Value of Lightweighting

Part 1

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Q. What is the value (Δ mpg, LCA, performance) of mass reduction?

A. It depends on:

- driving cycle
- engine type
- simple weight reduction
- simple weight reduction and powertrain matching

Approach / Methodology to Consumption Model by Ricardo Inc.

- Value of mass reduction to fuel consumption reduction determined by using a full forward-looking, physics-based model. *(Ricardo Inc. ran simulations.)*
  - Baseline mass, then 5, 10, 20% mass reduction (not material specific)
  - 5 vehicles (small car to truck)
  - Performance equal to loaded vehicle
  - With and without resized (displacement only) ICE or Diesel engines
  - EPA and Euro ECE test cycles

Mass vs. Fuel Consumption: Vehicle Selection

- 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

Source: RICARDO

Vehicle Simulations

- 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.

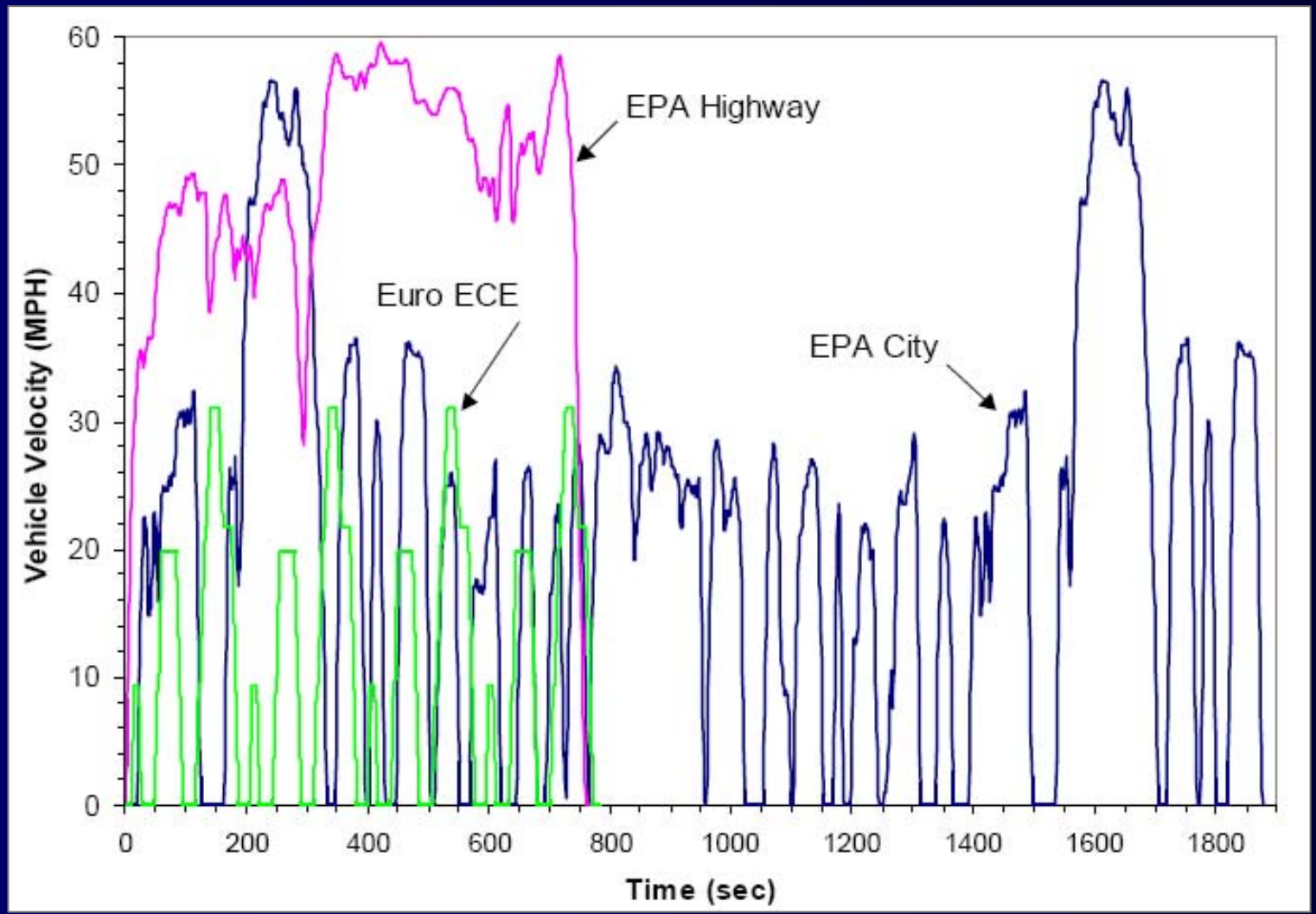
Source: RICARDO

Vehicle Performance Matching

- 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).

Source: RICARDO

Simulation Drive Cycles



Source:

Fuel Economy Simulation Results

Mid-Size Car 3.0L-4V Gas Engine with Variable Intake Cam Timing

DRIVE CYCLE			EPA								European	
						FUEL ECONOMY BENEFIT						FE BENEFIT
			City FTP75	Highway HWFET	Combined	City FTP75	Highway HWFET	Combined	City Label	Highway Label	ECE	
			(mpg)	(mpg)	(mpg)	%	%	%	(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%

Vehicle Performance Simulation Results

Mid-Size Car 3.0L-4V Gas Engine with Variable Intake Cam Timing

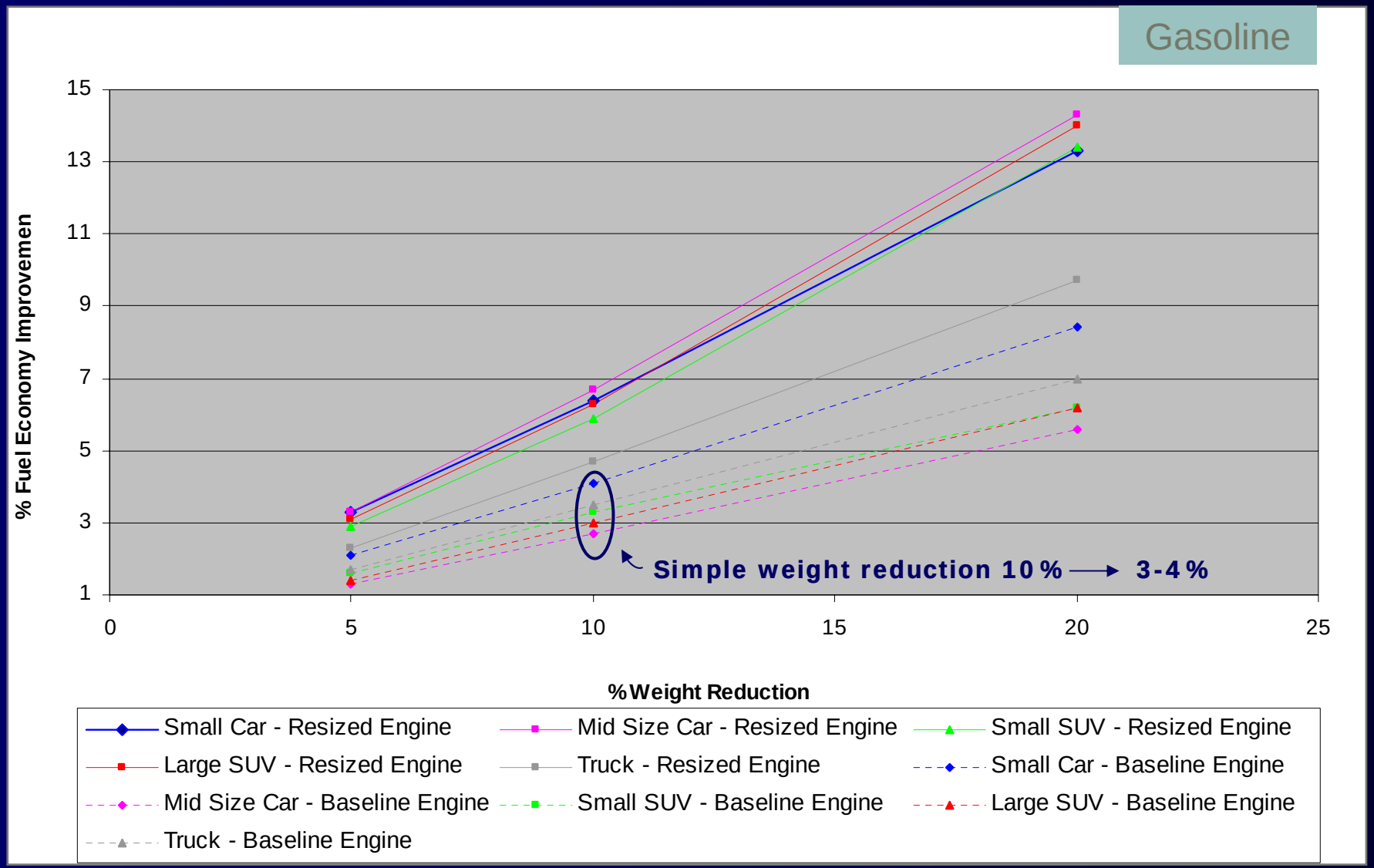
			0 - 10 MPH	0 - 60 MPH	30 - 50 MPH	50 - 70 MPH
			(sec)	(sec)	(sec)	(sec)
		Baseline	1.49	9.7	3.2	4.6
Weight Reduction	5%	Baseline Engine	1.45	9.4	3.1	4.4
	10%		1.41	9.0	2.9	4.2
	20%		1.34	8.4	2.7	3.8
	5%	Engine Downsized to Baseline Performance	1.51	9.7	3.2	4.6
	10%		1.51	9.7	3.2	4.5
	20%		1.54	9.6	3.1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

Source: RICARDO

Model Input-Downsized Gasoline Engines

	Small Car	Mid-Size Car	Small SUV	Large SUV	Truck
5% Weight Reduction					
Weight ETW - Fuel Economy (lb)	2731	3444	4038	4988	5700
Weight PTW - Performance (lb)	3031	3894	4588	5738	
Weight GCW - Performance (lb)					15500
Engine	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
10% Weight Reduction					
Weight ETW - Fuel Economy (lb)	2588	3263	3825	4725	5400
Weight PTW - Performance (lb)	2888	3713	4375	5475	
Weight GCW - Performance (lb)					15200
Engine	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
20% Weight Reduction					
Weight ETW - Fuel Economy (lb)	2300	2900	3400	4200	4800
Weight PTW - Performance (lb)	2600	3350	3950	4950	
Weight GCW - Performance (lb)					14600
Engine	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

Percent Fuel Economy Improvement vs. Percent Weight Reduction



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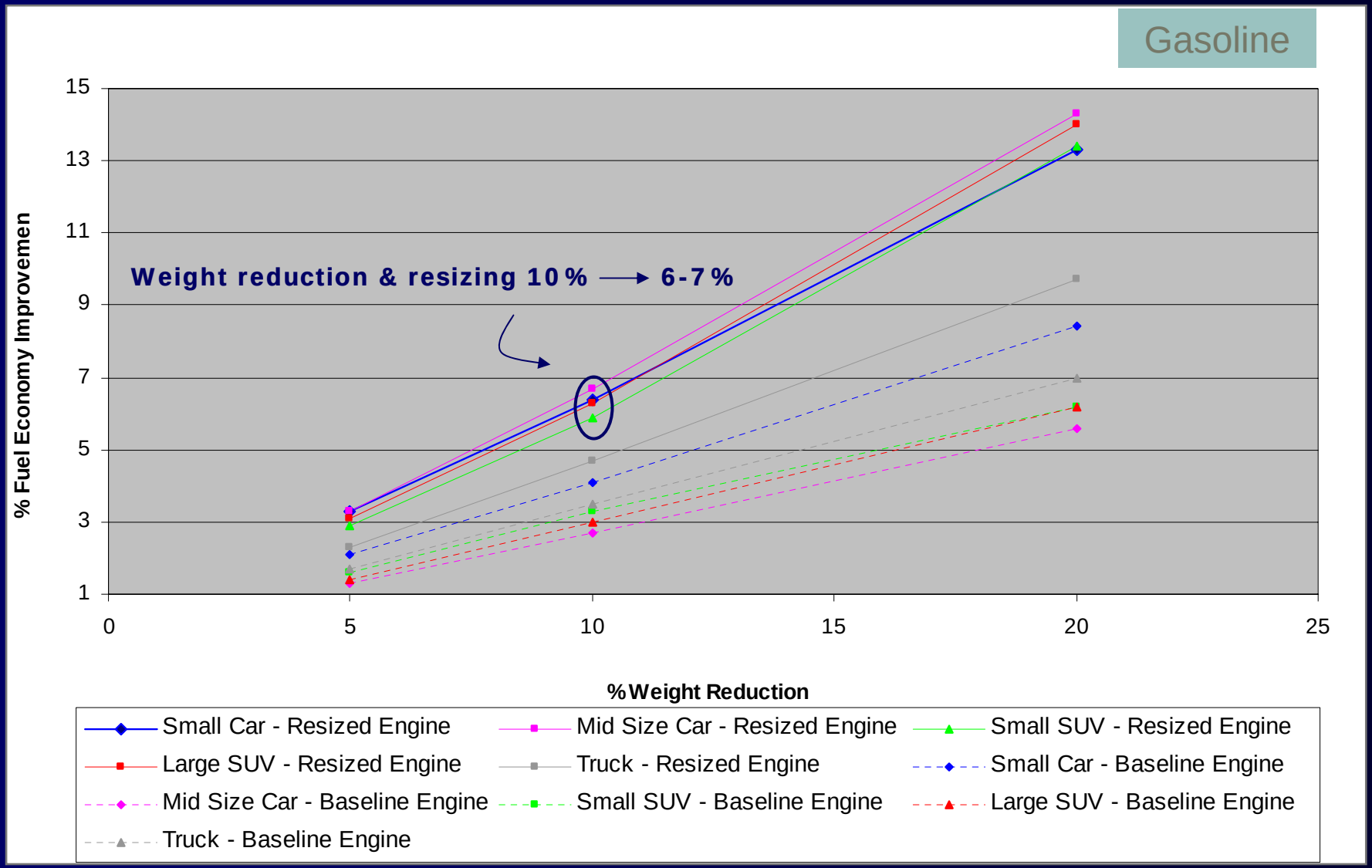

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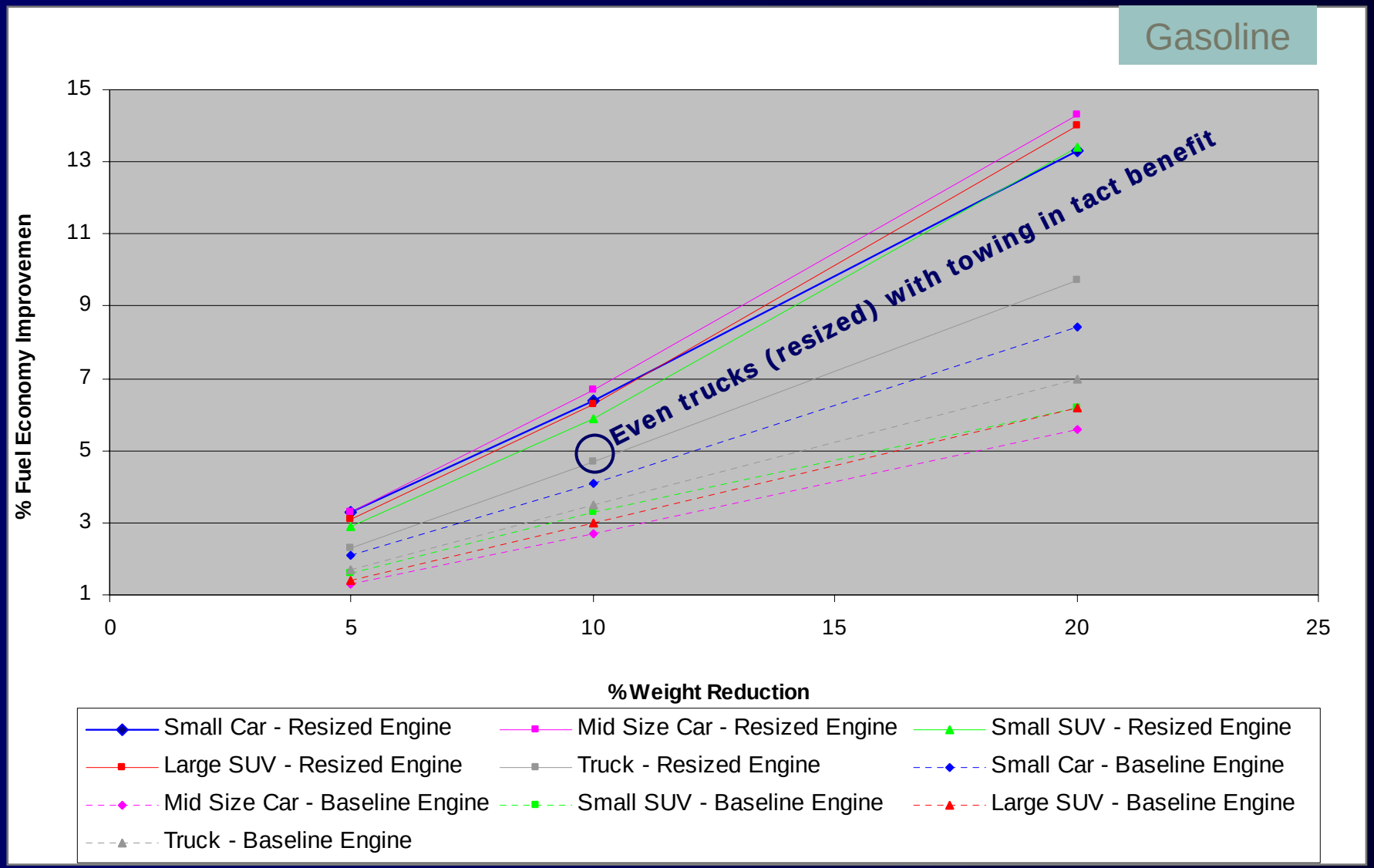
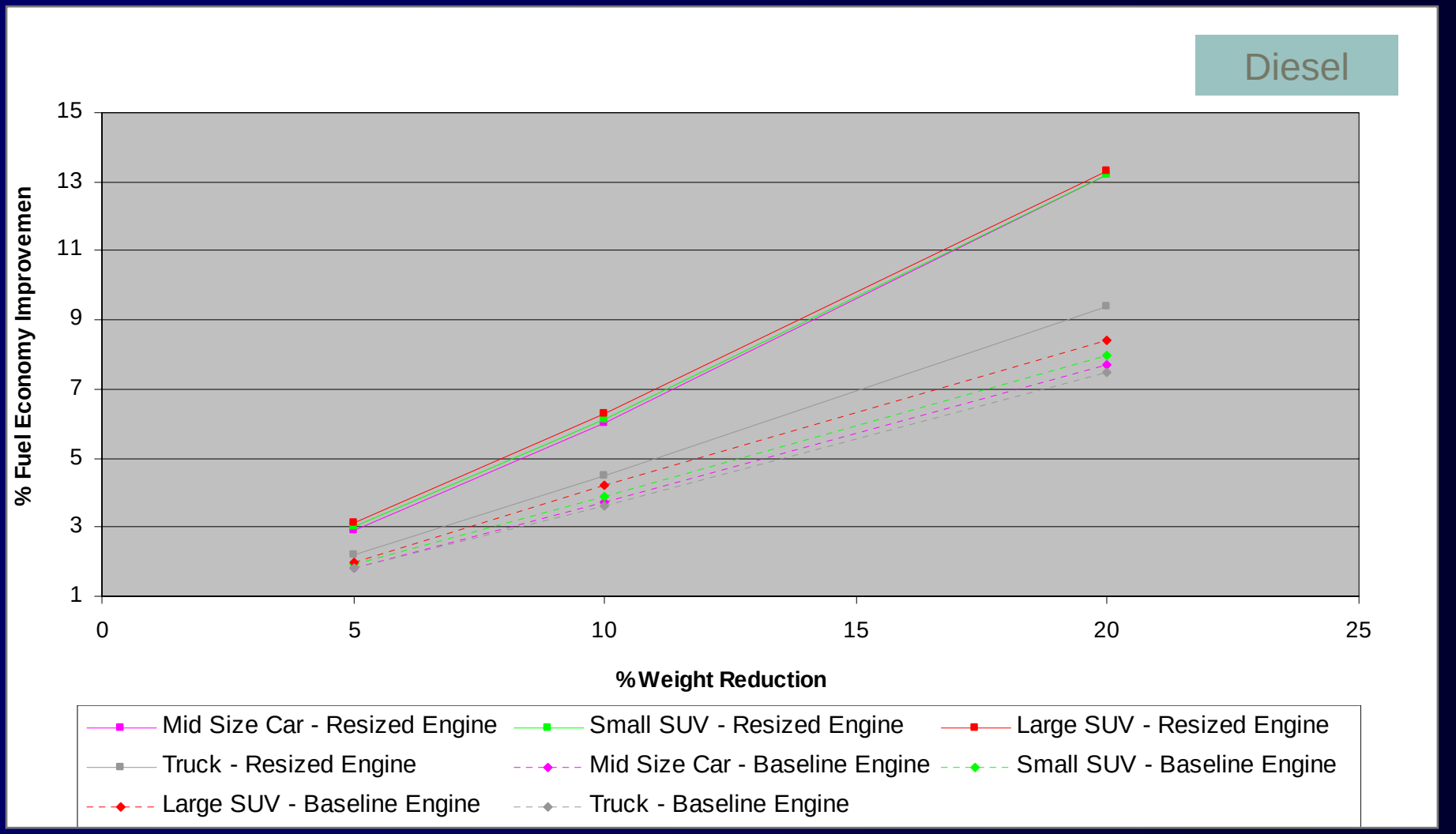


Fuel Economy Simulation Results

Mid-Size Car – 2.2L I4 Diesel Engine

DRIVE CYCLE			EPA								European	
						FUEL ECONOMY BENEFIT						FE BENEFIT
			City FTP75	Highway HWFET	Combined	City FTP75	Highway HWFET	Combined	City Label	Highway Label	ECE	
			(mpg)	(mpg)	(mpg)	%	%	%	(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%

Percent Fuel Economy Improvement vs. Percent Weight Reduction



Summary

- Cars and trucks, gasoline and diesel, have similar weight vs. consumption sensitivities.
- Reducing mass helps all situations; but, maximum benefit occurs when the powertrain is matched up.

MANAGEMENT BRIEFING SEMINARS

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CAR
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Aluminum Lightweighting

Part 2

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A History of Providing Solutions

- Power / weight ⟹ performance
- Un-sprung mass
- Balance, center of gravity, yaw moments
- Weight class management
- Swing panels (lift gates)
- Heat exchangers, wheel, sub-frames, bumpers, IP beams, etc.

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- **Historical and on-going**
- **Selective component weight management**

New challenges call for new solutions

- Operational cost (and purchase price)
- Green House Gases and CO2
- Alternative powertrains / fuel

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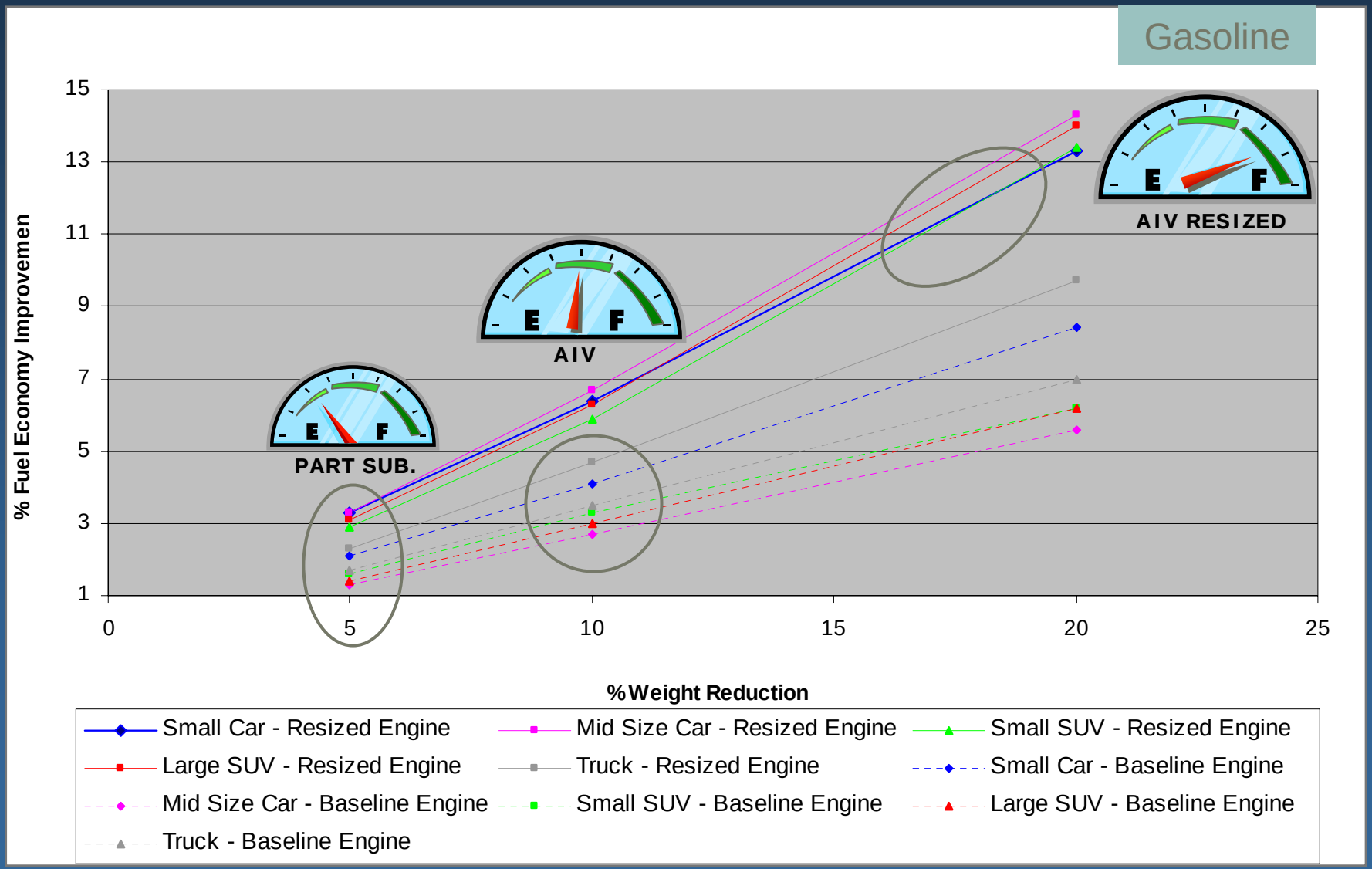
- **Maximize MPG**
- **Full vehicle**
- **Lower power, lower mass**
- **Increased powertrain costs**

What does 5, 10 and 20% weight savings mean in terms of aluminum?

	Weight (lbs)	Weight Saved	Substitution	plus AIV	plus power
Base Ricardo	3625	0			
-5%	3444	181	138.1		
-10%	3263	363	138.1	416.1	
-20%	2900	725	138.1	416.1	572.1
Base IBIS	3376	0			
-5%	3207	169	138.1		
-10%	3038	338	138.1	416.1	
-20%	2701	675	138.1	416.1	572.1

	Aluminum	Steel	Delta (lbs)
Hood	17	31	14
Deck	13.2	24	10.8
Fenders	4.8	9.6	4.8
Fr Doors	40.4	62.2	21.8
Rr Doors	38.4	59.1	20.7
Sum			**72.1**
Cradle	46.2	77	**30.8**
Bumper	13.2	19.8	**6.6**
Wheels	167.2	180.4	**13.2**
Suspension	88	103.4	**15.4**

Percent Fuel Economy Improvement vs. Percent Weight Reduction



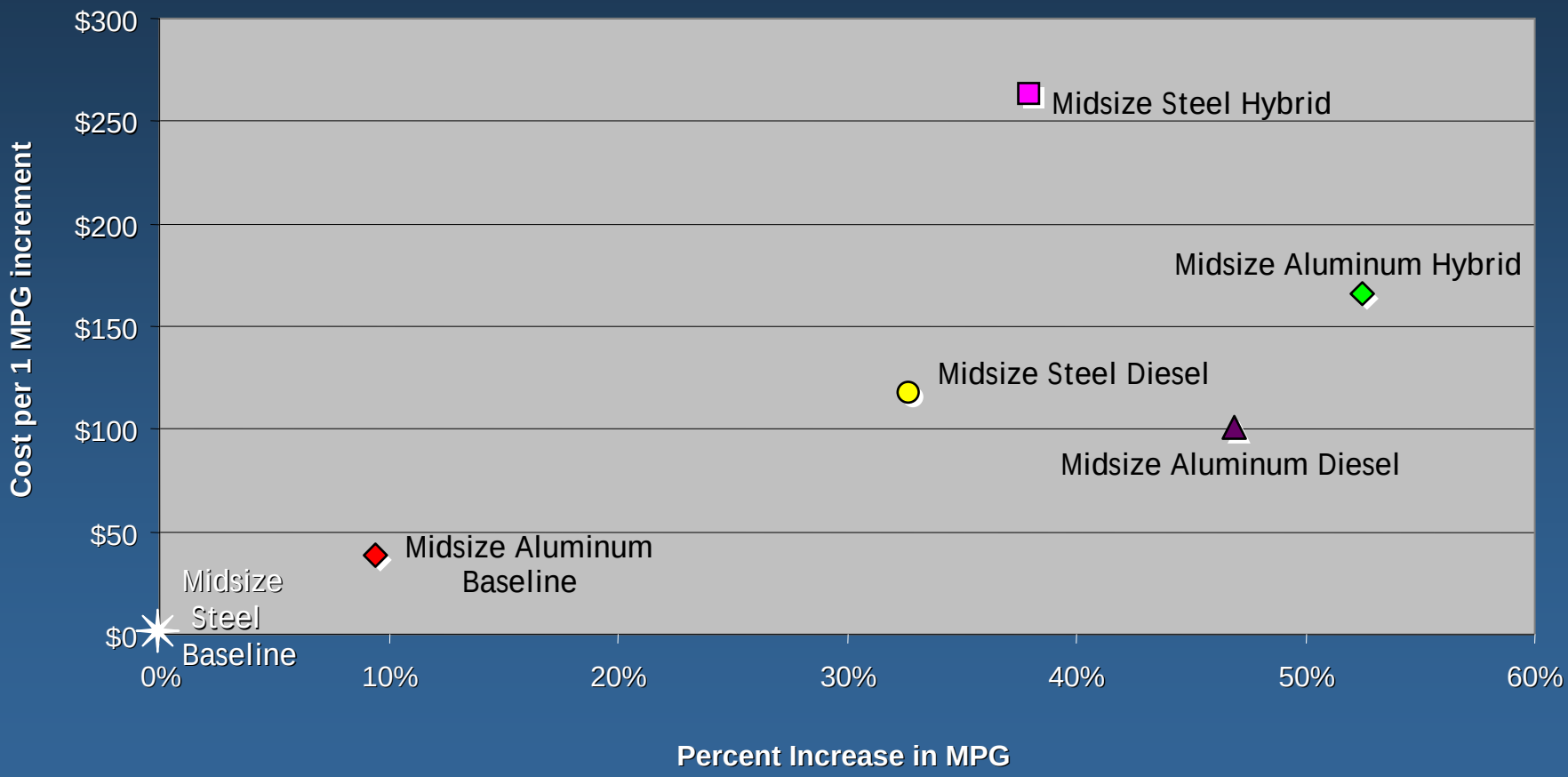
Weight and Cost Summary From IBIS

	Steel Baseline		Aluminum Baseline		Steel Diesel		Aluminum Diesel		Steel Hybrid		Aluminum Hybrid	
	Mass (kg)	**Cost ($)**	**Mass (kg)**	**Cost ($)**	**Mass (kg)**	**Cost ($)**	**Mass (kg)**	**Cost ($)**	**Mass (kg)**	**Cost ($)**	Mass (kg)	Cost ($)
BIW Structure	272	1405	145	1816	272	1405	145	1816	272	1405	145	1816
Panels	84	230	52	379	84	230	52	379	84	230	52	379
Engine	233	3131	201	2691	236	3873	203	3430	167	2244	144	1925
Motor									76	1267	65	1087
Controller/Inverter									47	965	40	866
Batteries	23	66	19	56	23	66	20	57	49	1303	42	1119
Exhaust & Emissions	58	700	58	700	71	1055	71	1055	39	602	39	595
Power Train	314	3897	278	3447	330	4994	294	4542	378	6381	330	5592
Fuel System	81	379	72	357	Same as Steel Baseline		Same as Aluminum Baseline		Same as Steel Baseline		Same as Aluminum Baseline	
Transmission	88	1197	76	1169								
Cradle	35	82	21	133								
Glass	37	250	37	250								
Paint	11	450	11	495								
Corner Suspension	47	218	40	197								
Braking System	48	416	41	376								
Front / Rear Bumpers	9	30	6	50								
Wheels & Tires	82	317	76	407								
Steering System	28	572	21	489								
Total Weight (kg)	1532		1272		1535		1279		1577		1313	

Cost and MPG Summary

	Steel Baseline	Aluminum Baseline	Steel Hybrid	Steel Diesel	Aluminum Diesel	Aluminum Hybrid
Cost $ (BIW+Panels+PowerTrain)	5532	5642	8016	6629	6737	7787
Combined Mileage MPG	25.2	27.7	34.8	33.5	36.8	38.2
Mileage Improvement Over Steel Baseline MPG (%)		2.5 (9.9%)	9.6 (38.1%)	8.3 (32.9%)	11.6 (46.0%)	13 (51.6%)
Delta Cost per 1MPG improvement $/MPG		44	259	132	104	173

Combined MPG Improvement vs. Cost of 1 MPG Increment Improvement



Source: IBIS '07

Aluminum, in all product forms, continues to find applications to lighten the vehicle, from managing the “ounces”, to maximizing the mpg.

- Maximize the secondary weight savings and associated cost savings to reduce the cost of the lightweight structure.
- The relative costs of the powertrain and structure need to be jointly considered. This is particularly true if the next increment in power comes with a relatively high cost.
- Lightweight structures are a significant enabler for the new powertrain technologies. Smaller and less expensive powertrains are required and the combination of reduced power and lightweight positively reinforce each other. The $/delta mpg is minimized.