Lightweight Materials Enhance PEV and PHEV Efficiency

Doug Richman
Kaiser Aluminum

on behalf of
The Aluminum Association,
Aluminum Transportation Group (ATG)

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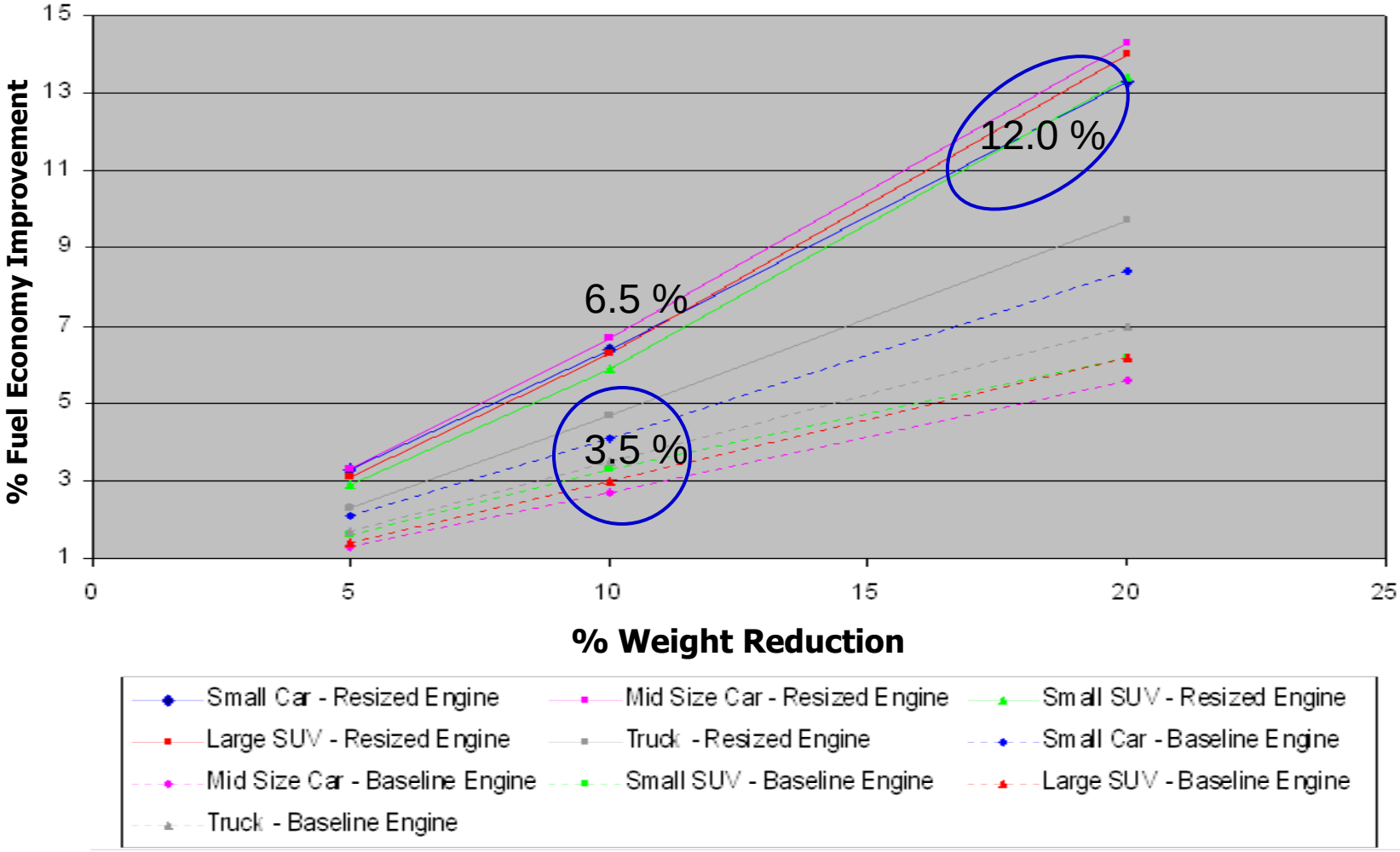
Outline:

- **Weight Reduction vs. Energy Consumption**
- **Regenerative Braking**
  - Impact
  - Weight sensitivity
- **Weight Reduction Trade-offs**
  - Structure cost vs. Battery cost

Weight Reduction vs. Fuel Economy - Conventional Vehicles



PEV Study Criteria

- **Analytical Model (Ricardo)**

  Easy 5 simulation - Ricardo vehicle and component models

- **Vehicles – converted to PEV/PHEV**

  Small car – typ. BMW Mini

  Small SUV – typ. Saturn Vue

- **Performance**

  Range: 40 / 80 miles

  Acceleration: 10 sec. 0-60 MPH, FTP75

  Top speed: 100 MPH

Note: PHEV, operates on batteries only,

carries mass of ICE engine and associated "support systems"

Simulation Assumptions

- **Rolling and aero resistance** – from baseline vehicles

  No secondary loads – steering, HVAC, etc.

  No additional structure to support battery (51 – 209 Kg)

- **Battery** - Lithium-ion, sized for range

  SOC 0.9-0.25, 115 W-h/kg, 155 W-h/l

- **Motor** - sized for performance

  (FTP75, 0-60 time)

  top speed

  3.05 kW/kg motor power density

- **Regen-braking** @1000N, throttle = 0
- **Final drive ratio** - fixed

Vehicle Weight Analysis – Small Car

Base (Fe)		**1,304 Kg**
- Powertrain system	(571) Kg	
+ Hybrid charging	348	
+ e Powertrain	124	
	(99)	
PHEV (Fe)		**1,205 Kg**
- Hybrid charging	(348)	
- Structure design (PT)	(52)	
- Light Weighting (AlV)	(140) *(12%)*	
- e Powertrain	(36)	
	(576)	
HEV Light Weight (Al)		**627 Kg**

Vehicle Weight Analysis – Small Car

Materials part of the story:

Light Weighting (AIV)

BIW	96 KG
Closures	28
Chassis	23
Total	147 KG

*** 19 % of EV final weight (627 Kg)!**

Small Car Results

PHEV (Fe) | PHEV (Al) | PEV (Fe) | PEV (Al) | PHEV (Fe) | PHEV (Al) | PEV (Fe) | PEV (Al)

		40 MILE RANGE				80 MILE RANGE			
Small EV	Units	Case 1	Case 2	Case 3	Case 4	Case 1	Case 2	Case 3	Case 4
Base Weight	kg	1304	1142	684.6	539.2	1304	1142	684.6	539.2
OPTIMIZATION	Motor Size	kW	101.0	88.0	73.0	70.0	107.0	93.0	80.0	70.0
	FDR		5.37	5.34	5.37	5.20	5.32	5.37	5.34	5.31
	Rated Speed		0.58	0.58	0.61	0.70	0.58	0.58	0.62	0.58
	Battery Size [Total]	kWh	13.5	12.2	10.3	9.1	28.2	25.4	21.5	19.1
	Battery Weight	kg	77	69	58	51	159	17	121	108
	Motor + Controller Weight	kg	47	43	38	37	49	44	40	37
	Optimized Weight	kg	1,205	1,031	781	627	1,290	980	846	684
	HWFET Range	mi	37	36			76	74		
	45 mph range	mi	41	41			2	81		
	70 mph range	mi	28	26	24	21	57	54	49	46
	0-30 mph Accel Time	s	4.8	4.9	4.8	5.0	4.9	4.9	4.8	4.9
	0.60 mph Accel Time	s	9.9	10.0	10.0	9.9	10.0	10.0	10.0	10.0
	Top Speed	mph	100	100	100	100	101	100	100	100

Total Energy Consumption:

- 15 KW / 100 Mi

  (2.4 KW / 100 Mi / 100 Kg)

- 10% weight reduction = 6% consumption reduction
- 10% weight reduction = 6% battery reduction

150 Kg = 1.2 KW

150 Kg = 2.4 KW

Small SUV Results

PHEV (Fe) | PHEV (Al) | PEV (Fe) | PEV (Al) | PHEV (Fe) | PHEV (Al) | PEV (Fe) | PEV (Al)

		40 MILE RANGE				80 MILE RANGE			
Small SUV EV	Units	Case 1	Case 2	Case 3	Case 4	Case 1	Case 2	Case 3	Case 4
Base Weight	kg	1928	1689	1014	798	1928	1689	1014	798
OPTIMIZATION									
Motor Size	kW	96.0	84.0	71.0	70.0	100.0	89.0	74.0	70.0
FDR		7.00	7.00	6.46	6.00	7.00	7.00	6.70	6.66
Rated Speed		0.40	0.40	0.40	0.47	0.40	0.40	0.40	0.46
Battery Size [Total]	kWh	17.4	15.9	14.2	13.0	36.9	33.5	29.2	26.6
Battery Weight	kg	98	90	80	73	209	190	165	150
Motor + Controller Weight	kg	45	42	37	37	47	43	38	37
Optimized Weight	kg	1,711	1,460	1,132	909	1,822	1,561	1,218	986
HWFET Range	mi	35	34	33	32	73	70	66	63
45 mph range	mi	40	39	39	38	83	80	75	73
70 mph range	mi	24	23	22	21	51	48	44	41
0-30 mph Accel Time	s	4.5	4.5	4.5	4.5	4.5	4.5	4.5	4.4
0-60 mph Accel Time	s	10.0	10.0	10.0	10.0	10.0	10.0	10.0	9.7
Top Speed	mph	91	91	97	101	90	91	95	95

Total Energy Consumption:

- 21 KW / 100 Mi

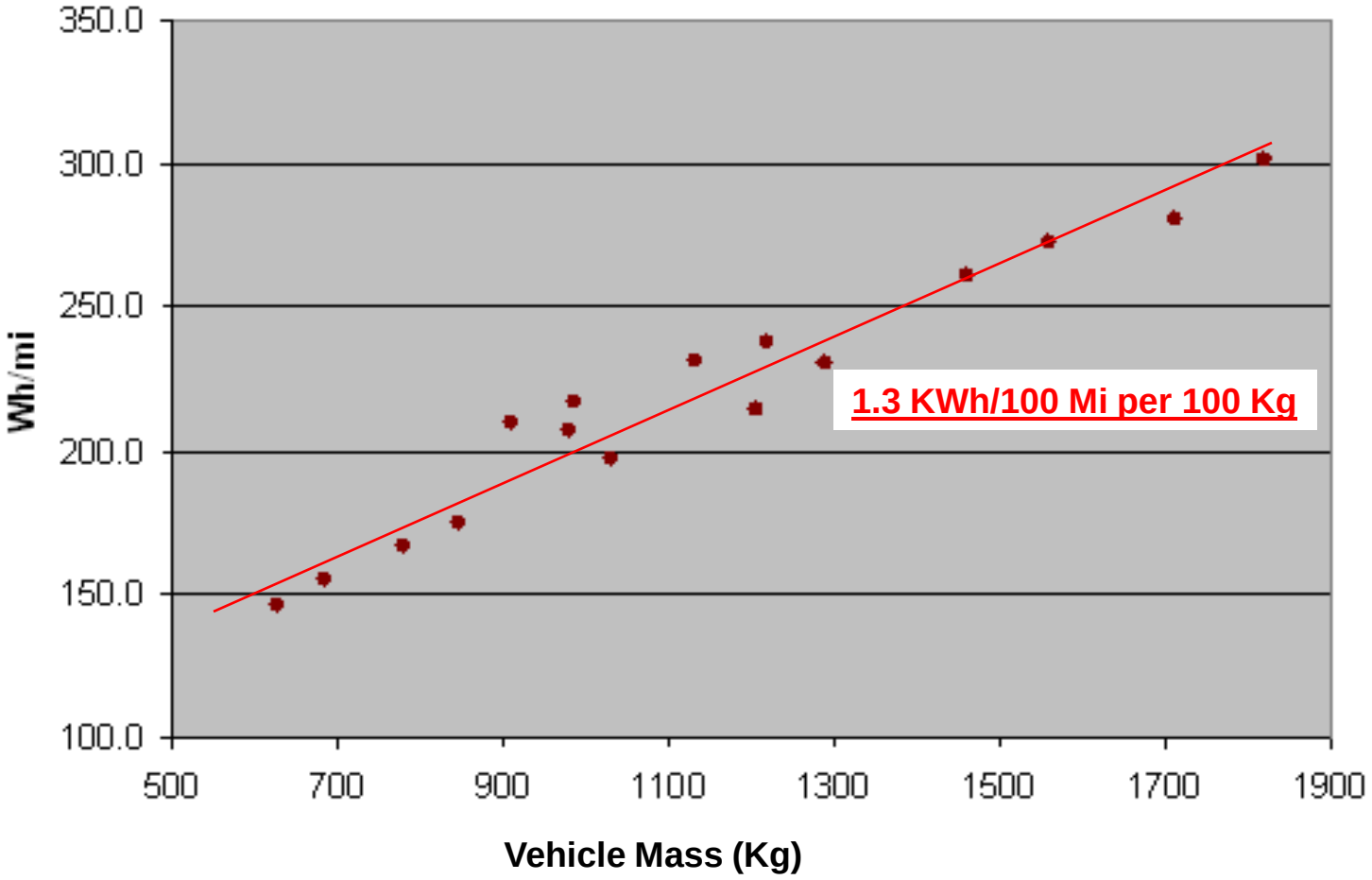
  (2.4 KW / 100 Mi / 100 Kg)

- 10% weight reduction = 4% consumption reduction
- 10% weight reduction = 4% battery reduction

225 Kg = 1.2 KW

225 Kg = 2.6 KW

Vehicle Mass vs. Energy Consumption
(16 case studies)

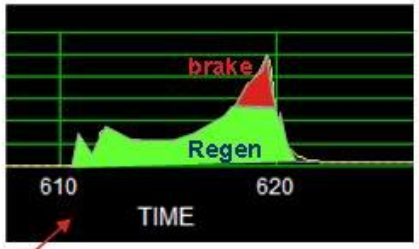


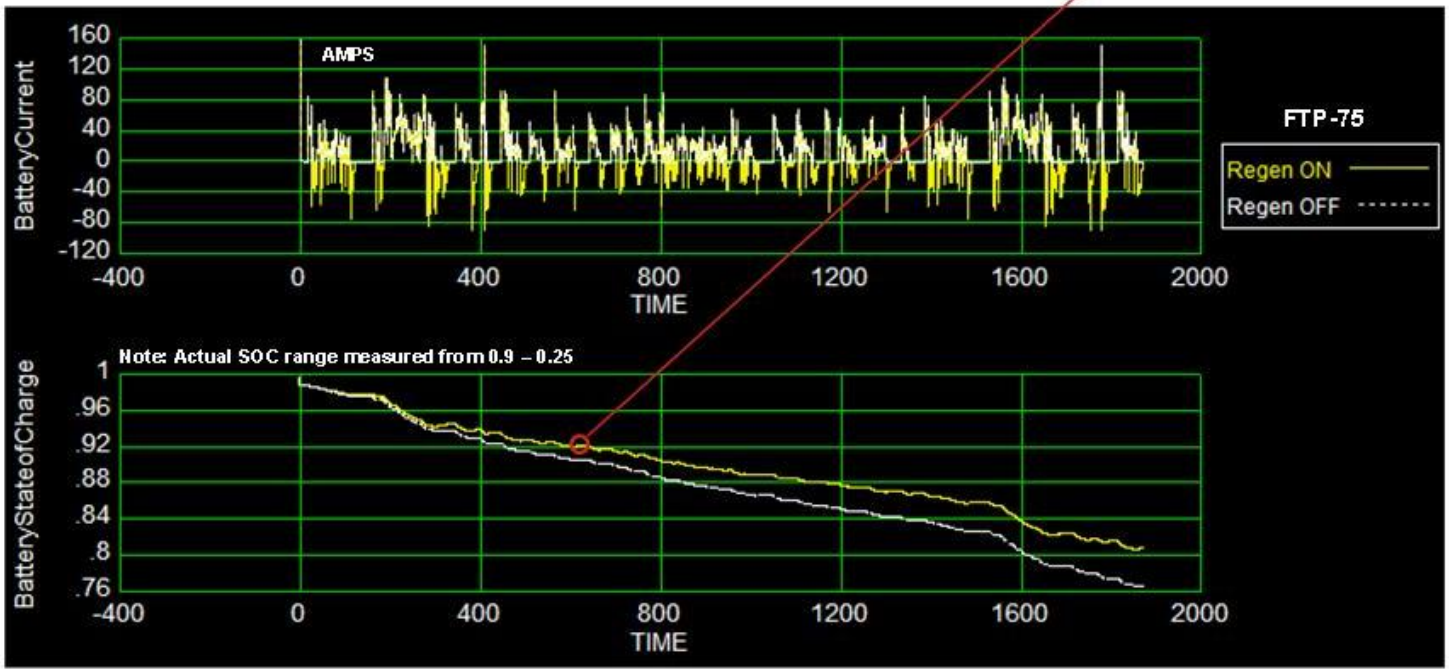
Regenerative Braking – PHEV (PEV)

- Impact of regenerative braking
- Effect of weight reduction on benefit

Regen Braking – Small Car

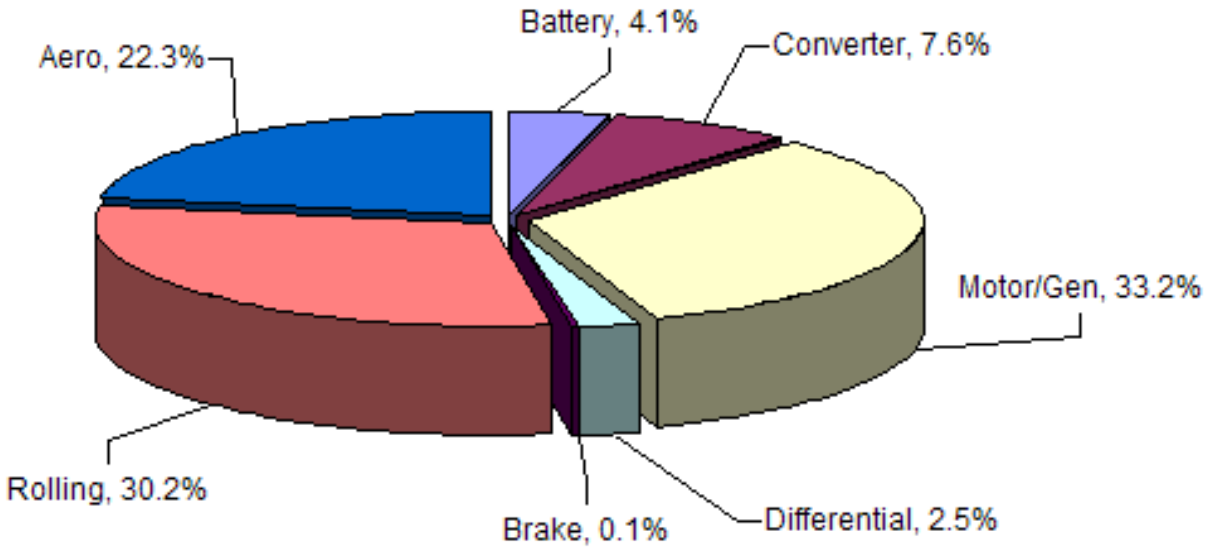
The EV motor and battery size allow for large brake regeneration capture. No safety control was implemented and a fixed threshold was used to separate regen braking from mechanical braking.





Small Car – Energy Usage

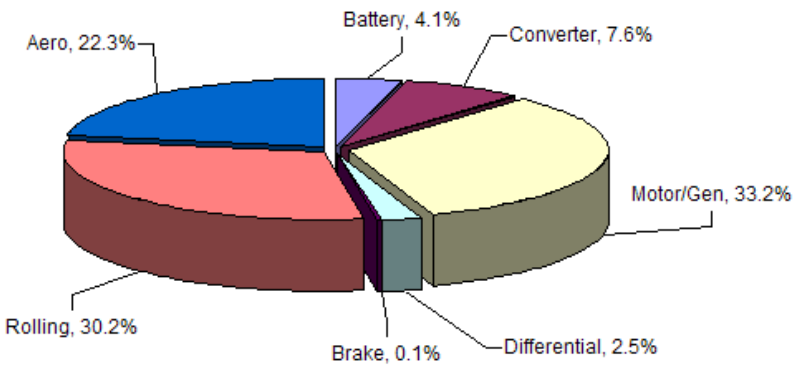
PHEV (Fe): 1205 kg
[Regen = 20.9%]



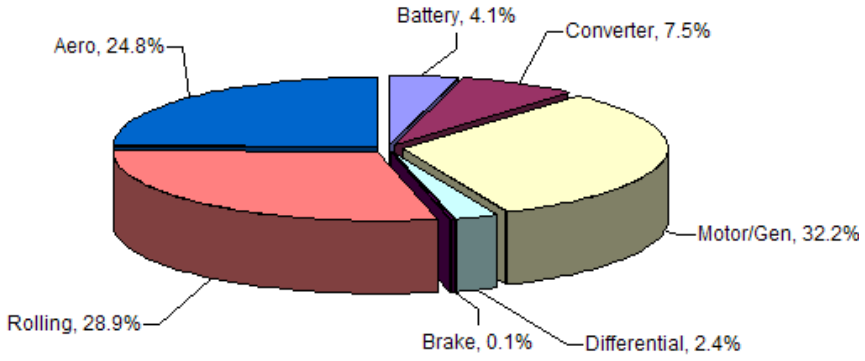
Schedule (FTP75)

Small Car – Energy Usage

PHEV (Fe): 1205 kg
[Regen = 20.9%]

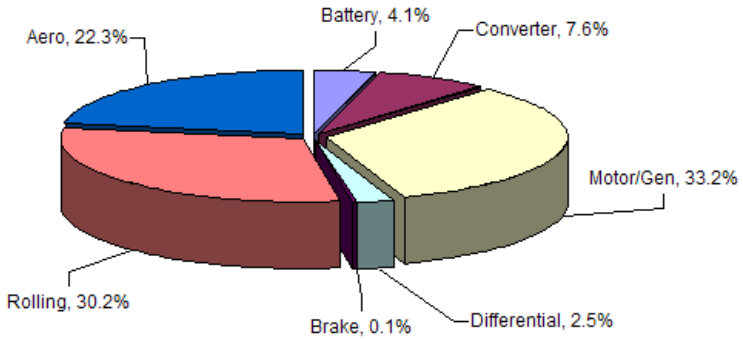


PHEV (Al): 1031 kg
[Regen = 20%]

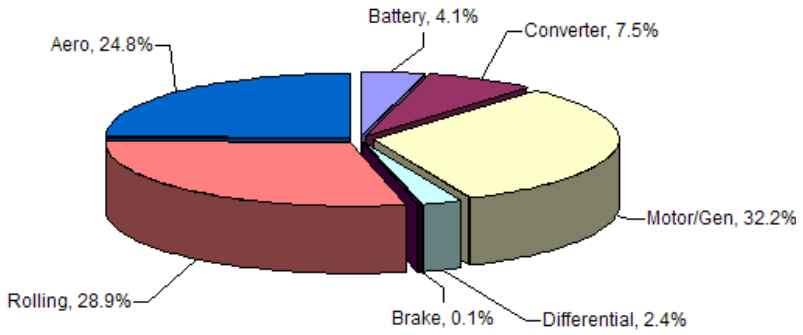


Small Car – Energy Usage

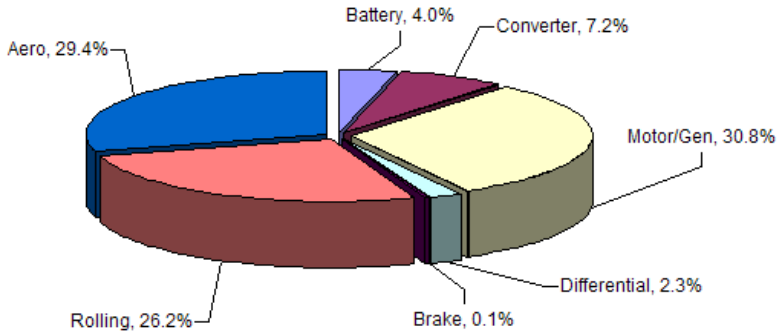
PHEV (Fe): 1205 kg
[Regen = 20.9%]



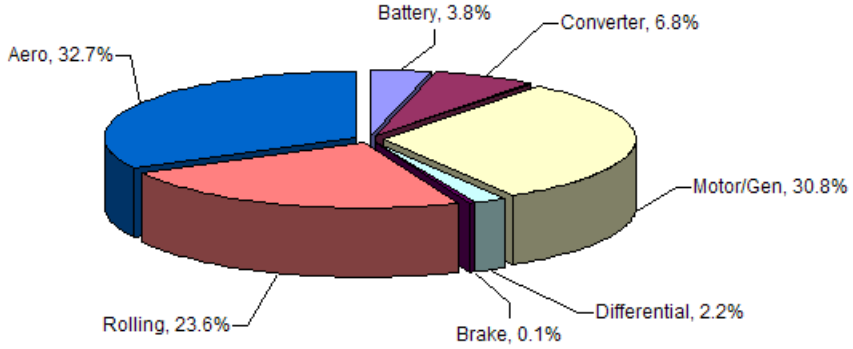
PHEV (Al): 1031 kg
[Regen = 20%]



PEV (Fe): 781 kg
[Regen = 18.1%]



PEV (Al): 627 kg
[Regen = 15.6%]



Small Car Energy Balance (40 mi range)

	PHEV (Fe) Case 1	PHEV (Al) Case 2	PEV (Fe) Case 3	PEV (Al) Case 4	PHEV (Fe) Case 1	PHEV (Al) Case 2	PEV (Fe) Case 3	PEV (Al) Case 4
	FTP %				FTP kWh			
Aero	22.3	24.8	29.4	32.7	1.97	1.97	1.97	1.93
Rolling	30.2	28.9	26.2	23.6	2.67	2.29	1.75	1.40
Battery	4.1	4.1	4	3.8	0.36	0.33	0.27	0.22
Converter	7.6	7.5	7.2	6.8	0.67	0.59	0.48	0.40
Motor / Generator	33.2	32.2	30.8	30.8	2.93	2.55	2.06	1.82
Differential	2.5	2.4	2.3	2.2	0.22	0.19	0.15	0.13
Brake	0.1	0.1	0.1	0.1	0.01	0.01	0.01	0.01
Regen	20.9	20	18.1	15.6	1.85	1.59	1.21	0.92
% of rolling					69%	69%	69%	66%

Light Weighting Trade-offs – PHEV (PEV)

Cost – Benefit Evaluation

Aluminum Vehicle Structure - System Cost Analysis

	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%

Manufacturing and Lifecycle Analysis of
Aluminum Vehicle Structures
July 2007

Summary – PEV (PHEV)

- **Low Mass Aluminum Structure Achieves:**

  EV weight reduction potential: 19%

  Reduce battery cost: $ 900 – $ 1,950 (@ $750/KWh)

  Expected aluminum structure cost premium : $ 630

  Reduced Energy Consumption: 1.3 KWh / 100 Mi per 100 Kg

- **10% mass reduction: 4 – 6% reduction in battery size**

- **Regenerative Braking**

  Recycles 15 – 20% of FTP75 drive cycle energy

  Benefit essentially independent of vehicles mass

Thank You

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