vehicles analyzed using this subset of “conventional” or “nearer-term” technologies, without altering weight or performance

- What is not included in the scope of this Study
  - No consideration, solely from this report, of what an appropriate GHG standard should be
  - No estimates of technology costs or lead time
  - Considers only a subset of vehicle technologies available for GHG reduction, several viable technologies not included in this analysis
    - No consideration of improved air conditioning efficiency
    - No estimates for any form of vehicle hybrid technology assessment
    - No consideration for fuel cells, battery electric vehicles
    - No consideration of material substitution for weight reduction

EPA-Defined Project Scope

- Five vehicles selected for vehicle simulation were chosen to be representative for a class and were anticipated to see no significant technology package changes before MY2010
  - Toyota Camry - Standard Car
  - Chrysler 300 - Full Size Car
  - Saturn Vue - Small Multi-Purpose Vehicle
  - Dodge Grand Caravan - Large Multi-Purpose Vehicle
  - Ford F-150 - Large Pickup Truck
- Twenty six technology packages
  - Representative of a range of options manufacturers might pursue to reach ~25% CO2 reduction.
  - Applied the same package to different classes, where vehicle attributes might affect benefits (e.g., power-to-weight ratio)
  - 28 different vehicle technologies considered; 25 presently in volume production
  - Conventional gasoline/diesel vehicles; no HEVs
- Evaluated to achieve equivalent drivability performance
  - 0-60 mph, launch, passing and gradeability performance

Further GHG Reductions

- Analytical support for consideration of further reductions in GHG could include additional simulation work:

- Vehicle simulation of the effects of vehicle attributes
  - Opportunities for weight reduction through material substitution
  - Added impact of hybrid technologies for further GHG reduction

- Focused simulation of HEVs
  - Resource and time limitations prevented us from simulating the full range of hybrid options (IMA/ISAD, 2-Mode, Powersplit, PHEV, EV) in a comprehensive, representative manner
  - Adapting a hybrid system to the baseline vehicle and optimizing it for best performance requires significant development, in many cases involving subjective factors that were not available to us for the present study.

Appendix

Background Slide

Baseline Vehicles

Vehicle Class		Standard Car	Full Size Car	Small MPV	Large MPV	Large Truck
Baseline Vehicle		Toyota Camry	Chrysler 300	Saturn VUE	Dodge Grand Caravan	Ford F-150
CO2 Emissions* (g/mi)		327	409	415	435	575
Vehicle Attributes	Base Engine	DOHC I4	DOHC V6	DOHC I4	OHV V6	SOHC V8
	Displacement (L)	2.4	3.5	2.4	3.8	5.4
	Rated Power (HP)	154	250	169	205	300
	Torque (ft-lbs)	160	250	161	240	365
	Valvetrain Type	VVT (DCP)	Fixed	VVT (DCP)	Fixed	VVT (CCP)
	Valves per Cyl	4	4	4	2	3
	Drivetrain	FWD	RWD	FWD	FWD	4WD
	Transmission	Auto	Auto	Auto	Auto	Auto
	Number of Forward Speeds	5	5	4	4	4
	Curb Wt (lbs)	3108	3721	3825	4279	5004
	ETW (lbs)	3500	4000	4000	4500	6000
	GVWR (lbs)	--	--	4300	5700	6800
	GCWR (lbs)	--	--	--	--	14000
	Front Track Width (in.)	62	63	61.4	63	67
	Wheelbase (in.)	109.3	120	106.6	119.3	144.5
Performance Characteristics	Displacement / Weight Ratio (L/ton)	1.54	1.88	1.25	1.78	2.16
	Power / Weight Ratio (HP/ton)	99.1	134.4	88.4	95.8	119.9

Background Slide

Vehicle Classes

Vehicle Class	Standard Car	Large Car	Small MPV	Large MPV	Large Truck
EPA Vehicle Types Included	Compact, Mid-size	Large car	Small SUV, Small Pickup	Minivans, Mid-SUVs	Large SUVs, Large Pickups
Curb Weight Range	2800-3600 lbs	>3600 lbs	3600-4200 lbs	4200-4800 lbs	>4800 lbs
Engine Type	I4	V6	I4	V6	V8
Drivetrain	FWD	RWD/AWD	FWD	FWD/AWD	4WD
Body Type	Unibody	Unibody	Unibody	Unibody	Ladder Frame
Towing Capability	None	None	Partial	Partial	Full
Example Vehicles	Toyota Camry, Chevy Malibu, Honda Accord	Chrysler 300, Ford 500 / Taurus	Saturn VUE, Ford Escape, Honda CR-V	Dodge Grand Caravan, GMC Acadia, Ford Flex	Ford F-150, Chevy Silverado 1500, Dodge Ram

Background Slide

Individual Technologies

Engine Technologies	
Abbrev.	**Description**
DOHC	Dual Overhead Camshaft
SOHC	Single Overhead Camshaft
OHV	Overhead Valve (pushrod)
CCP	Coordinated cam phasing
DCP	Dual (independent) cam phasing
DVVL	Discrete (two-step) Variable Valve Lift
CVVL	Continuous Variable Valve Lift
Deac	Cylinder Deactivation
CVA	Camless Valve Actuation (full)
Turbo	Turbocharging with engine downsizing
GDI	Gasoline Direct Injection
Diesel	Diesel with advanced aftertreatment
HCCI	Homogeneous Charge Compression Ignition (gasoline)
LUB	Low-friction engine lubricants
EFR	Engine friction reduction

Transmission Technologies	
Abbrev.	**Description**
L4	Lockup 4-speed automatic transmission
L5	Lockup 5-speed automatic transmission
L6	Lockup 6-speed automatic transmission
DCT6	6-speed dual clutch automated manual transmission
CVT	Continuously variable transmission
ASL	Aggressive shift logic
TORQ	Early torque converter lockup

Accessory Technologies	
Abbrev.	**Description**
ISG (42V)	42V Integrated Starter-Generator
EPS	Electric Power Steering
EACC	Electric Accessories (water pump, oil pump, fans)
HEA	High-Efficiency Alternator

Vehicle Technologies	
Abbrev.	**Description**
AERO	Aerodynamic drag reduction (10%-20%)
ROLL	Tire rolling resistance reduction (10%)

Background Slide

Technology Packages

Vehicle	Technology Package	Engine	Valvetrain	Transmission	Accessories
Standard car	**baseline**	**2.4-Liter I4**	**DOHC, DCP**	**L5**	
	Z	2.4L I4, PFI	CCP, DVVL	DCT6	ISG (42V), EPS, EACC
	1	2.4L I4, GDI	DCP, DVVL	CVT	EPS, EACC, HEA
	2	2.4L I4, GDI	DCP	L6	ISG (42V), EPS, EACC
Small MPV	**baseline**	**2.4-Liter I4**	**DOHC, DCP**	**L4**	**EPS**
	Z	2.4L I4, PFI	CCP, DVVL	DCT6	ISG (42V), EPS, EACC
	1	2.4L I4, GDI	DCP, DVVL	CVT	EPS, EACC, HEA
	2	2.4L I4, GDI	DCP	L6	ISG (42V), EPS, EACC
	15	1.5L I4, GDI, Turbo	DCP	DCT6	EPS, EACC, HEA
	15a	2.4L I4, GDI	CVA	DCT6	EPS, EACC, HEA
	15b	2.4L I4, GDI, HCCI	DCP, CVVL	DCT6	EPS, EACC, HEA
	5	1.9L I4, Diesel	DOHC	DCT6	EPS, EACC, HEA
Full Size car	**baseline**	**3.5-Liter V6**	**DOHC**	**L5**	
	4	2.2L I4, GDI, Turbo	DCP	L6	EPS, EACC, HEA
	5	2.8L I4, Diesel	DOHC	DCT6	EPS, EACC, HEA
	Y1	3.5L V6, GDI	CVA	DCT6	EPS, EACC, HEA
	Y2	3.5L V6, GDI, HCCI	DCP, CVVL	DCT6	EPS, EACC, HEA
	6a	3.0L V6, GDI	DCP, CVVL	DCT6	EPS, EACC, HEA
	16	3.5L V6, GDI	CCP, Deac	L6	ISG (42V), EPS, EACC
Large MPV	**baseline**	**3.8-Liter, V6**	**OHV**	**L4**	
	4	2.1L I4, GDI, Turbo	DCP	L6	EPS, EACC, HEA
	6b	3.0L V6, GDI	CCP, Deac	DCT6	EPS, EACC, HEA
	16	3.8L V6, GDI	CCP, Deac	L6	ISG (42V), EPS, EACC
Large Truck	**baseline**	**5.4-Liter V8**	**SOHC, CCP**	**L4**	
	9	5.4L V8, GDI	Deac	DCT6	ISG (42V), EPS, EACC
	10	3.6L V6, GDI, Turbo	DCP	DCT6	EPS, EACC, HEA
	11	4.8L V8, Diesel	DOHC	DCT6	EPS, EACC, HEA
	12	5.4L V8, GDI	CCP, Deac	L6	ISG (42V), EPS, EACC
	17	5.4L V8, GDI	DCP, DVVL	L6	EPS, EACC, HEA
	X1	5.4L V8, GDI	CVA	DCT6	EPS, EACC, HEA
	X2	5.4L V8, GDI, HCCI	DCP, CVVL	DCT6	EPS, EACC, HEA

Other:

20% Aerodynamic drag reduction, 10% tire rolling resistance reduction assumed for all vehicles, except Large Truck

10% Aerodynamic drag reduction assumed for Large Truck

Low-friction lubricants and moderate engine friction reductions are assumed for all vehicles

Aggressive shift logic and early torque converter lockup strategies are assumed for all vehicles, where applicable.

Performance Attributes

Characteristic	Performance Metric
Overall Performance	Time to accelerate from 0-60 mph*
Launch Acceleration	Time to accelerate from 0-30 mph
	Vehicle speed and distance after a 3-second acceleration from rest
Passing Performance	Time to accelerate from 30 to 50 mph
	Time to accelerate from 50 to 70 mph
Grade Capability	Maximum % grade at 70 mph (standard car, large car, small MPV and large MPV)
	Maximum % grade at 60 mph at GCVWR (large truck)*

Notes:
All accelerations are assumes at WOT (wide-open throttle) condition
GCVWR = EPA Gross Combined Vehicle Weight Rating

Package FE Results from Ricardo Report