

Aluminum Vehicle Structure: Manufacturing and Lifecycle Cost Analysis
Hybrid Drive and Diesel Fuel Vehicles

Research Report

Conducted by IBIS Associates, Inc
for The Aluminum Association
2008-05



IBIS Associates, Inc.

Founded in 1987 by professors and students of MIT's MSL

Principle business practices:

- Automotive
- Electronics
- Building Products
- Specialty Chemicals
- Power Generation

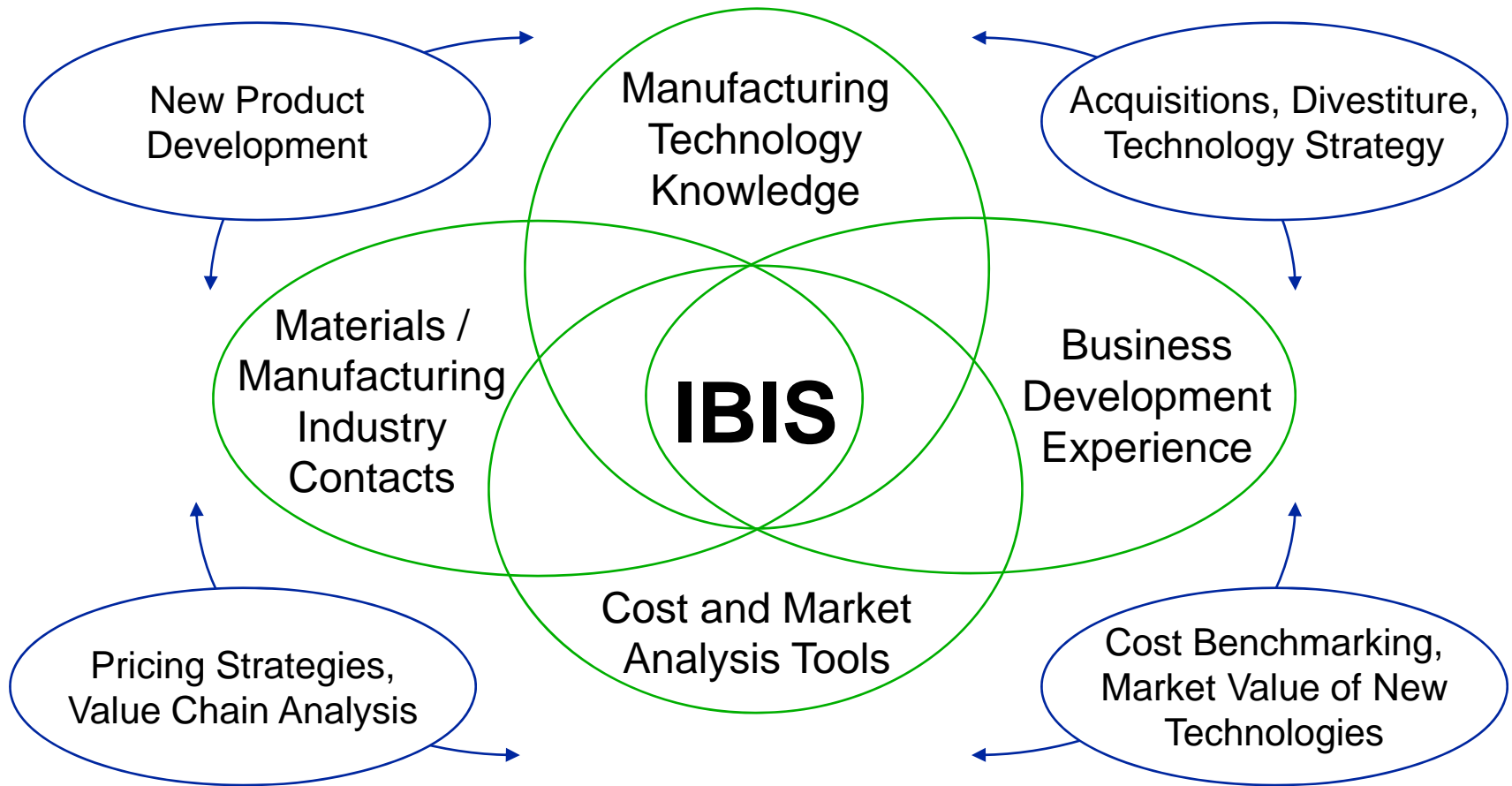


IBIS Associates, Inc. - Waltham, MA

Comprised of persons who hold bachelors and advanced degrees in various engineering disciplines

- Strong information collection, quantitative analyses capabilities

What does IBIS offer?



IBIS - Automotive BIW History

BIW Material Systems Lifecycle Costs

- Multiclient study for OEMs, material suppliers, Tier 1's
- Primary manufacturing, operation, disposal/recycle costs
- Comparative economics: steel, aluminum, composite

ULSAB vehicle-concept manufacturing costs







DOE, PNGV, FreedomCar

- Forward looking analysis of developmental technologies
- Selection of vehicle systems; power-wgt interrelationships
- Conventional, hybrid, electric, fuel cell powertrains
- Multiple vehicle classes

Workplan

- Review and modification of existing baseline scenarios
- Characterization of Hybrid and Diesel scenarios for comparison
 - *ICE (gas & diesel) and electric motor specifications and costs*
 - *storage batteries, controllers, electrical system requirements*
 - *transmission, clutch, differential, tire, and brake system differences*
 - *diesel engine, NOx control, particulate emission equipment*
- Development of model structure
- System requirement relationships
- Data collection
- Cost model refinement
- Review scenario, process assumptions with AA technical team

Scenario Definitions and Assumptions

	Conventional ICE	Hybrid	Diesel
Steel			
Aluminum			

- *Structures remain essentially the same across powertrain types*
 - > Structures consistent with previous body analysis (P2000)
 - > Update aluminum and steel material prices
- *Incorporate component differences by engine type*
 - > Hybrids: controller/inverter, elec. Motors, battery systems
 - > Diesels: Oxidizing catalysts, NOx reduction, PM traps
- *Address “performance equivalence”*
 - > Mass reduction impact on fuel economy based on known relationships
 - > Diesels & Hybrids relative to conventional gasoline from existing data
 - > Flex-fuel systems to be treated as additional cost, but equivalent performance

Baseline Steel and Aluminum Conventional ICEs

VEHICLE LIFECYCLE COST SUMMARY						
	Midsize Steel Baseline ICE Midsize Steel Unibody			Midsize Aluminum Baseline ICE Midsize Aluminum Unibody		
	System Name	Mass (kg)	Cost (\$)	System Name	Mass (kg)	Cost (\$)
TOTAL MANUFACTURING		1,533	\$15,381		1,272	\$15,469
RETAIL PRICE			\$24,534			\$24,657
TOTAL OWNERSHIP			\$0			\$0
Powertrain		672	\$7,433		602	\$6,989
Engine	V-6 DOHC AL/AL	233	\$3,131	V-6 DOHC AL/AL	201	\$2,691
Energy Storage	Lead-Acid, standard	23	\$66	Lead-Acid, standard	19	\$56
Fuel System	Gasoline	81	\$379	Gasoline	74	\$362
Transmission	Automatic, 4 speed car	88	\$1,197	Automatic, 4 speed car	76	\$1,169
P/T Thermal	Generic car	29	\$150	Generic car	29	\$150
Driveshaft/Diff/Axle	generic	100	\$1,303	generic	99	\$1,302
Cradle	Sheet steel	35	\$82	Extruded aluminum	21	\$133
Exhaust System	generic	48	\$300	generic	48	\$300
Oil and Grease	generic	15	\$25	generic	15	\$25
Powertrain Electronics	generic	10	\$400	generic	10	\$400
Emission Control Electronics	generic	10	\$400	generic	10	\$400
Body		433	\$2,665		270	\$3,250
Body-in-White	Midsize Steel Unibody	272	\$1,405	Midsize Aluminum Unibody	145	\$1,816
Panels	Stamped Steel Mid	84	\$230	Stamped Aluminum Mid	52	\$379
Front/Rear Bumpers	Sheet steel	9	\$30	Extruded aluminum	6	\$50
Glass	Conventional, 4mm	37	\$250	Conventional, 4mm	37	\$250
Paint	Solventborne, avg color	11	\$450	Solventborne, avg color	11	\$450
Exterior Trim	generic	9	\$50	generic	9	\$50
Body Hardware	generic	9	\$226	generic	9	\$226
Body Sealers and Deadeners	generic	2	\$24	generic	2	\$29
Chassis		205	\$1,522		178	\$1,469
Corner Suspension	generic	47	\$218	generic	40	\$197
Braking System	ABS	48	\$416	ABS	41	\$376
Wheels and Tires	generic steel	82	\$317	aluminum 15"	76	\$407
Steering System	generic	28	\$572	generic	21	\$489
Interior		156	\$2,156		156	\$2,156
Instrument Panel	generic	25	\$110	generic	25	\$110
Trim and Insulation	generic	23	\$429	generic	23	\$429
Door Modules	generic	26	\$220	generic	26	\$220
Seating and Restraints	generic	62	\$1,122	generic	62	\$1,122
HVAC	generic	21	\$275	generic	21	\$275
Electrical		27	\$1,000		27	\$1,000
Interior Electrical	generic	9	\$400	generic	9	\$400
Chassis Electrical	generic	9	\$400	generic	9	\$400
Exterior Electrical	generic	9	\$200	generic	9	\$200
Final Assembly		40	\$605		40	\$605
Interior to Body	World Class Interior	5	\$140	World Class Interior	5	\$140
Chassis to Body	World Class Chassis	10	\$90	World Class Chassis	10	\$90
Powertrain to Body	World Class Powertrain	10	\$90	World Class Powertrain	10	\$90
Electronics to Body	World Class Electronics	5	\$80	World Class Electronics	5	\$80
Other Systems to Body	World Class Other Systems	10	\$205	World Class Other Systems	10	\$205
Overhead		0	\$9,153		0	\$9,188

	Midsize Steel Baseline		Midsize Aluminum Baseline		Differentials			
	Mass (kg)	Cost (\$)	Mass (kg)	Cost (\$)	Mass (kg)	Cost (\$)	Mass (%)	Cost (%)
Body	433	\$2,665	270	\$3,250	163	-\$585	38%	-22%
Engine	233	\$3,131	201	\$2,691	33	\$440	14%	14%
Energy Storage	23	\$66	19	\$56	3	\$9	14%	14%
Transmission	88	\$1,197	76	\$1,169	12	\$28	14%	2%
Driveshaft/Diff/Axle	100	\$1,303	99	\$1,302	0	\$1	0%	0%
Cradle	35	\$82	21	\$133	14	-\$51	41%	-62%
Corner Suspension	47	\$218	40	\$197	7	\$21	15%	10%
Braking System	48	\$416	41	\$376	7	\$39	15%	9%
Steering System	28	\$572	21	\$489	6	\$63	22%	14%
Fuel P/V Cost	0	\$9,578	0	\$8,325	0	\$0	0%	0%
TOTAL MANUFACTURING	1,533	\$15,381	1,272	\$15,469	260	-\$88	17%	-1%
RETAIL PRICE	0	\$24,534	0	\$24,657	0	-\$123	0%	0%
TOTAL OWNERSHIP	0	\$0	0	\$0	0	\$0	0%	0%

	Midsize Steel Baseline		Midsize Aluminum Baseline		Differentials			
	Mass (kg)	Cost (\$)	Mass (kg)	Cost (\$)	Mass (kg)	Cost (\$)	Mass (%)	Cost (%)
BMW Structure	272	\$1,405	145	\$1,816	128	-\$411	47%	-29%
Engine	233	\$3,131	201	\$2,691	33	\$440	14%	14%
Batteries	23	\$66	19	\$56	3	\$9	14%	14%
Exhaust & Emissions	58	\$700	58	\$700	0	\$0	0%	0%
Vehicle Total	1,533	\$15,381	1,272	\$15,469	260	-\$88	17%	-1%

Hybrid Vehicle Data Collection

- Characterized the components and cost for (9) production hybrids

	Toyota Prius	Honda Accord	Ford Escape	Chevy Silverado
Base ICE Engine	1.5L I4	3.0L V6	2.3L I4	5.3L V8
	57 kW	179 kW	99 kW	220 kW
Mass (kg)	91 kg	288 kg	159 kg	341 kg
Cost (\$)	\$1,191	\$3,907	\$2,084	\$4,723
Electric Motor/Generator	Permanent mag AC	16 hp	94 hp	flywheel alt/starter
	50 kW	12 kW	70 kW	6 kW
Mass (kg)	37.5 kg	9 kg	52.5 kg	4.5 kg
Cost (\$)	\$625	\$150	\$875	\$75

- Four (4) systems compared to non-hybrid equivalents, in detail

Total Net Power	110 hp 82 kW	255 hp 190 kW	155 hp 116 kW	295 hp 220 kW
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Inverter/Controller				
Mass (kg)	23 kg	5.52 kg	32.2 kg	2.76 kg
Cost (\$)	\$609	\$345	\$748	\$304
Battery System	21kW, 201.6V, 1.3kWh	13.8kW, NIMH 0.87kWh	39kW, 330V NIMH	3 lead acid, 600CCA
	500 v	144 v	330 v	42 v
Mass (kg)	38 kg	22 kg	66.3 kg	65 kg
Cost (\$)	\$950	\$2,347	\$1,755	\$98
Transmission	ECVT	5sp Automatic	auto CVT	4 sp Auto
Mass (kg)	41 kg	126 kg	58 kg	149
Cost (\$)	\$1,323	\$1,335	\$1,374	\$1,113
Tires		18" alloy		
Mass (kg)	9 kg/tire	10 kg/tire	15 kg/tire	15 kg/tire
Cost (\$)	110 /tire	119 \$/tire	130 /tire	132 /tire

Vehicle Mass	1250 kg	1591 kg	1644 kg	2276 kg
MSRP	\$21,725	\$26,990	\$26,900	\$28,550

Hybrid Scenario

- Develop hybrid equivalent to *Contour*-baseline
- Characterize relative power sizing of system components for hybrids
- *Camry* used for component sizing basis
- Hybrid case built from the power rating of the previous baseline

- For reference, current *Camry Hybrid*:
to wheels : 143 kW
engine: 110 kW
elec motor: 105 kW
battery sys: 30 kW

Relative power of hybrid components	Total Powertrain	Engine Power	Elec Motor Power	Battery System
Prius	100.00%	69.09%	60.91%	25.58%
Camry	100.00%	76.56%	73.28%	20.94%
Highlander	100.00%	77.61%	61.50%	25.00%
Rx400h	100.00%	77.61%	61.50%	25.00%
Insight	100.00%	89.04%	23.86%	25.33%
Civic	100.00%	86.36%	12.18%	16.81%
Accord	100.00%	94.12%	6.31%	7.25%
Escape	100.00%	85.81%	60.52%	33.72%
Silverado	100.00%	100.00%	2.73%	11.45%

Previous baseline		
engine:	118 kw	158 hp
to wheels	106 kw	142 hp
Hybrid equivalent, based on Camry power profile		
to wheels	102 kw	
engine	78 kw	105 hp
elec motor	75 kw	100 hp
battery system	21 kw	

Diesel Scenario Definition

- Data collected on diesel engine and after treatment manufacturing costs
 - *Most detailed data from EPA study cost projections on differential manufacturing costs*
 - *High correlation between OEM experts' opinions and results in trade studies (EPA, ORNL, MIT) on cost*
- Mass differential more difficult to quantify
 - *Engine equivalency unclear*
 - *Block material differences by displacement (Al, CGI, Nod.Iron)*
- 30-40% fuel economy improvement often cited and supported by European real world data (33% used in analysis)

Diesel Data – differential manufacturing costs

Incremental powertrain costs		
Component	SUV	Midsize
add high pressure, common rail diesel fuel injection system	\$980	\$630
less gasoline fuel injection system	-\$245	-\$165
add variable geometry turbocharger	\$175	\$126
less gasoline ignition system	-\$120	-\$75
less fuel pump and other fuel system changes	-\$94	-\$75
additional powertrain mounting system	\$87	\$107
other engine changes	\$80	\$70
add air intercooler, ducts, and sensor	\$80	\$55
Increase battery starter, add glow plugs	\$72	\$50
less exhaust gas oxygen sensor	-\$60	-\$30
add supplemental heater	\$50	\$15
modify transmission	\$25	\$25
enhance sound insulation package	\$25	\$10
reduce radiator	-\$13	-\$4
Total	\$1,042	\$739

Incremental exhaust treatment costs		
	SUV	Midsize
substrate cost difference (wall flow vs flow through)	\$210	\$130
OBD and regeneration system difference	\$100	\$100
Coatings (PGM and Adsorbant) difference	\$45	\$25
Total	\$355	\$255

Relative to conventional 3-catalyst flow through system, approx \$400 base cost

OBD = On Board Diagnostics
PGM = Platinum Metal Group materials

This data compiled based on current diesel performance (45 state compliance)
 \$100-\$375 additional cost estimated for urea-injection (50 state compliance) (low value +\$100 used in current analysis)
 Approx \$560 estimated additional cost for 2012 lean burn engines w/o urea (expected 2% increase in fuel economy)

Diesel Scenario Modeling Differences

	Midsize Steel Baseline			Midsize Steel Diesel			Differentials			
	ICE Midsize Steel Unibody			ICE Midsize Steel Unibody			Mass (kg)	Cost (\$)	Mass (%)	Cost (%)
	System Name	Mass (kg)	Cost (\$)	System Name	Mass (kg)	Cost (\$)				
TOTAL MANUFACTURING		1,533	\$15,381		1,535	\$16,455				
RETAIL PRICE			\$24,534			\$26,037				
TOTAL OWNERSHIP			\$0			\$0				
Powertrain		672	\$7,433		674	\$8,499	-2	-\$1,066	0%	-14%
Engine	V-6 DOHC AL/AL	233	\$3,131	V-6 DOHC AL/AL	236	\$3,873	-2	-\$742	-1%	-24%
Energy Storage	Lead-Acid, standard	23	\$66	Lead-Acid, standard	23	\$66	0	-\$1	-1%	-1%
Fuel System	Gasoline	81	\$379	Diesel	66	\$345	15	\$34	18%	9%
Transmission	Automatic, 4 speed car	88	\$1,197	Automatic, 4 speed car	89	\$1,199	-1	-\$2	-1%	0%
P/T Thermal	Generic car	29	\$150	Generic car	29	\$150	0	\$0	0%	0%
Driveshaft/Diff/Axle	generic	100	\$1,303	generic	100	\$1,303	0	\$0	0%	0%
Cradle	Sheet steel	35	\$82	Sheet steel	35	\$83	0	\$0	-1%	-1%
Exhaust System	generic	48	\$300	generic	48	\$300	0	\$0	0%	0%
Oil and Grease	generic	15	\$25	generic	15	\$25	0	\$0	0%	0%
Powertrain Electronics	generic	10	\$400	generic	10	\$400	0	\$0	0%	0%
Emission Control Electronics	generic	10	\$400	Part Trap, Nox w/Urea	23	\$755	-13	-\$355	-130%	-89%

- Notable difference in Diesel cost are
 - (+) engine cost (diesel has more torque, but same hp and mass)
 - (+) emission control
 - (-) fuel system cost

E85 / Flex Fuel Vehicles

Unclear how to compare to fuel economy improvement technologies ...

... because it makes fuel economy worse

- E85 has 72% energy content of gasoline
 - *20-30% fewer miles per gallon*
 - *But average \$0.30/gallon less cost of fuel*
- No additional cost added to vehicle price
 - *Less than \$150 in equipment modifications*
 - > Fuel monitoring, injection & combustion controls
 - > Corrosion resistant elements (injector heads, piston rings)

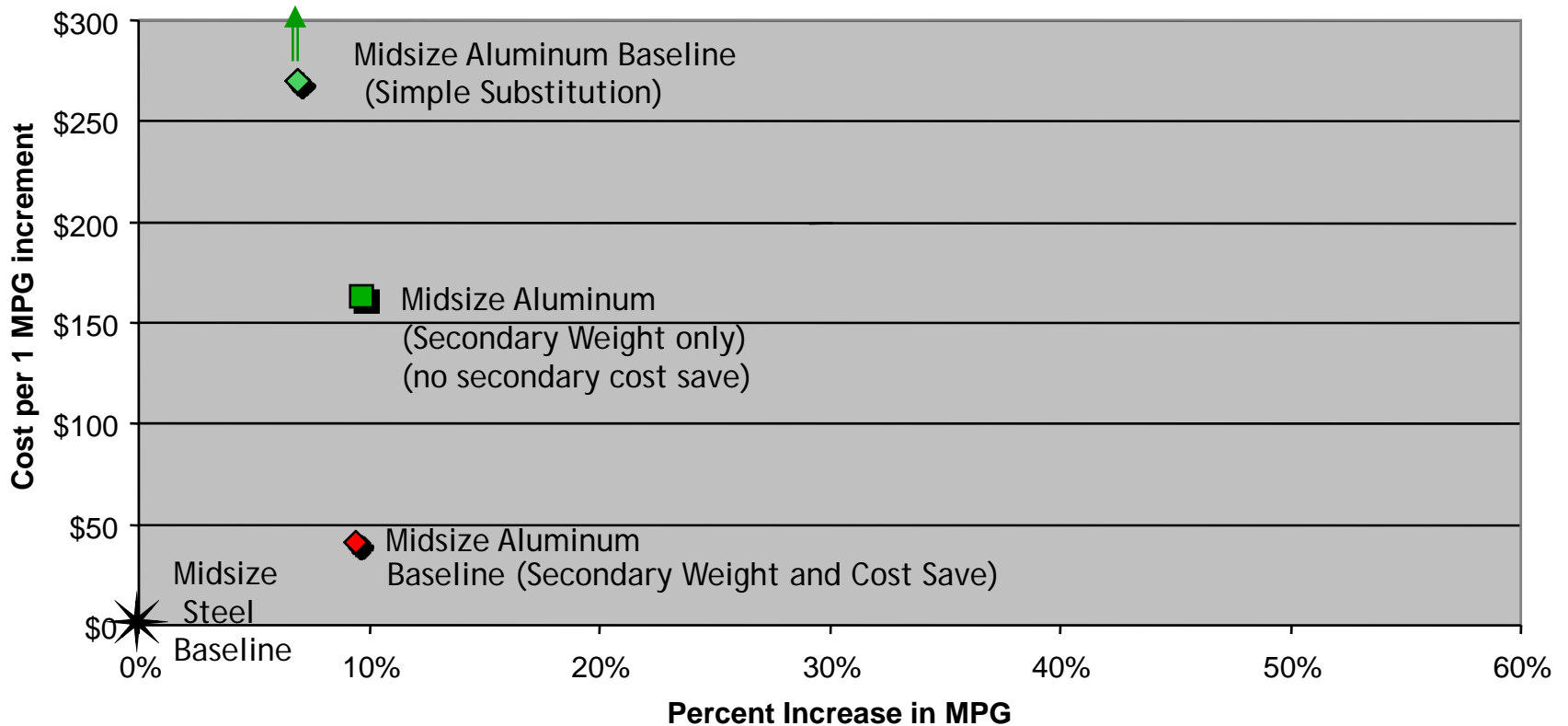
Scenario Comparison

	Midsize Steel Baseline		Midsize Aluminum Baseline		Midsize Steel Hybrid		Midsize Steel Diesel		Midsize Aluminum Diesel		Midsize Aluminum Hybrid	
	Mass (kg)	Cost (\$)	Mass (kg)	Cost (\$)	Mass (kg)	Cost (\$)	Mass (kg)	Cost (\$)	Mass (kg)	Cost (\$)	Mass (kg)	Cost (\$)
Body	433	\$2,665	270	\$3,250	433	\$2,665	433	\$2,665	271	\$3,245	271	\$3,250
Engine	233	\$3,131	201	\$2,691	167	\$2,244	236	\$3,873	203	\$3,430	144	\$1,925
Motor					76	\$1,267					65	\$1,087
Controller/Inverter					47	\$965					40	\$866
Energy Storage	23	\$66	19	\$56	49	\$1,303	23	\$66	20	\$57	42	\$1,119
Transmission	88	\$1,197	76	\$1,169	93	\$1,207	89	\$1,199	76	\$1,171	80	\$1,178
Driveshaft/Diff/Axle	100	\$1,303	99	\$1,302	100	\$1,304	100	\$1,303	99	\$1,302	100	\$1,303
Cradle	35	\$82	21	\$133	36	\$84	35	\$83	21	\$135	21	\$137
Corner Suspension	47	\$218	40	\$197	49	\$223	48	\$219	41	\$199	42	\$202
Braking System	48	\$416	41	\$376	50	\$425	48	\$418	41	\$379	42	\$385
Steering System	28	\$572	21	\$489	29	\$591	28	\$576	22	\$495	23	\$507
Fuel PV Cost		\$8,047		\$7,336		\$5,831		\$6,051		\$5,515		\$5,315
TOTAL MANUFACTURING COST	1,532	\$15,381	1,272	\$15,469	1,577	\$17,876	1,535	\$16,455	1,279	\$16,546	1,313	\$17,539
RETAIL PRICE		\$24,534		\$24,657		\$28,026		\$26,038		\$26,164		\$27,554

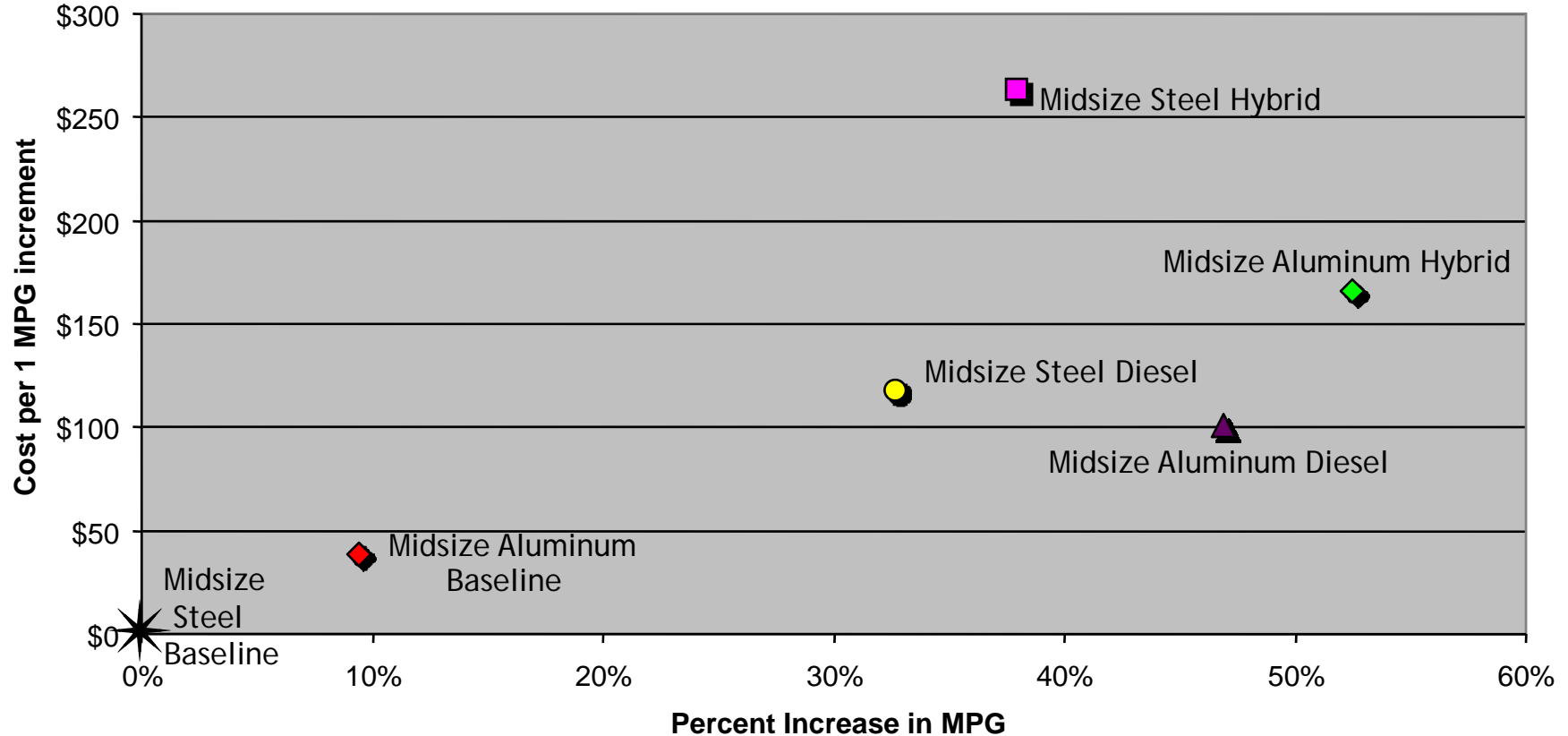
Scenario Comparison

	Midsize Steel Baseline		Midsize Aluminum Baseline		Midsize Steel Hybrid		Midsize Steel Diesel		Midsize Aluminum Diesel		Midsize Aluminum Hybrid	
	Mass (kg)	Cost (\$)	Mass (kg)	Cost (\$)	Mass (kg)	Cost (\$)	Mass (kg)	Cost (\$)	Mass (kg)	Cost (\$)	Mass (kg)	Cost (\$)
BIW Structure	272	\$1,405	145	\$1,816	272	\$1,405	272	\$1,405	145	\$1,816	145	\$1,816
Powertrain	314	\$3,897	278	\$3,447	378	\$6,382	330	\$4,994	294	\$4,542	330	\$5,592
Engine	233	\$3,131	201	\$2,691	167	\$2,244	236	\$3,873	203	\$3,430	144	\$1,925
Motor					76	\$1,267					65	\$1,087
Controller/Inverter					47	\$965					40	\$866
Batteries	23	\$66	19	\$56	49	\$1,303	23	\$66	20	\$57	42	\$1,119
Exhaust & Emissions	58	\$700	58	\$700	39	\$602	71	\$1,055	71	\$1,055	39	\$595
Vehicle Total	1,532	\$15,381	1,272	\$15,469	1,577	\$17,876	1,535	\$16,455	1,279	\$16,546	1,313	\$17,539
Engine Power kW		146		125		105		147		127		90
Elec Motor Power kW		0		0		101		0		0		87
Vehicle mpg (city)		21.1		22.9		30.1		26.9		29.1		32.5
Vehicle mpg (hwy)		30.2		33.5		31.7		37.8		42.0		35.1
Vehicle mpg (comp)		25.2		27.7		34.8		33.5		36.8		38.2
Fuel tank size (gallons)		18.5		16.8		13.4		13.9		12.7		12.2
Vehicle range (miles)		466		466		466		466		466		466
Comp MPG improvement				10%		38%		33%		46%		51%
Cost/1mpg increment				\$36		\$260		\$129		\$101		\$166
City MPG improvement				8%		42%		27%		38%		54%
Cost/1mpg increment				\$51		\$280		\$186		\$146		\$190
Hwy MPG improvement				11%		5%		25%		39%		16%
Cost/1mpg increment				\$26		\$1,673		\$140		\$98		\$434

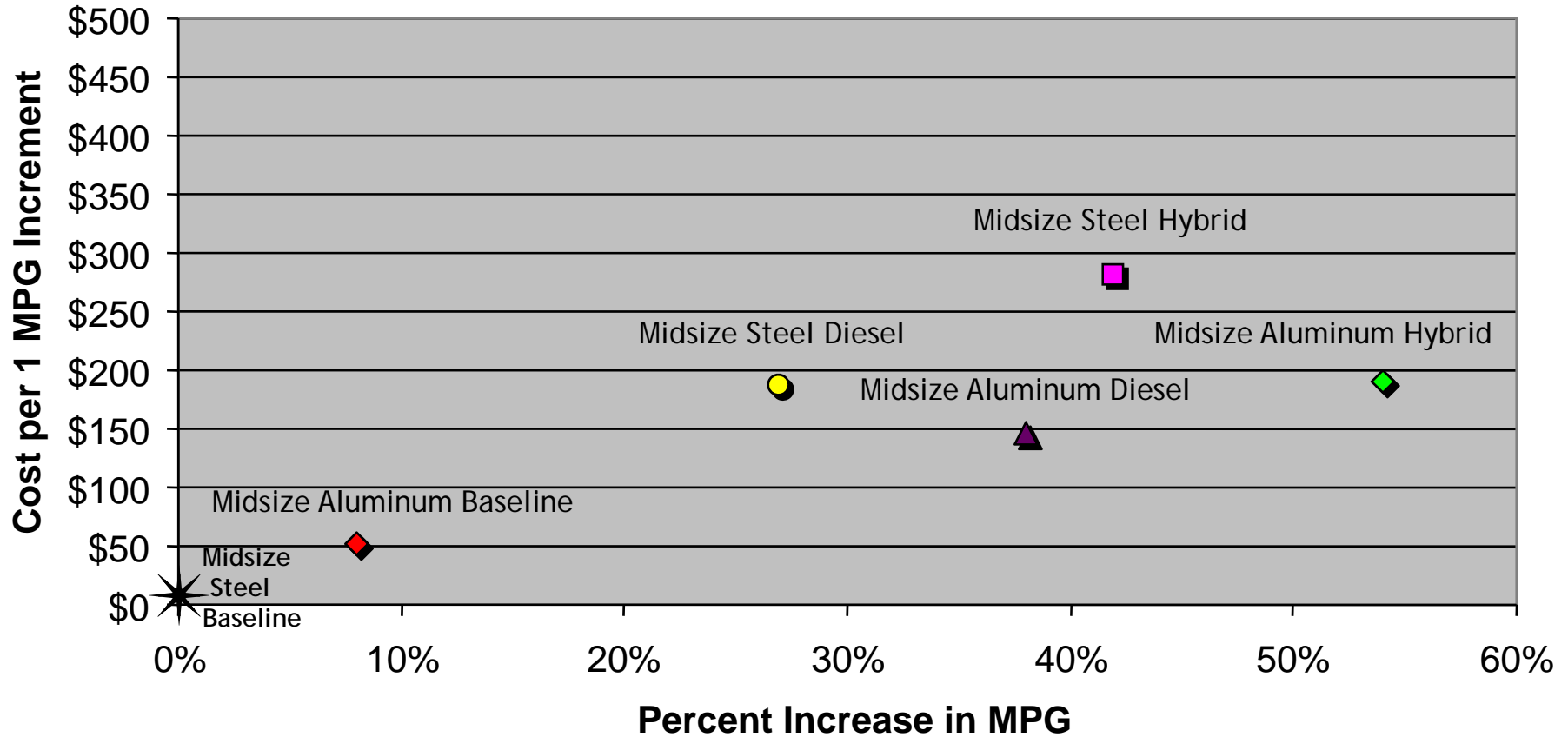
Cost per Incremental MPG Improvement



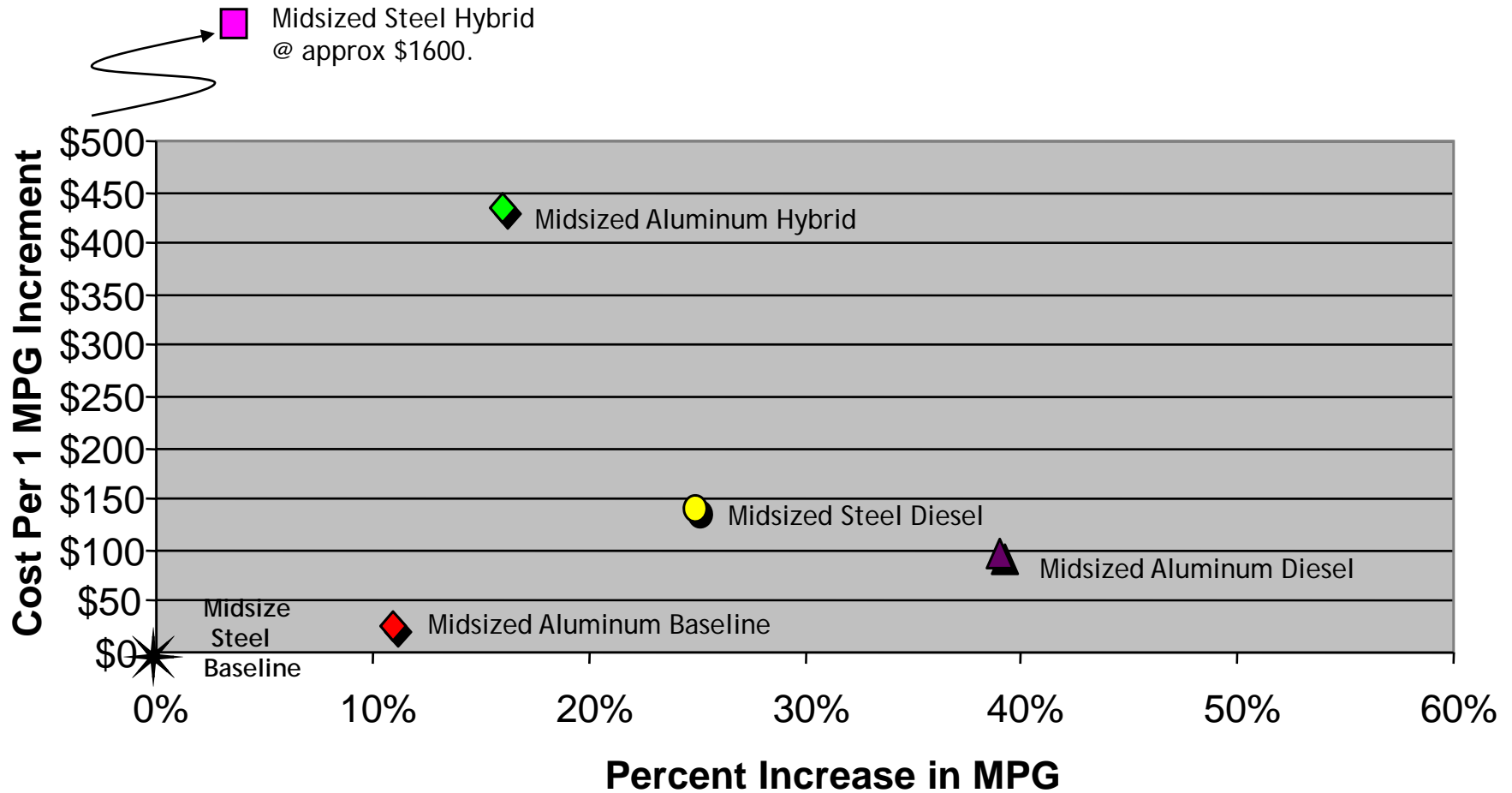
Cost per Increment versus Total Potential Gains



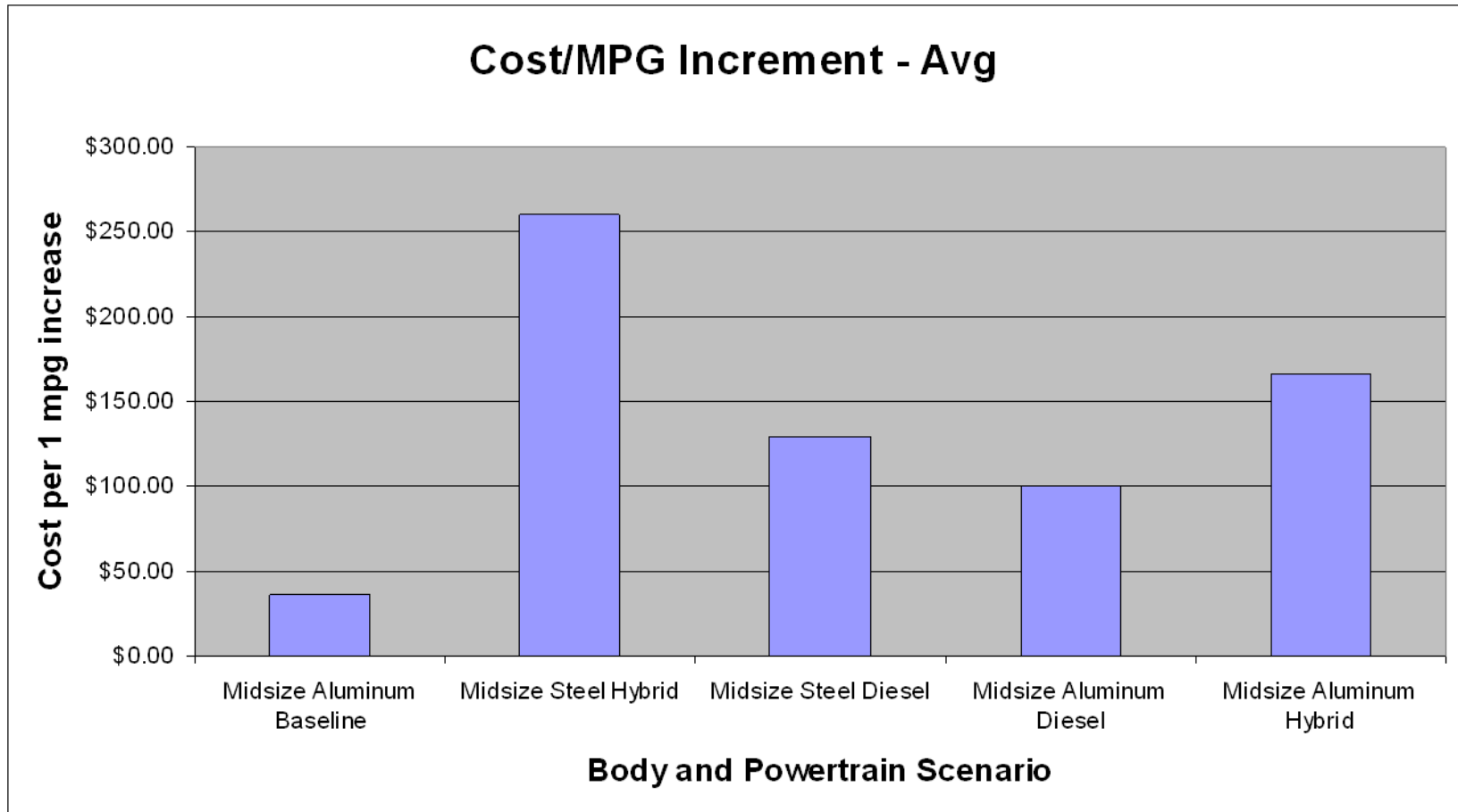
Cost per Incremental City MPG Gains



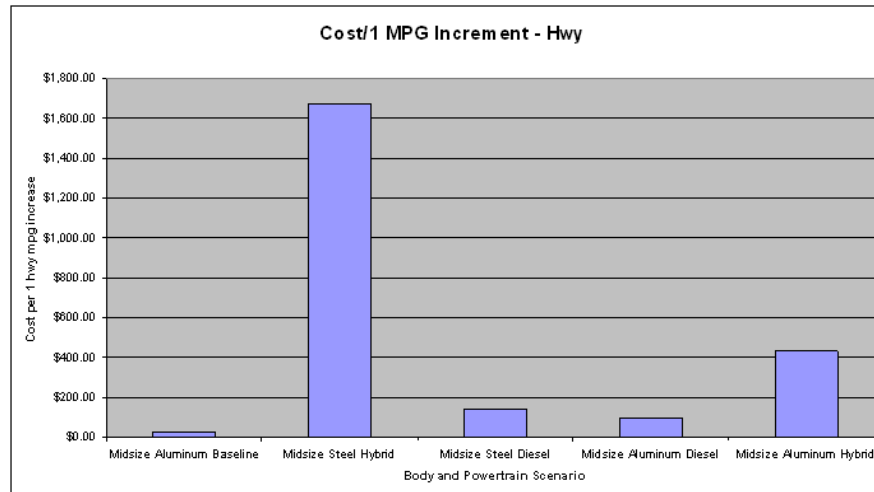
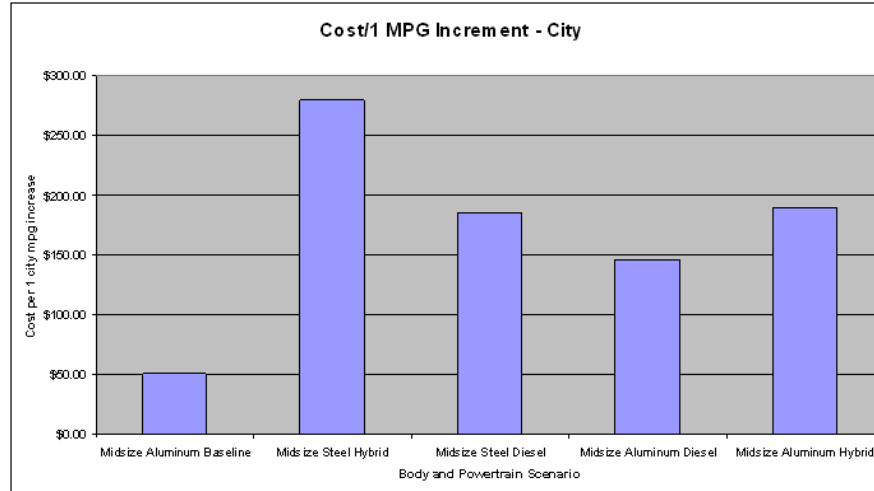
Cost per Incremental Highway MPG Gains



Relative Cost for Fuel Economy Improvement (Avg MPG)



Relative Cost for Fuel Economy Improvement



Conclusions

- Lightweighting through Aluminum usage:
 - *Most effective approach to fuel economy improvement*
 - > Simpler, less costly than alternative powertrains
 - > For moderate MPG improvement
 - *Synergistic with Diesel and Hybrid powertrains*
 - > Reduced body mass yields reduced engine power demand
 - + Lower cost powertrain
 - + Compounded by secondary and tertiary mass/cost savings
 - > Results in substantially better MPG than steel BIW versions

Appendices

Additional Detail and Background Data

Scope – Vehicle System Elements

Body	Powertrain	Chassis	Final Assembly	Overhead
Body-in-White	Engine	Corner Suspension	Interior to Body	OEM Overhead
Panels	Fuel System	Braking System	Chassis to Body	Dealer Cost
Front/Rear Bumpers	Transmission	Wheels and Tires	Powertrain to Body	
Glass	Driveshaft/Axle	Steering System	Electronics to Body	
Paint	Differential	Cradle	Other Systems to Body	
Exterior Trim		Exhaust System		Operation
Body Hardware		Oil and Grease		Financing PV Cost
Body Sealers and Deadeners				Insurance PV Cost
				Local Fees PV Cost
Interior		Electrical		Fuel PV Cost
Instrument Panel		Interior Electrical		Replacement Battery PV Cost
Trim and Insulation		Chassis Electrical		Maintenance PV Cost
Door Modules		Exterior Electrical		Repair PV Cost
Seating and Restraints		Powertrain Electronics		Disposal PV Cost
		Emission Controls		
		HVAC		

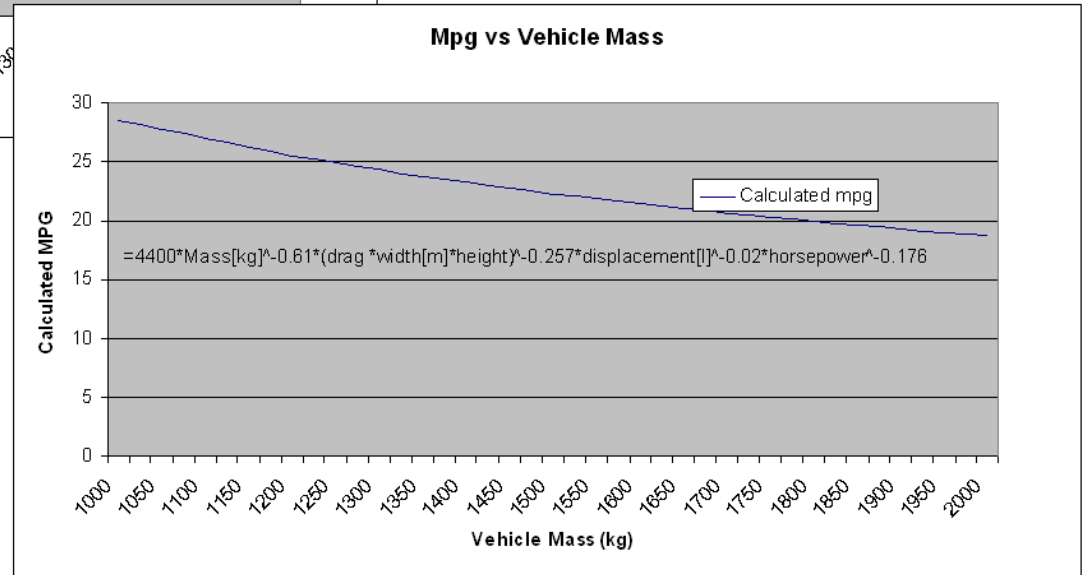
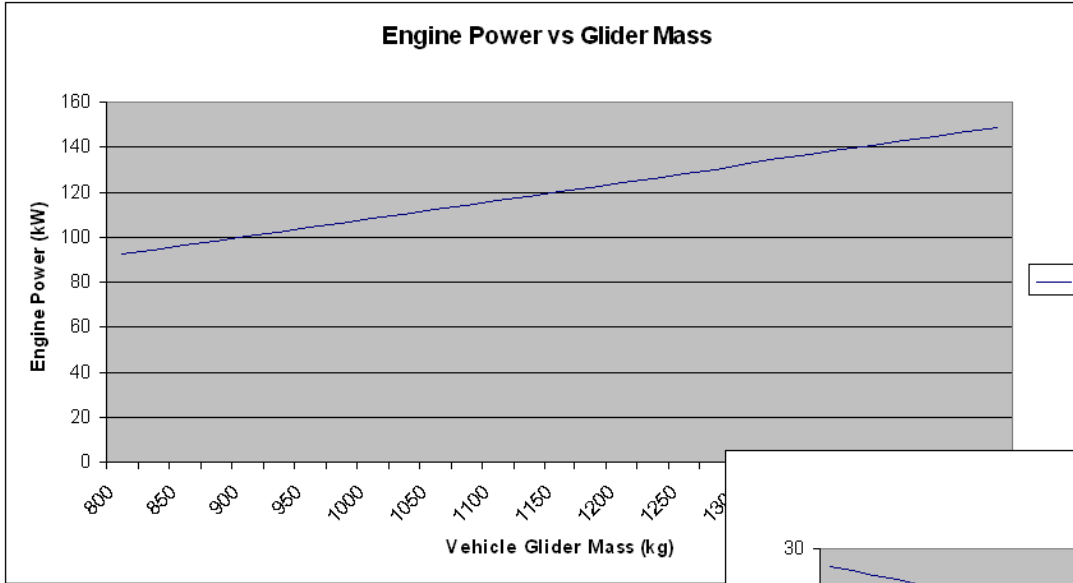
System Cost Results - detailed

VEHICLE LIFECYCLE COST SUMMARY										
	Baseline Steel			Baseline Aluminum			Differentials			
	Gasoline ICE Midsize Steel Unibody			Gasoline ICE Midsize Aluminum Unibody			Mass (kg)	Cost (\$)	Mass (%)	Cost (%)
	System Name	Mass (kg)	Cost (\$)	System Name	Mass (kg)	Cost (\$)				
TOTAL MANUFACTURING		1,564	\$14,871		1,288	\$14,974	275	-\$103	17.61%	-0.69%
RETAIL PRICE			\$23,819			\$23,964				-0.61%
TOTAL OWNERSHIP			\$51,520			\$50,344		\$1,176		2.28%
Powertrain		701	\$6,908		617	\$6,446	84	-\$463	11.98%	6.70%
Engine	V-6 DOHC CVT	257	\$2,556	V-6 DOHC CVT	219	\$2,160	38	-\$375	14.78%	14.78%
Energy Storage	Lead-Acid, standard	18	\$53	Lead-Acid, standard	16	\$46	3	-\$8	14.78%	14.78%
Fuel System	Gasoline, 18.5 gal	89	\$388	Gasoline, 17 gal	83	\$376	6	-\$12	7.03%	3.09%
Transmission	Automatic, 4 speed car	79	\$1,177	Automatic, 4 speed car	67	\$1,151	12	-\$26	14.78%	2.22%
P/T Thermal	Generic car	29	\$150	Generic car	29	\$150	0	\$0	0.00%	0.00%
Driveshaft/Axle	generic	110	\$1,397	generic	99	\$1,304	11	-\$93	9.59%	0.00%
Cradle	Sheet steel	36	\$83	Extruded aluminum	21	\$134	15	-\$51	41.70%	-60.75%
Exhaust System	generic	48	\$300	generic	48	\$300	0	\$0	0.00%	0.00%
Oil and Grease	generic	15	\$25	generic	15	\$25	0	\$0	0.00%	0.00%
Powertrain Electronics	generic	10	\$400	generic	10	\$400	0	\$0	0.00%	0.00%
Emission Control Electronics	generic	10	\$400	generic	10	\$400	0	\$0	0.00%	0.00%
Body		433	\$2,666		270	\$3,295	163	-\$630	37.68%	-23.63%
Body-in-White	Midsize Steel Unibody	272	\$1,405	Midsize Aluminum Unibody	146	\$1,816	128	-\$411	46.88%	-29.25%
Panel	Stamped Steel Mid	94	\$230	Stamped Aluminum Mid	52	\$379	32	-\$149	38.10%	-64.78%
Front/Rear Bumpers	Sheet steel	9	\$30	Extruded aluminum	6	\$50	4	-\$20	40.00%	-66.67%
Glass	Conventional, 4mm	37	\$250	Conventional, 4mm	37	\$250	0	\$0	0.00%	0.00%
Paint	Solventborne, avg color	11	\$460	Solub on Al, avg color	11	\$495	0	-\$45	0.00%	-10.00%
Exterior Trim	generic	9	\$50	generic	9	\$50	0	\$0	0.00%	0.00%
Body Hardware	generic	9	\$228	generic	9	\$228	0	\$0	0.00%	0.00%
Body Sealers and Deadeners	generic	2	\$24	generic	2	\$29	0	-\$5	-19.57%	-20.00%
Chassis		207	\$1,537		178	\$1,473	29	-\$64	13.80%	4.16%
Corner Suspension	generic	48	\$220	generic	40	\$198	8	-\$22	15.96%	10.16%
Braking System	ABS	40	\$420	ABS	41	\$377	8	-\$43	16.37%	10.13%
Wheels and Tires	generic steel	82	\$317	aluminum 15"	76	\$407	6	-\$90	7.71%	-28.39%
Steering System	generic	28	\$590	generic	22	\$491	7	-\$89	23.45%	15.36%
Interior		196	\$2,158		196	\$2,158	0	\$0	0.00%	0.00%
Instrument Panel	generic	25	\$110	generic	25	\$110	0	\$0	0.00%	0.00%
Trim and Insulation	generic	23	\$429	generic	23	\$429	0	\$0	0.00%	0.00%
Door Modules	generic	26	\$220	generic	26	\$220	0	\$0	0.00%	0.00%
Seating and Restraints	generic	62	\$1,122	generic	62	\$1,122	0	\$0	0.00%	0.00%
HVAC	generic	21	\$275	generic	21	\$275	0	\$0	0.00%	0.00%
Electrical		27	\$1,000		27	\$1,000	0	\$0	0.00%	0.00%
Interior Electrical	generic	9	\$400	generic	9	\$400	0	\$0	0.00%	0.00%
Chassis Electrical	generic	9	\$400	generic	9	\$400	0	\$0	0.00%	0.00%
Exterior Electrical	generic	9	\$200	generic	9	\$200	0	\$0	0.00%	0.00%
Final Assembly		40	\$656		40	\$656	0	\$0	0.00%	0.00%
Interior to Body	World Class Interior	5	\$140	World Class Interior	5	\$140	0	\$0	0.00%	0.00%
Chassis to Body	World Class Chassis	10	\$90	World Class Chassis	10	\$90	0	\$0	0.00%	0.00%
Powertrain to Body	World Class Powertrain	10	\$90	World Class Powertrain	10	\$90	0	\$0	0.00%	0.00%
Electronics to Body	World Class Electronics	5	\$80	World Class Electronics	5	\$80	0	\$0	0.00%	0.00%
Other Systems to Body	World Class Other Systems	10	\$205	World Class Other Systems	10	\$205	0	\$0	0.00%	0.00%
Overhead		0	\$5,948		0	\$5,990	0	-\$41	0.00%	-0.46%
OEM Overhead	Baseline	0	\$3,000	Baseline	0	\$3,000	0	\$0	0.00%	0.00%
Dealer Cost	Function of Mfg. Cost	0	\$5,948	Function of Mfg. Cost	0	\$5,990	0	-\$41	0.00%	-0.69%
Operation			\$27,700			\$26,380	0	\$1,320	0.00%	4.77%
Financing PV Cost	Baseline		\$18,819	Baseline		\$18,964	0	-\$144	0.00%	-0.77%
Insurance PV Cost	Baseline		\$12,050	Baseline		\$12,050	0	\$0	0.00%	0.00%
Local Fees PV Cost	Baseline		\$1,928	Baseline		\$1,936	0	-\$8	0.00%	-0.39%
Fuel PV Cost	Baseline		\$9,342	Baseline		\$8,071	0	\$1,272	0.00%	13.61%
Maintenance PV Cost	Baseline		\$3,591	Baseline		\$3,591	0	\$0	0.00%	0.00%
Repair PV Cost	Baseline		\$810	Baseline		\$810	0	\$0	0.00%	0.00%
Disposal PV Cost	Baseline		-\$21	Baseline		-\$77	0	\$56	0.00%	-267.98%

System Cost Results - differentials

	Baseline Steel		Baseline Aluminum		Differentials			
	Mass (kg)	Cost (\$)	Mass (kg)	Cost (\$)	Mass (kg)	Cost (\$)	Mass (%)	Cost (%)
Body	433	\$2,665	270	\$3,295	163	-\$630	37.58%	-23.63%
Engine	257	\$2,535	219	\$2,160	38	\$375	14.78%	14.78%
Energy Storage	18	\$53	16	\$45	3	\$8	14.78%	14.78%
Transmission	79	\$1,177	67	\$1,151	12	\$26	14.78%	2.22%
Driveshaft/Diff/Axle	110	\$1,397	99	\$1,304	11	\$93	9.59%	0.00%
Cradle	36	\$83	21	\$134	15	-\$51	41.70%	-60.75%
Corner Suspension	48	\$220	40	\$198	8	\$22	15.96%	10.16%
Braking System	49	\$420	41	\$377	8	\$43	16.37%	10.13%
Steering System	28	\$580	22	\$491	7	\$89	23.45%	15.36%
Fuel PV Cost	0	\$9,342	0	\$8,071	0	\$1,272	0.00%	13.61%
TOTAL MANUFACTURING	1,564	\$14,871	1,288	\$14,974	275	-\$103	17.61%	-0.69%
RETAIL PRICE	0	\$23,819	0	\$23,964	0	-\$144	0.00%	-0.61%
TOTAL OWNERSHIP	0	\$51,520	0	\$50,344	0	\$1,176	0.00%	2.28%

Impact of Mass Savings



Value of Mass Savings

	Baseline Steel		Baseline Aluminum	
	Mass (kg)	Cost (\$)	Mass (kg)	Cost (\$)
BIW Cost (w closures)	356	1635	197	2,195
Total Mfg Cost	1,564	\$14,871	1,288	\$14,974

	Baseline Steel	Baseline Aluminum
Calc avg mpg	21.7	25.1

Only Structure and Closure Differences	
Cost of mass savings (BIW only) (\$/kg)	\$3.51

Secondary Mass Savings, but no sec cost savings	
Cost of mass savings (vehicle) (\$/kg)	\$2.03
Cost of mpg improvement (\$/mpg)	\$163.67

Assumes secondary mass savings as addressed in the analysis, but does include the associated secondary cost savings.

Secondary Mass and Cost Savings	
Cost of mass savings (vehicle) (\$/kg)	\$0.37
Cost of mpg improvement (\$/mpg)	\$30.09

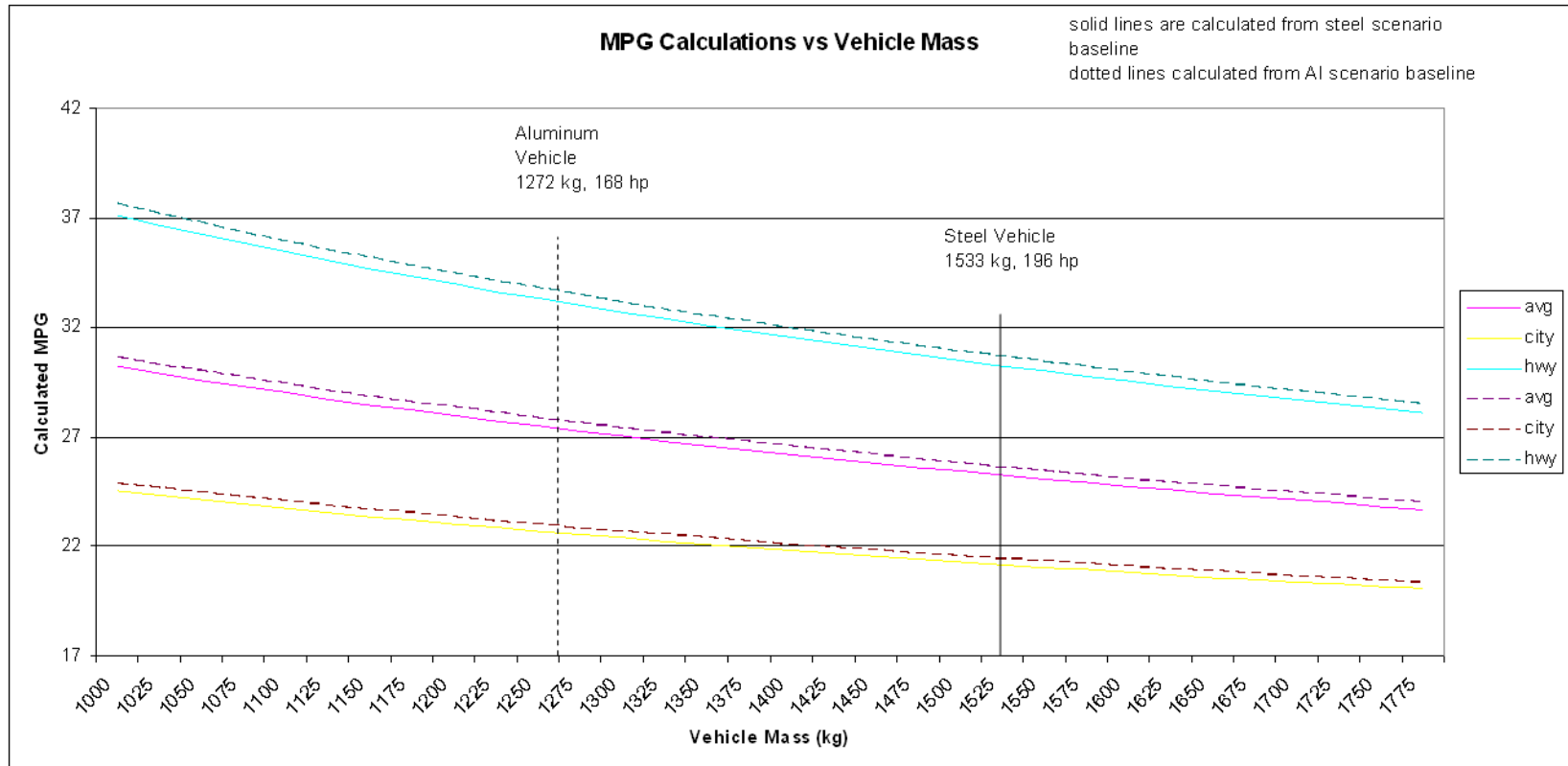
This cost includes both the cost premium of the Aluminum structure and the secondary savings from reduced powertrain and chassis components.

HSS BIW Component Detail

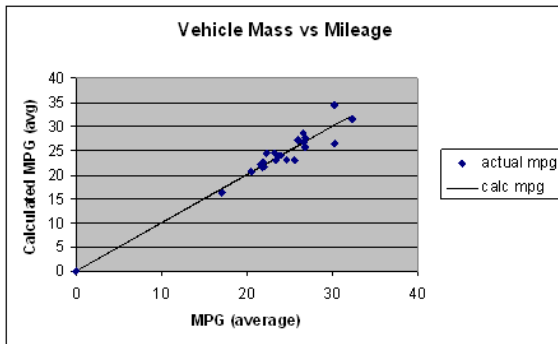
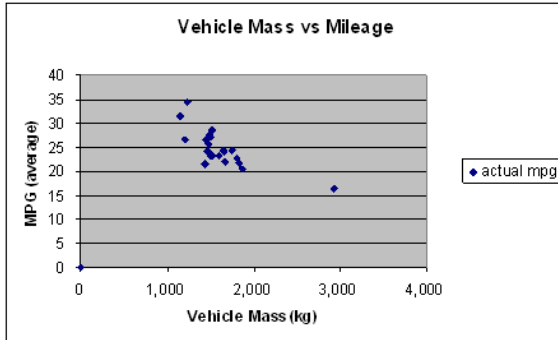
Part #	Description	Old Mtl	New Mtl	Old Thk mm	New Thk mm	Old Mass lbs	New Mass lbs	Mass Sav e lbs/piece	No pcs (unit)	Tot Mass Sav e lbs/unit	Old Cost \$/unit	New Cost \$/unit	Cost Δ \$/unit
Class D:													
	92 Reinforced Anchor Front Floor	HSLA	DP780	1.5	1.35	3.37	3.033	0.337	2	0.67	\$13.02	\$15.02	\$2.00
	180 Filler Flr Side Inner	HSLA	DP780	1.25	1.125	3.38	3.042	0.338	2	0.68	\$13.37	\$15.52	\$2.14
	181 Reinf Flr Side Inner	HSLA	DP780	0.75	0.675	3.13	2.817	0.313	2	0.63	\$14.05	\$16.61	\$2.56
	216 Reinf Roof Side Rail	HSLA	DP780	1	0.9	2.66	2.394	0.266	2	0.53	\$12.27	\$14.57	\$2.30
	206 Reinf Center Pillar	HSLA	DP780	1.25	1.125	5.32	4.788	0.532	2	1.06	\$16.76	\$19.43	\$2.66
Class C:													
	71 Ext Front Fender Apron	Mild Steel	DP590	1	0.93	2.74	2.5482	0.1918	2	0.38	\$12.42	\$13.54	\$1.13
	33 Reinf Member Floor SD Inr Frt	HSLA	DP590	2	1.86	5.65	5.2545	0.3955	2	0.79	\$22.60	\$23.46	\$0.86
	20 Front Rail Inner RH	Mild Steel	DP590	1.38	1.2834	9.83	9.1419	0.6881	1	0.69	\$15.58	\$16.55	\$0.96
	75 Reinf Rail Inner RR	0 DP590	0	0	0	0	0	0	2	0.00			
	54 Member Front Cross @ Dash Panel	Mild Steel	DP590	0.8	0.744	2.41	2.2413	0.1687	1	0.17	\$6.12	\$6.65	\$0.54
	50 Ext Floor SD Member FT	Mild Steel	DP590	1.75	1.6275	5.07	4.7151	0.3549	2	0.71	\$15.19	\$16.67	\$1.49
	17 Front Rail Inner LH	Mild Steel	DP590	1.38	1.2834	9.83	9.1419	0.6881	1	0.69	\$15.58	\$16.55	\$0.96
	22 Reinf Front Fender Apron RH	HSLA	DP590	0.75	0.6975	0.77	0.7161	0.0539	1	0.05	\$2.68	\$2.71	\$0.03
	23 Reinf Front Fender Apron LH	HSLA	DP590	0.75	0.6975	1.4	1.302	0.098	1	0.10	\$3.37	\$3.42	\$0.06
	62 Ext Dash Panel LHD	Mild Steel	DP590	0.8	0.744	3.89	3.6177	0.2723	1	0.27	\$7.55	\$8.20	\$0.65
	81 Member Floor Side Center	HSLA	DP590	1	0.93	2.41	2.2413	0.1687	2	0.34	\$11.80	\$12.87	\$1.07
	85 Member Front Floor Cross	HSLA	DP590	1	0.93	1.41	1.3113	0.0987	2	0.20	\$6.43	\$6.55	\$0.11
	87 Member Front Floor Cross RR LWR	Mild Steel	DP590	1	0.93	1.14	1.0602	0.0798	2	0.16	\$5.82	\$6.00	\$0.18
	88 Member Front Floor Cross OTR	Mild Steel	DP590	1.25	1.1625	0.46	0.4278	0.0322	2	0.06	\$2.61	\$2.68	\$0.07
	111 Pnl Windshield Header	Mild Steel	DP590	0.7	0.651	1.57	1.4601	0.1099	0	0.00	\$3.53	\$3.65	\$0.12
	112 Reinforce Anchor Front Floor	Mild Steel	DP590	0.75	0.6975	1.6	1.488	0.112	0	0.00	\$3.51	\$3.64	\$0.12
	113 Reinforce Anchor Front Floor	Mild Steel	DP590	0.65	0.6045	1.05	0.9765	0.0735	0	0.00	\$3.03	\$3.11	\$0.08
	121 Member Front Floor Cross RR	HSLA	DP590	0.75	0.6975	4.63	4.3059	0.3241	1	0.32	\$8.51	\$9.05	\$0.54
	124 Center Mount Rear Axle	Mild Steel	DP590	0.8	0.744	3.42	3.1806	0.2394	1	0.24	\$7.10	\$7.72	\$0.62
	134 Member Floor Side RR	HSLA	DP590	1.5	1.395	7.91	7.3563	0.5537	2	1.11	\$28.38	\$29.42	\$1.04
	135 Reinf Floor Side RR	HSLA	DP590	1.38	1.2834	5.65	5.2545	0.3955	2	0.79	\$24.80	\$25.66	\$0.86
	145 Panel RR Flr (RH)	Mild Steel	DP590	0.8	0.744	1.71	1.5903	0.1197	1	0.12	\$3.58	\$3.71	\$0.13
	146 Panel RR Flr (LH)	Mild Steel	DP590	0.8	0.744	1.71	1.5903	0.1197	1	0.12	\$3.58	\$3.71	\$0.13
Class B:													
	53 Panel Dash LHD	Mild Steel	DP590	0.75	0.6975	9.48	8.8164	0.6636	1	0.66	\$16.88	\$17.82	\$0.94
	49 PLR Body Side INR	Mild Steel	DP590	1.38	1.2834	4.8	4.464	0.336	2	0.67	\$15.27	\$16.72	\$1.44
	80 Panel Front Floor	Mild Steel	DP590	0.7	0.651	22.71	21.1203	1.5897	1	1.59	\$28.50	\$30.45	\$1.96
	203 Reinf Hinge Pillar	Mild Steel	DP590	1.38	1.2834	5.97	5.5521	0.4179	2	0.84	\$23.52	\$24.85	\$1.33
	190 Panel Bodyside Inner RR	Mild Steel	DP590	0.75	0.6975	6.97	6.4821	0.4879	1	0.49	\$22.01	\$23.40	\$1.39
	200 Panel Bodyside Outer	Mild Steel	DP590	0.8	0.744	18.9	17.577	1.323	2	2.65	\$49.34	\$52.67	\$3.33
	217 Reinf Qtr Upper	0 DP590	0	0	0	0	0	0	2	0.00			
	120 Panel Rear Floor Front	Mild Steel	DP590	1	0.93	7.51	6.9843	0.5257	1	0.53	\$7.50	\$8.17	\$0.67
	160 Panel Rear Floor Tub	Mild Steel	DP590	0.7	0.651	5.19	4.8267	0.3633	1	0.36	\$8.98	\$9.73	\$0.75
	161 Panel Rear Floor Tub	0 DP590	0	0	0	0	0	0	1	0.00			
	208 Reinf Center Plr Lwr Hinge	Mild Steel	DP590	1.25	1.1625	0.22	0.2046	0.0154	2	0.03	\$1.26	\$1.29	\$0.03
Total mass Saved:										18.70 lbs			

Total mass Saved: 18.70 lbs

MPG Calculations



MPG Data and Calculations



Avg MPG Parameter:

Constant 1019.892
 Wgt -0.42357
 Aero -0.111
 Disp -0.13856
 HP -0.09086

City MPG Parameter:

Constant 540.4993
 Wgt -0.35024
 Aero -0.11688
 Disp -0.22067
 HP -0.08915

Hwy MPG Parameter:

Constant 1782.959
 Wgt -0.48427
 Aero -0.10701
 Disp -0.06917
 HP -0.09246

Vehicle Mass	Steel Baseline			Aluminum Baseline		
	avg	city	hwy	avg	city	hwy
1000	25.21066	21.13807	30.17636	25.56015	21.42552	30.6021
1025	30.20774	24.54721	37.10693	30.6265	24.88103	37.63044
1050	29.89344	24.33583	36.66585	30.30784	24.66678	37.18314
1075	29.58987	24.13131	36.24046	30.00006	24.45947	36.75175
1100	29.29641	23.93325	35.82984	29.70254	24.25872	36.33533
1125	29.01252	23.74132	35.43315	29.41471	24.06418	35.93305
1150	28.73766	23.55519	35.04962	29.13604	23.87552	35.54411
1175	28.47136	23.37456	34.67854	28.86605	23.69244	35.16779
1200	28.21318	23.19916	34.31924	28.60429	23.51465	34.80343
1225	27.96271	23.02873	33.97112	28.35035	23.3419	34.45039
1250	27.71955	22.86302	33.63359	28.10382	23.17394	34.1081
1275	27.48336	22.70182	33.30614	27.86435	23.01054	33.77603
1300	27.2538	22.54492	32.98826	27.63161	22.8515	33.45367
1325	27.03056	22.39211	32.67951	27.40527	22.69662	33.14058
1350	26.81334	22.24322	32.37944	27.18505	22.54571	32.83628
1375	26.60189	22.09808	32.08766	26.97066	22.39859	32.54038
1400	26.39593	21.95652	31.8038	26.76185	22.25511	32.25249
1425	26.19524	21.81839	31.52749	26.55838	22.1151	31.97229
1450	25.99959	21.68356	31.25841	26.36001	21.97843	31.69941
1475	25.80877	21.55188	30.99625	26.16654	21.84496	31.43355
1500	25.62257	21.42323	30.74071	25.97776	21.71457	31.1744
1525	25.44081	21.2975	30.49152	25.79348	21.58712	30.9217
1550	25.26331	21.17456	30.24842	25.61352	21.46251	30.67517
1575	25.0899	21.05431	30.01116	25.43772	21.34063	30.43457
1600	24.92044	20.93665	29.77952	25.2659	21.22137	30.19965
1625	24.75476	20.82149	29.55327	25.09792	21.10464	29.97021
1650	24.59272	20.70874	29.33221	24.93364	20.99035	29.74603
1675	24.4342	20.5983	29.11614	24.77292	20.87841	29.52691
1700	24.27906	20.4901	28.90487	24.61563	20.76874	29.31267
1725	24.12718	20.38405	28.69823	24.46164	20.66125	29.10312
1750	23.97844	20.28009	28.49606	24.31085	20.55588	28.89809
1775	23.83275	20.17815	28.29819	24.16313	20.45255	28.69742
1775	23.68998	20.07815	28.10447	24.01839	20.3512	28.50097

$$\text{Mpg} = \text{constant} \times (\text{kg})^{\text{Wgt}} \times (\text{wid} \times \text{hgt} \times \text{Cd})^{\text{Aero}} \times (\text{liters})^{\text{Disp}} \times (\text{horsepower})^{\text{HP}}$$

260 kg saved

Al improvement vs Steel Mass			same engine hp		
different engine hp					
9.37%	7.92%	10.60%	7.88%	6.47%	9.06%

AL 160kg BIW mass delta only:		
4.48%	3.69%	5.14%

Calculating Diesel and Hybrid MPG

EPA data, average versus city and hwy, midsize autos
hwy & city mileage relative to composite mpg

	Gas	Diesel	Hybrid
city	87%	90%	109%
hwy	122%	123%	93%

given an average of 33% improved fuel economy for dies
and 38% improved fuel economy for hybrids
then, relative to "equivalent" gas vehicle:

	Gas	Diesel	Hybrid
average	100%	133%	138%
city	100%	127%	142%
hwy	100%	125%	105%

- First, the the city and hwy MPG ratings, relative to avg MPG, were calculated from 2007 EPA data for each of gas, diesel, and hybrids
- Then, assuming the claimed mpg benefits for diesels and hybrids are based on avg MPG, the relative city and hwy percentages above are used to calculate a MPG multiplier for the Diesel and Hybrid scenarios