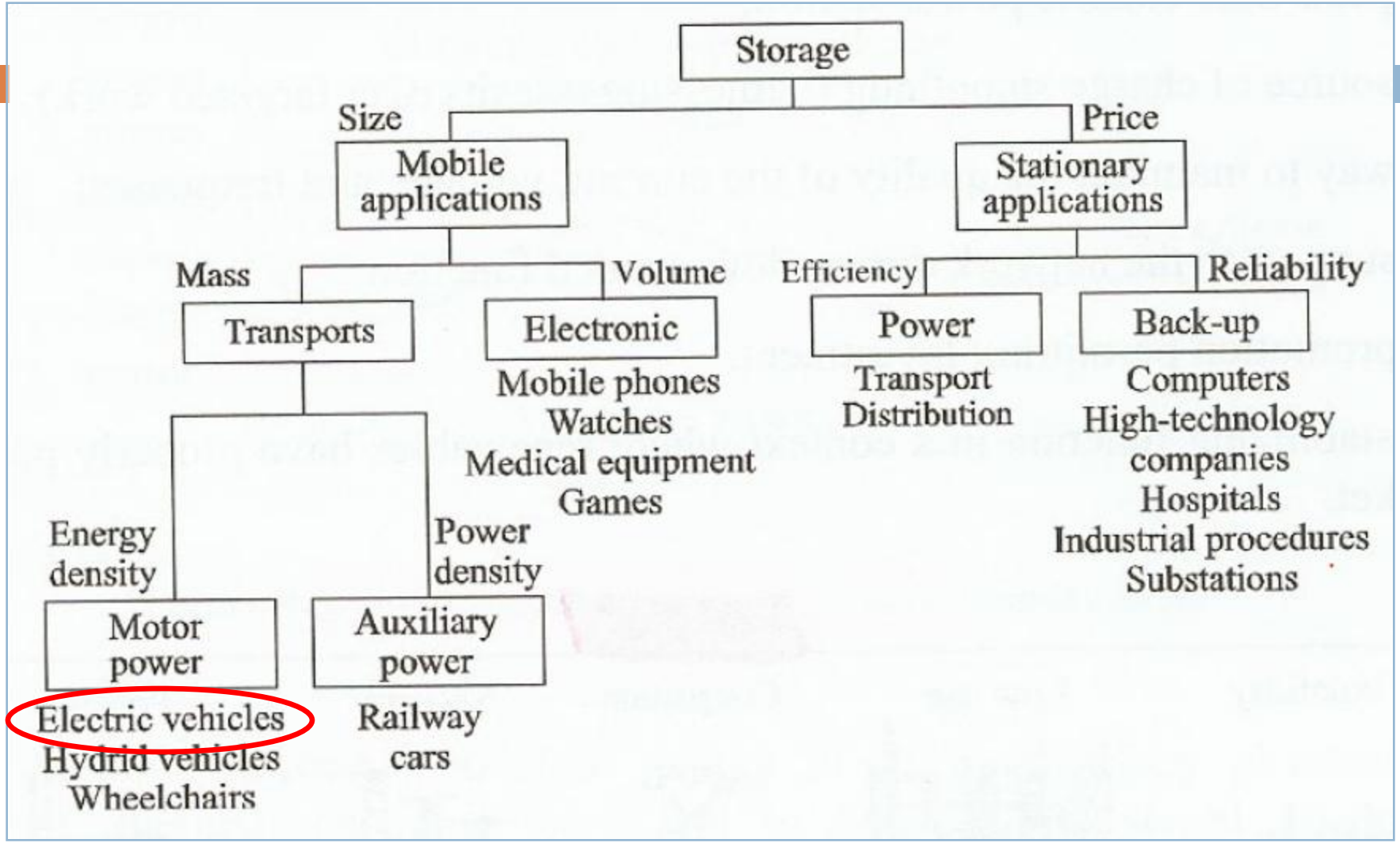
NPRE 498 – Energy Storage Systems

Application Project: Batteries for an EV conversion

Nov 4th 2011


Storage
Size
Price
Mobile applications
Stationary applications
Mass
Volume
Efficiency
Reliability
Transports
Electronic
Power
Back-up
Mobile phones
Watches
Medical equipment
Games
Transport
Distribution
Computers
High-technology companies
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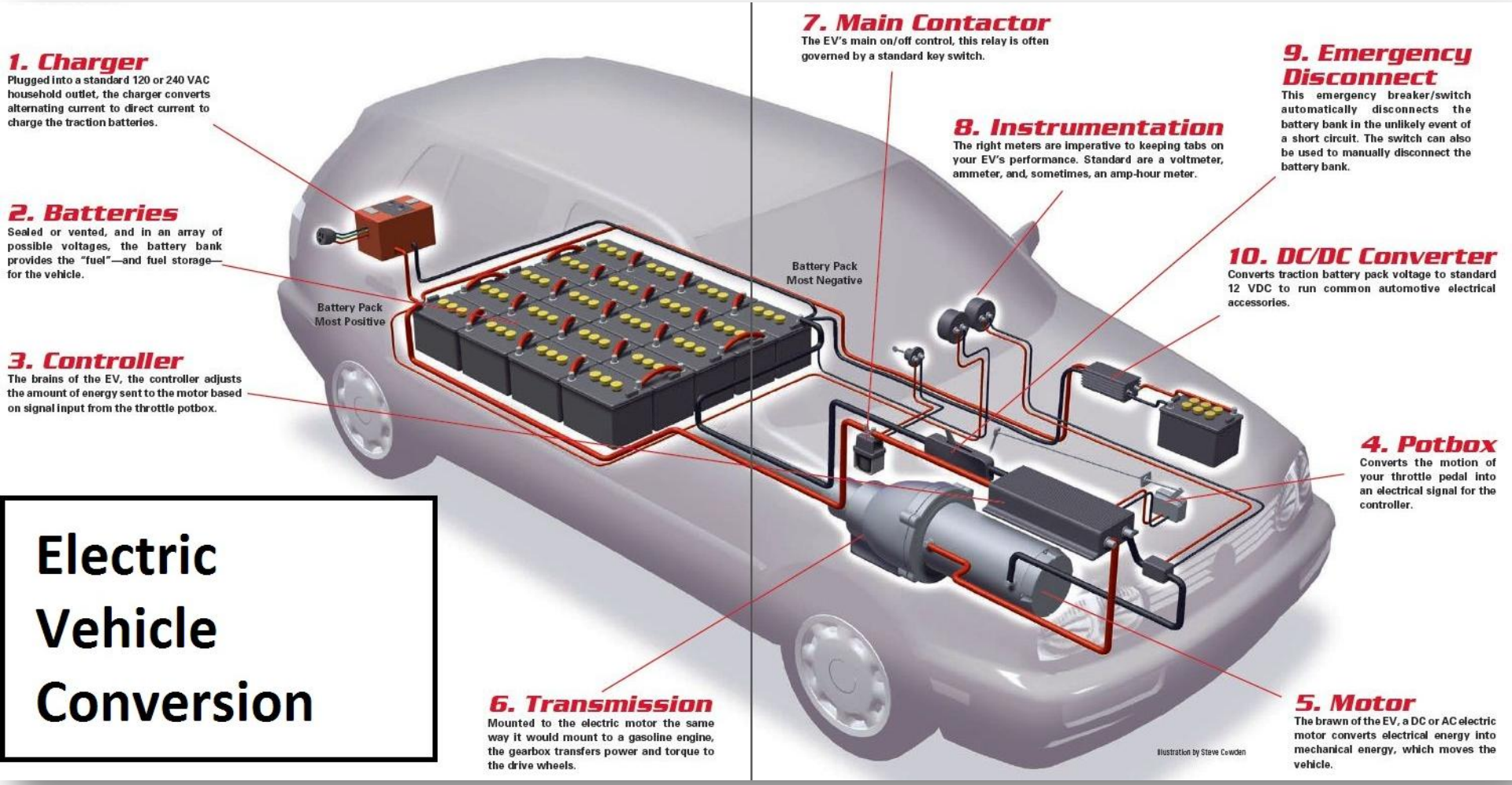
Industrial procedures
Substations
Energy density
Power density
Motor power
Auxiliary power
Electric vehicles
Hydrid vehicles
Wheelchairs
Railway cars

Content

- EV Conversion
- Energy Measurement
- Case1- City driving
- Case2- Highway driving
- Vehicle Dynamics Considerations
- Conclusions

What components go into an EV conversion?



Conversion Cost (without batteries)

Part Description	Qty	Cost/per [$/unit]	Cost [$]	Source
NetGain Warp9 dual shaft motor	1	1,875.00	1,875.00	http://www.go-ev.com/Next_Gen.html
Belktronix EV controller system	1	2,250.00	2,250.00	2008 price
Motor adapter plate and hub	1	850.00	850.00	ElectroAuto
Gast Vacuum Pump system (switch, tank, pump)	1	360.00	360.00	special pick-up order from EV-supply
Xantrex Link-10 Battery monitor	1	215.00	215.00	affordable-solar.com
AirPax circuit breaker	1	175.00	175.00	KTA services
2/0 gauge welding cable (??? Feet)	45	3.00	135.00	Great deal at United Welding Supply
40 2/0 gauge magna lugs 3/8" hole	40	2.50	100.00	special pick-up order from EV-supply
Angle iron steel, plate	1	100.00	100.00	estimate since I got free stuff
Yuasa YIX30L 12V motorcycle battery	1	100.00	100.00	theridestop.com
PowderCoating service	1	100.00	100.00	classactpp.com
Custom 2" tachometer with shift LED output	1	96.00	96.00	speedhut.com (Added "Civic EV" text for free!)
Bolts to hold on adapter plate and racks (grade 8)	1	75.00	75.00	Parkrose Hardware (TrueValue)
40 2/0 gauge terminal covers	40	1.50	60.00	special pick-up order from EV-supply
Labor at Les Schwab to swap springs	2	30.00	60.00	lesschwab.com
Beefed up springs for front end	2	26.00	52.00	rockauto.com
Zolox speed sensor to drive the tach	1	45.00	45.00	EVSource.com
Belktronix DC-DC for Link-10	1	35.00	35.00	belktronix.com
5/16" all thread (grade 8)(27 feet)	27	1.20	32.40	Parkrose Hardware (TrueValue)
Pillar pod for 92-95 civic	1	31.00	31.00	speedhut.com
18 feet of reinforced heater hose (cable covering)	18	1.70	30.60	Parkrose Hardware (TrueValue)
Belktronix 500V prescaler for Link-10	1	30.00	30.00	belktronix.com
Heat Shrink tubing	1	30.00	30.00	Parkrose Hardware (TrueValue)
Bracket to mount Zolox on tail shaft of Warp9	1	20.00	20.00	EVSource.com
Honda MTF manual transmission fluid	1	20.00	20.00	Honda Dealer
2"x2" plastic boxes for covering BatMons	12	1.50	18.00	electronicsusa.com
4-in-1 wire to route signals	10	1.70	17.00	Parkrose Hardware (TrueValue)
18 and 10 gauge automotive wire	1	15.00	15.00	Fred Meyer
variety of crimp connectors	1	15.00	15.00	Fred Meyer and Parkrose HW
Tie wraps	1	10.00	10.00	Parkrose Hardware (TrueValue)
Hose clamps for under car cables	6	1.50	9.00	Parkrose Hardware (TrueValue)
2 1/0 gauge lugs with 1/4" hole	2	2.50	5.00	quick buy from West Marine
60A fuse for main alternator fuse	1	3.00	3.00	Schucks auto supply
		sub total=	2844.00	
		TOTAL=	**$6,969.00**	

Energy Measurement

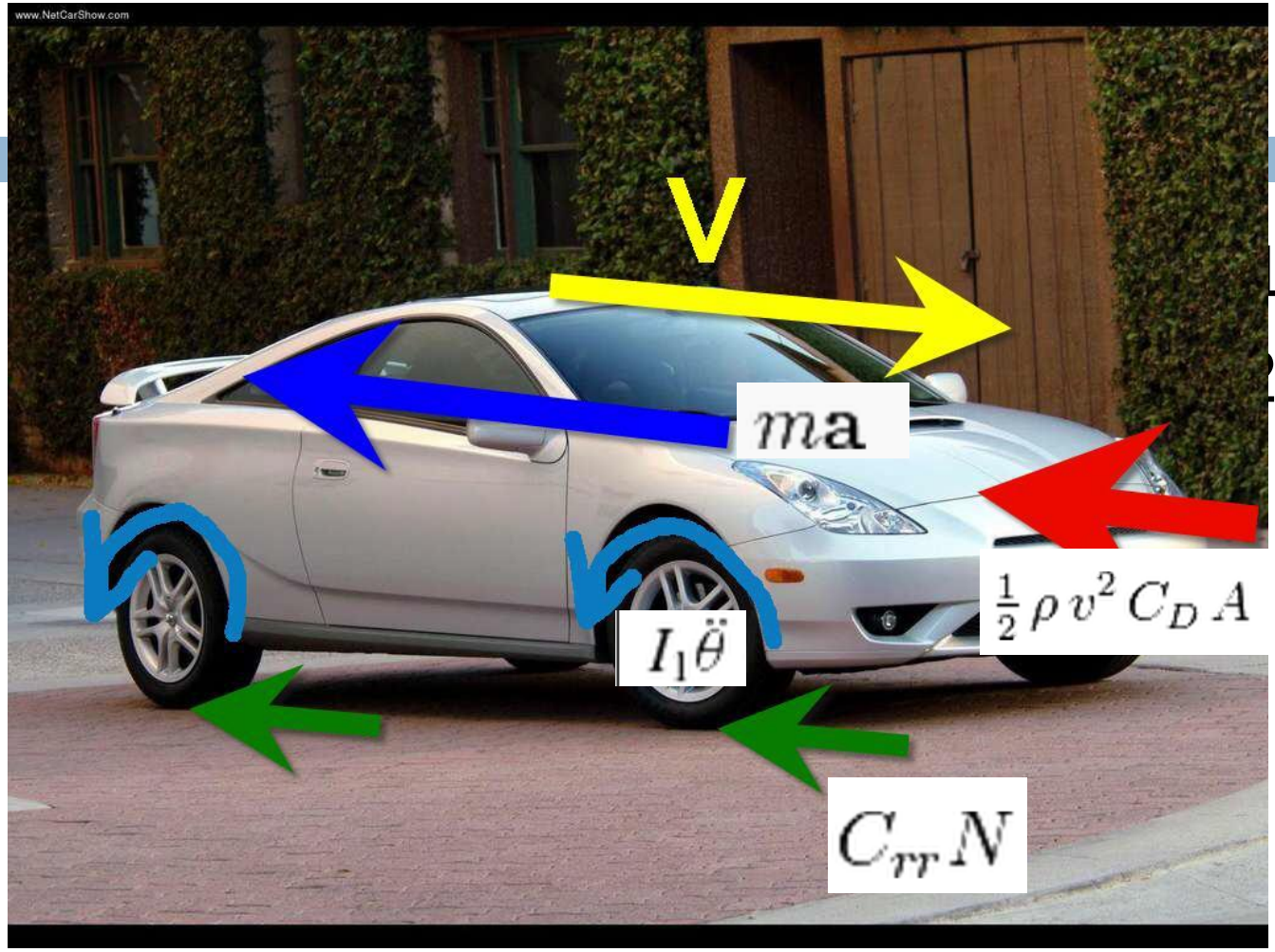
How to measure how much energy storage you need for you EV conversion?

- Use estimates for average vehicles.
- Measure Torque and RPM at the powertrain shaft.
- Make a few assumptions and use a GPS!!!!

Energy Measurement Assumptions

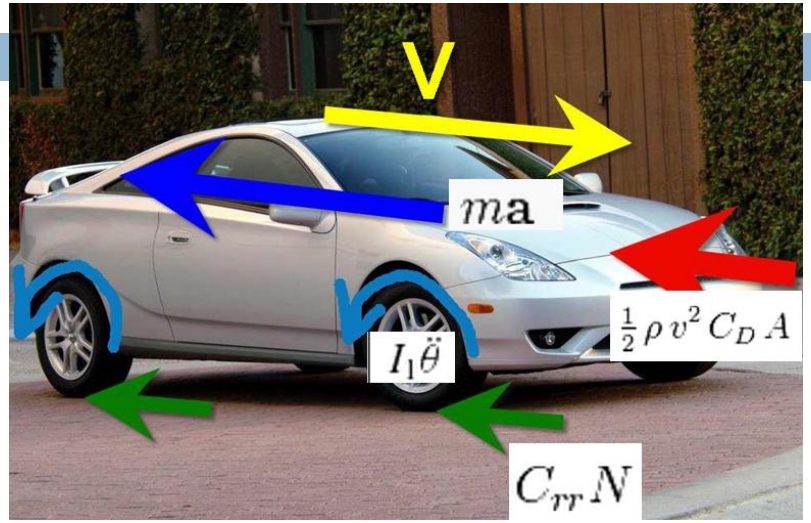
- No potential energy changes (terrain is relatively flat)
- No energy for cornering
- No wind speed

Forces acting on a moving vehicle



- Inertial forces -> heat brakes
- Rolling resistance -> heat tires(which heat the air and ground)
- Aerodynamic forces-> heat the air

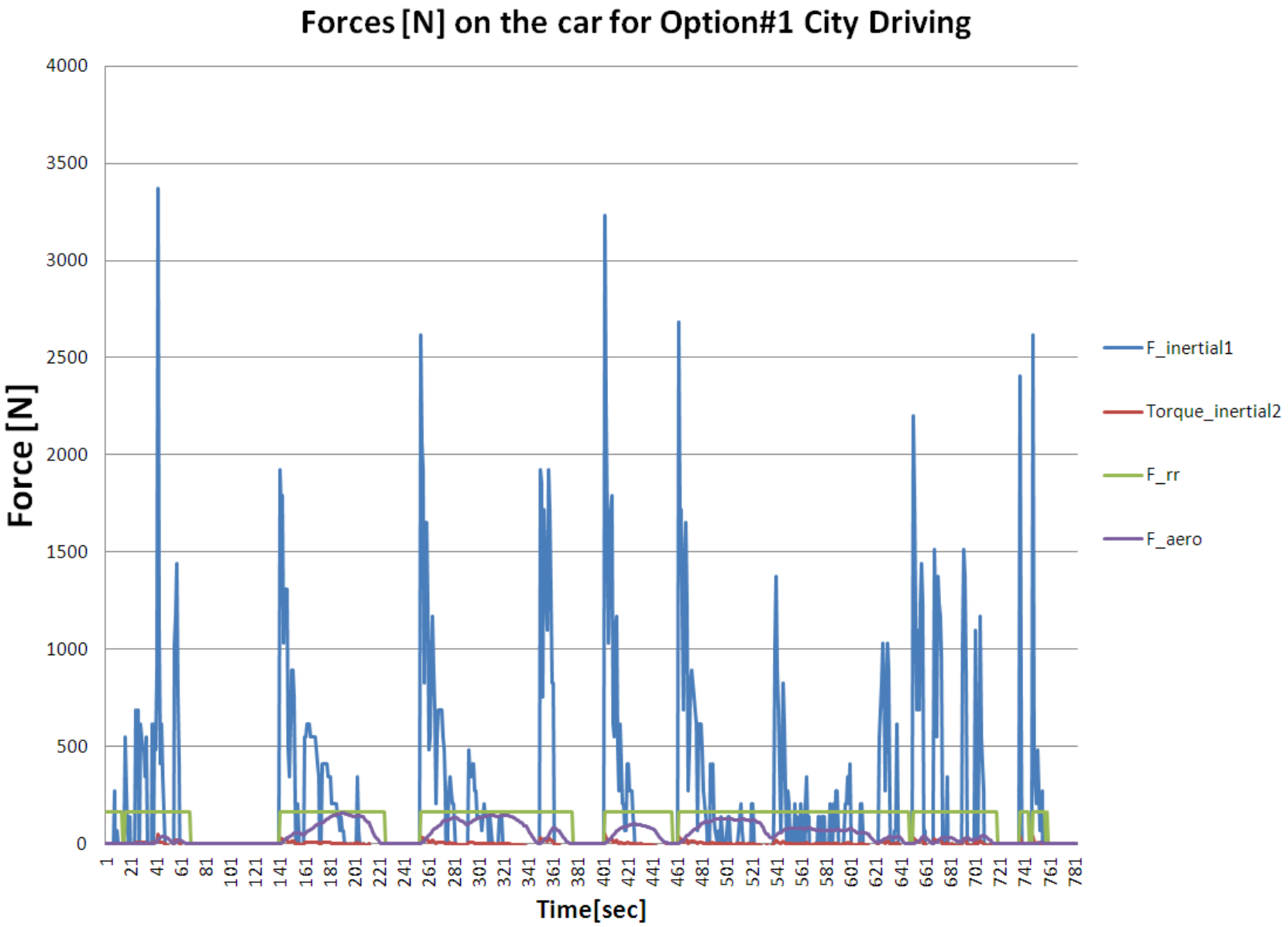
Power calculations



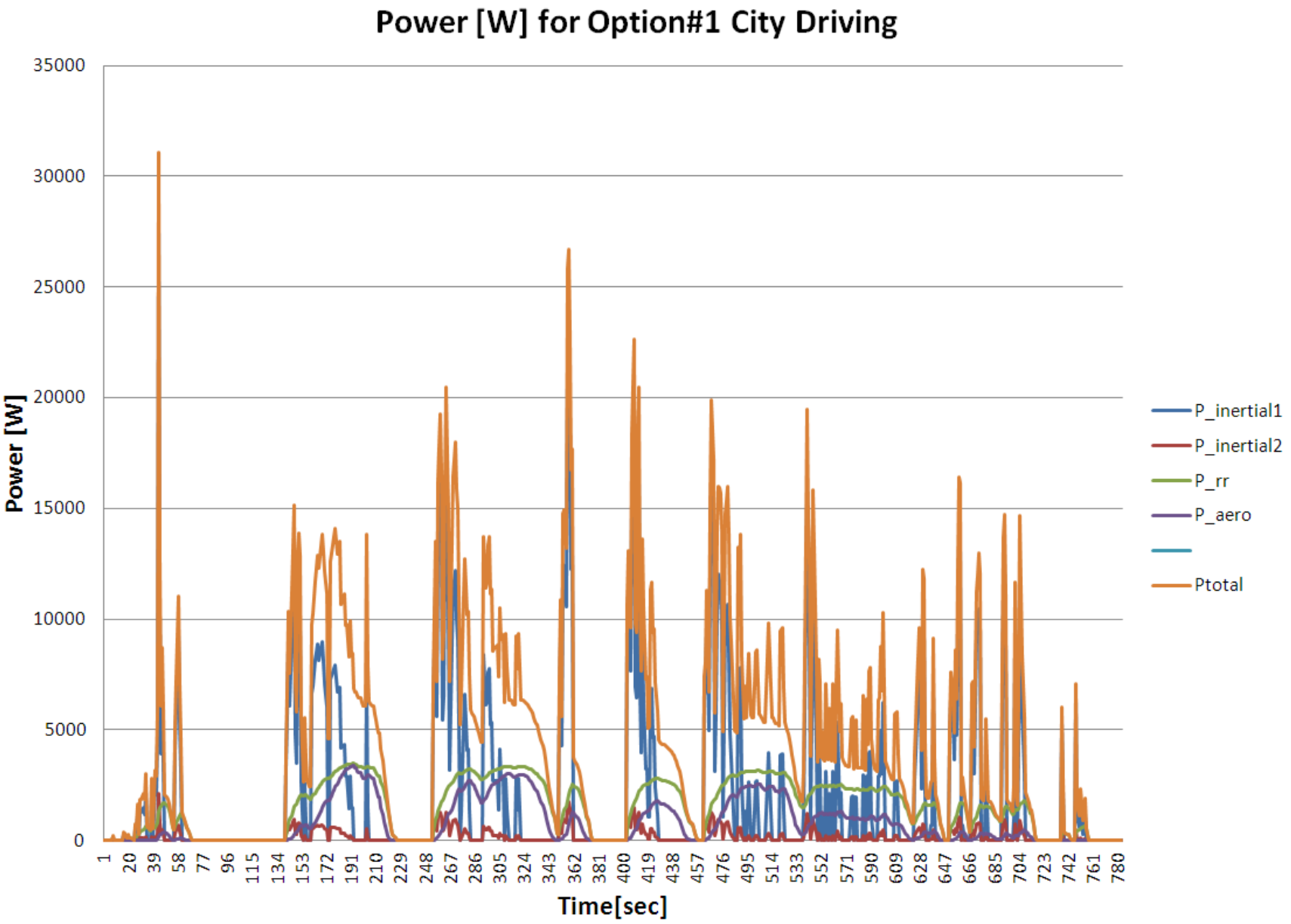
$$P_{engine} = m\,a\,V + I\,\ddot{\theta}\,\dot{\theta} + \frac{1}{2}\rho\,C_{drag}\,Area\,V^3 + C_{rollingResistance} m\,g\,V$$

Case#1 City Driving

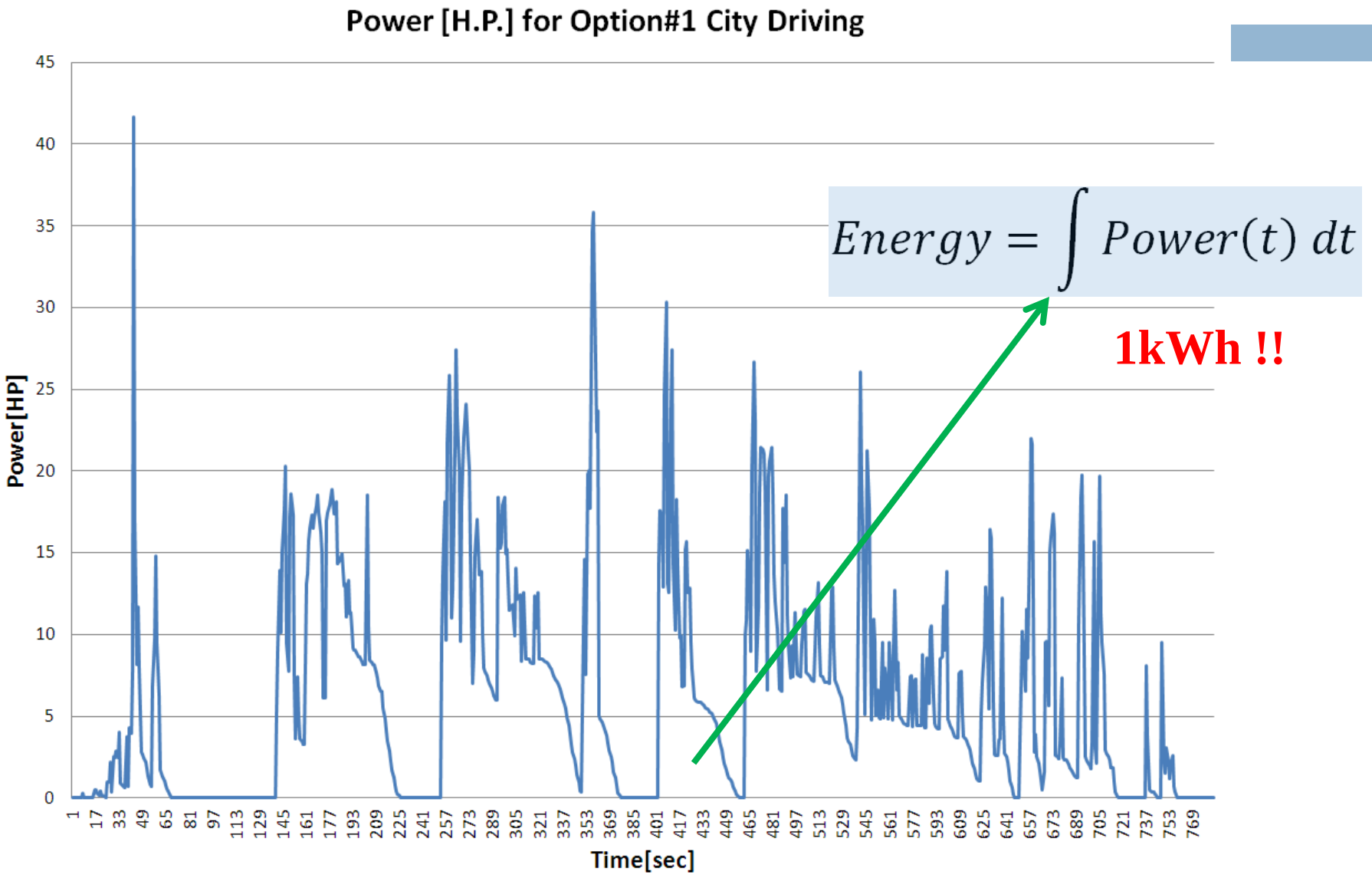
Case#1 City Driving - Forces



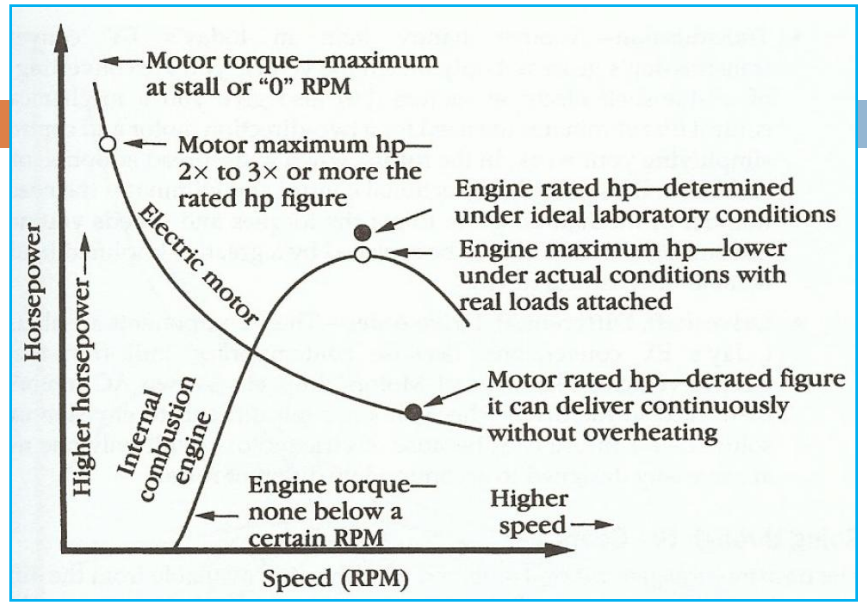
Case#1 City Driving - Power

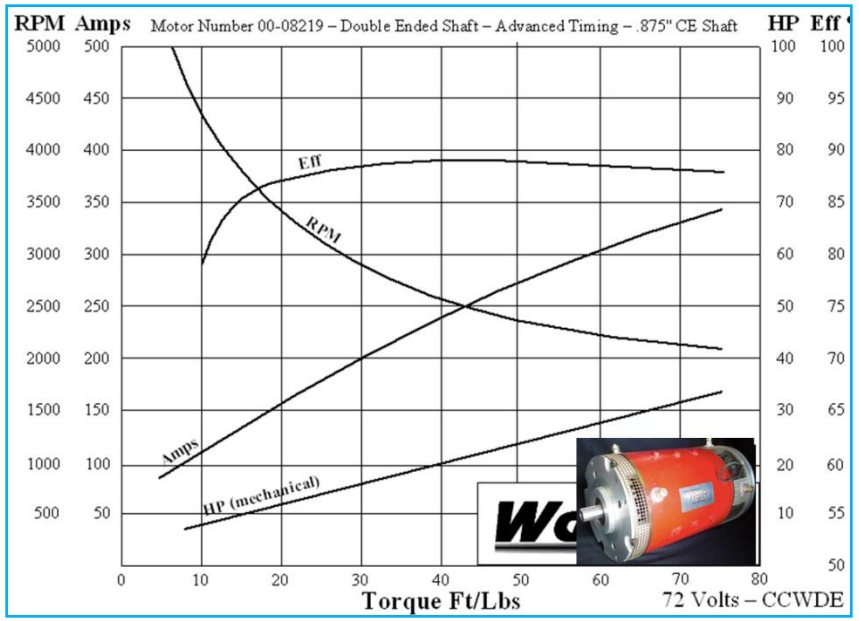


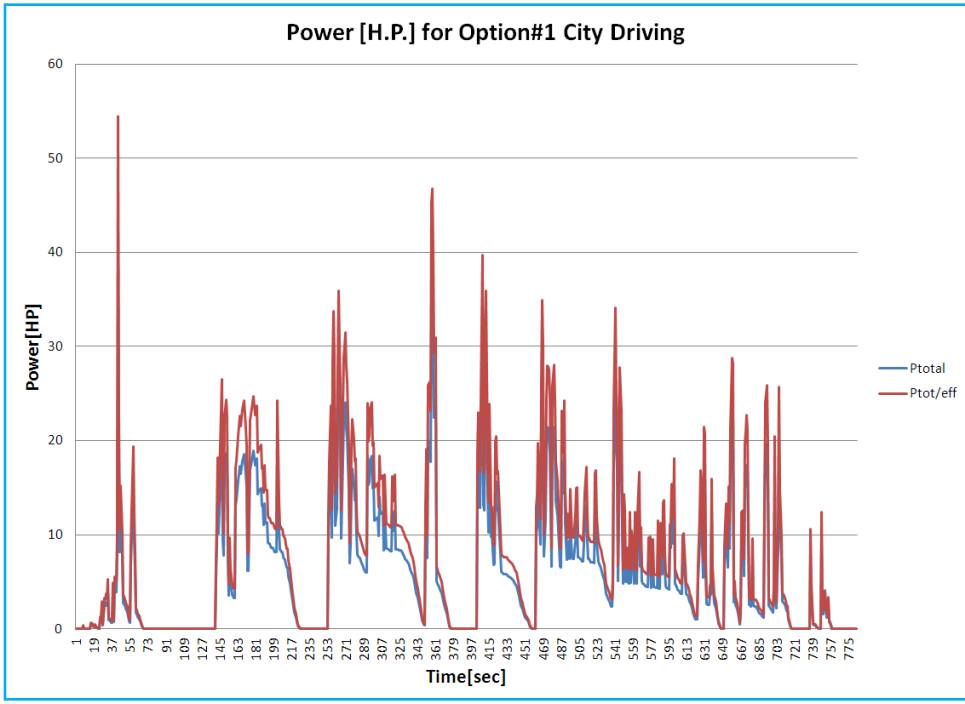
Case#1 City Driving - Power and Energy



Case#1 City Driving - Peak Power





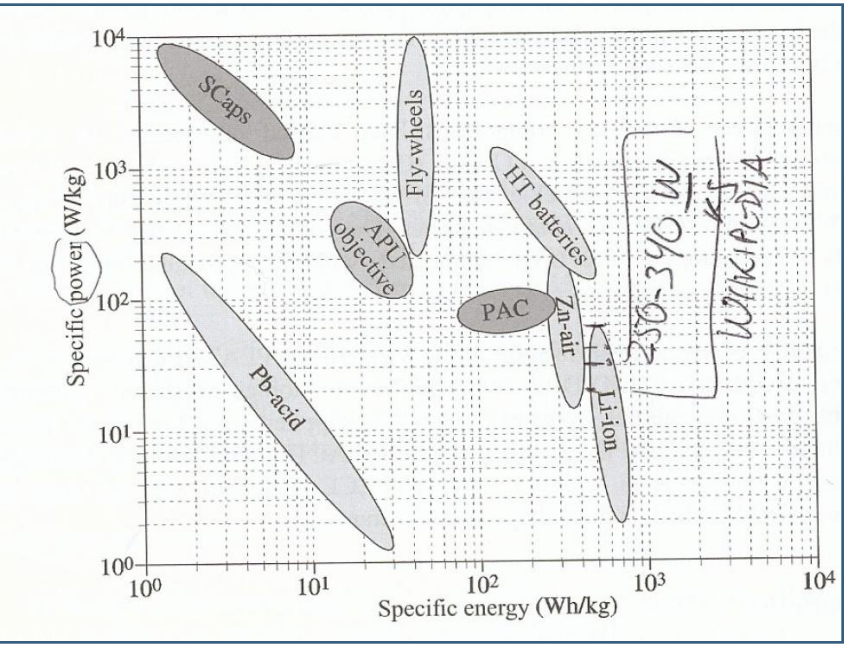


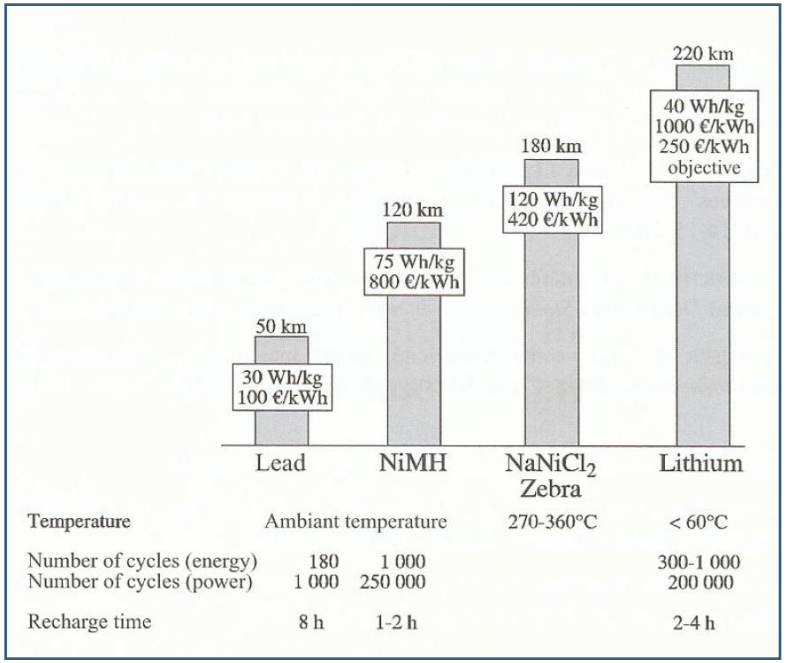
Case#1 City Driving – Energy

		Total E /trip	1.02	[kW.hr]
		(13mins city driving)		
	powertrain efficiency		0.9	
		E	1.13	[kW.hr]
	Motor+Control efficiency		0.85	
		E	1.33	[kW.hr]
	battery efficiency		0.8	
		E_stored	1.66	[kW.hr]
trips	4	Total Energy	6.6	[kW.hr]

S.F=	1.2	Energy=	8.0	[kWhr]	
		Lead Acid	specific energy	0.03	[kW*hr/kg]
			mass	265	[kg]
			cost/energy	170	[$/kW*hr]
			cost	1,354	[$]
		Li-Ion	specific energy	0.1	[kW*hr/kg]
			mass	80	[kg]
			cost/energy	375	[$/kW*hr]
			cost	2,986	[$]

Case#1 City Driving – Existing Technologies





Case#1 City Driving – Battery Options

- Flooded Lead Acid (for golf carts)

14 x TROJAN T-105 6V 225AH (20HR)

- 8 batteries x 6V = 48V
- 8 batteries x 6V x 225AmpHours = 10.8kWh
- 8 batteries x 28kg = 224kg
- 8 batteries x $135.00 = $1080
- Life=3-5yrs

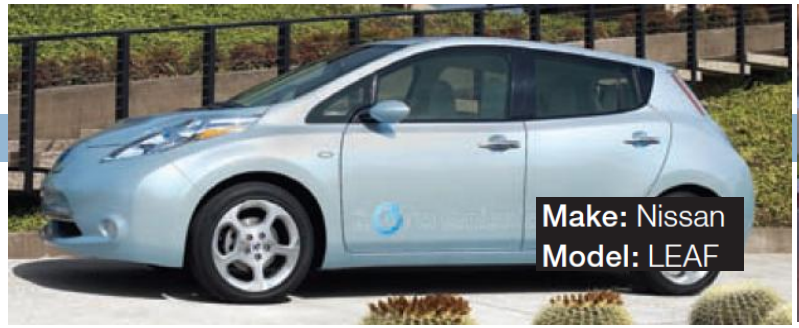
http://www.altestore.com/store/Deep-Cycle-Batteries/Batteries-Flooded-Lead-Acid/Trojan-T-105-6V-225AH-20HR-

- Lithium Ion

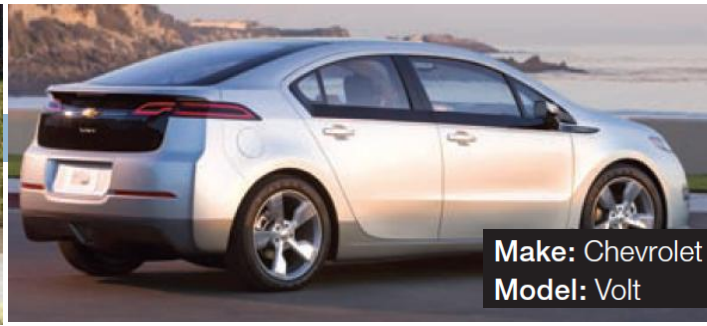
14 x 180 Amp hour CALB LiFePo4

- 14 batteries x 3.4V = 48V
- 14 batteries x 3.4V x 180AmpHours = 8.6kWh
- 14 batteries x 5.6kg = 78kg
- 14 batteries x $247.50 = $3465
- Life=3000cycles at 70%

How does it compare to existing EVs?



Battery size: 24 kWh
Range: 100 miles
Max. speed: 90 mph
MSRP: $32,780



Battery size: 16 kWh
Range: 40 miles all-electric
gas
Max. speed: 100 mph
MSRP: $41,000

10kWh

$8000

Battery size: 23 kWh
Range: 100 miles
Max. speed: 85 mph
MSRP: Approx. $30,000

Battery size: 80 kWh
Range: 150 miles
Max. speed: 120 mph
MSRP: $57,400

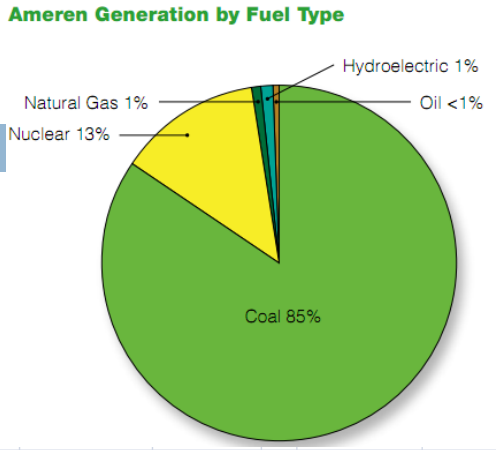
Case#1 City Driving – Economics

	E/day	6.6	kwh	E/day	6.6	kwh	miles/day	20		miles/day	20		E/day	6.6	kwh
							mpg	24		mpg	29				
	cost E	0.1	$/kwh	cost E	0.1	$/kwh	cost Gas	4	$/gal	cost Gas	4	$/gal	cost E	0.1	$/kwh
	 			 											
	EV Conversion Lead Acid Batteries			**EV Conversion Lithium Ion Batteries**			**Change Engine**			**New Car**			**EV Nissan Leaf ($7500 tax credit)**		
		fuel	maint.		fuel	maint.		fuel	maint.		fuel	maint.		fuel	maint.
0	8000	0	0	10500	0	0	4000	0	0	15000	0	0	27500	0	0
1	0	206	400	0	206	400	0	1043	600	0	863	250	0	206	200
2	0	206	400	0	206	400	0	1043	600	0	863	250	0	206	200
3	0	206	400	0	206	400	0	1043	600	0	863	250	0	206	200
4	1000	206	400	0	206	400	0	1043	600	0	863	250	0	206	200
5	0	206	400	0	206	400	0	1043	600	0	863	250	0	206	200
6	0	206	400	0	206	400	0	1043	600	0	863	250	0	206	200
7	0	206	400	0	206	400	0	1043	600	0	863	250	0	206	200
8	1000	206	400	0	206	400	0	1043	600	0	863	250	0	206	200
9	0	206	400	0	206	400	0	1043	600	0	863	250	0	206	200
10	0	206	400	0	206	400	0	1043	600	0	863	250	0	206	200
11	-2000	0	0	-3000	0	0	-500	0	0	-3000	0	0	-8000	0	0
NPV	$7,677.90	$1,761.37	$3,412.08	$7,500.00	$1,761.37	$3,412.08	$3,500.00	$8,895.78	$5,118.12	$12,000.00	$7,362.03	$2,132.55	$19,500.00	$1,761.37	$1,706.04
	TOTAL	**$12,851.34**		**TOTAL**	**$12,673.45**		**TOTAL**	**$17,513.90**		**TOTAL**	**$21,494.58**		**TOTAL**	**$22,967.41**	

Case#1 City Driving – Economics

	E/day	6.6	kwh	E/day	6.6	kwh	miles/day	20		miles/day	20		E/day	6.6	kwh		
							mpg	24		mpg	29						
	cost E	0.1	$/kwh	cost E	0.1	$/kwh	cost Gas	5	$/gal	cost Gas	5	$/gal	cost E	0.1	$/kwh		
	 			 													
	EV Conversion Lead Acid Batteries			**EV Conversion Lithium Ion Batteries**			**Change Engine**			**New Car**			**EV Nissan Leaf ($7500 tax credit)**				
		fuel	maint.		fuel	maint.		fuel	maint.		fuel	maint.		fuel	maint.		
0	8000	0	0	10500	0	0	4000	0	0	15000	0	0	27500	0	0		
1	0	206	400	0	206	400	0	1304	600	0	1079	250	0	206	200		
2	0	206	400	0	206	400	0	1304	600	0	1079	250	0	206	200		
3	0	206	400	0	206	400	0	1304	600	0	1079	250	0	206	200		
4	1000	206	400	0	206	400	0	1304	600	0	1079	250	0	206	200		
5	0	206	400	0	206	400	0	1304	600	0	1079	250	0	206	200		
6	0	206	400	0	206	400	0	1304	600	0	1079	250	0	206	200		
7	0	206	400	0	206	400	0	1304	600	0	1079	250	0	206	200		
8	1000	206	400	0	206	400	0	1304	600	0	1079	250	0	206	200		
9	0	206	400	0	206	400	0	1304	600	0	1079	250	0	206	200		
10	0	206	400	0	206	400	0	1304	600	0	1079	250	0	206	200		
11	-2000	0	0	-3000	0	0	-500	0	0	-3000	0	0	-8000	0	0		
NPV	$7,677.90	$1,761.37	$3,412.08	$7,500.00	$1,761.37	$3,412.08	$3,500.00	$11,119.73	$5,118.12	$12,000.00	$9,202.53	$2,132.55	$19,500.00	$1,761.37	$1,706.04		
	TOTAL	**$12,851.34**		**TOTAL**	**$12,673.45**		**TOTAL**	**$19,737.85**		**TOTAL**	**$23,335.08**		**TOTAL**	**$22,967.41**			

Case#1 City Driving – CO2 Emissions



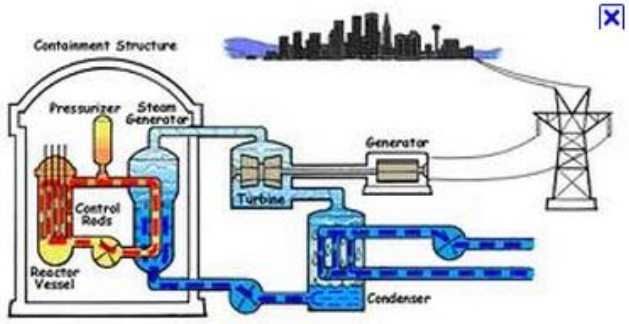
AMEREN					
Energy Mix				CO2 emissions	
Coal	85	%		1000	g/kwh
Nuclear	13	%		20	g/kwh
Renewable	2	%		5	g/kwh
		Equivalent		853	g_CO2/kWh

Internal Combustion

250-300 g/mile

Electric Vehicle

- Energy mix
- Energy chain



Case#1 City Driving – CO2 Emissions

E/day	6.6	kwh	E/day	6.6	kwh	miles/day	20		miles/day	20		E/day	6.6	kwh
 			 											
EV Conversion Lead Acid Batteries			**EV Conversion Lithium Ion Batteries**			**Change Engine**			**New Car**			**New EV Nissan Leaf ($7500 tax credit)**		
CO2 emission	853	g_CO2/kWh	CO2 emissions	853	g_CO2/kWh	CO2 emissions	185	g/km	CO2 emissions	158	g/km	CO2 emissions	853	g_CO2/kWh
							296	g/mi		253	g/mi			
CO2/yr	1761	kg/yr	CO2/yr	1761	kg/yr	CO2/yr	1852	kg/yr	CO2/yr	1582	kg/yr	CO2/yr	1761	kg/yr

Case#2 Highway 100miles

Case#2 Highway(100miles) - Energy

hwy_speed=	31.3	m/s
	70.0	mph

[N]	[N]	[N]	[N]
m*a	Izz*thetadotdot		
F_inertial1	F_inertial2	F_rr	F_aero
0	0	162	336

[W]	[hp]
Ptotal	
15570	20.9

	Total E /trip	22.11	[kW.hr]
powertrain efficiency		0.9	
	E	24.56	[kW.hr]
Motor+Control efficien		0.85	
	E	28.90	[kW.hr]
battery efficiency		0.8	
	E_stored	36.12	[kW.hr]

S.F=	1.2	Energy=	43.3	[kWhr]	
		Lead Acid	specific energy	0.03	[kW*hr/kg]
			mass	1,445	[kg]
			cost/energy	170	[$/kW*hr]
			cost	7,369	[$]
		Li-Ion	specific energy	0.1	[kW*hr/kg]
			mass	433	[kg]
			cost/energy	375	[$/kW*hr]
			cost	16,256	[$]

to pay for the battery					
1-ic fuel cost	34	mi/gal	**2-ev fuel cost**	43.3	kwh/day
	2.9	gal/day		0.1	$/kwh
	4	$/gal			
	12	$/day		4	$/day
	365	day/yr		365	day/yr
	4294	$/yr		1582	$/yr

Case#3 Highway100miles+Wind Speed

Case#3 Highway100miles+Wind Speed - Energy

	70mph+20mph(wind)	
hwy_speed=	40.3	m/s
	90.0	mph

[N]	[N]	[N]	[N]
m*a	Izz*thetadotdot		
F_inertial1	F_inertial2	F_rr	F_aero
0	0	162	555

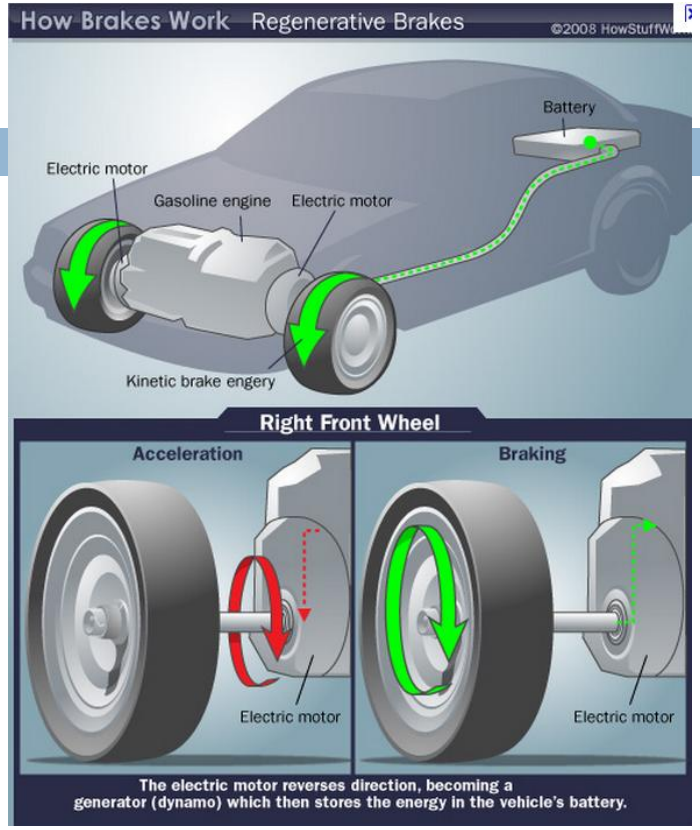
[W]	[hp]
Ptotal	
28850	38.7

	Total E /trip	31.86	[kW.hr]
powertrain efficiency		0.9	
	E	35.40	[kW.hr]
Motor+Control efficienc		0.85	
	E	41.64	[kW.hr]
battery efficiency		0.8	
	E_stored	52.05	[kW.hr]

S.F=	1.2	Energy=		62.5	[kWhr]
		Lead Acid	specific energy	0.03	[kW*hr/kg]
			mass	2,082	[kg]
			cost/energy	170	[$/kW*hr]
			cost	10,619	[$]
		Li-Ion	specific energy	0.1	[kW*hr/kg]
			mass	625	[kg]
			cost/energy	375	[$/kW*hr]
			cost	23,424	[$]

to pay for the battery					
1-ic fuel cost	26	mi/gal	**2-ev fuel cost**	62.5	kwh/day
	3.8	gal/day		0.1	$/kwh
	4	$/gal			
	15	$/day		6	$/day
	365	day/yr		365	day/yr
	5522	$/yr		2280	$/yr

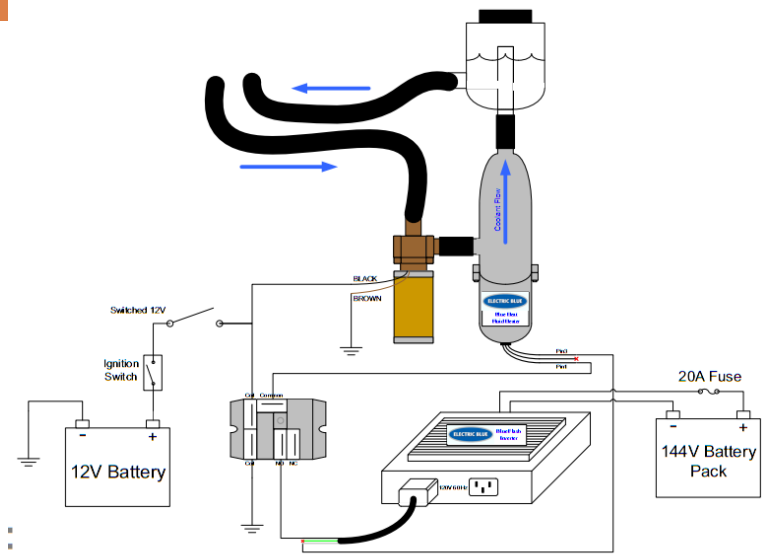
Brake Regeneration for EV Conversions



What sort of range can be gained from this feature?
The typical stated range gain for regenerative braking is about 10%. AC Propulsion states as high as 30%, US Electricar measured as high as 20+%, Toyota RAV4 owners report as high as 25%. This would obviously be more effective in city driving rather than highway where little braking occurs.

Is regenerative braking possible on a series wound DC-motor?
Yes, but it is difficult and can be dangerous to implement. Some controllers, such as the ZAPI H2 have regen abilities built in but some have questioned the controller's reliability. One successful DIY attempt by Otmar Ebenhoech of Cafe Electric is documented here. Early 90's Soleq brand EV's were DC and had regen built in.

Winter Heating Energy



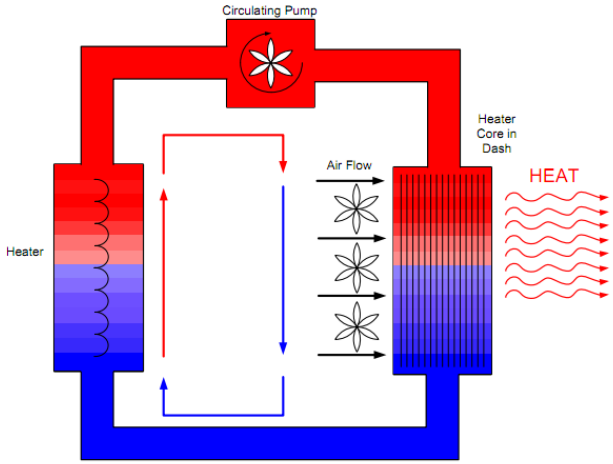
$375

$400

Blue Flash AC Power Source

Features:

- Easy to install
- Powerful 1500W Heater
- Contains all hard to get parts: heater, pump and relay
- 120V AC Input
- Integrated Package
- Light Weight
- Small Size



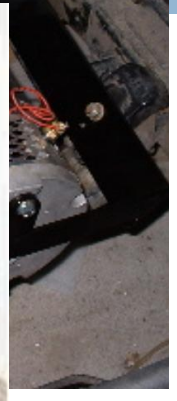
<u>Energy Usage for Heating (Max Power)</u>

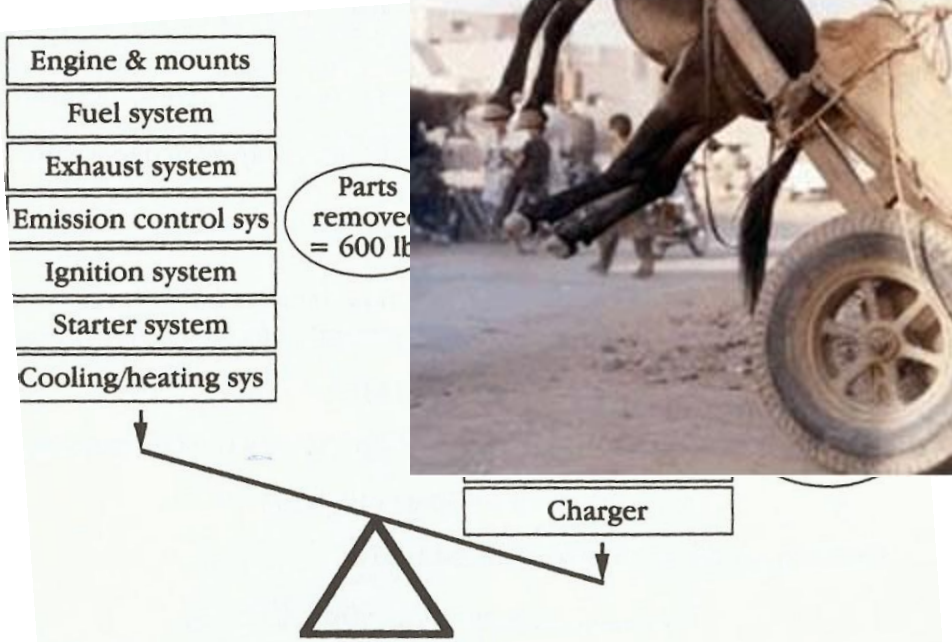
Energy=1500W*(13/60)hr= 0.325kWh

Extra Energy = 1.2*(4*0.325)=1.56kWh

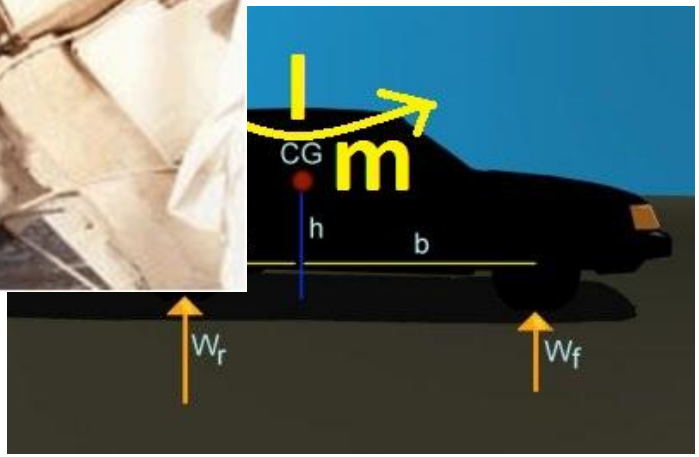
Vehicle Dynamics Considerations

Vehicle Dynamics Considerations

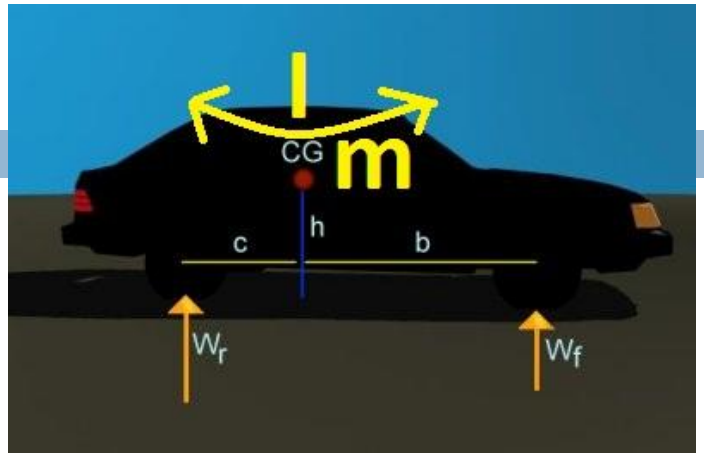




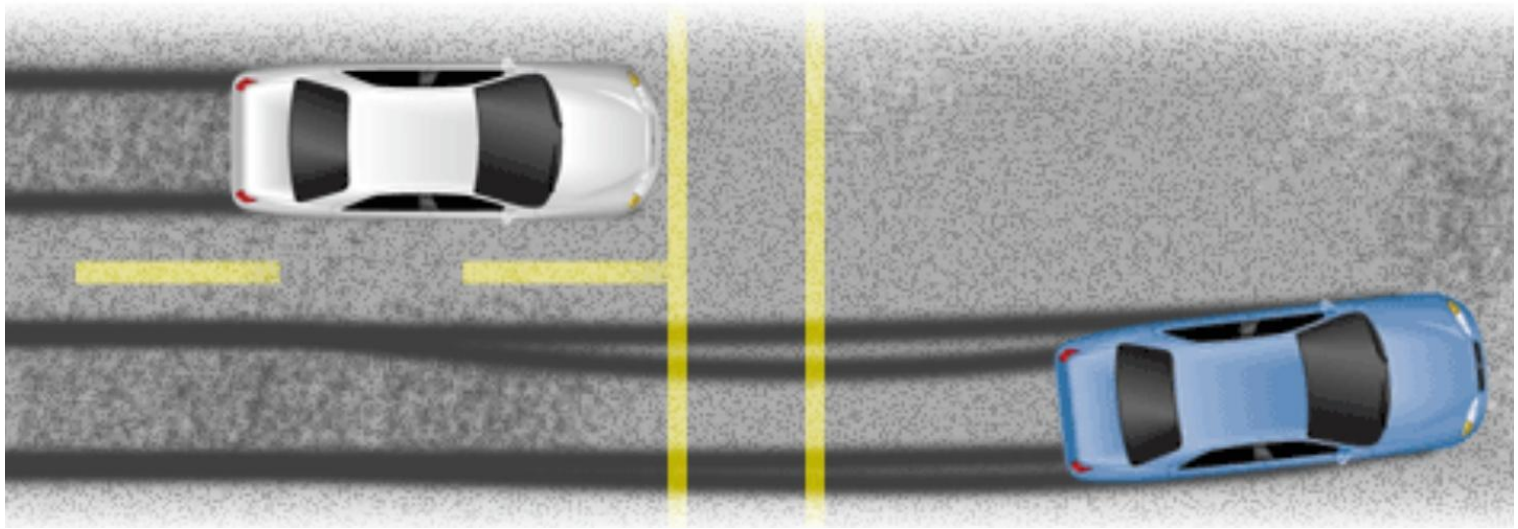
Front-to-rear weight distribution trade-off.



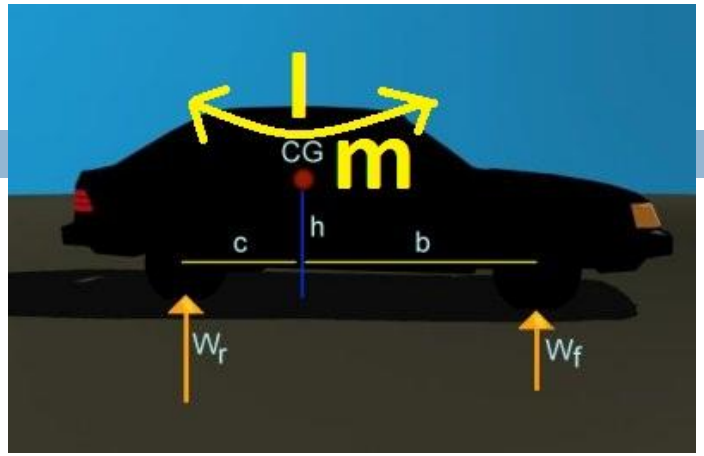
Vehicle Dynamics Considerations



- Braking
- Rollover
- Ride
- Handling

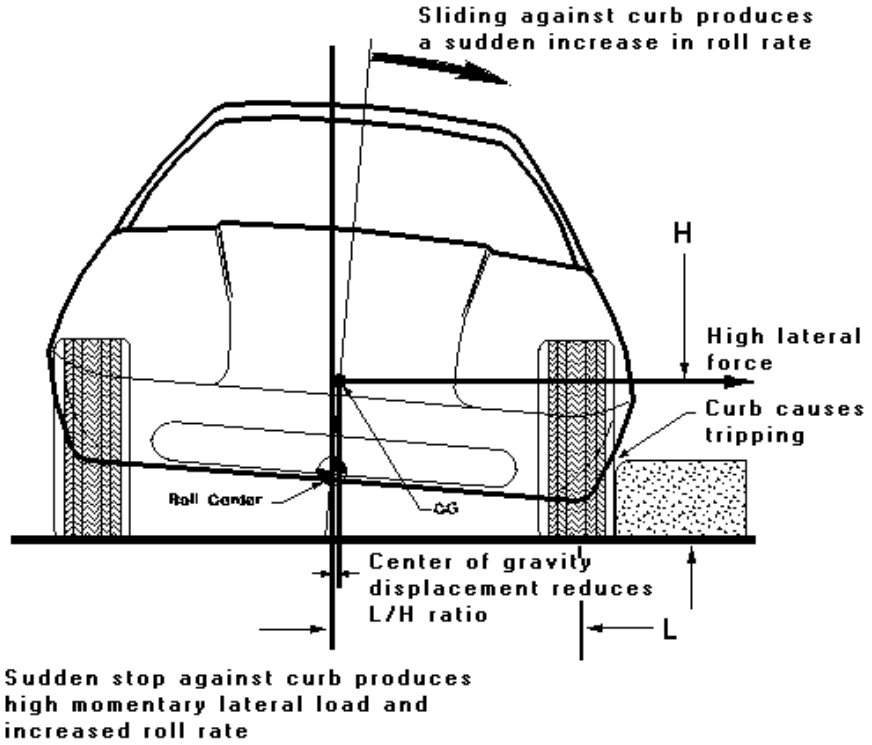


Vehicle Dynamics Considerations

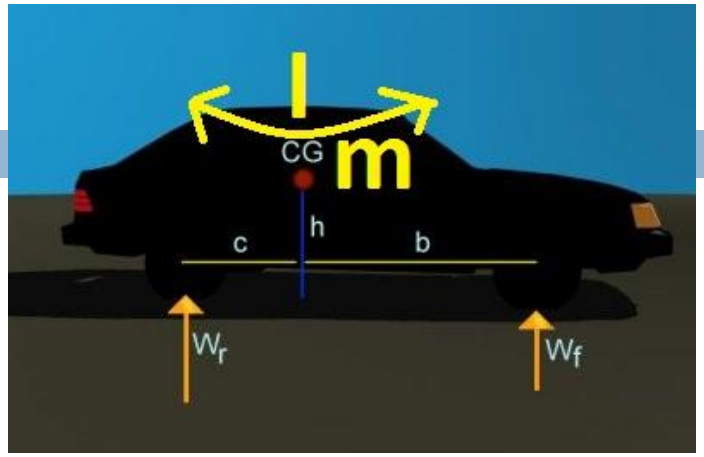


- Braking
- Rollover
- Ride
- Handling

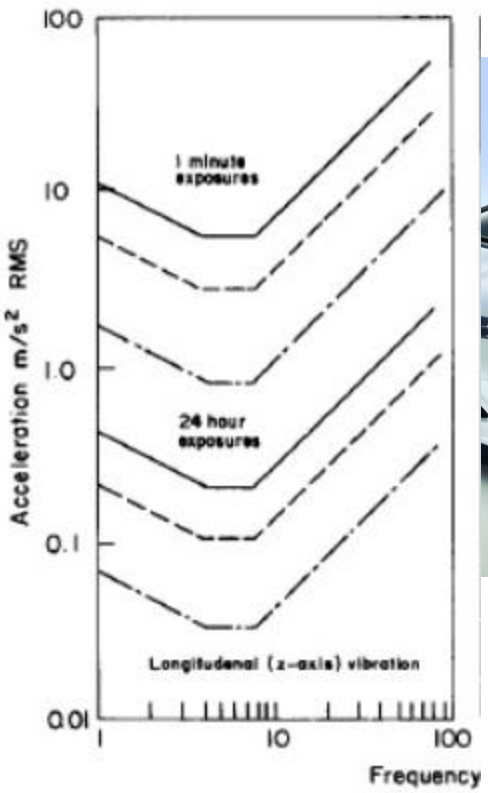
FIGURE 4: ROLLOVER CAUSED BY TRIPPING



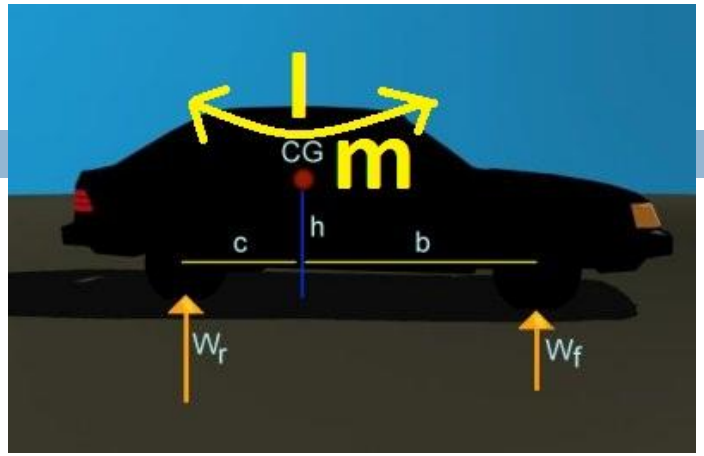
Vehicle Dynamics Considerations



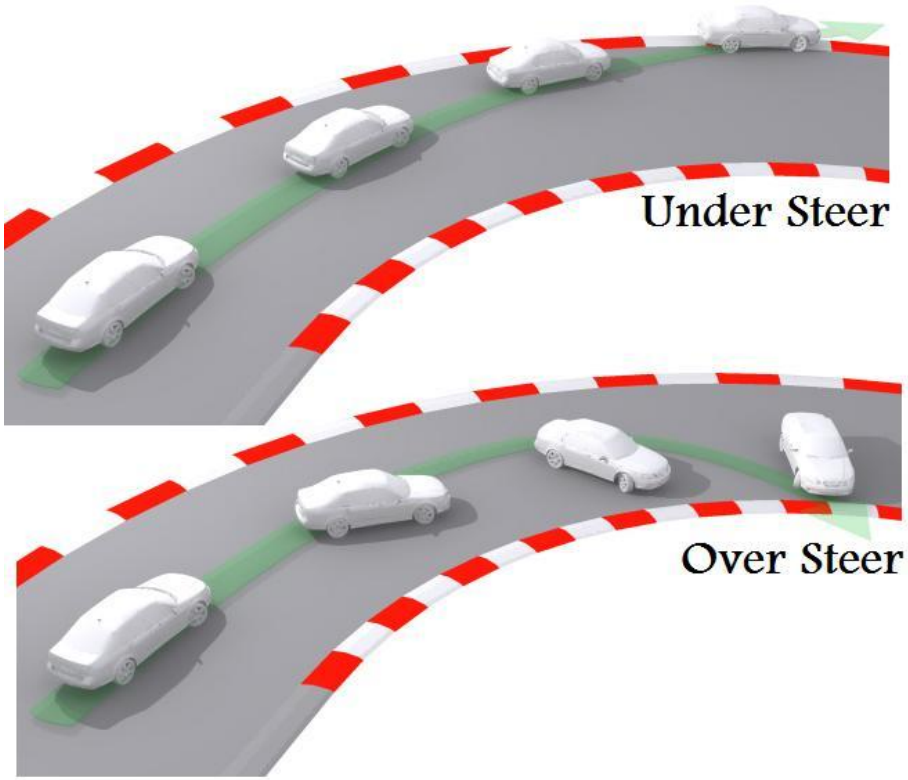
- Braking
- Rollover
- Ride
- Handling



Vehicle Dynamics Considerations



- Braking
- Rollover
- Ride
- Handling



Conclusions

- EV conversion for city driving is cost effective when compared to engine swap, old car purchase, new car purchase, or new EV purchase.
  - Lead Acid and Lithium Ion battery options have close to the same operating cost.
- For highway driving EV conversion is NOT an option (cost and vehicle dynamics).

Thanks!