

Impact of Vehicle Weight Reduction on Fuel Economy  
for Various Vehicle Architectures

Research Report

Conducted by Ricardo Inc.  
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# Impact of Vehicle Weight Reduction on Fuel Economy for Various Vehicle Architectures

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**Technical Approval:** \_\_\_ Reviewed by [**Frederic Jacquelin**]\_\_\_\_\_

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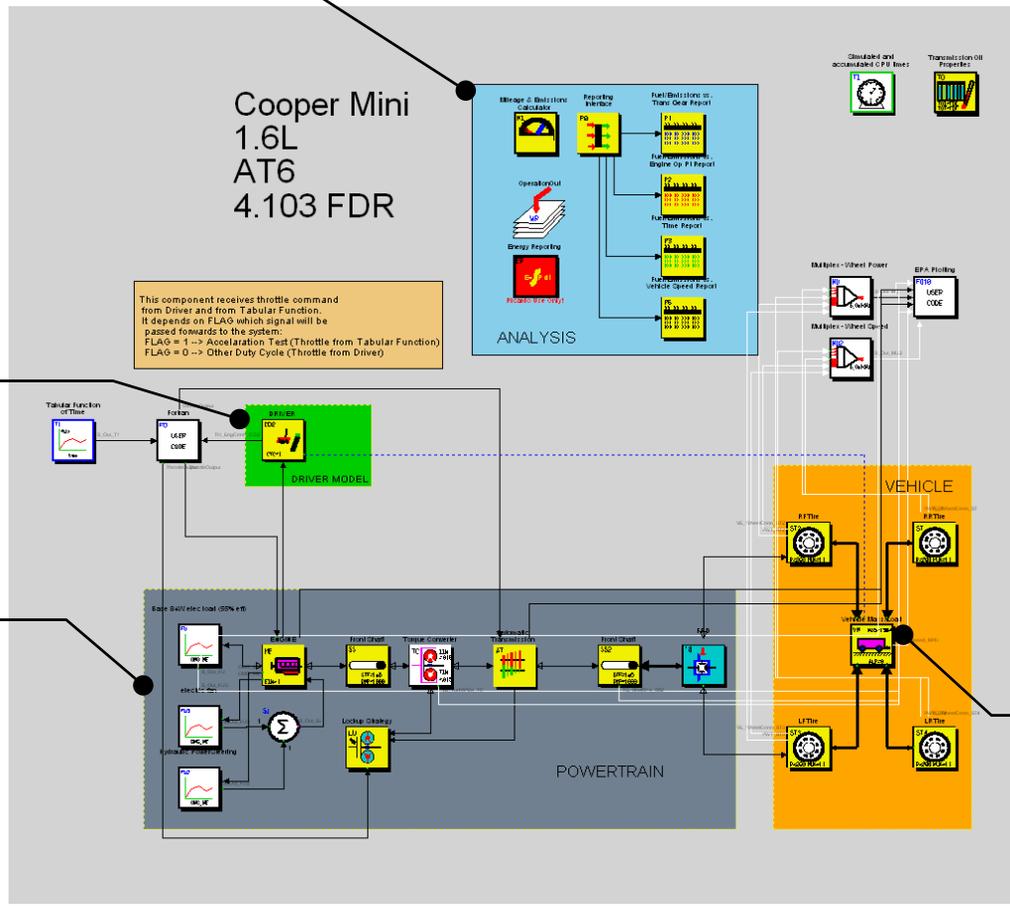
- ❑ Ricardo vehicle model development for high-level representation of existing vehicles
- ❑ Baseline vehicle selection
- ❑ Model inputs and assumptions
- ❑ Model validation
- ❑ Simulation Methodology
- ❑ Results
  - Gasoline vehicles
  - Diesel vehicles
- ❑ Conclusions

- ❑ A full forward-looking, physics-based model was developed for each baseline vehicle using commercially available MSC.EASY5™ simulation software with Ricardo proprietary data as well as published information.
- ❑ The model simulates what happens to the vehicle when the driver applies the accelerator and/or brake pedal in order to achieve a certain vehicle speed at a certain time.
- ❑ The simulation runs on a millisecond-by-millisecond basis and predicts the fuel usage and actual speed with time as the model driver follows a certain vehicle speed trace (drive cycle).
- ❑ The model physics includes torques and inertias as well as detailed sub-models for the influence of factors such as turbocharger lag and engine accessories.

# Example of Model Developed Using MSC.EASY5™ Software



Fuel Economy  
Post-processing  
Tools



Driver Model

Powertrain Model

Vehicle Model

## □ Engine

- Torque curves for full load and closed throttle motoring correlated to published power ratings
- Fuel consumption rates covering entire speed and load range
- Idle and redline speeds
- Rotational inertia
- Turbo-lag model for turbocharged diesel engines
- Alternator parasitic load (constant throughout drive cycle)
- Power steering parasitic load as a function of engine speed
- Cooling fan parasitic load
  - Electric (Small Car, Mid-Size Car, Small SUV) fan loads specific to duty cycle
  - Belt-driven (Large SUV, Truck) fan loads as a function of engine speed

## □ Transmission

- Torque converter characteristic curves for torque ratio and capacity factor
- Gear ratios
- Shift and lock-up clutch strategy maps for all engine throttle positions and vehicle speeds
- Efficiency and pumping losses for each gear
- Rotational inertias

- ❑ Final drive differential
  - Gear ratio
  - Efficiency
  - Rotational inertia
  
- ❑ The spin losses of the 4-wheel drive vehicle's front axle were also included in the model to simulate the fuel economy and performance of the 4-wheel drive powertrain operating in 2-wheel drive mode (similar to EPA procedure for emissions and fuel economy certification testing).

# Vehicle Model and Sub-Model Components



- ❑ Vehicle
  - Configuration (FWD, RWD or AWD)
  - Weight (front / rear distribution)
  - Center of gravity
  - Wheelbase
  - Frontal area
  - Coefficient of drag ( $C_d$ )
  
- ❑ Wheels / Tires
  - Rolling resistance coefficients
  - Rotational inertia
  - Rolling radius (tire size)
  - Maximum friction coefficient
  - Slip at peak tire force
  
- ❑ Driver
  - Drive cycle (time vs. velocity trace)

- ❑ Five vehicle classes were chosen to represent a variety of vehicle weights and engine sizes in the U.S passenger and light-duty truck vehicle fleet.
- ❑ A specific comparator vehicle for each class was chosen to verify that each vehicle model was representative of the class.
- ❑ Vehicle Class / Comparator Vehicle:
  - Small Car / Mini Cooper
  - Mid-Size Car / Ford Fusion
  - Small SUV / Saturn Vue
  - Large SUV / Ford Explorer
  - Truck / Toyota Tundra

# Model Input – Vehicle Parameters



Baseline Vehicle	Small Car	Mid-Size Car	Small SUV	Large SUV	Truck
Driveline configuration	Front Wheel Drive	Front Wheel Drive	Front Wheel Drive	4 Wheel Drive	4 Wheel Drive
Weight ETW - Fuel Economy (lb)	2875	3625	4250	5250	6000
Weight PTW - Performance (lb)	3175	4075	4800	6000	7200
Weight GCW - Performance (lb)					15800
Location of center of gravity from rear wheel (m)	1.134	1.146	1.083	1.148	1.295
Location of center of gravity from ground (m)	0.408	0.508	0.640	0.703	0.735
Weight distribution - % front / rear	55/45	55/45	55/45	50/50	55/45
Wheelbase (inches / m)	97.1 / 2.466	107.4 / 2.728	106.6 / 2.708	113.7 / 2.888	145.7 / 3.701
Length (inches)	145.6	190.2	180.1	193.4	228.7
Width (inches)	66.3	72.2	72.8	73.7	79.9
Height (inches)	55.4	57.2	67.0	72.8	75.6
Track F/R (inches)	57.4 / 57.8	61.6 / 61.3	61.4 / 61.8	60.9 / 61.8	67.9 / 67.9
Frontal area (m) / Coefficient of drag (Cd*A)	2.00 / 0.35 (0.700)	2.30 / 0.33 (0.759)	2.64 / 0.38 (1.00)	2.81 / 0.40 (1.12)	3.38 / 0.42 (1.42)
Tire size	P175/65R15	P205/60R16	P235/60R17	P235/70R16	P255/70R18
Tire rolling radius (m) / revs per mile	0.294 / 870.3	0.315 / 812.0	0.344 / 745.6	0.354 / 723.7	0.392 / 653.7

# Model Input – Baseline Gasoline Engine and Transmission



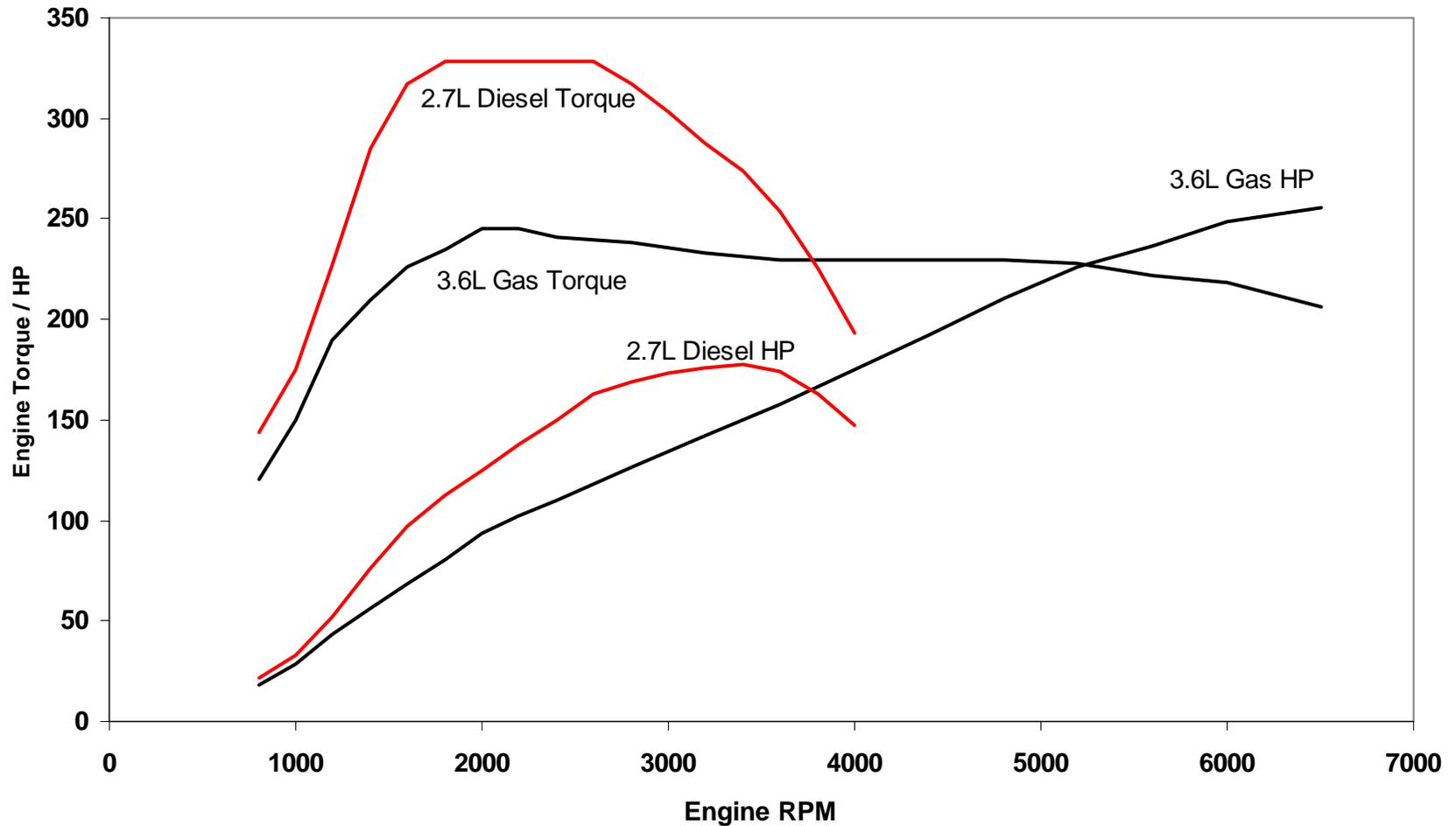
Baseline Vehicle	Small Car	Mid-Size Car	Small SUV	Large SUV	Truck
<b>Engine</b>	1.6L-4V DOHC I4 dual WT	3.0L-4V DOHC V6 WT	3.6L-4V DOHC V6 WT	4.6L-3V V8	5.7L-4V V8 DOHC dual WT
Fuel	gasoline	gasoline	gasoline	gasoline	gasoline
HP	118 HP @ 6000 RPM	221 HP @ 6250 RPM	257 HP @ 6500 RPM	292 HP @ 5750 RPM	381 HP @ 5600 RPM
Torque (lb-ft)	114 lb-ft @ 4250 RPM	205 lb-ft @ 3800 RPM	248 lb-ft @ 2100 RPM	300 lb-ft @ 3950 RPM	401 lb-ft @ 3600 RPM
Compression ratio (:1)	11.0	9.9	10.2	9.8	10.2
<b>Transmission</b>	6 speed auto	6 speed auto	6 speed auto	6 speed auto	6 speed auto
Transmission gear ratios					
1st	4.418	4.148	4.484	4.17	3.333
2nd	2.370	2.370	2.872	2.34	1.960
3rd	1.556	1.556	1.842	1.52	1.353
4th	1.155	1.155	1.414	1.14	1.000
5th	0.859	0.859	1.000	0.87	0.728
6th	0.686	0.686	0.742	0.69	0.588
Torque converter K-factor (at stall)	220	195	180	160	160
Torque converter torque ratio (at stall)	2.3	2.2	1.7	1.7	1.7
Final drive ratio	4.10	3.46	2.77	3.55	4.30
Top gear N/V (engine RPM / vehicle velocity)	40.8	32.1	25.5	29.6	27.6

- ❑ Diesel engines were selected to provide improved fuel economy and acceptable (not equivalent) vehicle performance.
- ❑ The characteristic turbocharged diesel power curve (high torque at low speed) has more torque in the typical cruising and light acceleration engine operating range (1100 – 3000 RPM). At 50 to 70 MPH in 6<sup>th</sup> gear the diesel provides more reserve torque so that light pedal “tip-in” acceleration demands are superior to the gasoline engine. Full pedal (WOT) accelerations at these speeds will be slower due to the lower maximum engine speed of the diesel (4000 RPM) and resultant lower horsepower vs. the high speed gasoline engine (5600 – 6500 RPM).

# Diesel Engine Power Curve



## 2.7L V6 Diesel vs. 3.6L V6 Gasoline Engines



# Model Input – Baseline Diesel Engine and Transmission



Baseline Diesel	Mid-Size Car	Small SUV	Large SUV	Truck
<b>Engine</b>	2.2L I4	2.7L V6	3.2L V6	4.8L V8
Fuel	diesel	diesel	diesel	diesel
HP	167 HP @ 4000 RPM	177 HP @ 3400 RPM	210 HP @ 3400 RPM	301 HP @ 3400 RPM
Torque (lb-ft)	270 lb-ft @ 3000 RPM	329 lb-ft @ 2200 RPM	389 lb-ft @ 2200 RPM	523 lb-ft @ 2000 RPM
<b>Transmission</b>	6 speed auto	6 speed auto	6 speed auto	6 speed auto
Transmission gear ratios				
1st	4.148	4.484	4.17	3.333
2nd	2.370	2.872	2.34	1.960
3rd	1.556	1.842	1.52	1.353
4th	1.155	1.414	1.14	1.000
5th	0.859	1.000	0.87	0.728
6th	0.686	0.742	0.69	0.588
Torque converter K-factor (at stall)	145	140	125	110
Torque converter torque ratio (at stall)	2.0	1.7	1.7	1.7
Final drive ratio	3.27	2.77	3.31	4.10
Top gear N/V	30.4	25.5	27.6	26.3

# Model Input – Downsized Gasoline Engines

(Displacement reduced to provide equivalent performance to baseline vehicles)



	Small Car	Mid-Size Car	Small SUV	Large SUV	Truck
<b>5% Weight Reduction</b>					
Weight ETW - Fuel Economy (lb)	2731	3444	4038	4988	5700
Weight PTW - Performance (lb)	3031	3894	4588	5738	
Weight GCW - Performance (lb)					15500
<b>Engine</b>	1.53L-4V DOHC I4 dual VVT	2.89L-4V DOHC V6 VVT	3.48L-4V DOHC V6 VVT	4.43L-3V V8	5.60L-4V V8 DOHC dual VVT
Fuel	gasoline	gasoline	gasoline	gasoline	gasoline
HP	113 HP @ 6000 RPM	213 HP @ 6250 RPM	248 HP @ 6500 RPM	281 HP @ 5750 RPM	374 HP @ 5600 RPM
Torque (lb-ft)	109 lb-ft @ 4250 RPM	197 lb-ft @ 3800 RPM	240 lb-ft @ 2100 RPM	289 lb-ft @ 3950 RPM	394 lb-ft @ 3600 RPM
<b>10% Weight Reduction</b>					
Weight ETW - Fuel Economy (lb)	2588	3263	3825	4725	5400
Weight PTW - Performance (lb)	2888	3713	4375	5475	
Weight GCW - Performance (lb)					15200
<b>Engine</b>	1.48L-4V DOHC I4 dual VVT	2.79L-4V DOHC V6 VVT	3.33L-4V DOHC V6 VVT	4.25L-3V V8	5.51L-4V V8 DOHC dual VVT
Fuel	gasoline	gasoline	gasoline	gasoline	gasoline
HP	109 HP @ 6000 RPM	206 HP @ 6250 RPM	238 HP @ 6500 RPM	270 HP @ 5750 RPM	368 HP @ 5600 RPM
Torque (lb-ft)	105 lb-ft @ 4250 RPM	191 lb-ft @ 3800 RPM	229 lb-ft @ 2100 RPM	277 lb-ft @ 3950 RPM	388 lb-ft @ 3600 RPM
<b>20% Weight Reduction</b>					
Weight ETW - Fuel Economy (lb)	2300	2900	3400	4200	4800
Weight PTW - Performance (lb)	2600	3350	3950	4950	
Weight GCW - Performance (lb)					14600
<b>Engine</b>	1.36L-4V DOHC I4 dual VVT	2.58L-4V DOHC V6 VVT	3.05L-4V DOHC V6 VVT	3.88L-3V V8	5.31L-4V V8 DOHC dual VVT
Fuel	gasoline	gasoline	gasoline	gasoline	gasoline
HP	100 HP @ 6000 RPM	190 HP @ 6250 RPM	218 HP @ 6500 RPM	246 HP @ 5750 RPM	355 HP @ 5600 RPM
Torque (lb-ft)	97 lb-ft @ 4250 RPM	176 lb-ft @ 3800 RPM	210 lb-ft @ 2100 RPM	253 lb-ft @ 3950 RPM	374 lb-ft @ 3600 RPM

# Model Input – Downsized Diesel Engines

(Displacement reduced to provide equivalent performance to baseline vehicles)



	Mid-Size Car	Small SUV	Large SUV	Truck
<b>5% Weight Reduction</b>				
Weight ETW - Fuel Economy (lb)	3444	4038	4988	5700
Weight PTW - Performance (lb)	3894	4588	5738	
Weight GCW - Performance (lb)				15500
<b>Engine</b>	2.12L I4	2.59L V6	3.07L V6	4.72L V8
Fuel	diesel	diesel	diesel	diesel
HP	161 HP @ 4000 RPM	170 HP @ 3400 RPM	201 HP @ 3400 RPM	296 HP @ 3400 RPM
Torque (lb-ft)	260 lb-ft @ 3000 RPM	316 lb-ft @ 2200 RPM	373 lb-ft @ 2200 RPM	514 lb-ft @ 2000 RPM
<b>10% Weight Reduction</b>				
Weight ETW - Fuel Economy (lb)	3263	3825	4725	5400
Weight PTW - Performance (lb)	3713	4375	5475	
Weight GCW - Performance (lb)				15200
<b>Engine</b>	2.04L I4	2.48L V6	2.94L V6	4.64L V8
Fuel	diesel	diesel	diesel	diesel
HP	155 HP @ 4000 RPM	163 HP @ 3400 RPM	193 HP @ 3400 RPM	291 HP @ 3400 RPM
Torque (lb-ft)	250 lb-ft @ 3000 RPM	302 lb-ft @ 2200 RPM	357 lb-ft @ 2200 RPM	506 lb-ft @ 2000 RPM
<b>20% Weight Reduction</b>				
Weight ETW - Fuel Economy (lb)	2900	3400	4200	4800
Weight PTW - Performance (lb)	3350	3950	4950	
Weight GCW - Performance (lb)				14600
<b>Engine</b>	1.86L I4	2.26L V6	2.68L V6	4.47L V8
Fuel	diesel	diesel	diesel	diesel
HP	141 HP @ 4000 RPM	148 HP @ 3400 RPM	176 HP @ 3400 RPM	280 HP @ 3400 RPM
Torque (lb-ft)	228 lb-ft @ 3000 RPM	275 lb-ft @ 2200 RPM	326 lb-ft @ 2200 RPM	487 lb-ft @ 2000 RPM

# Model Validation

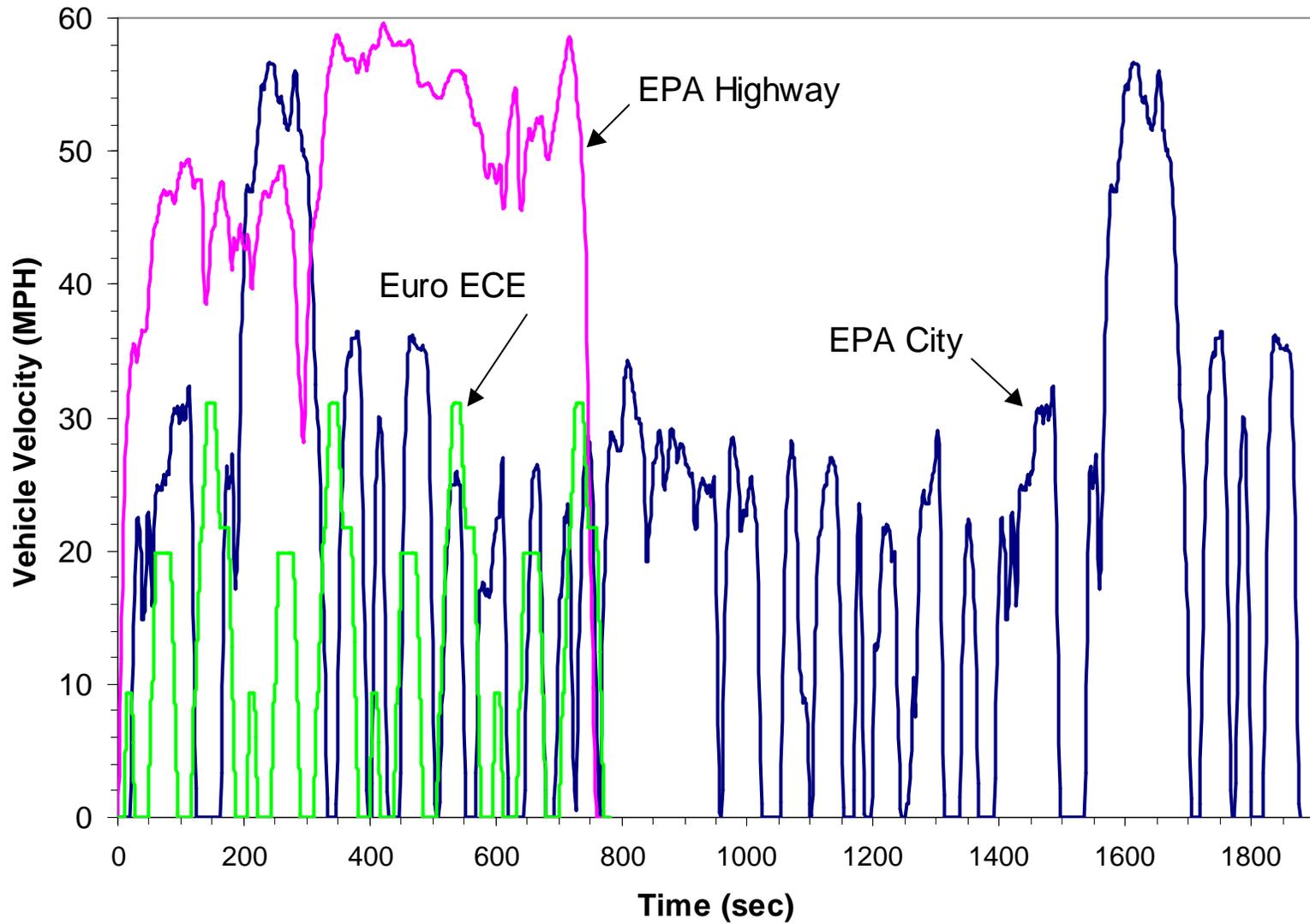


- ❑ Each vehicle model was run and the simulation output for total vehicle roadload tractive effort from 0 to 60 MPH and EPA City and Highway fuel economy was compared to published data for the comparator vehicle.
- ❑ No attempt was made to “calibrate” the model to achieve a given output result.

VEHICLE	Simulation Roadload Force	Simulated Fuel Economy vs. Comparator (% diff)		
	Maximum Variation vs. Comparator	EPA City	EPA Highway	Combined
Small Car	0.2%	2.5%	-0.6%	1.3%
Mid-Size Car	2.5%	0.2%	-1.4%	-0.4%
Small SUV	1.1%	1.8%	-4.4%	-0.4%
Large SUV	1.7%	5.9%	-1.1%	3.5%
Truck	-1.3%	2.2%	-1.9%	0.7%

- ❑ Vehicle fuel economy (MPG) is simulated over the following drive cycles at EPA Equivalent Test Weight (ETW):
  - EPA FTP75 (city)
  - EPA HWFET (highway)
  - ECE (European)
  - Steady State 30, 45, 60 and 75 MPH
- ❑ All simulations are performed with an engine at normal operating temperature. The EPA FTP (city) cycle result is obtained by using a bag #1 correction factor of 0.8 (bag #1 fuel economy = 80% of bag #3 fuel economy)
- ❑ Vehicle acceleration performance (sec.) is simulated over the following drive cycles at loaded vehicle weight conditions (GCVW for truck):
  - 0 – 10 MPH
  - 0 – 60 MPH
  - 30 – 50 MPH
  - 50 – 70 MPH
- ❑ Each vehicle is weight reduced by 5%, 10% and 20% and the engine downsized to match the baseline vehicle acceleration performance. Fuel economy benefits are recorded.

# Simulation Drive Cycles



- ❑ The Wide Open Throttle (WOT) performance of each vehicle is simulated at a loaded weight condition to approximate what a customer would expect from a given class of vehicle (number of passengers, luggage or trailer towing). All fuel economy simulations are performed at ETW.
- ❑ Additional Performance Weight:
  - Small Car – 300 lb. (2 passengers)
  - Mid-Size Car – 450 lb. (3 passengers)
  - Small SUV – 550 lb. (3 passengers + 100 lb. Luggage)
  - Large SUV – 750 lb. (5 passengers)
  - Truck – 9800 lb. (Trailer + load to rated combined weight of 15,800 lb.)
- ❑ Engines were downsized in displacement to give the weight reduced vehicles equivalent performance to the baseline vehicle with a priority given to passing maneuvers (30-50 and 50-70 MPH).

## Fuel Economy Labeling of Vehicles

- ❑ The EPA requires that all new light-duty motor vehicles have a fuel economy label that gives the consumer an estimate of the city and highway fuel economy. This estimate is used to compare to the fuel economy of other vehicles that they may be considering for purchase.
- ❑ Prior to the 2008 model year, the City fuel economy prediction for the vehicle window sticker was calculated as 90% of the EPA Federal Test Procedure (FTP) result and the Highway fuel economy was 78% of the EPA Highway Fuel Economy Test (HWFET) result.
- ❑ Starting with the 2008 model year, new test methods that include high speeds, aggressive accelerations, cold temperatures and the use of air conditioning have been introduced to more accurately reflect real world fuel economy.
- ❑ As a transition to the increased testing requirements, a manufacturer has the option of using a “derived 5-cycle” approach for fuel economy labels for the 2008-2010 model years that uses only the FTP and HWFET tests based on regression formulae derived from the fuel economy test results of more than 600 vehicles in the EPA database (subject to revision as more data becomes available).
  - City MPG =  $1 / (0.003259 + (1.1805 / \text{FTP MPG}))$
  - Highway MPG =  $1 / (0.001376 + (1.3466 / \text{HWFET MPG}))$

## Vehicles with Gasoline Engines

# Small Car – 1.6L-4V gas engine with variable intake and exhaust cam timing and lift



## Fuel Economy Simulation Results

DRIVE CYCLE		EPA							European			
		City FTP75	Highway HWFET	Combined	FUEL ECONOMY BENEFIT			City Label	Highway Label	ECE	FE BENEFIT	
					City FTP75	Highway HWFET	Combined				%	
		(mpg)	(mpg)	(mpg)	%	%	%	(mpg)	(mpg)	(mpg)	%	
Baseline		34.1	46.8	38.9				26.4	33.2	32.3		
Weight Reduction	5%	Baseline Engine	35.0	47.6	39.7	2.4%	1.6%	2.1%	27.0	33.7	32.9	1.8%
	10%		35.7	48.2	40.5	4.8%	3.0%	4.1%	27.6	34.1	33.5	3.7%
	20%		37.5	49.6	42.1	9.8%	5.9%	8.4%	28.8	35.1	34.8	7.6%
	5%	Engine Downsized to Baseline Performance	35.5	48.0	40.2	3.9%	2.4%	3.3%	27.4	33.9	33.7	4.2%
	10%		36.7	49.0	41.3	7.4%	4.7%	6.4%	28.2	34.7	34.8	7.9%
	20%		39.4	51.4	44.0	15.6%	9.8%	13.3%	30.1	36.3	37.6	16.5%

STEADY STATE CONDITIONS		FUEL ECONOMY BENEFIT								
		30 MPH	45 MPH	60 MPH	75 MPH					
		(mpg)	(mpg)	(mpg)	(mpg)					
		30 MPH	45 MPH	60 MPH	75 MPH					
		%	%	%	%					
Baseline		61.4	56.6	44.3	33.7					
Weight Reduction	5%	Baseline Engine	62.1	57.2	44.7	33.9	1.1%	1.0%	0.9%	0.7%
	10%		62.8	57.8	45.1	34.1	2.3%	2.1%	1.8%	1.4%
	20%		64.2	59.0	45.8	34.6	4.6%	4.2%	3.5%	2.8%
	5%	Engine Downsized to Baseline Performance	63.4	58.1	45.1	34.1	3.3%	2.6%	1.9%	1.4%
	10%		65.1	59.4	45.8	34.5	6.0%	4.8%	3.5%	2.6%
	20%		69.2	62.3	47.5	35.4	12.7%	10.0%	7.2%	5.2%

EPA fuel economy label projections are based on the derived 5-cycle regression equation for the 2008 model year.

# Small Car – 1.6L-4V gas engine with variable intake and exhaust cam timing and lift



## Vehicle Performance Simulation Results at Wide Open Throttle (WOT)

			<b>0 - 10 MPH</b>	<b>0 - 60 MPH</b>	<b>30 - 50 MPH</b>	<b>50 - 70 MPH</b>
			(sec)	(sec)	(sec)	(sec)
		Baseline	1.15	10.3	4.0	6.6
Weight Reduction	5%	Baseline Engine	1.12	9.9	3.8	6.3
	10%		1.11	9.5	3.6	6.0
	20%		1.08	8.7	3.3	5.4
	5%	Engine Downsized to Baseline Performance	1.18	10.4	4.0	6.7
	10%		1.19	10.3	4.0	6.6
	20%		1.22	10.3	3.9	6.6

# Mid-Size Car – 3.0L-4V gas engine with variable intake cam timing



## Fuel Economy Simulation Results

DRIVE CYCLE		EPA							European			
		City FTP75	Highway HWFET	Combined	FUEL ECONOMY BENEFIT			City Label	Highway Label	ECE	FE BENEFIT	
					City FTP75	Highway HWFET	Combined					
					(mpg)	(mpg)	(mpg)				%	
	Baseline	22.9	36.9	27.6				18.3	26.4	17.6		
Weight Reduction	5%	Baseline Engine	23.3	37.3	28.0	1.4%	1.2%	1.3%	18.5	26.7	17.8	1.0%
	10%		23.6	37.8	28.4	2.9%	2.4%	2.7%	18.8	27.0	18.0	2.1%
	20%		24.3	38.7	29.2	5.8%	5.0%	5.6%	19.3	27.7	18.3	4.1%
	5%	Engine Downsized to Baseline Performance	23.8	37.9	28.6	3.6%	2.7%	3.3%	18.9	27.1	18.3	4.0%
	10%		24.6	38.9	29.5	7.4%	5.4%	6.7%	19.5	27.8	19.0	7.9%
	20%		26.6	41.0	31.6	15.9%	11.3%	14.3%	21.0	29.3	20.6	16.9%

STEADY STATE CONDITIONS		FUEL ECONOMY BENEFIT								
		30 MPH	45 MPH	60 MPH	75 MPH					
		(mpg)	(mpg)	(mpg)	(mpg)					
		%	%	%	%					
	Baseline	32.6	44.0	35.8	28.6					
Weight Reduction	5%	Baseline Engine	32.7	44.4	36.0	28.8	0.2%	0.9%	0.8%	0.5%
	10%		32.7	44.8	36.3	29.0	0.5%	1.8%	1.5%	1.1%
	20%		32.9	45.7	36.9	29.3	1.0%	3.7%	3.1%	2.3%
	5%	Engine Downsized to Baseline Performance	33.7	45.1	36.5	29.1	3.6%	2.4%	1.9%	1.6%
	10%		34.9	46.2	37.1	29.6	7.1%	4.9%	3.8%	3.2%
	20%		37.5	48.5	38.6	30.5	15.1%	10.1%	7.9%	6.5%

EPA fuel economy label projections are based on the derived 5-cycle regression equation for the 2008 model year.

# Mid-Size Car – 3.0L-4V gas engine with variable intake cam timing



## Vehicle Performance Simulation Results at Wide Open Throttle (WOT)

			<b>0 - 10 MPH</b>	<b>0 - 60 MPH</b>	<b>30 - 50 MPH</b>	<b>50 - 70 MPH</b>	
			(sec)	(sec)	(sec)	(sec)	
			Baseline	1.49	9.7	3.2	4.6
Weight Reduction	5%	Baseline Engine	1.45	9.4	3.1	4.4	
	10%		1.41	9.0	2.9	4.2	
	20%		1.34	8.4	2.7	3.8	
	5%	Engine Downsized to Baseline Performance	1.51	9.7	3.2	4.6	
	10%		1.51	9.7	3.2	4.5	
	20%		1.54	9.6	3.1	4.5	

# Mid-Size Car – Additional Engine Downsizing Study



- ❑ Fuel economy simulation results with gasoline engine downsized to vehicle performance level at ETW (Degraded vehicle acceleration performance vs. baseline at loaded weight)
- ❑ Engine displacement is further reduced by 0.1% per 1% of weight reduction with a resultant improvement in fuel economy of 0.1%

DRIVE CYCLE			EPA								European		
			Engine Displ. (L)	City FTP75 (mpg)	Highway HWFET (mpg)	Combined (mpg)	FUEL ECONOMY BENEFIT			City Label (mpg)	Highway Label (mpg)	ECE (mpg)	FE BENEFIT (%)
							City FTP75 (%)	Highway HWFET (%)	Combined (%)				
		Baseline	3.0	22.9	36.9	27.6				18.3	26.4	17.6	
Weight Reduction	5%	Engine Downsized to Performance Level of Vehicle at ETW	2.87	23.8	38.0	28.6	3.9%	2.9%	3.6%	18.9	27.1	18.4	4.4%
	10%		2.75	24.8	39.1	29.7	8.2%	5.9%	7.4%	19.7	27.9	19.2	9.0%
	20%		2.49	27.1	41.5	32.1	18.2%	12.5%	16.2%	21.4	29.6	21.1	20.0%

STEADY STATE CONDITIONS			Engine Displ. (L)	FUEL ECONOMY BENEFIT									
				30 MPH (mpg)	45 MPH (mpg)	60 MPH (mpg)	75 MPH (mpg)	30 MPH (%)	45 MPH (%)	60 MPH (%)	75 MPH (%)		
				30 MPH (%)	45 MPH (%)	60 MPH (%)	75 MPH (%)						
		Baseline	3.0	32.6	44.0	35.8	28.6						
Weight Reduction	5%	Engine Downsized to Performance Level of Vehicle at ETW	2.87	33.9	45.2	36.5	29.1	4.1%	2.7%	2.1%	1.7%		
	10%		2.75	35.3	46.4	37.3	29.7	8.4%	5.4%	4.2%	3.6%		
	20%		2.49	38.6	49.1	39.0	30.7	18.6%	11.6%	8.9%	7.3%		

EPA fuel economy label projections are based on the derived 5-cycle regression equation for the 2008 model year.

# Mid-Size Car – Additional Engine Downsizing Study



- Vehicle performance simulation results with gasoline engine downsized to vehicle performance level at ETW (Degraded vehicle acceleration performance vs. baseline at loaded weight)

			<b>0 - 10 MPH</b>	<b>0 - 60 MPH</b>	<b>30 - 50 MPH</b>	<b>50 - 70 MPH</b>
			(sec)	(sec)	(sec)	(sec)
		Baseline (ETW)	1.39	8.9	2.9	4.1
Weight Reduction	5%	Baseline Engine	1.37	8.8	2.7	3.9
	10%		1.32	8.2	2.6	3.7
	20%		1.27	7.7	2.4	3.4
	5%	Engine Downsized to Performance Level of Vehicle at ETW	1.41	8.9	2.9	4.1
	10%		1.43	8.8	2.9	4.0
	20%		1.47	8.8	2.9	4.0

# Small SUV – 3.6L-4V gas engine with variable intake cam timing



## Fuel Economy Simulation Results

DRIVE CYCLE		EPA							European			
		City FTP75	Highway HWFET	Combined	FUEL ECONOMY BENEFIT			City Label	Highway Label	ECE	FE BENEFIT	
					City FTP75	Highway HWFET	Combined				%	
					(mpg)	(mpg)	(mpg)				%	
	Baseline	20.9	30.9	24.4				16.7	22.2	17.9		
Weight Reduction	5%	Baseline Engine	21.2	31.3	24.8	1.7%	1.3%	1.6%	17.0	22.5	18.1	1.3%
	10%		21.6	31.7	25.2	3.6%	2.7%	3.3%	17.3	22.8	18.4	2.7%
	20%		22.3	32.4	26.0	7.0%	4.9%	6.2%	17.8	23.3	18.9	5.5%
	5%	Engine Downsized to Baseline Performance	21.6	31.6	25.1	3.3%	2.2%	2.9%	17.2	22.7	18.5	3.6%
	10%		22.3	32.3	25.9	6.7%	4.6%	5.9%	17.8	23.2	19.3	8.0%
	20%		24.0	34.0	27.7	15.2%	10.2%	13.4%	19.1	24.4	21.1	17.8%

DRIVE CYCLE		STEADY STATE CONDITIONS				FUEL ECONOMY BENEFIT											
		30 MPH	45 MPH	60 MPH	75 MPH	30 MPH	45 MPH	60 MPH	75 MPH								
										(mpg)	(mpg)	(mpg)	(mpg)	%	%	%	%
										(mpg)	(mpg)	(mpg)	(mpg)	%	%	%	%
	Baseline	33.3	35.7	30.6	22.2												
Weight Reduction	5%	Baseline Engine	33.5	35.9	30.8	22.4	0.7%	0.6%	0.8%	0.7%							
	10%		33.7	36.1	31.1	22.5	1.4%	1.2%	1.6%	1.3%							
	20%		34.2	36.5	31.6	22.8	2.7%	2.4%	3.3%	2.7%							
	5%	Engine Downsized to Baseline Performance	34.2	36.5	31.0	22.4	2.9%	2.4%	1.3%	0.6%							
	10%		35.4	37.4	31.4	22.5	6.4%	4.9%	2.6%	1.3%							
	20%		37.9	39.3	32.2	22.9	14.0%	10.3%	5.3%	3.1%							

EPA fuel economy label projections are based on the derived 5-cycle regression equation for the 2008 model year.

# Small SUV – 3.6L-4V gas engine with variable intake cam timing



## Vehicle Performance Simulation Results at Wide Open Throttle (WOT)

			<b>0 - 10 MPH</b>	<b>0 - 60 MPH</b>	<b>30 - 50 MPH</b>	<b>50 - 70 MPH</b>
			(sec)	(sec)	(sec)	(sec)
		Baseline	1.82	9.2	2.9	4.6
Weight Reduction	5%	Baseline Engine	1.78	8.9	2.8	4.4
	10%		1.74	8.6	2.7	4.2
	20%		1.66	8.0	2.5	3.8
	5%	Engine Downsized to Baseline Performance	1.83	9.2	2.9	4.5
	10%		1.85	9.2	2.9	4.6
	20%		1.88	9.2	2.9	4.6

# Large SUV – 4.6L-3V gas engine



## Fuel Economy Simulation Results

DRIVE CYCLE		EPA							European			
		City FTP75	Highway HWFET	Combined	FUEL ECONOMY BENEFIT			City Label	Highway Label	ECE	FE BENEFIT	
					City FTP75	Highway HWFET	Combined					
					(mpg)	(mpg)	(mpg)				%	
	Baseline	16.7	25.7	19.9				13.6	18.6	13.8		
Weight Reduction	5%	Baseline Engine	17.0	25.9	20.1	1.8%	0.7%	1.4%	13.8	18.7	14.0	1.3%
	10%		17.3	26.3	20.5	3.5%	2.1%	3.0%	14.0	19.0	14.1	2.5%
	20%		17.9	26.9	21.1	7.1%	4.7%	6.2%	14.5	19.4	14.5	5.2%
	5%	Engine Downsized to Baseline Performance	17.3	26.2	20.5	3.6%	2.1%	3.1%	14.0	19.0	14.3	3.8%
	10%		18.0	26.8	21.1	7.4%	4.4%	6.3%	14.5	19.4	14.9	8.2%
	20%		19.5	28.2	22.6	16.4%	9.8%	14.0%	15.7	20.4	16.3	18.2%

DRIVE CYCLE		STEADY STATE CONDITIONS				FUEL ECONOMY BENEFIT				
		30 MPH	45 MPH	60 MPH	75 MPH	30 MPH	45 MPH	60 MPH	75 MPH	
										(mpg)
	Baseline	26.3	29.6	24.2	18.6					
Weight Reduction	5%	Baseline Engine	26.5	29.8	24.4	18.7	0.8%	0.8%	0.8%	0.6%
	10%		26.7	30.0	24.5	18.8	1.6%	1.6%	1.5%	1.2%
	20%		27.2	30.5	24.9	19.1	3.2%	3.2%	3.1%	2.5%
	5%	Engine Downsized to Baseline Performance	27.1	30.3	24.6	18.9	3.0%	2.5%	1.7%	1.4%
	10%		27.9	31.1	25.0	19.1	6.2%	5.3%	3.6%	2.8%
	20%		29.9	33.0	26.1	19.7	13.7%	11.5%	7.9%	5.9%

EPA fuel economy label projections are based on the derived 5-cycle regression equation for the 2008 model year.

# Large SUV – 4.6L-3V gas engine



## Vehicle Performance Simulation Results at Wide Open Throttle (WOT)

			<b>0 - 10 MPH</b>	<b>0 - 60 MPH</b>	<b>30 - 50 MPH</b>	<b>50 - 70 MPH</b>
			(sec)	(sec)	(sec)	(sec)
		Baseline	0.84	8.1	3.2	5.3
Weight Reduction	5%	Baseline Engine	0.81	7.8	3.0	5.0
	10%		0.79	7.4	2.9	4.8
	20%		0.74	6.7	2.6	4.3
	5%	Engine Downsized to Baseline Performance	0.84	8.1	3.1	5.3
	10%		0.84	8.1	3.1	5.3
	20%		0.86	8.1	3.1	5.3

# Truck – 5.7L-4V gas engine with variable intake and exhaust cam timing



## Fuel Economy Simulation Results

DRIVE CYCLE		EPA							European			
		City FTP75	Highway HWFET	Combined	FUEL ECONOMY BENEFIT			City Label	Highway Label	ECE	FE BENEFIT	
					City FTP75	Highway HWFET	Combined					
					(mpg)	(mpg)	(mpg)				%	
	Baseline	15.8	23.1	18.5				12.9	16.8	13.7		
Weight Reduction	5%	Baseline Engine	16.2	23.4	18.8	2.0%	1.3%	1.7%	13.1	17.0	13.9	1.4%
	10%		16.5	23.7	19.1	4.0%	2.5%	3.5%	13.3	17.2	14.1	2.9%
	20%		17.1	24.5	19.8	7.7%	5.8%	7.0%	13.8	17.7	14.5	5.9%
	5%	Engine Downsized to Baseline Performance	16.3	23.5	18.9	2.7%	1.6%	2.3%	13.2	17.0	14.0	2.5%
	10%		16.7	23.9	19.3	5.5%	3.3%	4.7%	13.5	17.3	14.4	5.0%
	20%		17.6	24.8	20.2	11.2%	7.0%	9.7%	14.2	17.9	15.1	10.4%

STEADY STATE CONDITIONS		FUEL ECONOMY BENEFIT								
		30 MPH	45 MPH	60 MPH	75 MPH					
		(mpg)	(mpg)	(mpg)	(mpg)					
		%	%	%	%					
	Baseline	25.5	26.0	21.1	15.7					
Weight Reduction	5%	Baseline Engine	25.6	26.2	21.3	15.8	0.7%	0.7%	0.9%	0.6%
	10%		25.8	26.4	21.5	15.9	1.3%	1.5%	1.8%	1.1%
	20%		26.1	26.7	21.9	16.1	2.6%	2.8%	3.5%	2.3%
	5%	Engine Downsized to Baseline Performance	25.9	26.3	21.3	15.8	1.7%	1.4%	0.8%	0.7%
	10%		26.4	26.7	21.5	16.0	3.5%	2.8%	1.6%	1.4%
	20%		27.3	27.5	21.8	16.2	7.2%	5.8%	3.3%	2.9%

EPA fuel economy label projections are based on the derived 5-cycle regression equation for the 2008 model year.

# Truck – 5.7L-4V gas engine with variable intake and exhaust cam timing



## Vehicle Performance Simulation Results at Wide Open Throttle (WOT)

			<b>0 - 10 MPH</b>	<b>0 - 60 MPH</b>	<b>30 - 50 MPH</b>	<b>50 - 70 MPH</b>
			(sec)	(sec)	(sec)	(sec)
		Baseline	1.46	16.0	6.5	10.5
Weight Reduction	5%	Baseline Engine	1.44	15.7	6.4	10.3
	10%		1.42	15.4	6.3	10.1
	20%		1.37	14.7	6.0	9.7
	5%	Engine Downsized to Baseline Performance	1.46	16.0	6.5	10.5
	10%		1.46	16.0	6.5	10.5
	20%		1.46	16.0	6.5	10.5

## Fuel Economy Improvement (%) per 100 lb. Weight Reduction - Gasoline Engines



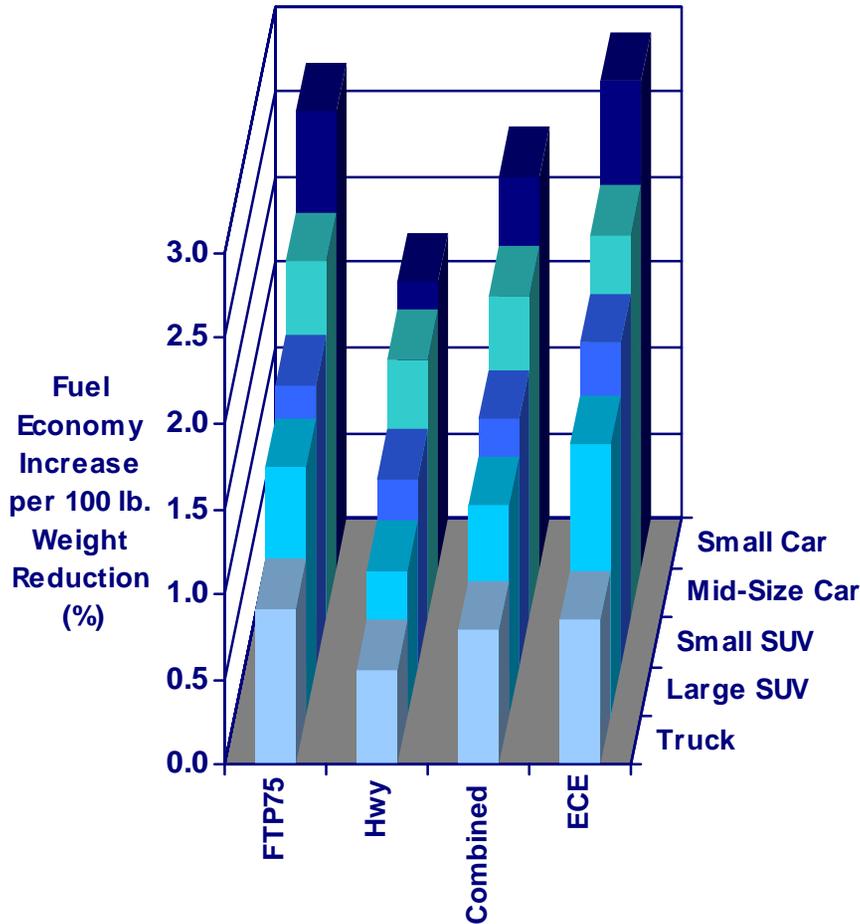
<b>BASELINE ENGINES</b>	<b>City FTP75</b>	<b>Highway HWFET</b>	<b>EPA Combined</b>	<b>Euro ECE</b>	<b>30 MPH</b>	<b>45 MPH</b>	<b>60 MPH</b>	<b>75 MPH</b>
<b>Small Car</b>	1.7%	1.1%	1.5%	1.3%	0.8%	0.7%	0.6%	0.5%
<b>Mid-Size Car</b>	0.8%	0.7%	0.8%	0.6%	0.1%	0.5%	0.4%	0.3%
<b>Small SUV</b>	0.8%	0.6%	0.7%	0.6%	0.3%	0.3%	0.4%	0.3%
<b>Large SUV</b>	0.7%	0.4%	0.6%	0.5%	0.3%	0.3%	0.3%	0.2%
<b>Truck</b>	0.7%	0.4%	0.6%	0.5%	0.2%	0.2%	0.3%	0.2%

<b>DOWNSIZED ENGINES</b>	<b>City FTP75</b>	<b>Highway HWFET</b>	<b>EPA Combined</b>	<b>Euro ECE</b>	<b>30 MPH</b>	<b>45 MPH</b>	<b>60 MPH</b>	<b>75 MPH</b>
<b>Small Car</b>	2.7%	1.7%	2.3%	2.9%	2.2%	1.7%	1.3%	0.9%
<b>Mid-Size Car</b>	2.1%	1.5%	1.9%	2.2%	2.0%	1.4%	1.1%	0.9%
<b>Small SUV</b>	1.6%	1.1%	1.5%	1.9%	1.5%	1.2%	0.6%	0.3%
<b>Large SUV</b>	1.4%	0.9%	1.2%	1.6%	1.2%	1.0%	0.7%	0.5%
<b>Truck</b>	0.9%	0.6%	0.8%	0.8%	0.6%	0.5%	0.3%	0.2%

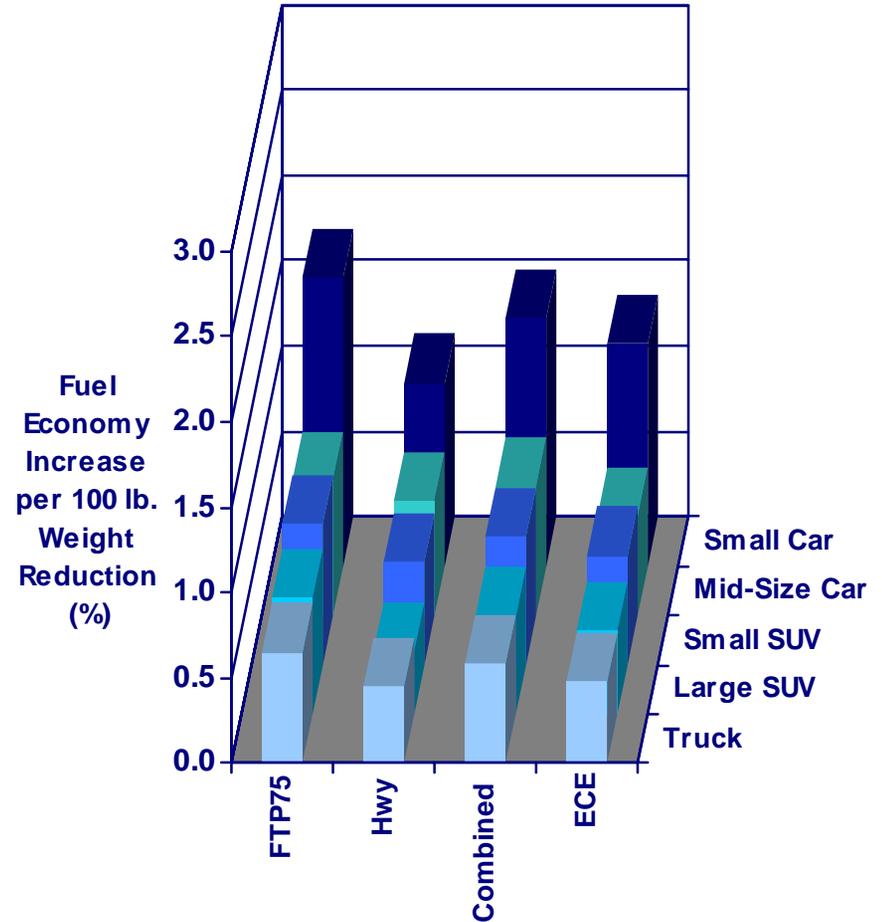
# Drive Cycle Fuel Economy Improvement (%) per 100 lb. Weight Reduction - Gasoline Engines



Engine Downsized to Baseline Performance



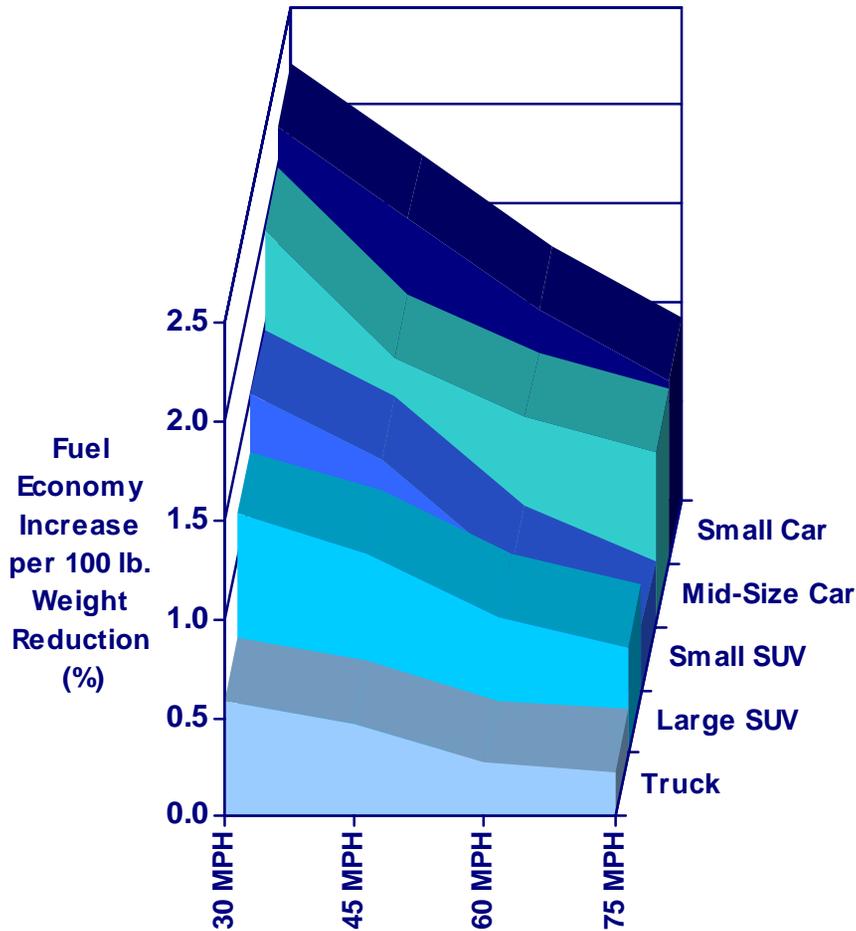
Baseline Engine



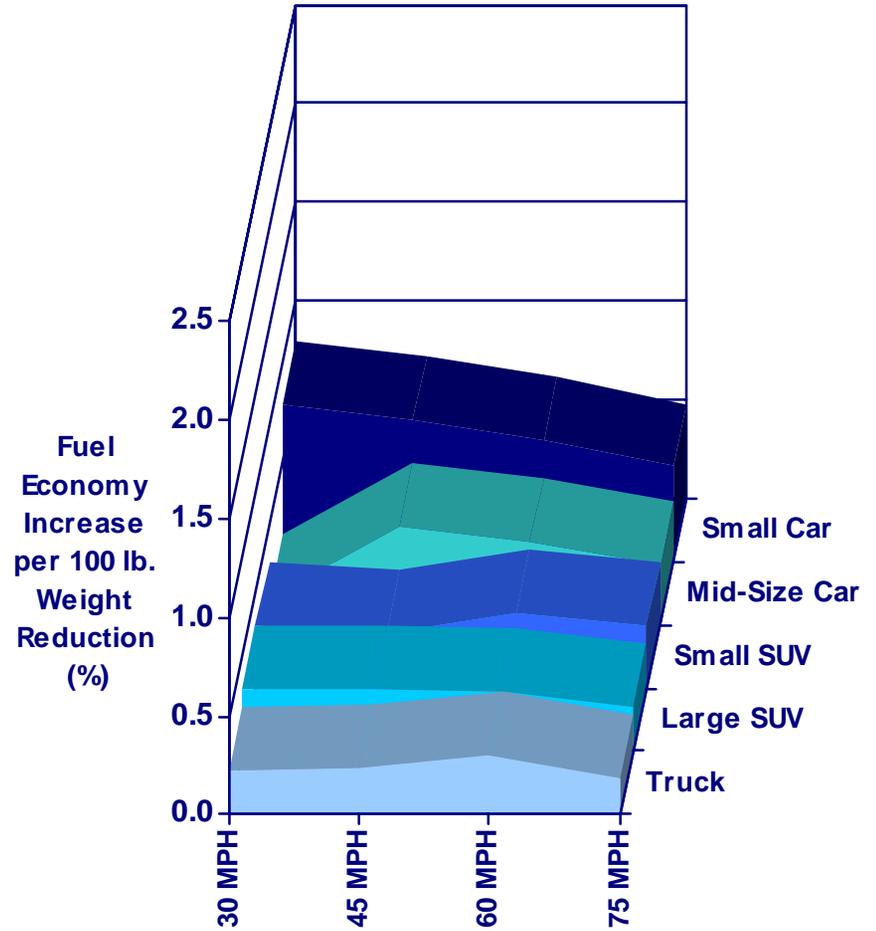
# Steady State Fuel Economy Improvement (%) per 100 lb. Weight Reduction - Gasoline Engines



Engine Downsized to Baseline Performance



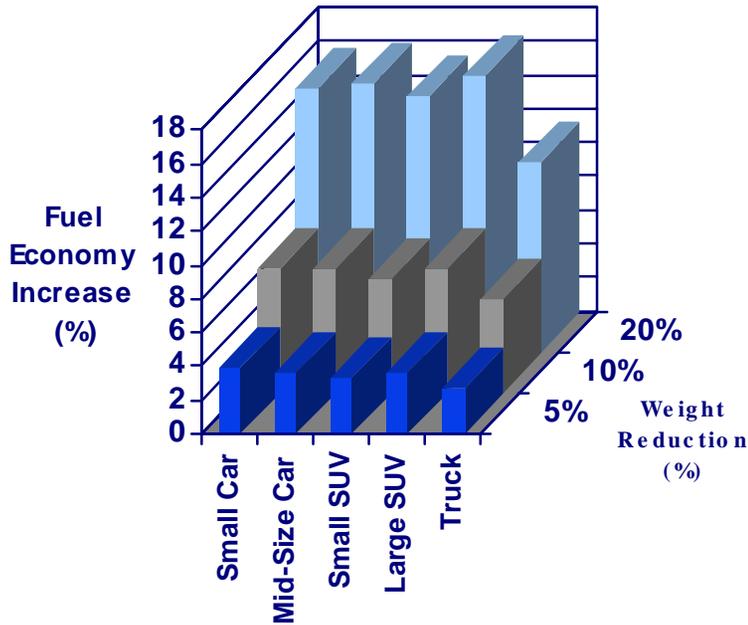
Baseline Engine



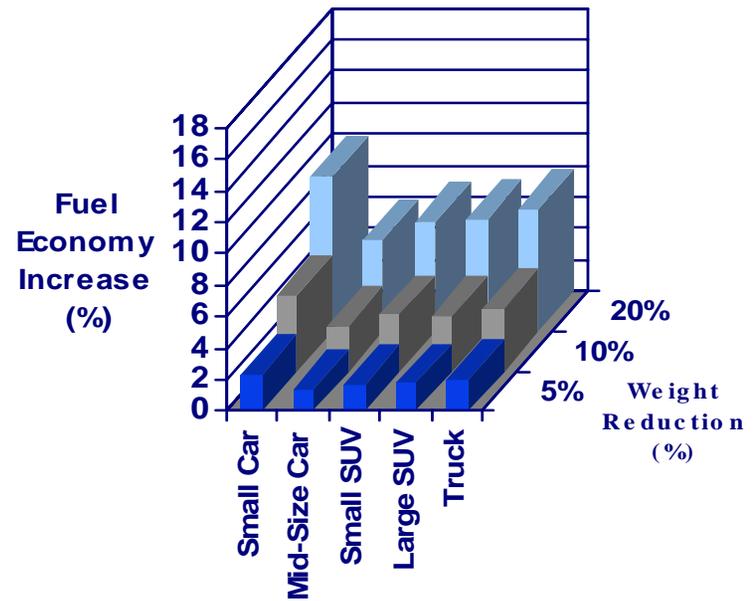
# EPA City (FTP75) Drive Cycle – Fuel Economy Improvement (%) - Gasoline Engines



## Engine Downsized to Baseline Performance



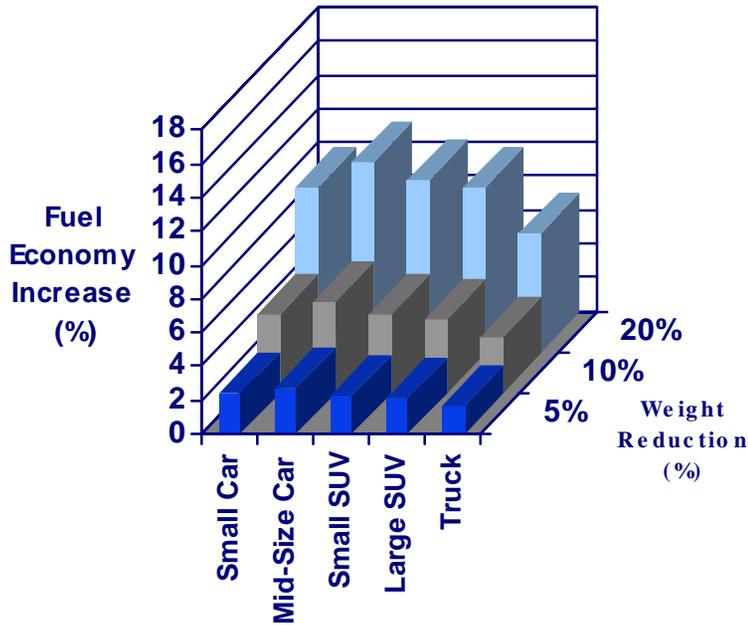
## Baseline Engine



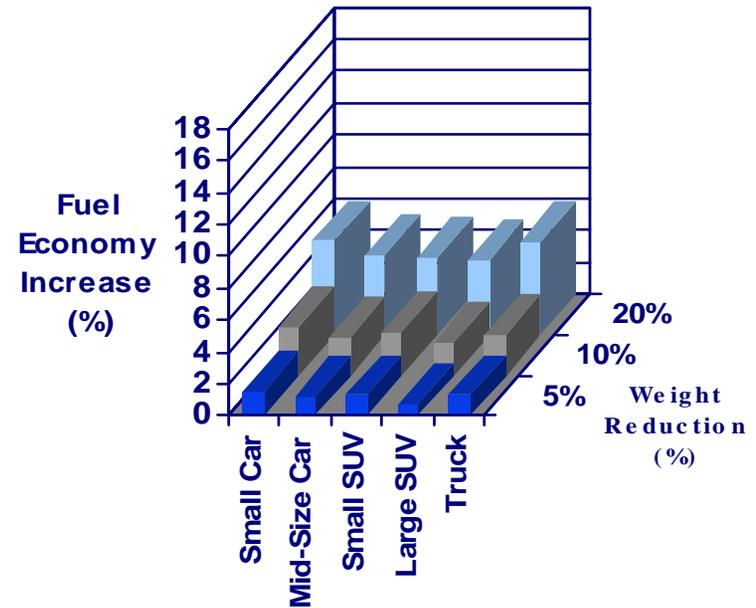
# EPA Highway (HWFET) Drive Cycle – Fuel Economy Improvement (%) - Gasoline Engines



## Engine Downsized to Baseline Performance



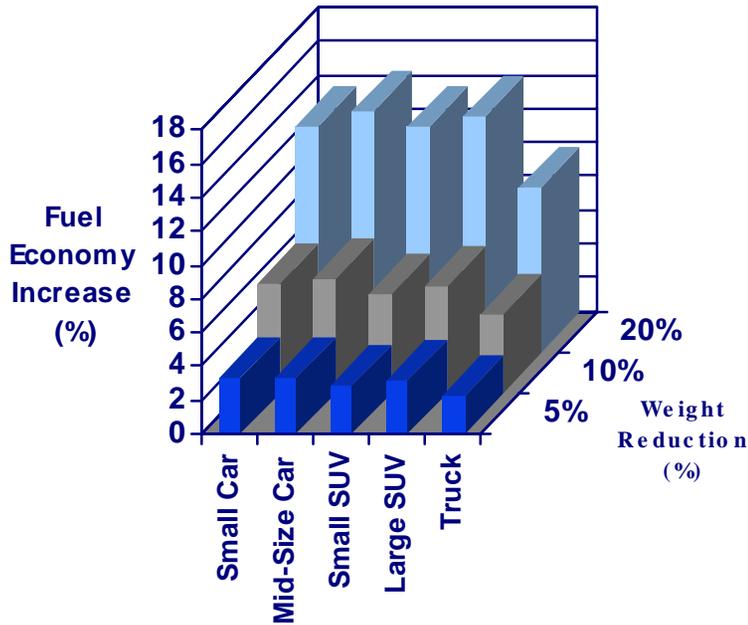
## Baseline Engine



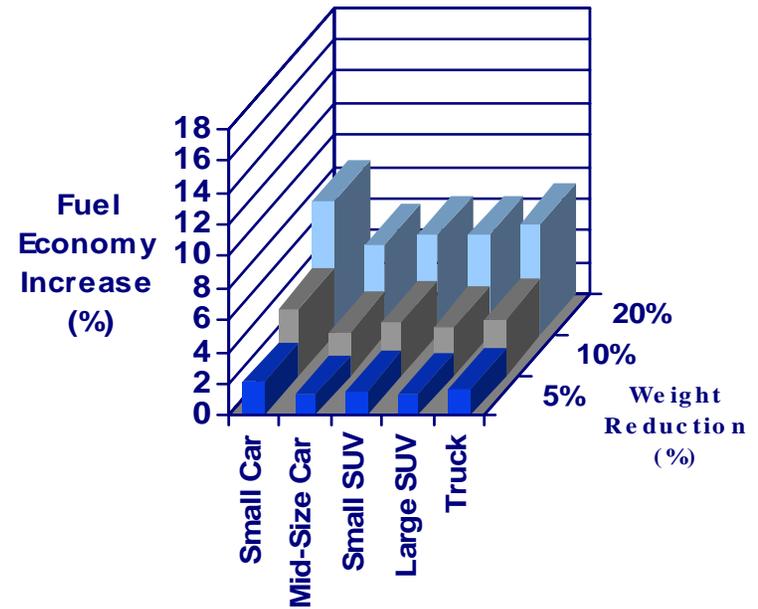
# EPA Combined Drive Cycle – Fuel Economy Improvement (%) - Gasoline Engines



## Engine Downsized to Baseline Performance



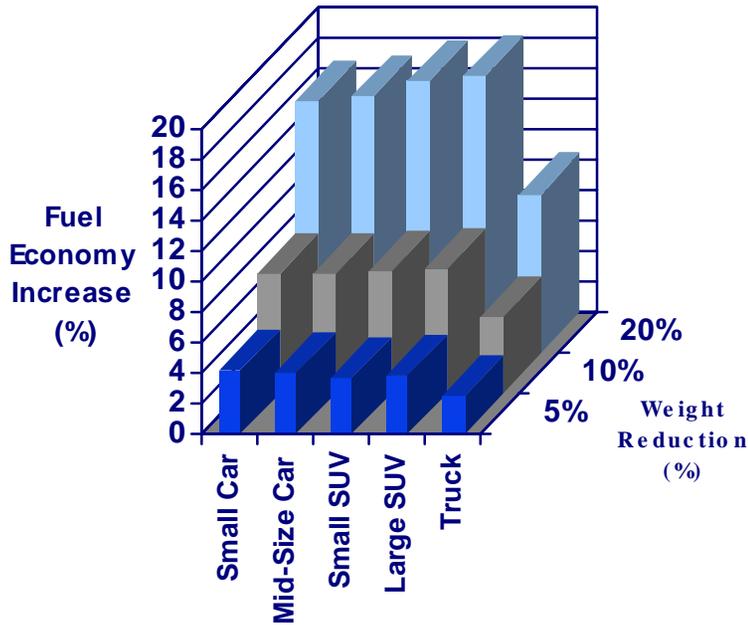
## Baseline Engine



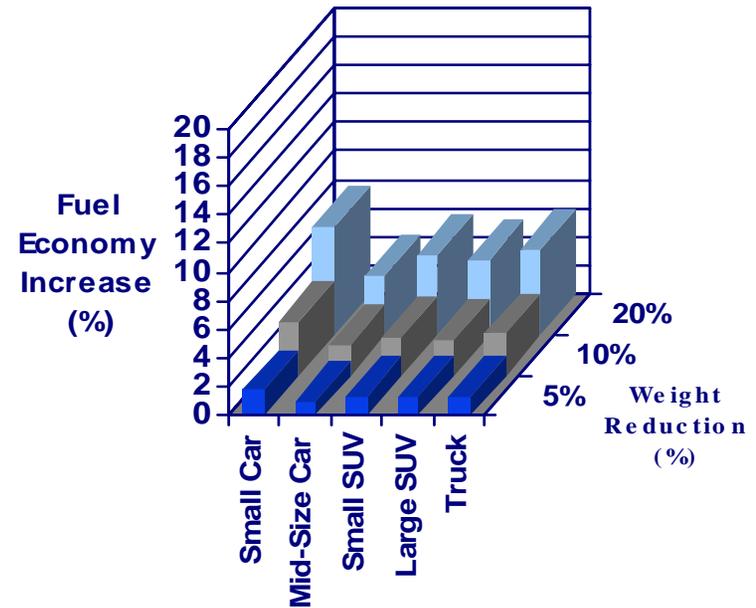
# European (ECE) Drive Cycle – Fuel Economy Improvement (%) - Gasoline Engines



## Engine Downsized to Baseline Performance



## Baseline Engine



- ❑ Vehicles with Diesel Engines

# Mid-Size Car – 2.2L I4 diesel engine



## Fuel Economy Simulation Results

DRIVE CYCLE		EPA							European			
		City FTP75	Highway HWFET	Combined	FUEL ECONOMY BENEFIT			City Label	Highway Label	ECE	FE BENEFIT	
					City FTP75	Highway HWFET	Combined					
					(mpg)	(mpg)	(mpg)				%	
	Baseline	32.0	45.0	36.8				24.9	32.0	27.3		
Weight Reduction	5%	Baseline Engine	32.7	45.7	37.5	2.1%	1.4%	1.8%	25.4	32.4	27.7	1.5%
	10%		33.4	46.3	38.2	4.2%	2.8%	3.7%	25.9	32.8	28.1	2.9%
	20%		34.8	47.7	39.7	8.8%	5.9%	7.7%	26.9	33.8	28.9	5.7%
	5%	Engine Downsized to Baseline Performance	33.1	46.0	37.9	3.3%	2.2%	2.9%	25.7	32.6	28.2	3.3%
	10%		34.3	47.1	39.0	6.9%	4.6%	6.0%	26.5	33.4	29.2	6.9%
	20%		36.9	49.6	41.7	15.1%	10.0%	13.2%	28.3	35.0	31.4	15.0%

DRIVE CYCLE		STEADY STATE CONDITIONS				FUEL ECONOMY BENEFIT				
		30 MPH	45 MPH	60 MPH	75 MPH	30 MPH	45 MPH	60 MPH	75 MPH	
										(mpg)
	Baseline	66.1	56.7	39.0	30.0					
Weight Reduction	5%	Baseline Engine	67.0	57.3	39.4	30.1	1.4%	1.1%	0.8%	0.4%
	10%		67.7	57.9	39.7	30.2	2.5%	2.2%	1.7%	0.8%
	20%		69.1	59.2	40.4	30.5	4.5%	4.6%	3.5%	1.6%
	5%	Engine Downsized to Baseline Performance	67.7	57.8	39.7	30.6	2.5%	2.1%	1.6%	2.1%
	10%		69.5	59.2	40.3	31.3	5.2%	4.4%	3.3%	4.3%
	20%		73.4	62.0	41.8	32.8	11.1%	9.5%	7.2%	9.3%

EPA fuel economy label projections are based on the derived 5-cycle regression equation for the 2008 model year.

## Mid-Size Car – 2.2L I4 diesel engine



### Vehicle Performance Simulation Results at Full Engine Load (WOT)

			<b>0 - 10 MPH</b>	<b>0 - 60 MPH</b>	<b>30 - 50 MPH</b>	<b>50 - 70 MPH</b>
			(sec)	(sec)	(sec)	(sec)
Baseline			1.41	9.7	3.5	5.7
Weight Reduction	5%	Baseline Engine	1.38	9.3	3.3	5.4
	10%		1.35	9.0	3.2	5.2
	20%		1.29	8.3	2.9	4.7
	5%	Engine Downsized to Baseline Performance	1.46	9.7	3.5	5.6
	10%		1.52	9.7	3.4	5.6
	20%		1.75	9.8	3.4	5.6

# Small SUV – 2.7L V6 diesel engine



## Fuel Economy Simulation Results

DRIVE CYCLE		EPA							European			
		City FTP75	Highway HWFET	Combined	FUEL ECONOMY BENEFIT			City Label	Highway Label	ECE	FE BENEFIT	
					City FTP75	Highway HWFET	Combined				%	
					(mpg)	(mpg)	(mpg)				(mpg)	(mpg)
Baseline		26.0	37.3	30.1				20.6	26.7	22.0		
Weight Reduction	5%	Baseline Engine	26.6	37.9	30.7	2.2%	1.4%	1.9%	21.0	27.1	22.3	1.5%
	10%		27.2	38.4	31.3	4.4%	2.9%	3.9%	21.4	27.5	22.7	3.1%
	20%		28.4	39.6	32.5	9.1%	6.1%	8.0%	22.3	28.3	23.4	6.3%
	5%	Engine Downsized to Baseline Performance	26.9	38.1	31.0	3.6%	2.1%	3.0%	21.2	27.2	22.8	3.5%
	10%		27.9	38.8	32.0	7.3%	4.0%	6.1%	22.0	27.7	23.7	7.5%
	20%		30.1	40.6	34.1	15.9%	8.7%	13.2%	23.6	28.9	25.7	16.7%

DRIVE CYCLE		STEADY STATE CONDITIONS				FUEL ECONOMY BENEFIT											
		30 MPH	45 MPH	60 MPH	75 MPH	30 MPH	45 MPH	60 MPH	75 MPH								
										(mpg)	(mpg)	(mpg)	(mpg)	%	%	%	%
										(mpg)	(mpg)	(mpg)	(mpg)	%	%	%	%
Baseline		47.0	42.4	33.9	25.9												
Weight Reduction	5%	Baseline Engine	47.3	42.8	34.2	26.0	0.6%	0.9%	0.8%	0.5%							
	10%		47.6	43.1	34.4	26.1	1.1%	1.8%	1.5%	0.9%							
	20%		48.1	43.9	35.0	26.4	2.3%	3.7%	3.1%	1.8%							
	5%	Engine Downsized to Baseline Performance	48.6	43.3	34.4	26.3	3.3%	2.1%	1.4%	1.7%							
	10%		50.2	44.2	34.9	26.8	6.7%	4.3%	2.9%	3.4%							
	20%		53.3	46.2	36.1	27.6	13.4%	8.9%	6.4%	6.5%							

EPA fuel economy label projections are based on the derived 5-cycle regression equation for the 2008 model year.

## Small SUV – 2.7L V6 diesel engine

### ❑ Vehicle Performance Simulation Results at Full Engine Load (WOT)

			<b>0 - 10 MPH</b>	<b>0 - 60 MPH</b>	<b>30 - 50 MPH</b>	<b>50 - 70 MPH</b>
			(sec)	(sec)	(sec)	(sec)
		Baseline	1.36	10.8	4.0	6.9
Weight Reduction	5%	Baseline Engine	1.32	10.4	3.8	6.6
	10%		1.29	10.1	3.6	6.3
	20%		1.22	9.2	3.3	5.7
	5%	Engine Downsized to Baseline Performance	1.36	10.8	3.9	6.9
	10%		1.38	10.8	3.9	6.9
	20%		1.42	10.8	3.9	6.9

# Large SUV – 3.2L V6 diesel engine



## Fuel Economy Simulation Results

DRIVE CYCLE		EPA							European			
		City FTP75	Highway HWFET	Combined	FUEL ECONOMY BENEFIT			City Label	Highway Label	ECE	FE BENEFIT	
					City FTP75	Highway HWFET	Combined				%	
					(mpg)	(mpg)	(mpg)				(mpg)	(mpg)
Baseline		21.4	30.9	24.8				17.1	22.3	18.1		
Weight Reduction	5%	Baseline Engine	21.9	31.4	25.3	2.3%	1.5%	2.0%	17.5	22.6	18.4	1.8%
	10%		22.4	31.9	25.9	4.8%	3.1%	4.2%	17.9	22.9	18.7	3.7%
	20%		23.5	32.8	26.9	9.7%	6.2%	8.4%	18.7	23.6	19.4	7.3%
	5%	Engine Downsized to Baseline Performance	22.2	31.6	25.6	3.6%	2.2%	3.1%	17.7	22.7	18.8	3.9%
	10%		23.0	32.3	26.4	7.3%	4.5%	6.3%	18.3	23.2	19.5	7.9%
	20%		24.7	33.8	28.1	15.6%	9.4%	13.3%	19.6	24.3	21.1	17.1%

DRIVE CYCLE		STEADY STATE CONDITIONS				FUEL ECONOMY BENEFIT											
		30 MPH	45 MPH	60 MPH	75 MPH	30 MPH	45 MPH	60 MPH	75 MPH								
										(mpg)							
										%	%	%	%	%	%	%	
Baseline		40.3	38.4	27.4	21.3												
Weight Reduction	5%	Baseline Engine	40.7	38.7	27.6	21.4	1.1%	0.9%	0.8%	0.5%							
	10%		41.2	39.1	27.9	21.5	2.3%	1.9%	1.6%	1.0%							
	20%		42.1	39.8	23.8	21.7	4.6%	3.8%	-13.2%	1.9%							
	5%	Engine Downsized to Baseline Performance	41.4	39.1	27.9	21.7	2.9%	2.0%	1.6%	1.9%							
	10%		42.6	39.7	28.3	22.1	5.8%	3.4%	3.4%	3.7%							
	20%		45.2	40.7	29.4	22.9	12.3%	6.2%	7.2%	7.8%							

EPA fuel economy label projections are based on the derived 5-cycle regression equation for the 2008 model year.

# Large SUV – 3.2L V6 diesel engine



## Vehicle Performance Simulation Results at Full Engine Load (WOT)

			<b>0 - 10 MPH</b>	<b>0 - 60 MPH</b>	<b>30 - 50 MPH</b>	<b>50 - 70 MPH</b>
			(sec)	(sec)	(sec)	(sec)
		Baseline	0.76	10.3	4.3	7.5
Weight Reduction	5%	Baseline Engine	0.74	9.9	4.1	7.1
	10%		0.74	9.5	3.9	6.8
	20%		0.74	8.7	3.5	6.1
	5%	Engine Downsized to Baseline Performance	0.77	10.3	4.3	7.5
	10%		0.77	10.3	4.3	7.5
	20%		0.77	10.3	4.2	7.5

# Truck – 4.8L V8 diesel engine



## Fuel Economy Simulation Results

DRIVE CYCLE		EPA							European			
		City FTP75	Highway HWFET	Combined	FUEL ECONOMY BENEFIT			City Label	Highway Label	ECE	FE BENEFIT	
					City FTP75	Highway HWFET	Combined				%	
					(mpg)	(mpg)	(mpg)				(mpg)	(mpg)
	Baseline	19.9	27.7	22.8				16.0	20.0	17.1		
Weight Reduction	5%	Baseline Engine	20.3	28.0	23.2	2.1%	1.4%	1.8%	16.3	20.2	17.3	1.3%
	10%		20.7	28.4	23.6	4.1%	2.8%	3.6%	16.6	20.5	17.5	2.8%
	20%		21.6	29.3	24.5	8.4%	5.9%	7.5%	17.3	21.1	18.1	5.9%
	5%	Engine Downsized to Baseline Performance	20.4	28.1	23.3	2.6%	1.7%	2.2%	16.4	20.3	17.4	2.1%
	10%		21.0	28.6	23.8	5.2%	3.4%	4.5%	16.8	20.6	17.8	4.4%
	20%		22.1	29.6	24.9	10.9%	7.0%	9.4%	17.6	21.3	18.7	9.4%

DRIVE CYCLE		STEADY STATE CONDITIONS				FUEL ECONOMY BENEFIT											
		30 MPH	45 MPH	60 MPH	75 MPH	30 MPH	45 MPH	60 MPH	75 MPH								
										(mpg)	(mpg)	(mpg)	(mpg)	%	%	%	%
										(mpg)	(mpg)	(mpg)	(mpg)	%	%	%	%
	Baseline	34.1	31.0	24.4	18.2												
Weight Reduction	5%	Baseline Engine	34.4	31.3	24.6	18.3	0.9%	0.8%	0.8%	0.5%							
	10%		34.7	31.5	24.8	18.4	1.8%	1.7%	1.6%	1.1%							
	20%		35.3	32.1	25.2	18.6	3.6%	3.5%	3.1%	2.2%							
	5%	Engine Downsized to Baseline Performance	34.7	31.4	24.6	18.4	1.7%	1.4%	0.9%	0.8%							
	10%		35.3	31.9	24.9	18.5	3.5%	2.8%	1.9%	1.5%							
	20%		36.6	32.8	25.4	18.8	7.3%	5.7%	3.9%	3.2%							

EPA fuel economy label projections are based on the derived 5-cycle regression equation for the 2008 model year.

# Truck – 4.8L V8 diesel engine



## Vehicle Performance Simulation Results at Full Engine Load (WOT)

			<b>0 - 10 MPH</b>	<b>0 - 60 MPH</b>	<b>30 - 50 MPH</b>	<b>50 - 70 MPH</b>
			(sec)	(sec)	(sec)	(sec)
Baseline			1.29	18.0	7.5	12.6
Weight Reduction	5%	Baseline Engine	1.27	17.6	7.4	12.4
	10%		1.25	17.3	7.2	12.1
	20%		1.22	16.6	6.9	11.6
	5%	Engine Downsized to Baseline Performance	1.29	17.9	7.5	12.6
	10%		1.28	17.9	7.5	12.6
	20%		1.28	17.9	7.5	12.6

## Fuel Economy Improvement (%) per 100 lb. Weight Reduction - Diesel Engines



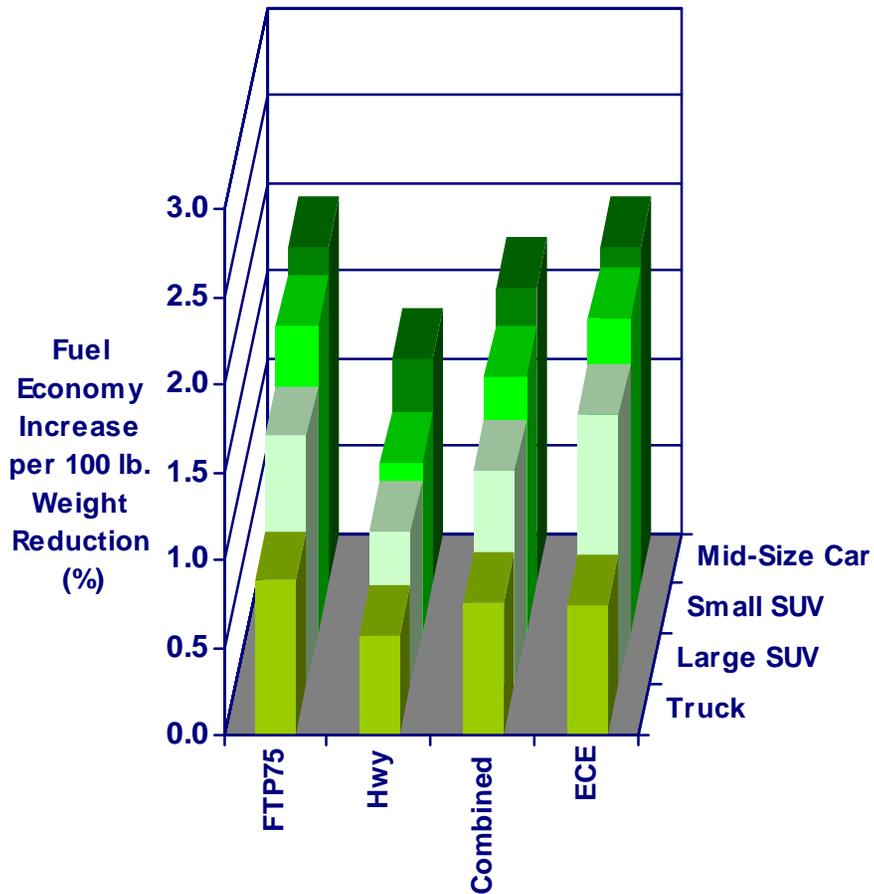
<b>BASELINE ENGINES</b>	<b>City FTP75</b>	<b>Highway HWFET</b>	<b>EPA Combined</b>	<b>Euro ECE</b>	<b>30 MPH</b>	<b>45 MPH</b>	<b>60 MPH</b>	<b>75 MPH</b>
<b>Mid-Size Car</b>	1.2%	0.8%	1.0%	0.8%	0.7%	0.6%	0.5%	0.2%
<b>Small SUV</b>	1.0%	0.7%	0.9%	0.7%	0.3%	0.4%	0.4%	0.2%
<b>Large SUV</b>	0.9%	0.6%	0.8%	0.7%	0.4%	0.4%	0.3%	0.2%
<b>Truck</b>	0.7%	0.5%	0.6%	0.5%	0.3%	0.3%	0.3%	0.2%

<b>DOWNSIZED ENGINES</b>	<b>City FTP75</b>	<b>Highway HWFET</b>	<b>EPA Combined</b>	<b>Euro ECE</b>	<b>30 MPH</b>	<b>45 MPH</b>	<b>60 MPH</b>	<b>75 MPH</b>
<b>Mid-Size Car</b>	1.9%	1.3%	1.7%	1.9%	1.4%	1.2%	0.9%	1.2%
<b>Small SUV</b>	1.8%	1.0%	1.5%	1.8%	1.6%	1.0%	0.7%	0.8%
<b>Large SUV</b>	1.4%	0.9%	1.2%	1.5%	1.1%	0.7%	0.7%	0.7%
<b>Truck</b>	0.9%	0.6%	0.8%	0.7%	0.6%	0.5%	0.3%	0.3%

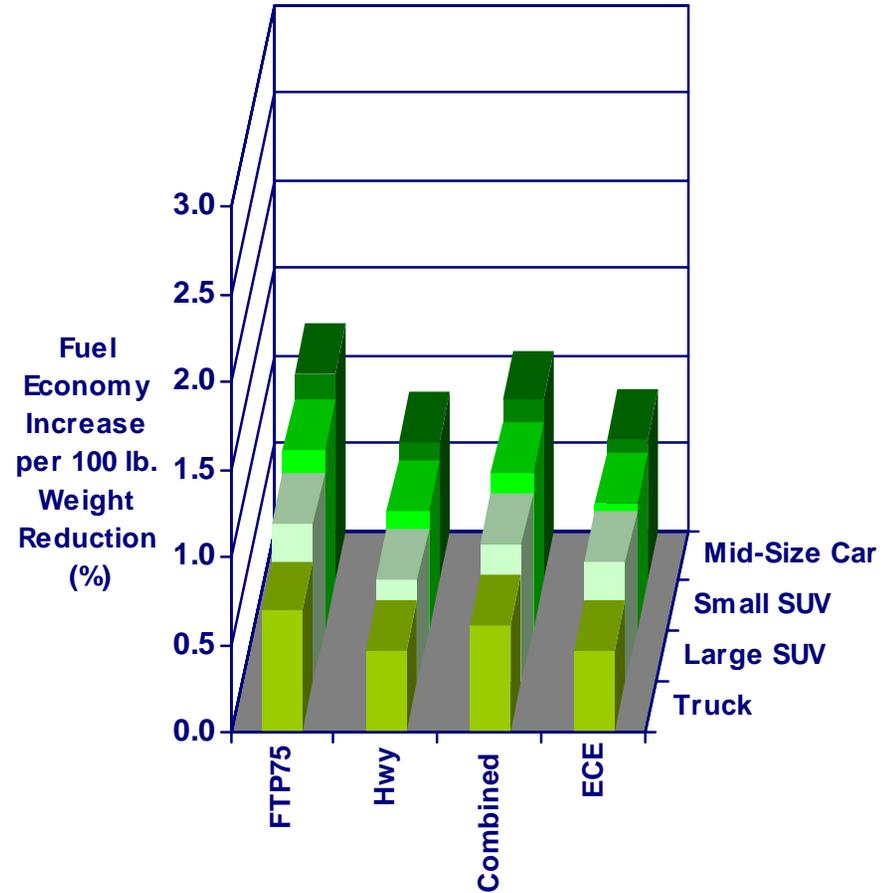
# Drive Cycle Fuel Economy Improvement (%) per 100 lb. Weight Reduction - Diesel Engines



Engine Downsized to Baseline Performance



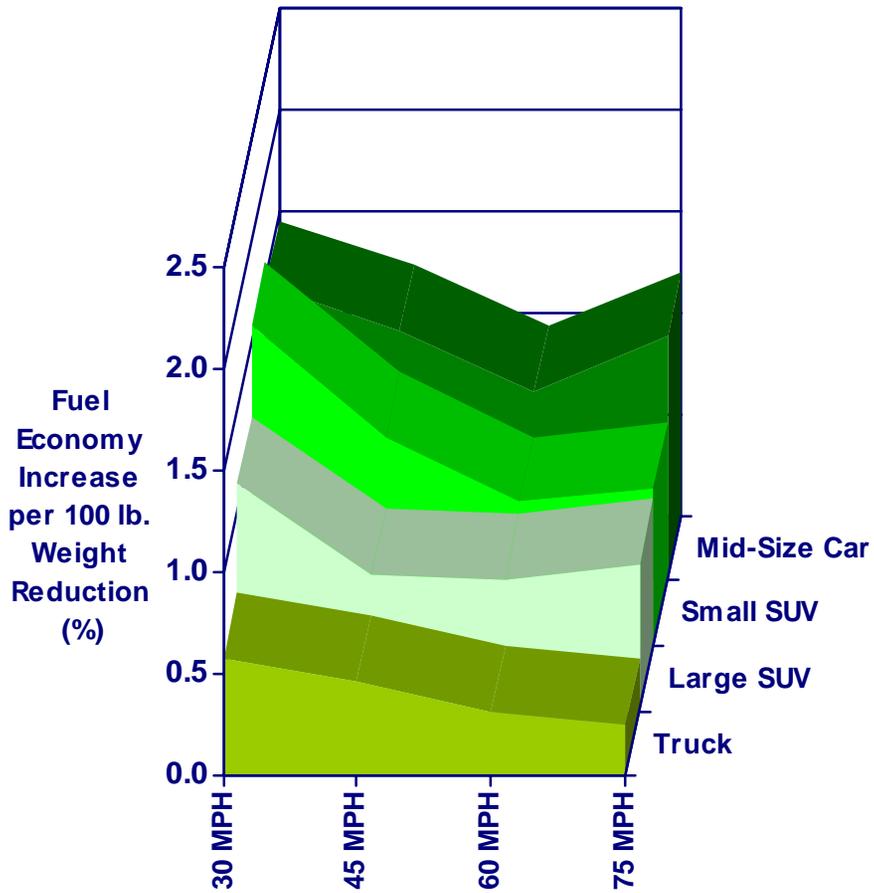
Baseline Engine



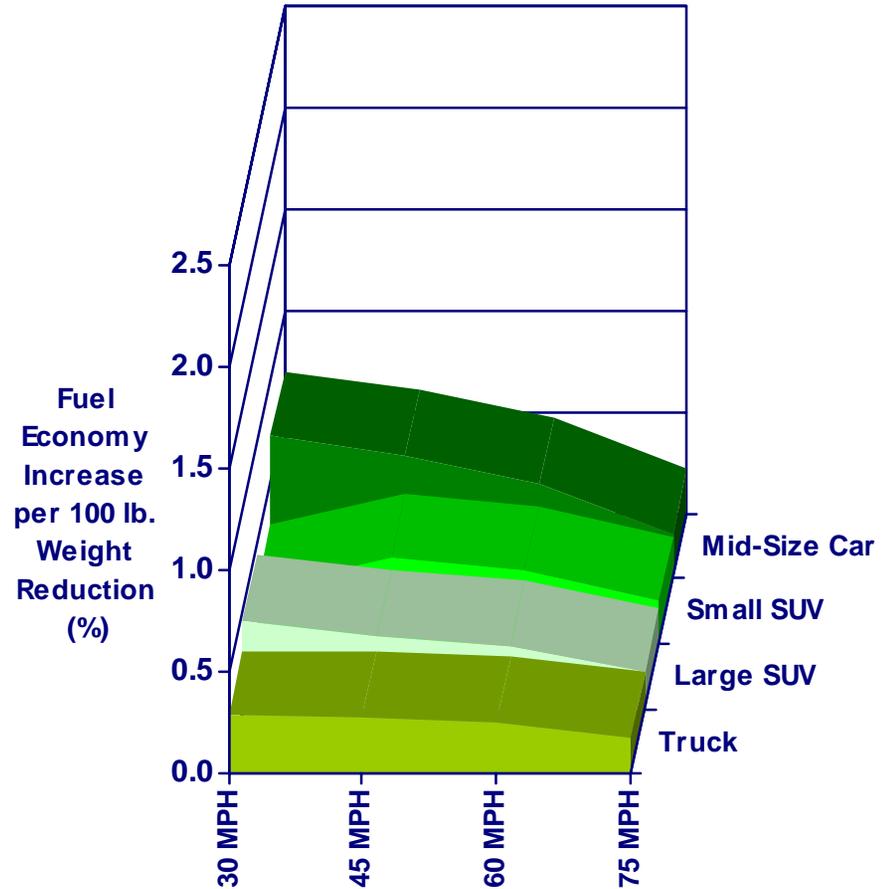
# Steady State Fuel Economy Improvement (%) per 100 lb. Weight Reduction - Diesel Engines



Engine Downsized to Baseline Performance



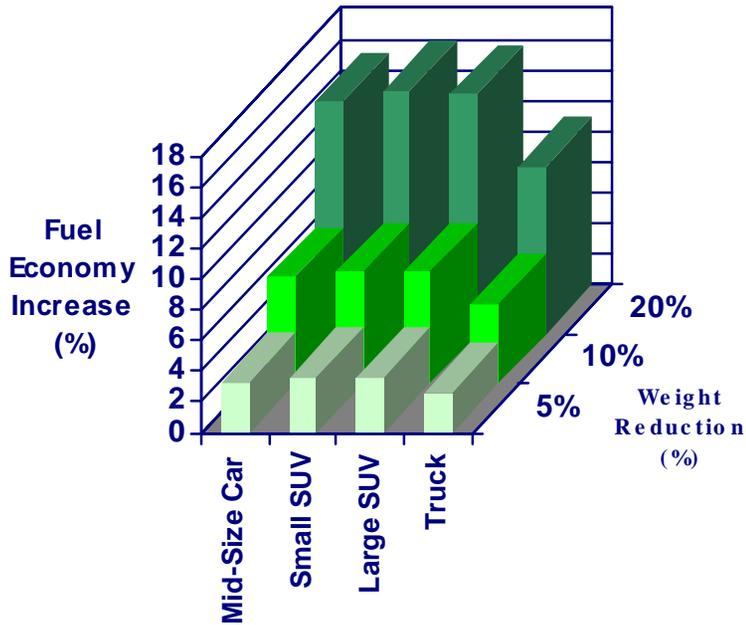
Baseline Engine



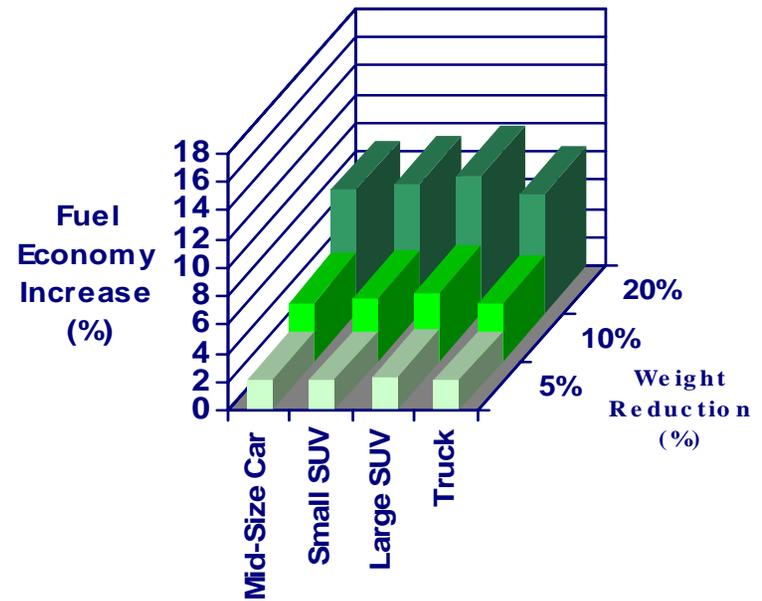
# EPA City (FTP75) Drive Cycle – Fuel Economy Improvement (%) - Diesel Engines



## Engine Downsized to Baseline Performance



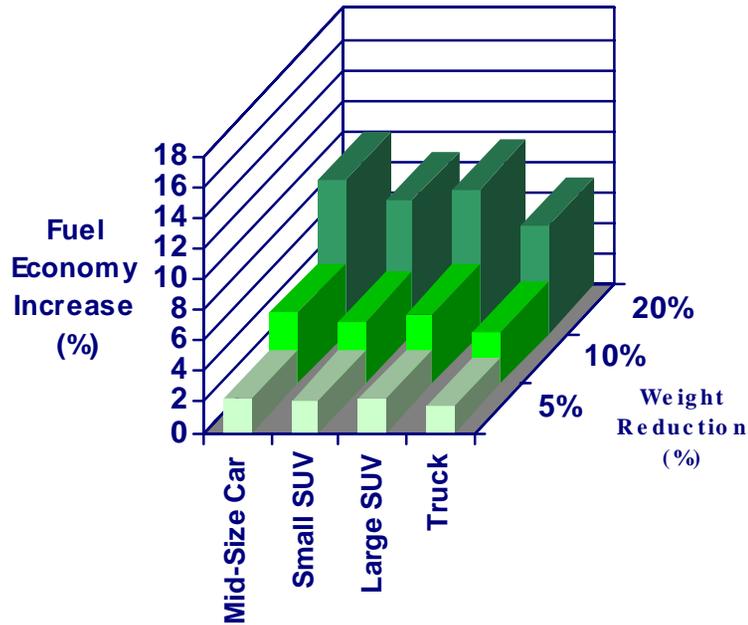
## Baseline Engine



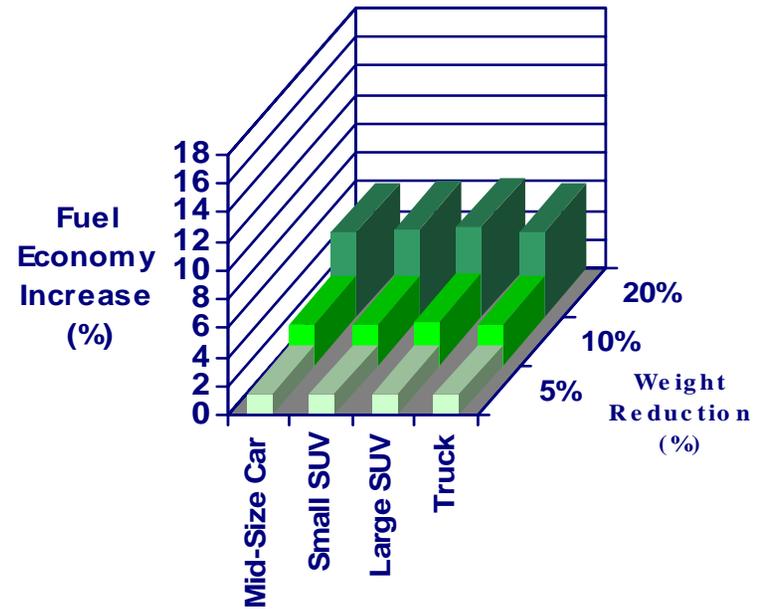
# EPA Highway (HWFET) Drive Cycle – Fuel Economy Improvement (%) - Diesel Engines



## Engine Downsized to Baseline Performance



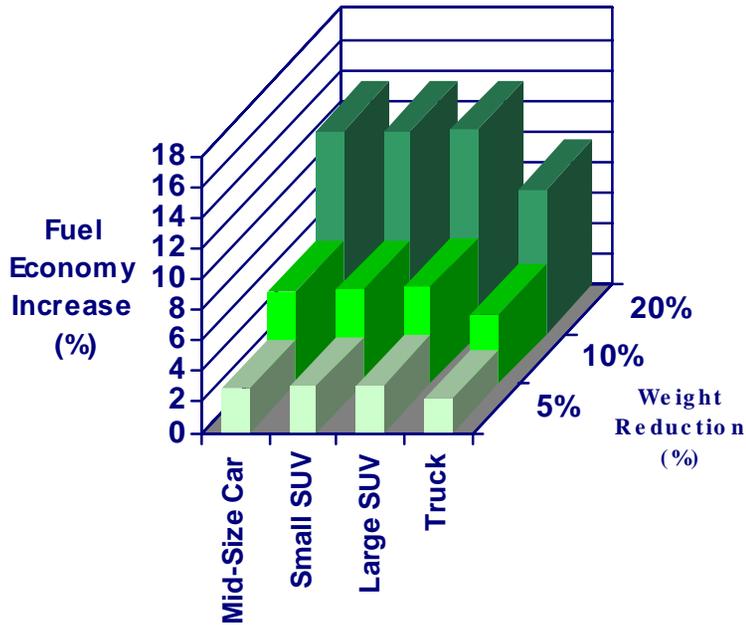
## Baseline Engine



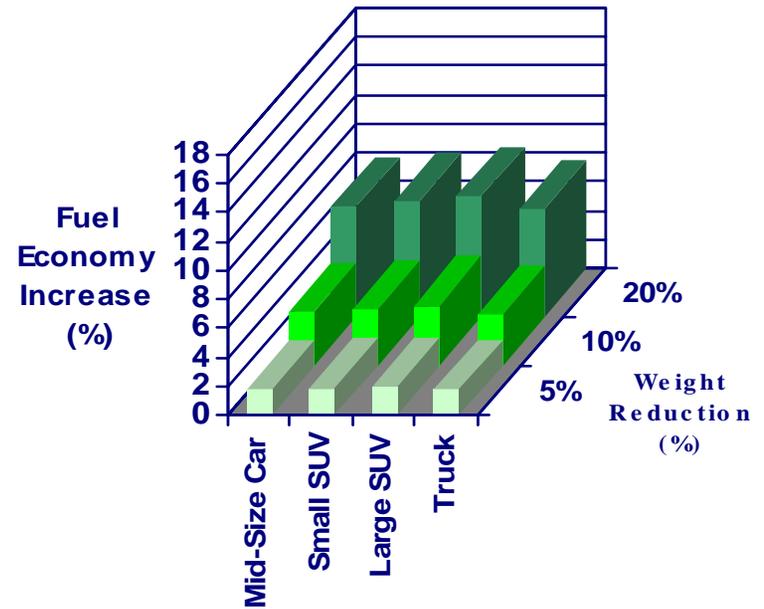
# EPA Combined Drive Cycle – Fuel Economy Improvement (%) - Diesel Engines



## Engine Downsized to Baseline Performance



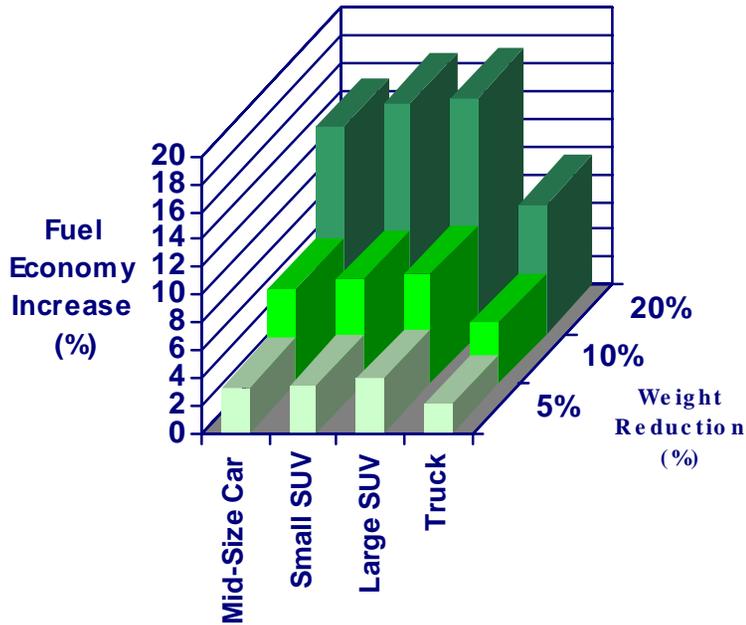
## Baseline Engine



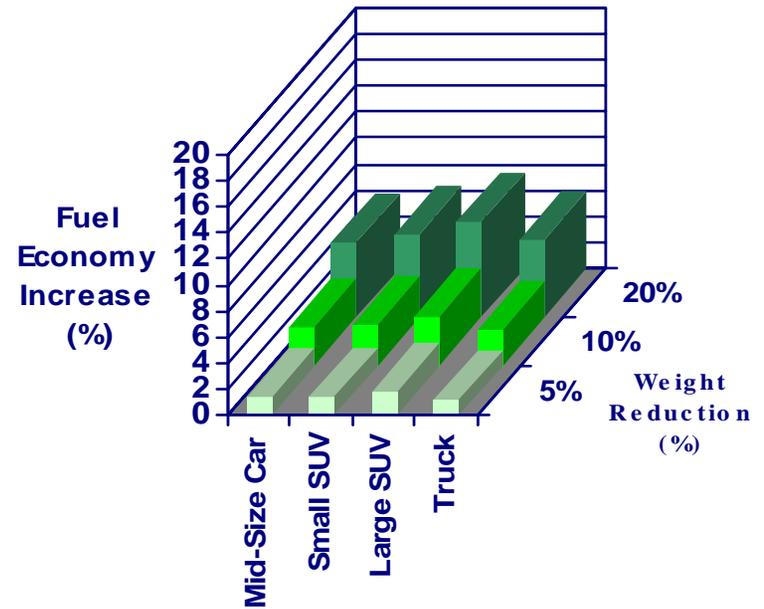
# European (ECE) Drive Cycle – Fuel Economy Improvement (%) - Diesel Engines



## Engine Downsized to Baseline Performance



## Baseline Engine



## Summary – EPA Combined Drive Cycle - % Improvement in Fuel Economy per % Weight Reduction



- ❑ The fuel economy benefit from weight reduction is similar for gasoline and diesel powered light duty vehicles.
- ❑ Truck engines were downsized to a lesser degree than the passenger vehicle engines due to the performance demands on trucks when loaded. Vehicles rated to tow a trailer benefit the least from weight reduction and subsequent engine downsizing if acceleration performance while towing is maintained.

	% Improvement in Fuel Economy / % Weight Reduction EPA Combined (Metro-Highway) Drive Cycle			
	Passenger Vehicle		Truck	
	Base Engine	Downsized Engine	Base Engine	Downsized Engine
	Gasoline	0.33%	0.65%	0.35%
Diesel	0.39%	0.63%	0.36%	0.46%

## Conclusions / Observations



- ❑ Reducing vehicle weight (mass) results in less tractive effort required to accelerate the vehicle and less rolling resistance from the tires. Drive cycles with more acceleration events (EPA city and European) show greater fuel economy benefits from weight reduction than highway or steady state conditions. Also, at higher vehicle speeds the engine is typically at higher throttle (better BSFC) operating points and provides less opportunity for improvement. Since the tire losses are a greater percentage of total tractive effort at lower speeds (aerodynamic losses increase by velocity squared) the potential for fuel economy gain from weight reduction is greater at lower vehicle speeds.
- ❑ Fuel economy results (and improvements) at the steady 30 MPH drive condition vary because most vehicles are not in top gear yet and are operating the engine at a higher speed / lower load point that is less efficient.
- ❑ Less tractive effort results in less engine torque demand at a given point in the drive cycle. The lower load (throttle) demand puts the engine at a less efficient point with more pumping loss and lower brake specific fuel consumption (grams fuel / power produced). Reducing the engine displacement of the weight-reduced vehicle to equal baseline vehicle performance increases the brake mean effective pressure (BMEP) of the engine operating points and improves efficiency. A final drive ratio change could also partially offset the pumping loss increase but was not investigated.
- ❑ The Small Car with a 1.6L engine with variable valve timing and variable lift technologies that reduce pumping losses shows the largest % fuel economy benefit with the baseline engine since it can operate at the reduced engine load points more effectively (0.42% fuel economy benefit / % weight reduction vs. other gas engine vehicles at 0.27-0.32% FE benefit). When the engine is downsized it produces fuel economy gains similar to the other passenger vehicles (0.66 vs. 0.61-0.68 % FE / % weight reduction).