Introduction to Electric Vehicles

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www.nbeaa.org/osev/presentations/ev_intro.pdf.

> **Introduction to EVs**

What do You Want in an EV?

What are Your EV Choices?

The Economics of EVs

The EV Conversion Process

EV Resources

Introduction to EVs

- Why EVs?
- Types of EVs
- EV History
- EV Charging

Why EVs?

All of these issues showed up in the paper one morning.

Why EVs?

Energy Independence

60% of 2006 US oil consumption was imported per the US Government Energy Information Administration Basic Petroleum Statistics, www.eia.doe.gov/neic/quickfacts/quickoil.html.

Greenhouse Gas Reduction

Transportation accounted for 42% of greenhouse gas emissions in Sonoma County in 2000, according to the Climate Protection Campaign's January 2005 report "Greenhouse Gas Emission Inventory for all sectors of Sonoma County, California", www.climateprotectioncampaign.org/news/documents/AP_INVEN.PDF.

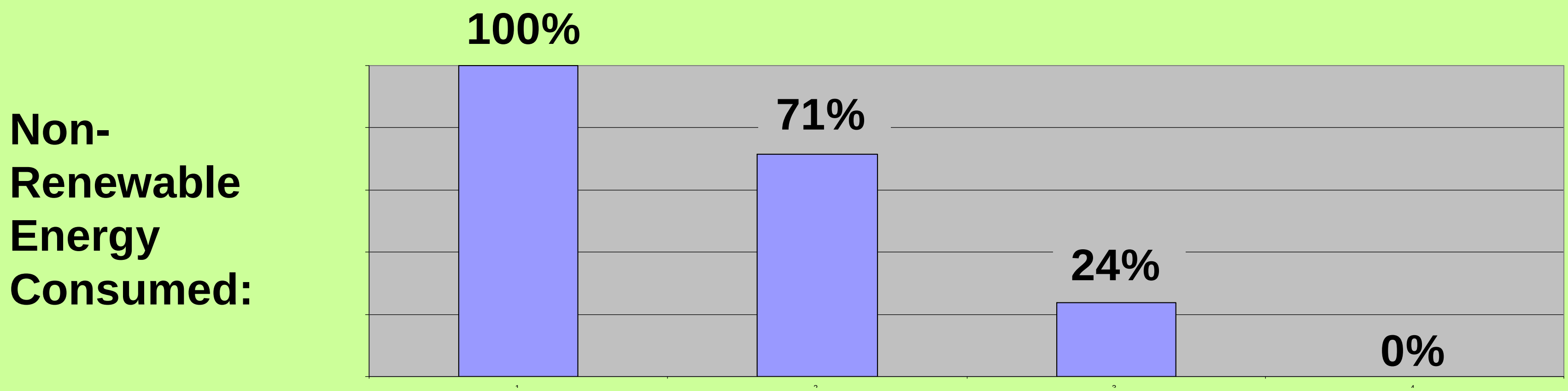
Air and Water Pollution Reduction

Asthma cost $12.7B in 1998 and can be caused by vehicle exhaust, per the Center for Disease Control "Asthma Speaker's Kit", www.cdc.gov/asthma/speakit/default.htm.

See www.nbeaa.org/bev_faq.htm for more frequently asked EV questions.

Why EVs?

EV Energy Consumption



Efficiency:	**Petrol ICE**	**EVs charged by ICE grid**	**EVs offset by PVs made by ICE grid**	**EVs offset by PVs made by PV grid**
Combustion	15%	35%	35%	n/a
Grid	n/a	90%	90%	90%
Energy Generation	n/a	n/a	300%	300%
Charger	n/a	90%	90%	90%
Battery	n/a	90%	90%	90%
AC Drive System	n/a	85%	85%	85%
TOTAL	15%	21%	63%	Infinite for 5.5B years

Efficiency of fuel input to motor shaft output only. Energy to make EV can be higher, but it makes up a small amount of the total energy consumed from cradle to grave of an ICE.

Types of EVs

Hybrid

Ford Escape HEV

Plug-in Hybrid

Toyota Prius PHEV conversion

Battery Only

Tesla Roadster BEV

Fuel Cell

Honda FCX hydrogen FCV

EV History:

Examples of low speed past production EVs

1914 Detroit Electric: 80 mile range, 20 MPH, NiFe batteries

1980 Commuter Vehicles CommutaCar: 30 MPH, 40 mile range, PbA batteries

1974 Zagato Elcar: 35 MPH, 35 mile range, PbA batteries

EV History:

Examples of high speed past production EVs that were sold that can still be found for sale used

1997 Chevrolet S10 EV: 95 mile range, NiMH batteries

1998 Ford Ranger EV: 82 mile range, NiMH batteries

1998 Solectria Force: 84 mile range, NiMH batteries

2002 Toyota RAV4 EV: 94 mile range, NiMH batteries

EV History:

Examples of high speed past production EVs that were leased only and can not be found used

1999 Chrysler EPIC: 79 mile range, NiMH batteries

1999 General Motors EV1: 140 mile range, NiMH batteries

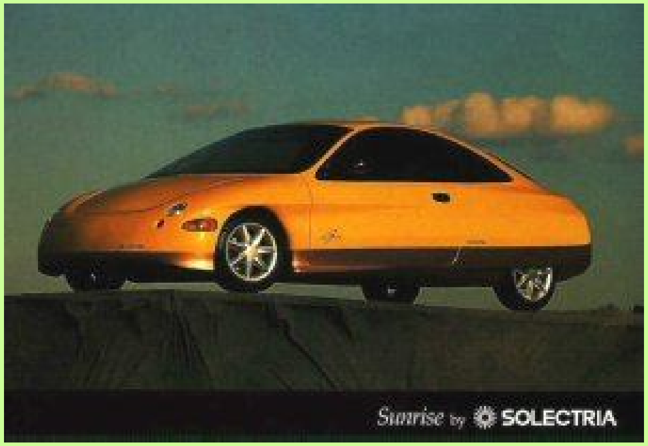
1999 Honda EV Plus: 80 mile range, NiMH batteries

2000 Th!nk City: 55 MPH, 45 mile range, NiCd batteries

EV History:
Range Record Holders

AC Propulsion tZero: drove 302 miles on a single charge at 60 MPH_in 2003, Lithium Ion batteries

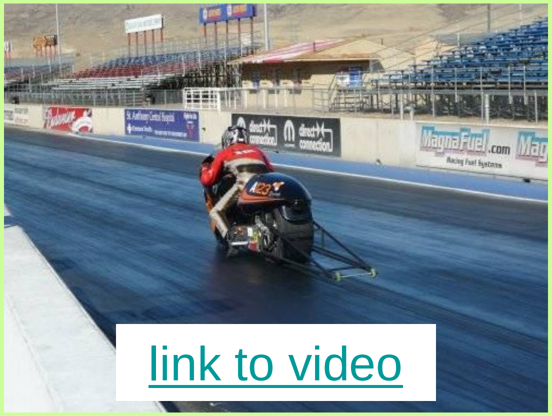
Phoenix Motorcars SUT: charged 50 times in 10 minutes with no degradation in 2007; 130 mile range



Solectria Sunrise: drove 375 miles on a single charge in 1996, NiMH batteries

DIT Nuna: drove 1877 miles averaging 55.97 MPH on solar power in 2007, LiPo batteries

EV History:
Speed Record Holders



Motorcycle: Killa-Cycle, 7.890 seconds and 167.99 MPH quarter mile in 2008 with A123 Systems nano-LiFePO4 batteries

Dragster: Current Eliminator V, 7.956 seconds and 159.85 MPH quarter mile in 2007 with Altairnano Li4Ti5O12 batteries

Modified Conversion: Smoke Screen S10, 11.083 seconds and 119.91 MPH quarter mile in 2008 with AGM batteries

Pro Street Conversion: White Zombie, 11.466 seconds and 114.08 MPH quarter mile in 2007 with A123 Systems nano-LiFePO4 batteries

EV Charging

At home

At an RV park

At a public on-grid PV charging station in Vacaville

From an off-grid PV generator trailer

Introduction to EVs

> **What do You Want in an EV?**

What are Your EV Choices?

The Economics of EVs

The EV Conversion Process

EV Resources

What do You Want in an EV?

Students to brainstorm key features:

What do You Want in an EV?

Students to brainstorm key features:

Payload

What do You Want in an EV?

Students to brainstorm key features:

Range

What do You Want in an EV?

Students to brainstorm key features:

Speed

What do You Want in an EV?

Students to brainstorm key features:

Charge Time

Introduction to EVs

What do You Want in an EV?

> **What are Your EV Choices?**

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EV Resources

What are Your EV Choices?

Buy

- 2, 3 or 4 wheel
- limited or full speed

Make

- Conversion Overview
- Donor Vehicle
- Batteries
- Drive System
- Charging System
- Examples

Wait

- EV Research

Buy:
Examples of Current Production 4 Wheel EVs

www.acpropulsion.com

AC Propulsion eBox conversion: 120 mile range, LiIon batteries; $55K plus Scion xB

www.teslamotors.com

Tesla Motors Roadster: 220 mile range, LiIon batteries; $109K

www.commutercars.com

Commuter Cars Tango T600: 200 mile range, LiIon batteries; $109K

www.venturifetish.fr

Venturi Fetish:155 mile range, LiIon batteries; $400K

Current Production 3 and 2 Wheel EVs

www.zapworld.com

Zap Xebra conversion: 40 MPH, 25 mile range with AGM PbA batteries; $12K

www.myersmotors.com

Myers Motors NmG: 45 mile range with LiIon batteries; $30K

www.vectrix.com

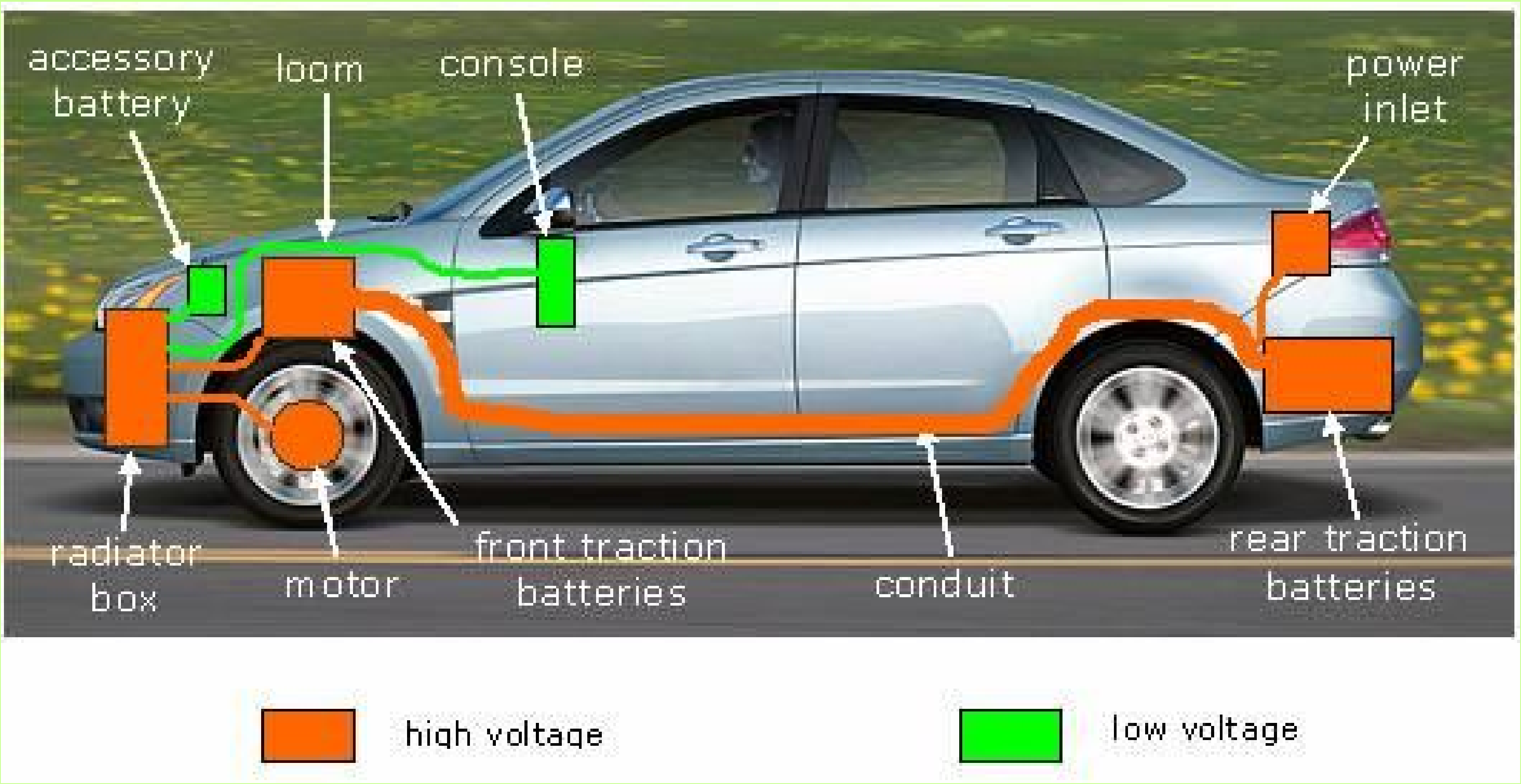
Vectrix Motorcycle: 62 MPH, 60 miles with NiMH batteries, $12K

www.thunderstruck-ev.com/Lepton.htm

Lepton Scooter: 28 MPH, 30 miles with AGM PbA batteries, $2K

Make:

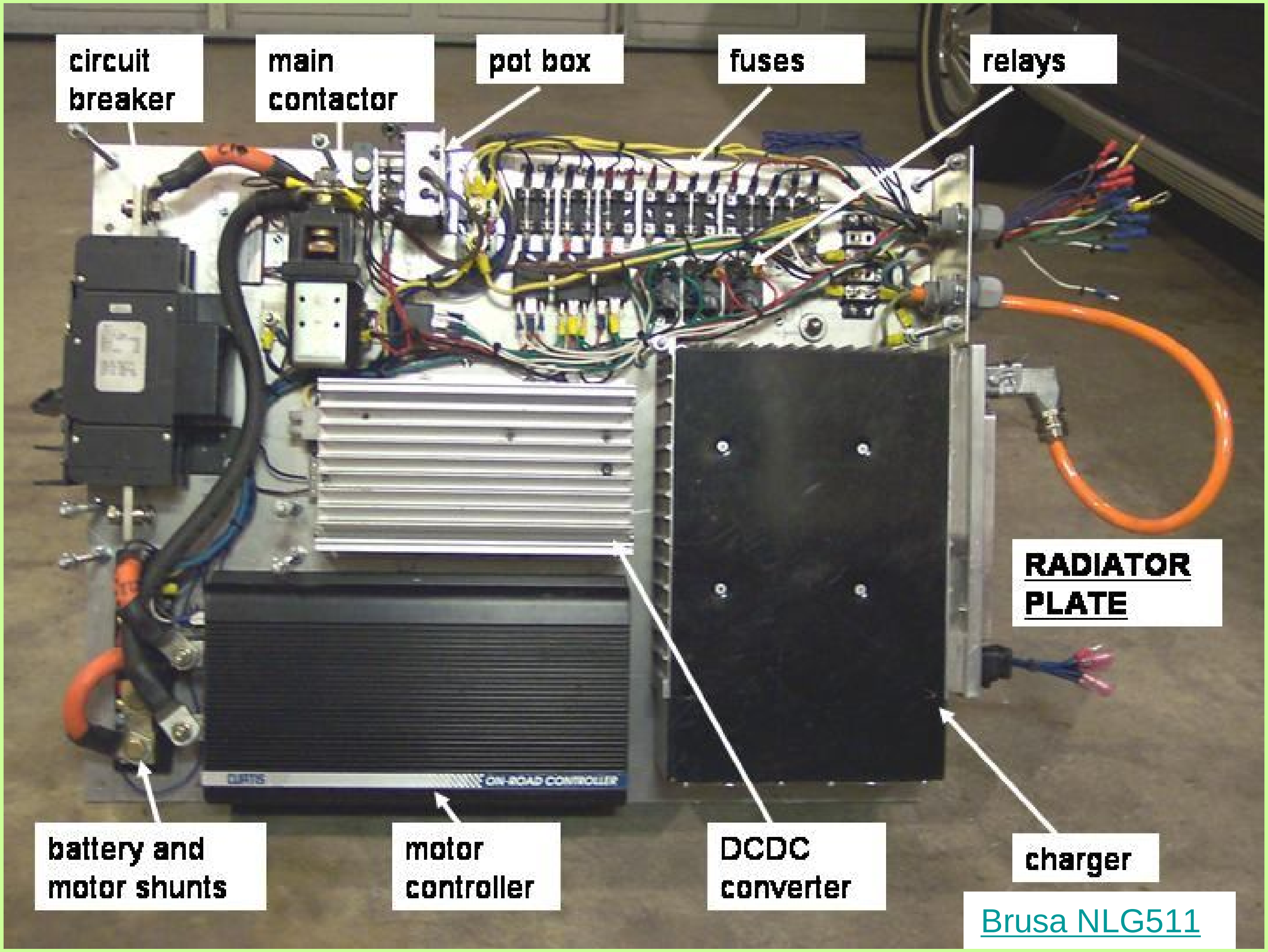
Conversion Overview



Make:

Conversion Overview

Components found on radiator plate



[Brusa NLG511]

Make:

Conversion Overview

Major EV components not in radiator box

Azure Dynamics AC24LS
(DMOC445 Controller not shown)

motor

Electro Automotive Custom

motor to clutch and transmission adapter

Valence Technologies U24-12XP

batteries

console

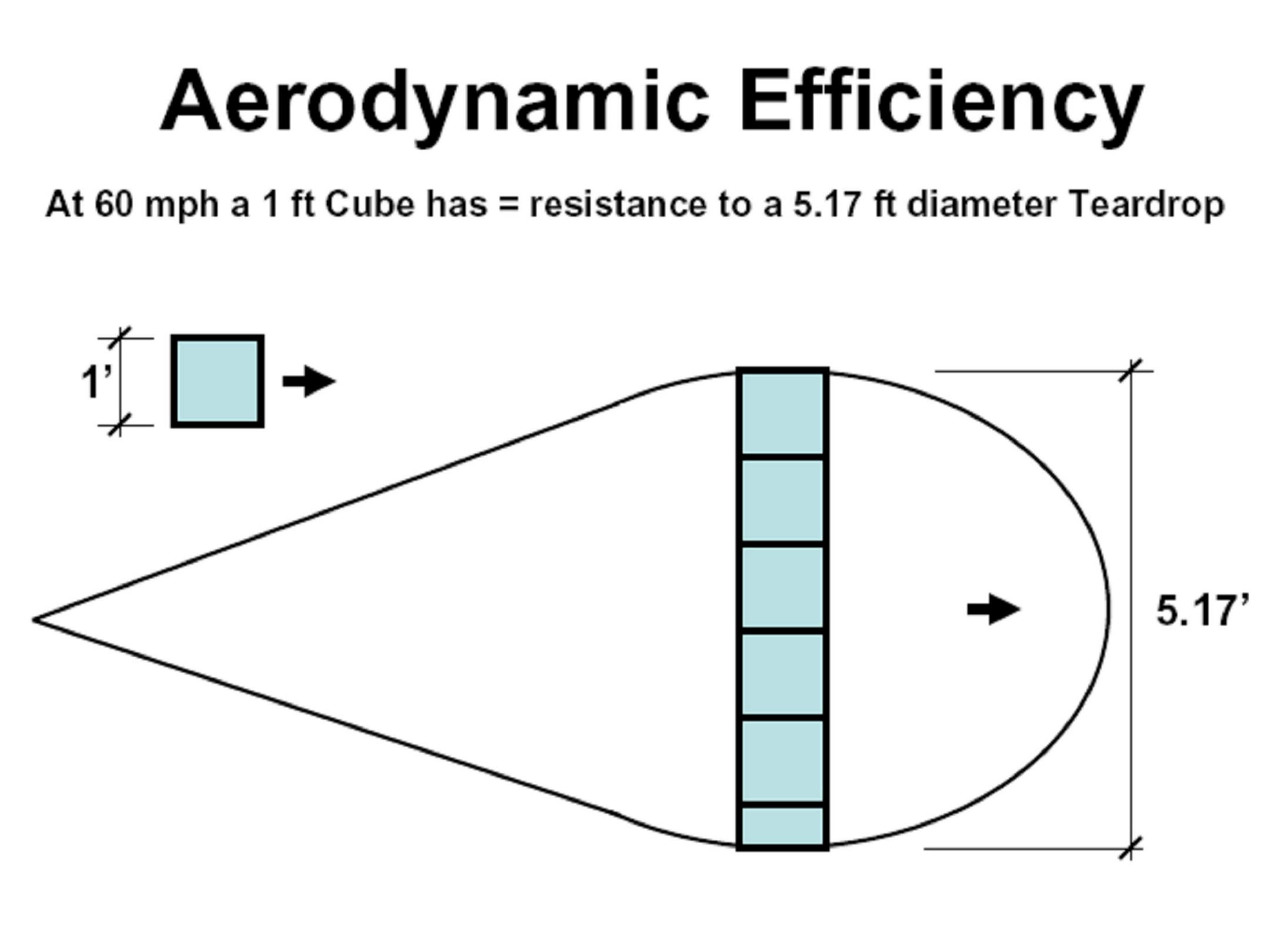
Make:

Donor Vehicle

Class	Payload after ICE removed vs. weight	Space to put EV components	Cost of conversion components
Scooter	~	~	+
Motorcycle	~	~	+
Mini car	~	~	~
Compact car	+	+	~
Compact truck	+	+	~
Mid-size car	~	+	-
Mid size truck	~	+	-
Full size car	-	+	-
Full size truck	-	+	-

Make:

Donor Vehicle



Make:

Batteries

Type	Power	Energy	Stability	Max temp	Life	Toxicity	Cost
LiFePO4	+	+	+	~	~	+	-
LiCO2	+	+	-	-	-	+	-
NiZn	~	~	~	~	-	+	~
NiCd	-	~	~	~	+	-	+
PbA AGM	+	-	+	~	-	-	+
PbA gel	~	-	+	~	-	-	+
PbA flooded	~	-	-	~	-	-	+

Available large format only considered; NiMH, small format lithium and large format nano lithium not included.

Make:

Batteries

Type	Makes	Models
LiFePO4	Thunder Sky Valence Technologies	LMP U-Charge XP
LiCO2	Kokam	SLPB
NiZn	SBS	Evercel
NiCd	Saft	STM
PbA AGM	BB Battery Concorde EnerSys Hawker Exide Optima	EVP Lifeline Genesis Odyssey Orbital Extreme Cycle Duty Yellow Top Blue Top
PbA gel	East Penn Deka	Dominator
PbA flooded	Trojan US Battery	Golf & Utility Vehicle BB Series

Examples of commonly used EV batteries.

Search EV Discussion List Photo Album at www.evalbum.com for details.

Make:

Batteries

Calculating Voltage Drop

Voltage sags with increased current and internal resistance per Ohm's Law, robbing potential output power to generate heat.

voltage = current x resistance

V = I x R

Volts = Amps x Ohms

1000 milli-Ohms = 1 Ohm

Example voltage drop on 12 Valence U24-12XPs at continuous current rating:

12 x 150 Amps x .006 Ohms = 10.8V on 154V nominal pack = -7%

Make:

Batteries

Calculating Battery Power

Acceleration rate varies with peak power.
Top speed and hill climbing ability varies with continuous power.

power = current x voltage

$$P = I \times V$$

Watts = Amps x Volts

1000 watts = 1 kilo-Watt = 1 kW
1 kW = 1.34 Horsepower

Example battery power of 12 Valence U24-12XPs at continuous current rating:
12 x 150 Amps x (12.8 Volts - .006 Ohms x 150 Amps) = 21.4 kW

Make:

Batteries

Calculating Energy

Battery capacity is how much energy it will hold.

Capacity = power x time

Wh = W x h

Watt-hours = Watts x hours

1 Watt-hour is equivalent to 1 Watt drawn for 1 hour
1000 Wh = 1 kWh
1 kWh = 3413 BTUs

Example capacity of 12 Valence U24-12XPs at continuous current rating:
12 x 100 Amp-hours x (12.8 Volts - .006 Ohms x 150 Amps) = 14.2 kWh

Make:

Batteries

Estimating Range

Range varies directly with battery capacity.
Range varies inversely with DC energy consumption rate.

Range = capacity / DC consumption rate

= Watt-hours / Watt-hours per mile

Example range estimate of Mustang EV:

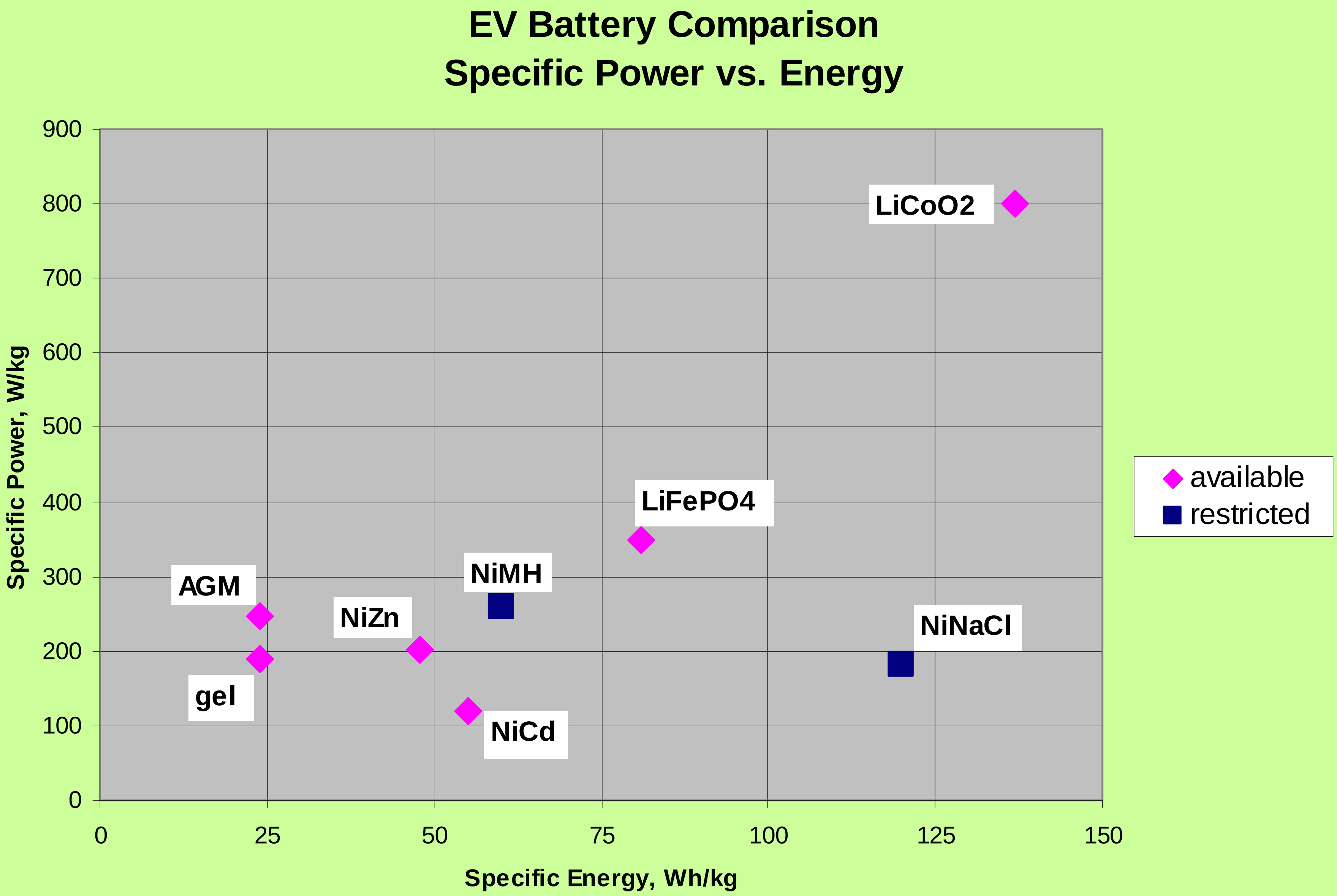
14,200 Wh / 375 Wh / mi = 37.9 miles with new batteries

37.9 miles x 0.8 = 30.2 miles after 5 years, assuming 4% decline per year

See http://www.geocities.com/chris_b_jones@prodigy.net/EV/1.htm for details.

Make:

Batteries



Make:

Drive System

Controller	Power	AC: regen, efficient, brushless	Safety	Available	Cost
Solectria	~	+	+	+	~
MES-DEA	+	+	+	+	-
Siemens	+	+	+	+	-
AC Propulsion	+	+	+	+	-
Curtis	~	-	-	+	+

Make:

Drive System

Calculating Motor Power

Motor Power varies with power input and drive system efficiency.

output power = input power x efficiency

Po = Pi x Eff

Watts = Watts x efficiency ratio

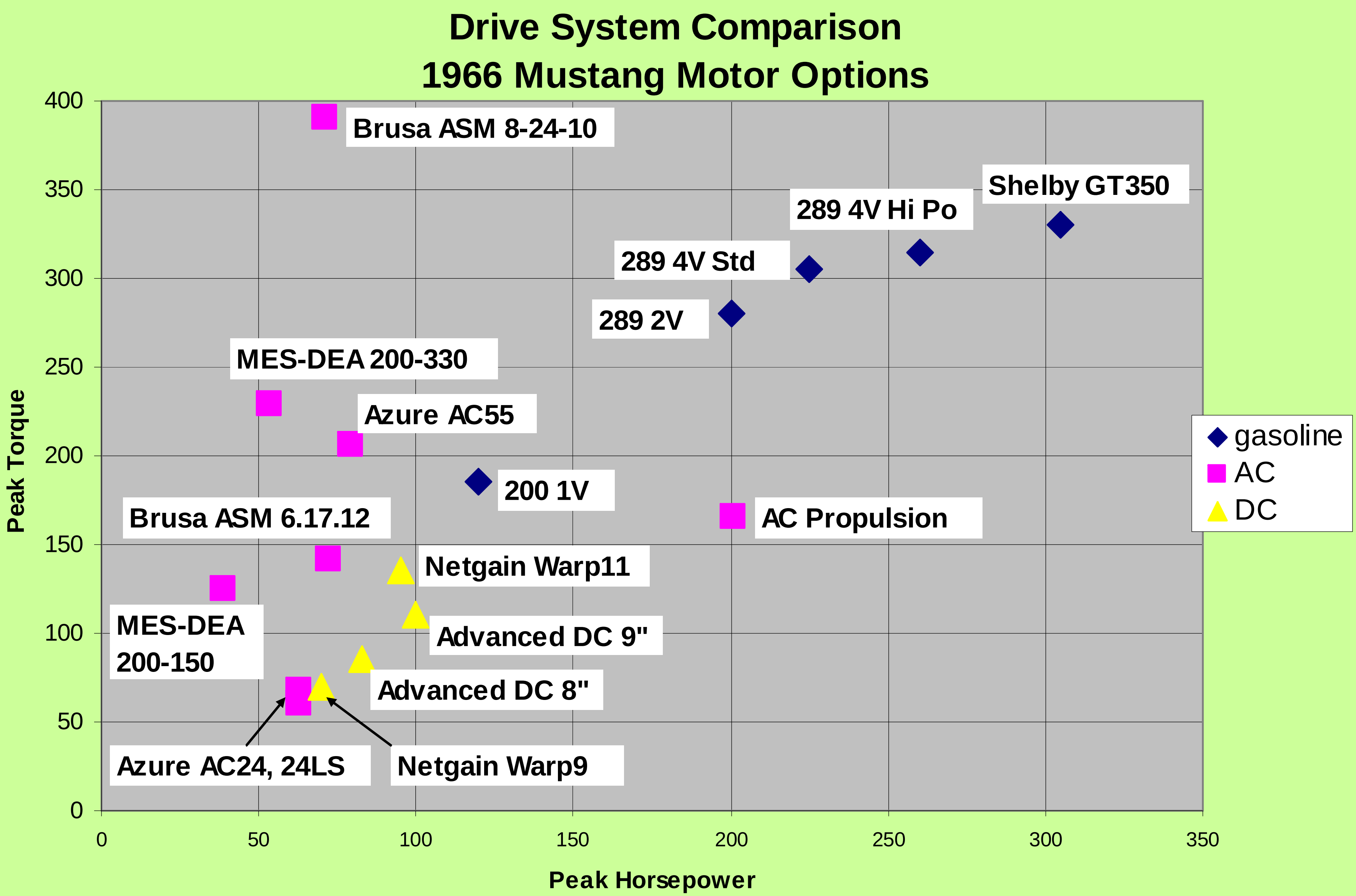
Example peak motor shaft power of Mustang EV :

325 Amps x 12 x (12.8 Volts - .006 Ohms x 325 Amps) x 75%

= 31.7 kW = 42.5 Horsepower

Note: this propels a 3000 pound car 0-60 MPH in 23 seconds, approximately at the flow of traffic – much less than the peak rating of gasoline cars.

Make:



Note: EV motors have wider RPM torque band so they better compare to ICE motors with ~25% more torque and horsepower.

Make:

Charging System

Brand	power	isolated	Input voltage range	Power Factor Correction	Sealed	UL, FCC	cost
Brusa	~	+	+	+	+	+	-
DeltaQ	-	+	+	+	+	+	-
Zivan	+	+	-	-	-	+	+
Manzanita Micro	+	-	+	+	-	-	+
Russco	~	-	-	+	-	-	+

Make:

Charging System

Estimating Charge Time

Charge time varies with charger output power.

charge time ~= battery capacity / charger power

t = Wh / W

hours = Watt-hours / Watts

Example charge time of Mustang EV :

12 x 12.8 Volts x 100 Ah / 3300 W ~= 4.7 hours

Make:
Examples

John Warobiew's 1983 Volkswagen Rabbit GTI, 35 mile range, PbA batteries

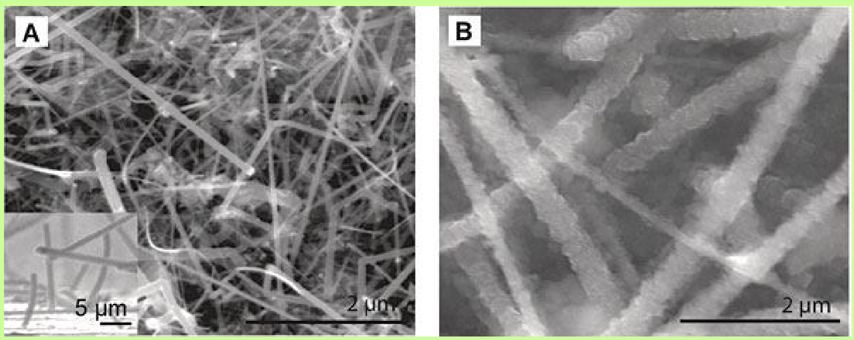
Chris Jones' 1966 Ford Mustang Convertible, 33 mile range, LiFePO4 batteries

Peter Oliver's 1956 Porsche 356 Speedster replica, 100 mile range, LiFePO4 batteries

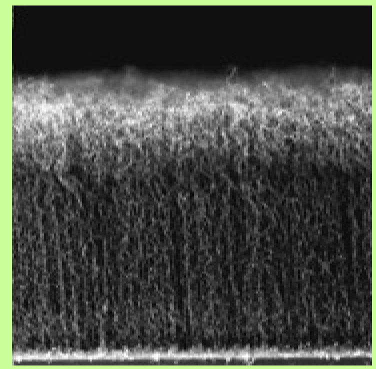
Ed Ristad's 1990 Volkswagen Cabriolet, in process

Wait:

EV Research



Stanford University Silicon Nanowire electrodes: 3X capacity improvement expected for Lithium batteries



MIT Nanotube ultracapacitors: very high power, 1M+ cycle energy storage approaching Lithium battery capacity

What do You Want to Do?

Students to brainstorm their thoughts about their own EV plans, including:

Make
Buy
Wait

Introduction to EVs

What do You Want in an EV?

What are Your EV Choices?

> **The Economics of EVs**

The EV Conversion Process

EV Resources

The Economics of EVs:

Worst Case Example

	2008 Mustang Convertible ICE	1966 Mustang Valence LiFePO4 EV Conversion
Durable hardware cost, excluding batteries	$24K new Kelley Blue Book value	$13K conversion components $5K conversion labor $10K donor car $28K subtotal: **$4K more**
Battery amortization	n/a	$17K every 5 years Financed at 5% APR $12 per day
Fuel efficiency	20 MPG	2 miles per kWh
Fuel cost	$2 per gallon	12 cents per kWh
Fuel cost per mile	10 cents	6 cents
Daily ongoing cost at 20 miles per day	$2	$13.25: **$11.25 more per day**

Assumes maintenance cost is low for both vehicles.

The Economics of EVs:

Ways to break even

- Gas price rises 6.5X to $13 per gallon

  Gas is now $10 per gallon in England

- Battery price reduced 85% to $2.6K

  PbA achieves this, but significantly reduces available payload for passengers and cargo, is toxic, and requires hydrogen gas management; Loose LiFePO4 cells are cheaper, but reliability and BMSs just being proven; volume discounts could help

- Battery life extended 6.5X to 33 years

- Government Incentives for EVs were $4K per year

Or some combination of the above.

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> **The EV Conversion Process**

EV Resources

The EV Conversion Process

Preparation

Fabrication and Assembly
- Machining
- Welding
- Metalworking
- Wiring
- Installation in to Vehicle

Test

Preparation:

Refurbish non-ICE systems including brakes, steering, suspension, electrical, interior and exterior, then measure ride height

Preparation:

Make transmission locating fixture

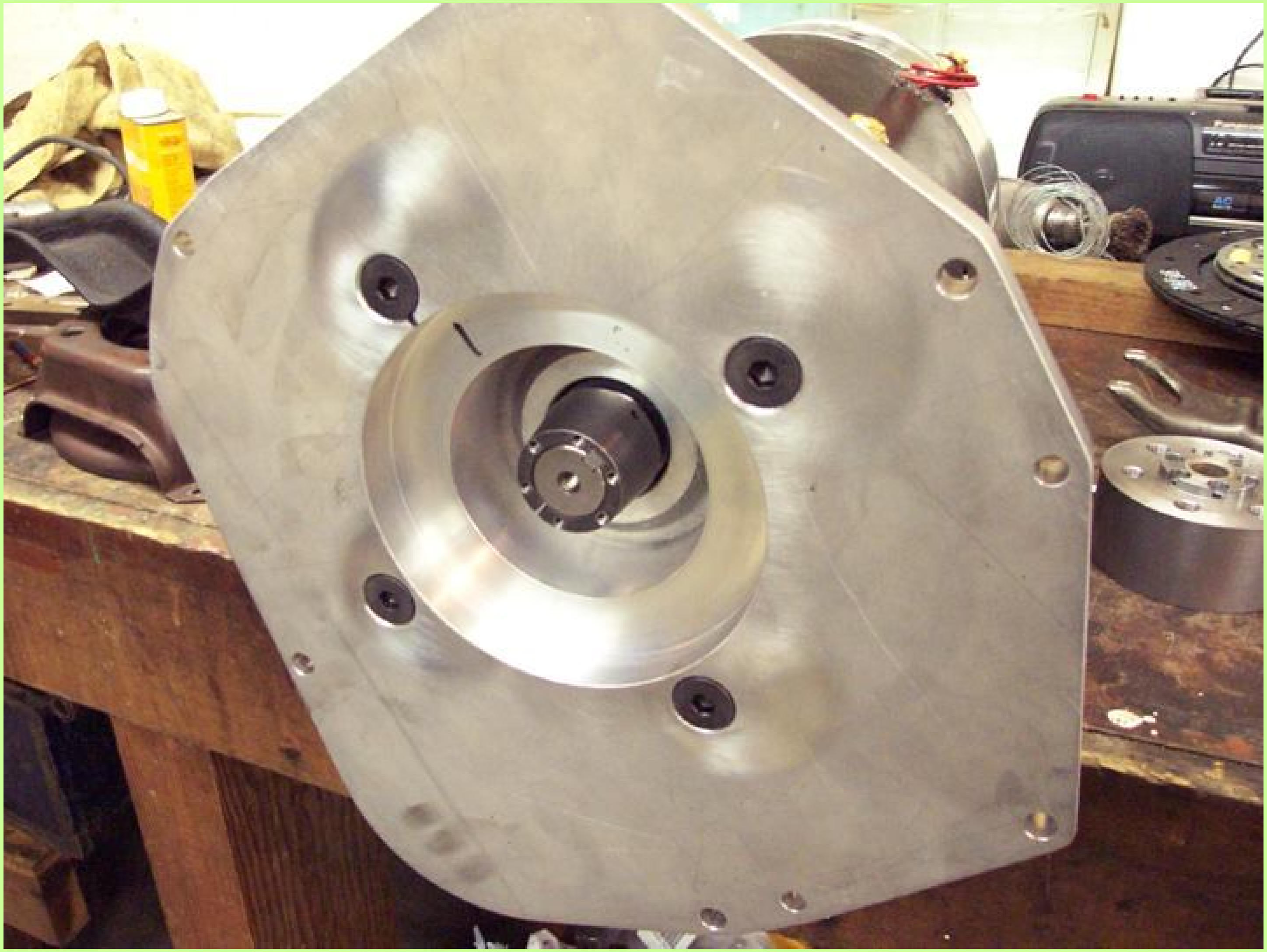
Preparation:

Pull transmission and measure depth from flywheel to block, then pull motor, radiator, exhaust system and gas tank

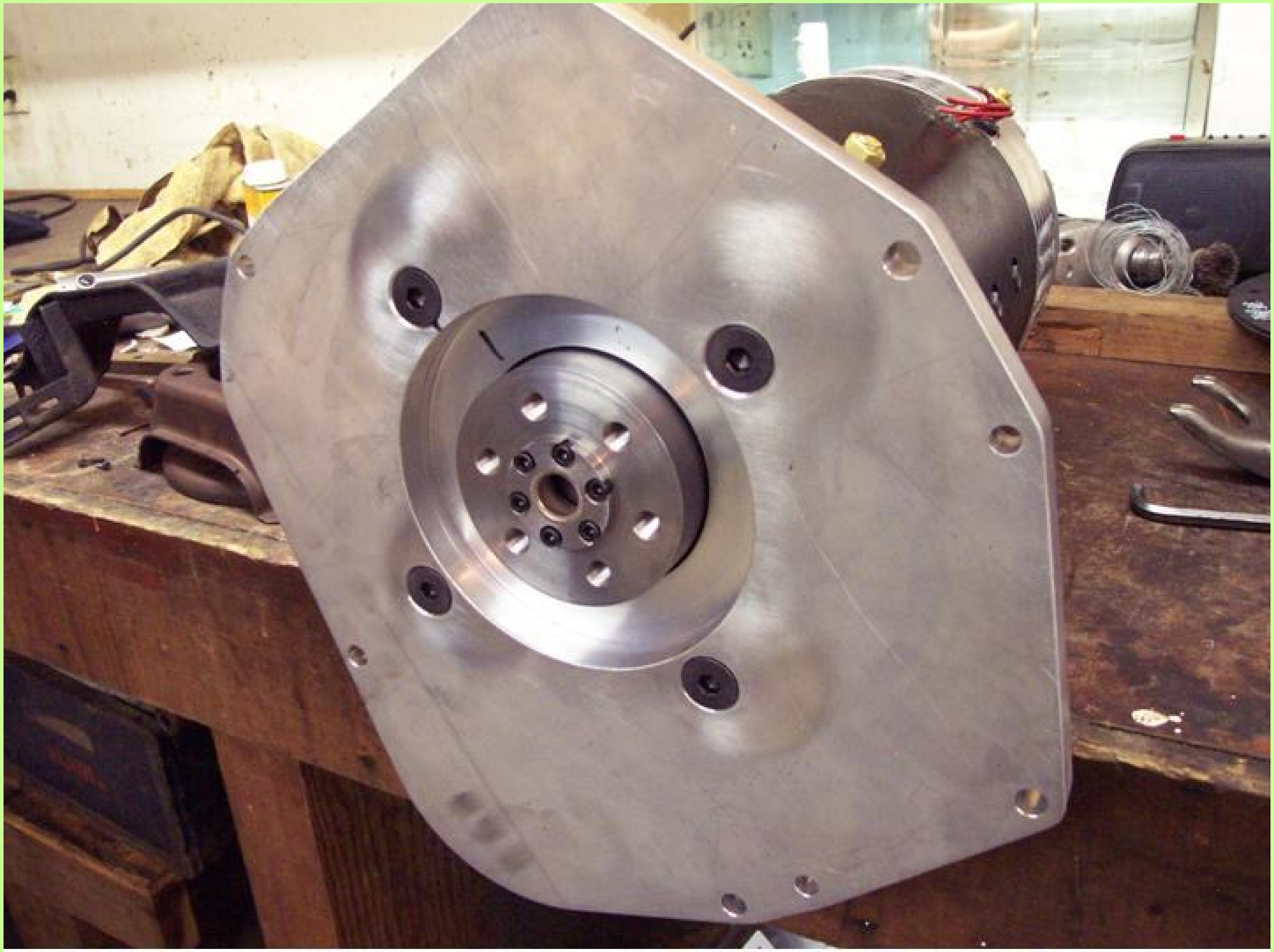
Fabrication and Assembly:

Have custom motor adapter ring, plate and hub with pilot bushing made, then assemble ring and plate to motor

Fabrication and Assembly:
Install taper lock bushing

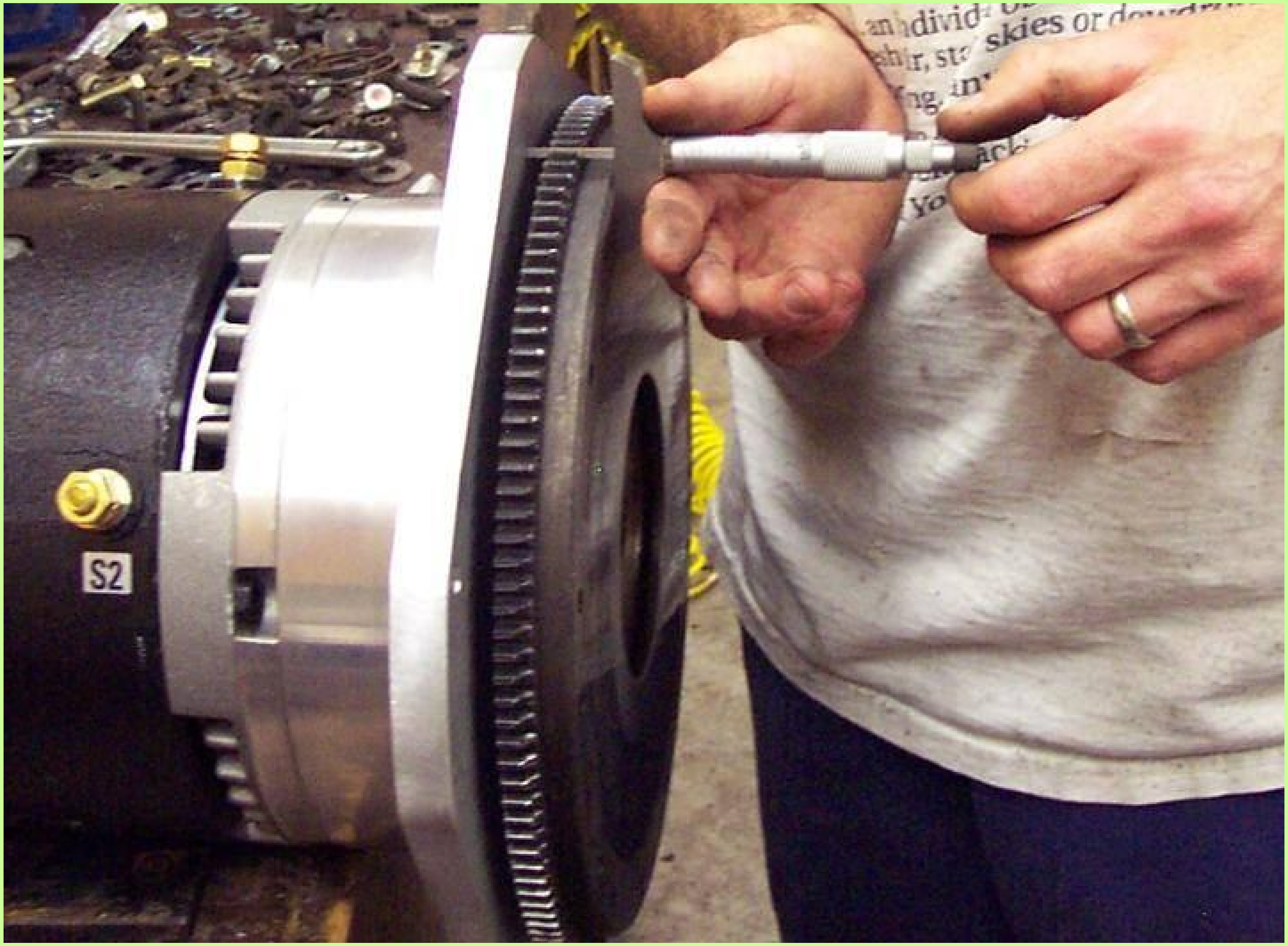


Fabrication and Assembly:
Loosely attach hub to taper lock bushing



Fabrication and Assembly:

Loosely install flywheel and set to proper depth from plate



Fabrication and Assembly:

Remove flywheel, torque hub, then check dimensions

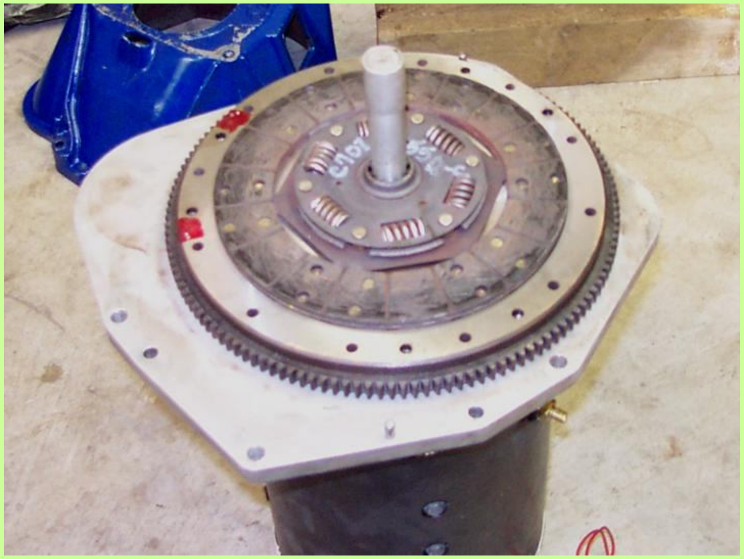
Note: adapter plate was off .062” that caused clutch scraping in this example.

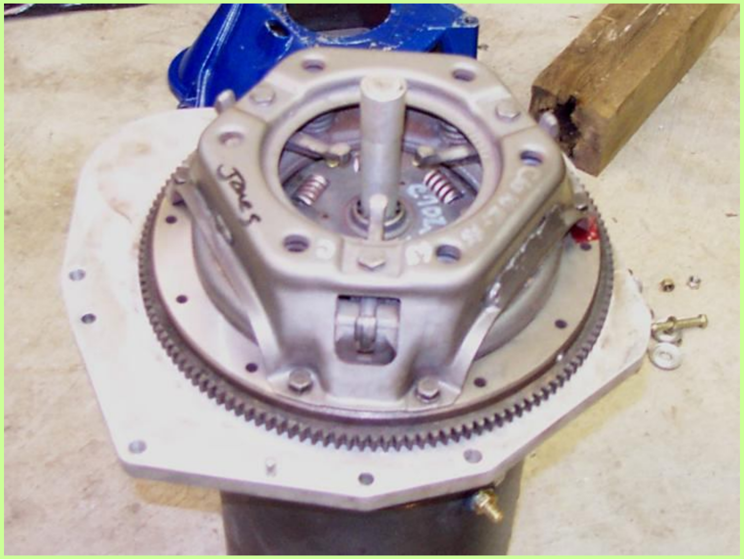
Fabrication and Assembly:
Replace flywheel and torque to specification

Fabrication and Assembly:

Check flywheel for dimensions

Fabrication and Assembly:
Assemble clutch





Fabrication and Assembly:

Lube clutch fingers; install clutch pivot fork, throw out bearing and dust boot; attach bell housing to plate; attach transmission to bell housing

Fabrication and Assembly:

Place drive train in car; mount transmission end; use transmission fixture to align transmission; weld and paint motor mount adapters; attach motor mount adapters to plate and motor

Fabrication and Assembly:

Weld and paint accessory battery mount and hold down; install accesory battery where starter battery was

Fabrication and Assembly:

Weld and paint front battery mounts and hold downs and attach them to motor mount adapter; install front batteries, assemble radiator plate and connect accelerator rod to pot box

Fabrication and Assembly:

Weld and paint rear rack; make, rubber paint and mount rear splash shield on to rear rack; install where gas tank was

Fabrication and Assembly:
Assemble front to rear underbody conduit subassembly

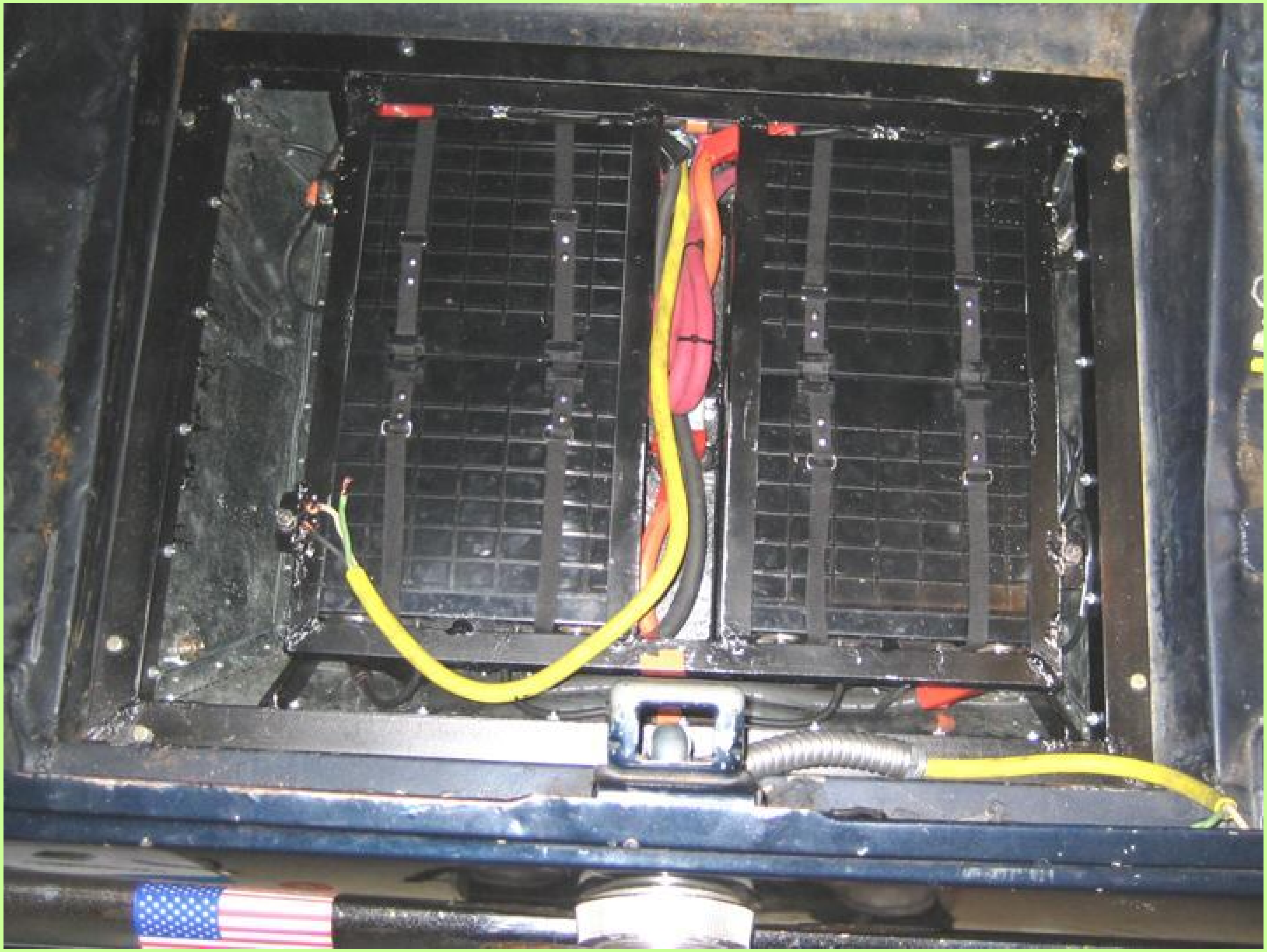
front end

rear end

Fabrication and Assembly:
Install conduit assembly in to car

Fabrication and Assembly:
Machine and assemble AC inlet

Fabrication and Assembly:
Install rear batteries and AC inlet



Fabrication and Assembly:

Wire up rear batteries and AC inlet; fabricate and install trunk floor

Fabrication and Assembly:
Fabricate AC extension cord and adapters

Fabrication and Assembly:

Install trunk floor pad, trunk rug and spare tire; place AC extension cord and AC adapters in trunk

Fabrication and Assembly:

Fabricate, wire up and install console and interconnecting wire looms

Fabrication and Assembly:

Verify no ride height change; align wheels to 1/16” toe-in; program motor controller, charger, and BMS as necessary; charge pack then each cell individually

Test:

Attach data acquisition system to vehicle; drive vehicle around town, on the freeway and up hills at varying speeds; drive until the first cell drops to manufacturer's minimum specification but no further to avoid permanent damage

Test:

Verify key parameters meet or exceed expectations.

Parameter	Expected	Measured
Weight, pounds: curb resulting payload	2975 704	TBD TBD
0-60 MPH, seconds	23	23
Top Speed, MPH	70	70
Range, miles	38	40
Battery capacity: Ah kWh	100 14.2	104 15.1
Battery current at 65 MPH, Amps	150	144
Charge time, hours: 240V 120V	5 20	5 20

Example results for Mustang EV with new battery pack.

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> **EV Resources**

EV Resources

EV Conversion Classes

Santa Rosa Junior College DET 193 all semester long Saturday class, busapp02.santarosa.edu/SRweb/SR_CourseOutlines.aspx?CVID=18632&Semester=20087

Solar Living Institute EV201 1 week class, http://www.solarliving.org/store/product.asp?catid=13&pid=2009

General EV Information

Electric Auto Association, www.eaaev.org; a local chapter www.nbeaa.org

EV Tradin' Post electric vehicle classified ads, www.austinev.org/evtradinpost/

Vacaville PV EV incentives and charging stations: www.cityofvacaville.com/departments/public_works/evprogram.php

EV World Magazine www.evworld.com

Idaho National Laboratory and National Renewable Energy Laboratory Advanced Vehicle Testing EV test data, avt.inel.gov/fsev.shtml

EV Resources

Local Custom EV Conversion Shops

Make Mine Electric www.makemineelectric.com

Thunderstruck Motors www.thunderstruck-ev.com

EV Component Suppliers

Electro Automotive www.electroauto.com

Metric Mind www.metricmind.com

PV Information

Solar Rover mobile power systems, www.solarover.com

EV Resources

Fast Charging EV Components

A123 Systems nano LiFePO4 batteries, www.a123racing.com
Altairnano nano LiIon batteries, www.altairnano.com/markets_energy_systems.html

AeroVironment off-board charger, www.avinc.com/PosiCharge.asp

Phoenix Motorcars SUT using Altairnano batteries, www.phoenixmotorcars.com

EV Racing

Delft University of Technology (Netherlands) solar powered race car, en.wikipedia.org/wiki/Nuna4

National Electric Drag Racing Association, www.nedra.com

EV Research

Stanford University silicon nanowire battery electrodes, news-service.stanford.edu/news/2008/january9/nanowire-010908.html

Massachusetts Institute of Technology nanotube ultracapacitors, web.mit.edu/erc/spotlights/ultracapacitor.html