FocusEV

Conversion of a Gasoline Powered Automobile to a Battery Powered Electric Vehicle

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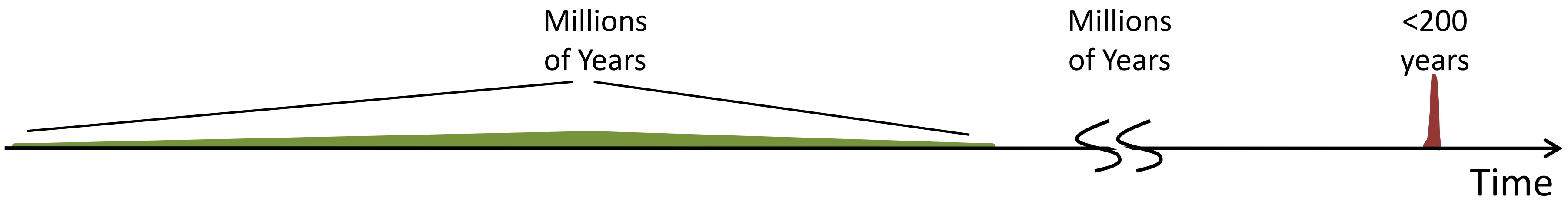
Minnesota
Electric Auto Association
Land of 10,000 Outlets

All of the energy that we use ultimately comes from the Sun. The electricity that powers the screen that you are viewing. The energy your body is using at this moment to read and think and breath. The energy that transported you to wherever you are right now.

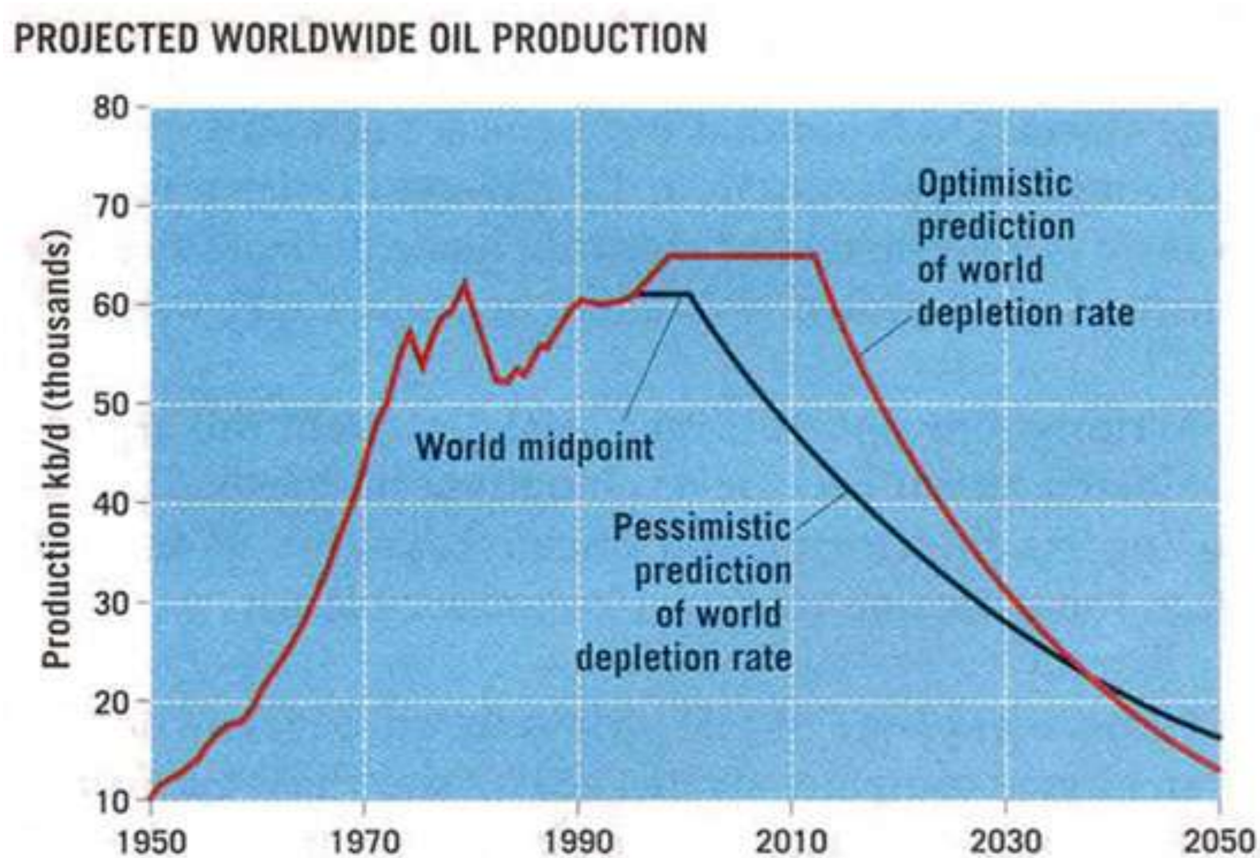
Much of that energy was locked away in fossil fuels (petroleum, or coal) long ago.

Fossil Fuel Timeline



- Oil formation took ***millions*** of years
- The human race will completely consume it in ***hundreds*** of years
- The fossil-fuel dependent society is unsustainable
- The cost of fuel will increase dramatically as we get nearer to the end of the supply.

Fossil Fuel Timeline



- (Need to find a chart from a known reputable source)

Considerations for an EV Conversion

What "donor car"?

How many batteries?

What type of motor?

What type of battery charger?

What type of batteries?

How do I keep warm?

What electronic controller should I use?

What high voltage contactor is available?

What special instrumentation do I need?

Before answering these you really need to ask:

What are my goals for an electric vehicle?

Considerations for an EV Conversion

Here are the goals that I wrote down for an Electric Vehicle:
(in somewhat priority order)

- Range that allows for my daily commute (Greater than 35 miles at 40 MPH, even in winter)
- Use of an American donor car
- A donor car with a manual transmission
- Maximize the life of the batteries, which is the largest ongoing expense with an EV.
- Ease of use (A vehicle that anyone can drive, with self-management of battery charging)
- All components extendable to higher range and performance when better batteries become available)
- Parts that are "Made in USA" where possible (Easier to deal with the suppliers if there's a problem.)
- A design that prioritizes higher range over faster acceleration.
- Quiet operation
- Keep the weight down – stay close to the GVWR (Gross Vehicle Weight Rating)
- Top speed of at least 65 MPH
- Minimize initial cost of battery pack
- Total conversion project cost less than $10,000 (not counting donor car)
- Include heater and defroster for comfort through the Minnesota winter.
- Flexible battery layout (not size specific) to allow an upgrade at a later date.
- Suspension modified to compensate for additional weight of the batteries.
- Brakes must operate as before conversion using a vacuum pump.

My Choices

- **Donor car - 2001 Ford Focus SE**
  - American made - Car and Driver's "10 Best" multiple years
  - Lightweight for efficiency, but reasonably high GVWR (to carry the weight of the batteries)
- **Motor - 9 inch diameter series-wound brushed DC motor (143 lbs.)**
  - Low cost ($1550) - Widely used in on-the-road EVs - High reliability
- **Batteries - 17 series 8V wet cell lead acid batteries (Golf cart)**
  - Wet cell Golf Cart batteries have long life for deep cycles (compared AGM or Gel batteries)
  - Higher voltage (8V vs. 6V batteries) means higher top speed
  - Low cost ($1800) because I was told "Everyone murders their first pack"
  - The downside is **WEIGHT** (1,080 lbs of lead!)
- **Controller - Curtis 144V PWM controller with heatsink and fans**
  - Low cost ($1400) - High reliability (if properly cooled)
- **Electric Power Brake Vacuum Pump - MES-DEA 70/6E (with integral vacuum switch)**
  - Quiet (Relatively)
  - Designed specifically for use in EVs
- **Electric Power Steering Pump – TBD**
- **Instrumentation – Voltmeter (180 VDC) and Ammeter (500 ADC)**
  - Planning to add a uprocessor battery monitor system with dashboard-mounted display (VFD)
- **DC/DC Converter**
  - IOTA - 55 Ampere power supply – modified with inrush current limiter and power-on relay

Removal and Installation

Removed

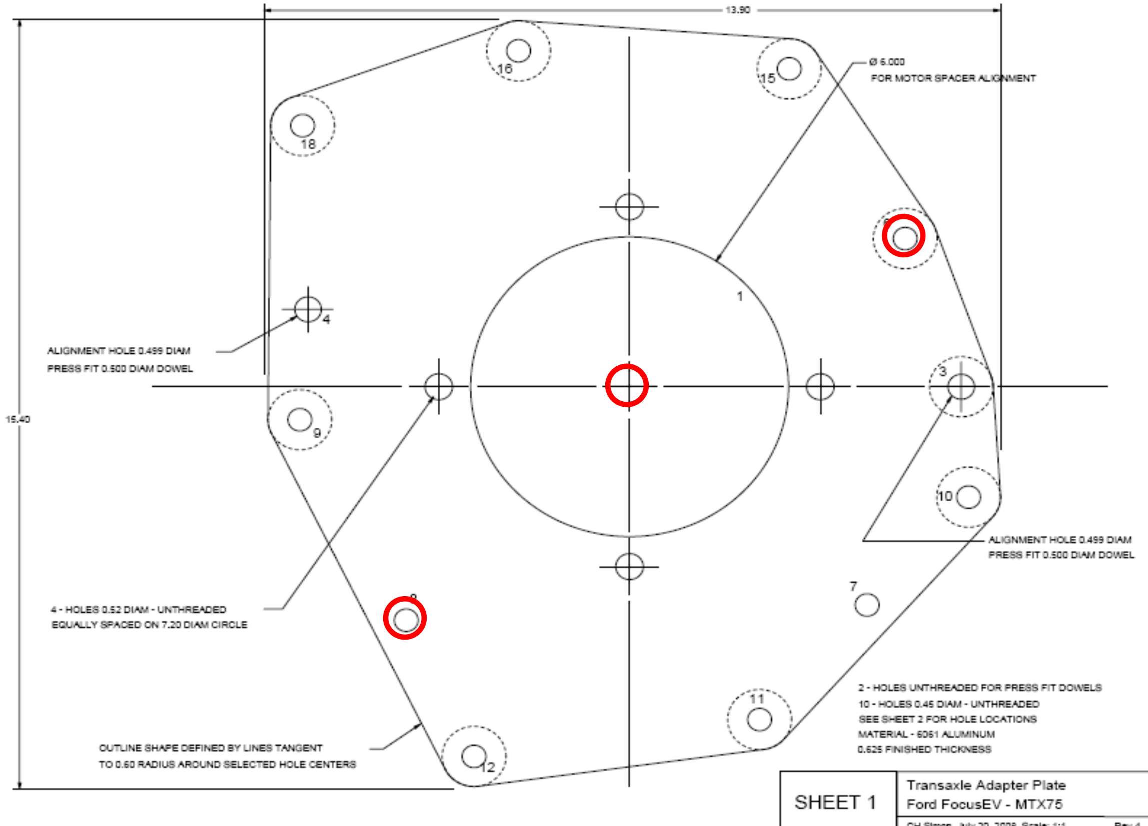
- Internal Combustion Engine (ICE)
- Alternator
- Gas tank
- Fuel pump
- Fuel filler tube
- Power steering pump
- Power steering hoses and cooler
- Exhaust pipe and muffler
- Catalytic converter
- Radiator
- Coolant hoses and reservoir
- Air conditioning compressor
- Air conditioning condenser
- Liquid heater core
- Floor of the trunk
- Rear springs
- Dashboard “idiot lights”

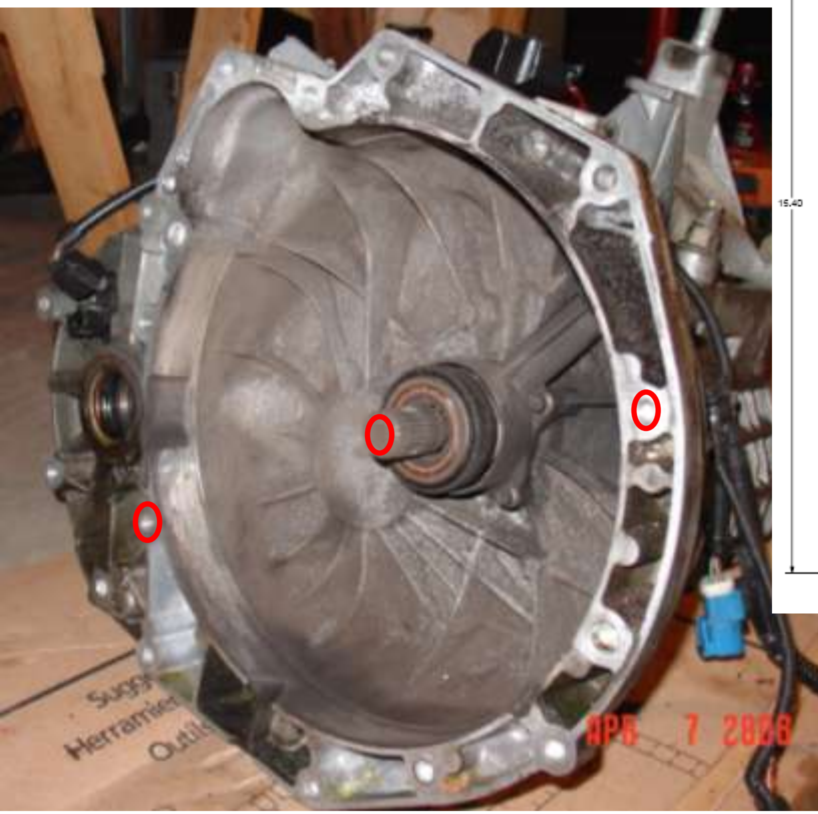
Installed

- Electric motor with adapter
- 4 battery racks
- Insulation in 4 battery racks
- Heaters in 4 battery racks
- 17 batteries
- High-power cables
- High-power circuit breaker
- Motor Controller
- PotBox (connected to accelerator)
- High-Voltage contactors
- Control relays
- Vacuum Pump
- DC/DC converter
- Electric heater element
- Heavy duty rear springs
- Ammeter and Voltmeter
- Lots of wiring

The Internal Combustion Engine (ICE) Comes Out

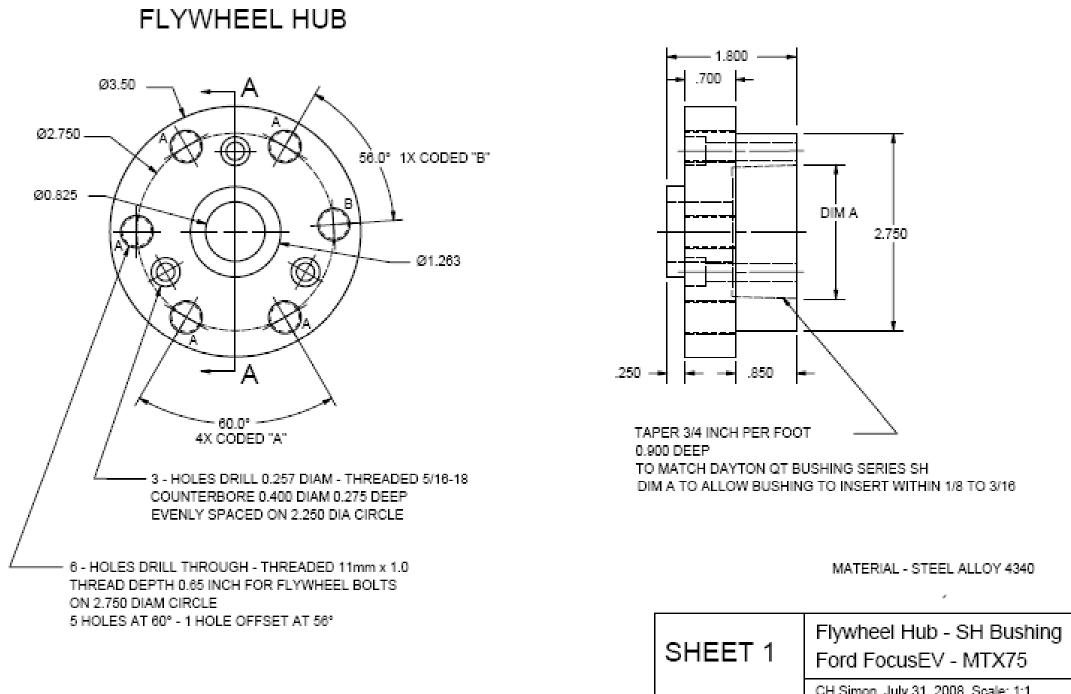
Adapter Design

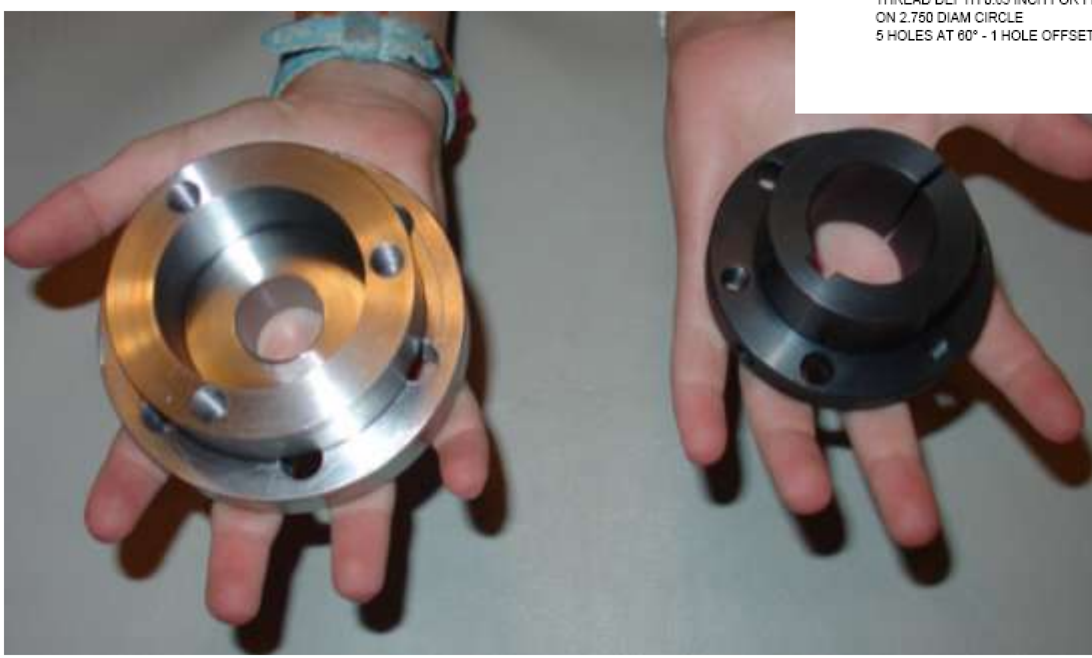




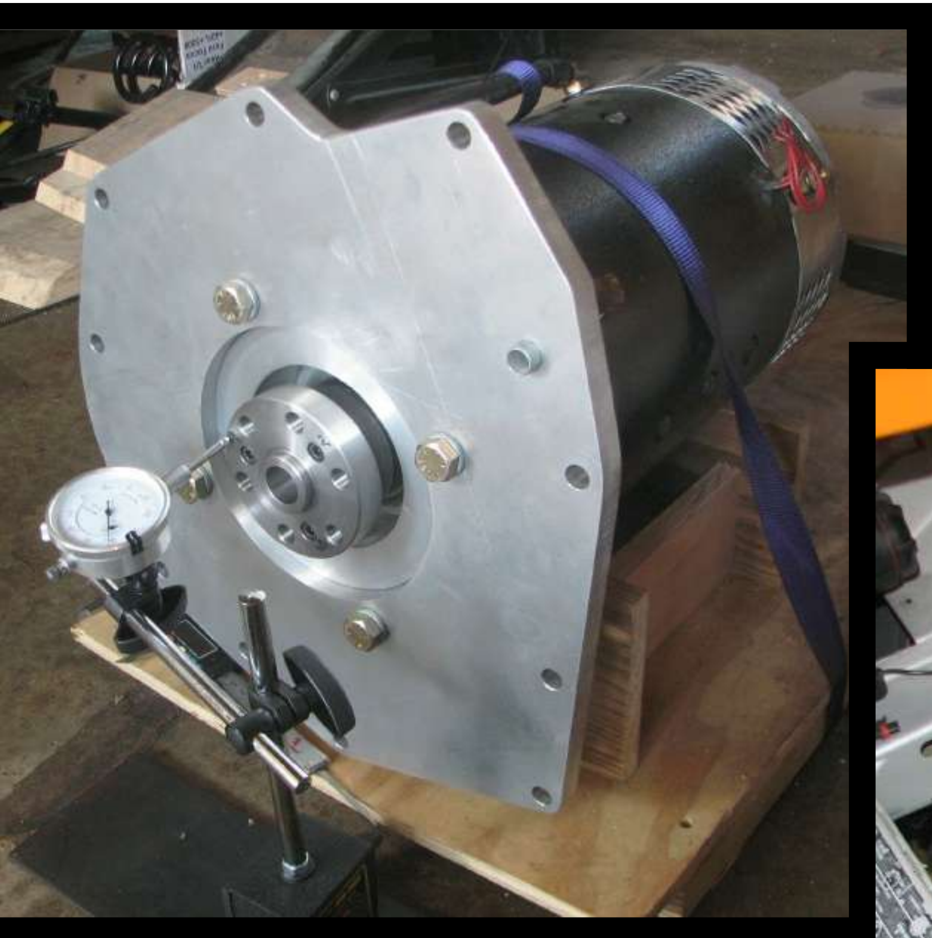
Mating face of the transaxle

Flywheel Hub Design



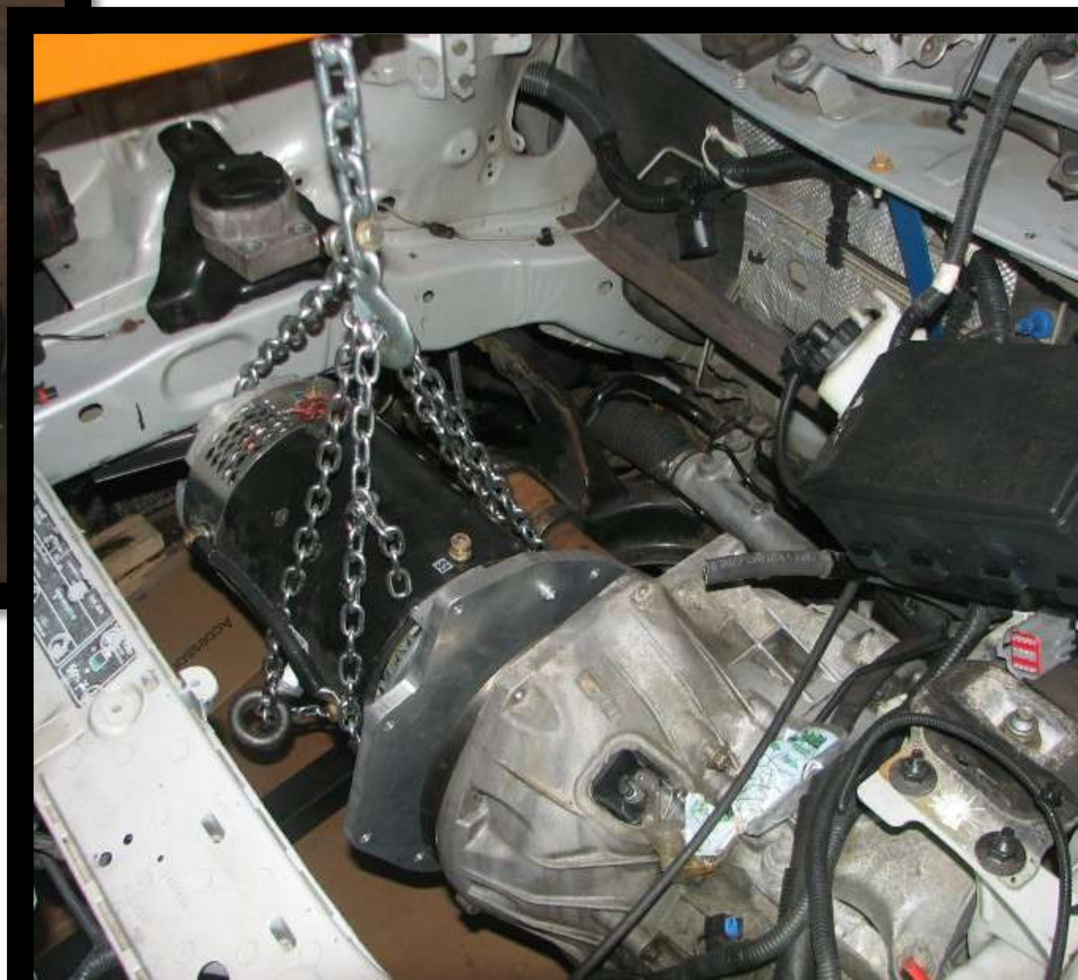


The Electric Motor Goes In



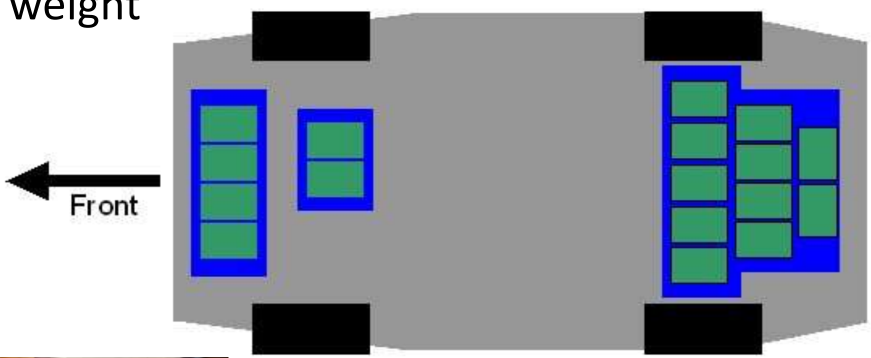
Dial Indicator to check flywheel hub alignment and runout

Aligning the motor to the already installed transaxle



Battery Layout

- What are the guidelines for adding 1,080 lbs of lead batteries?
  1. Keep them out of the passenger compartment
     - They are filled with acid and vent hydrogen at the end of charging
  2. Keep them low and near the center of the car
     - Low center of gravity for better handling
- My car is a compromise based on where they'll fit and the structure that can support the weight



Front and mid battery racks

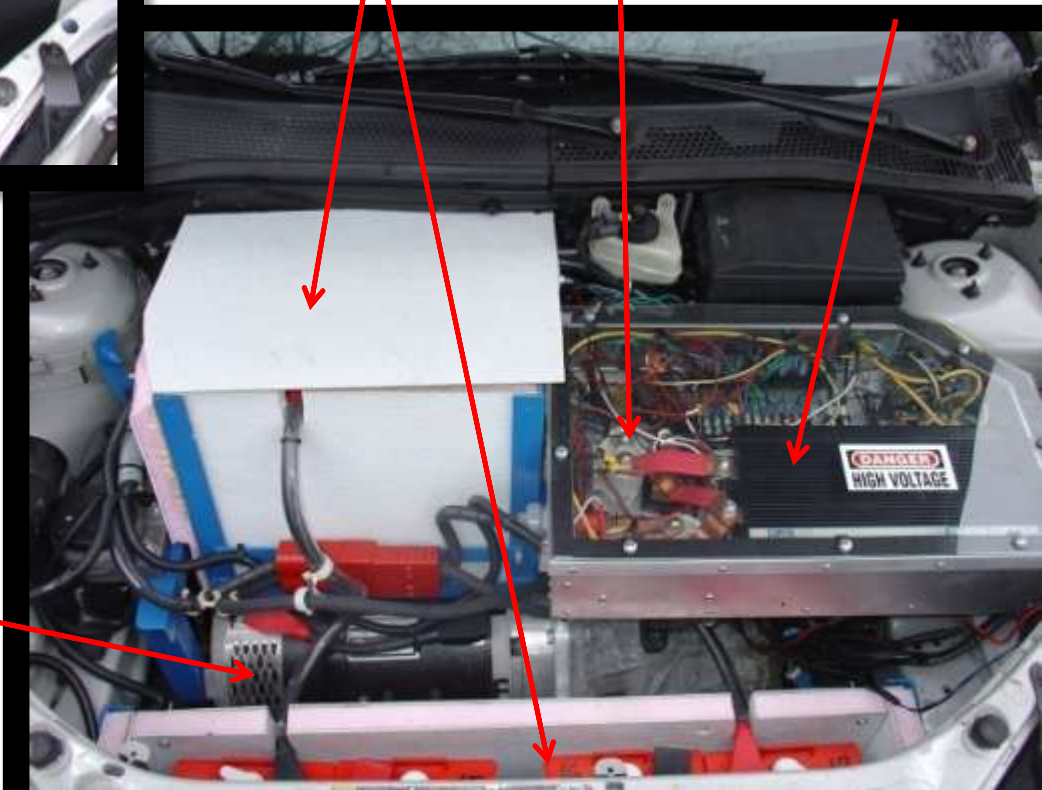
Rear battery rack

Before and After

Contactors and relays

Electronic Controller

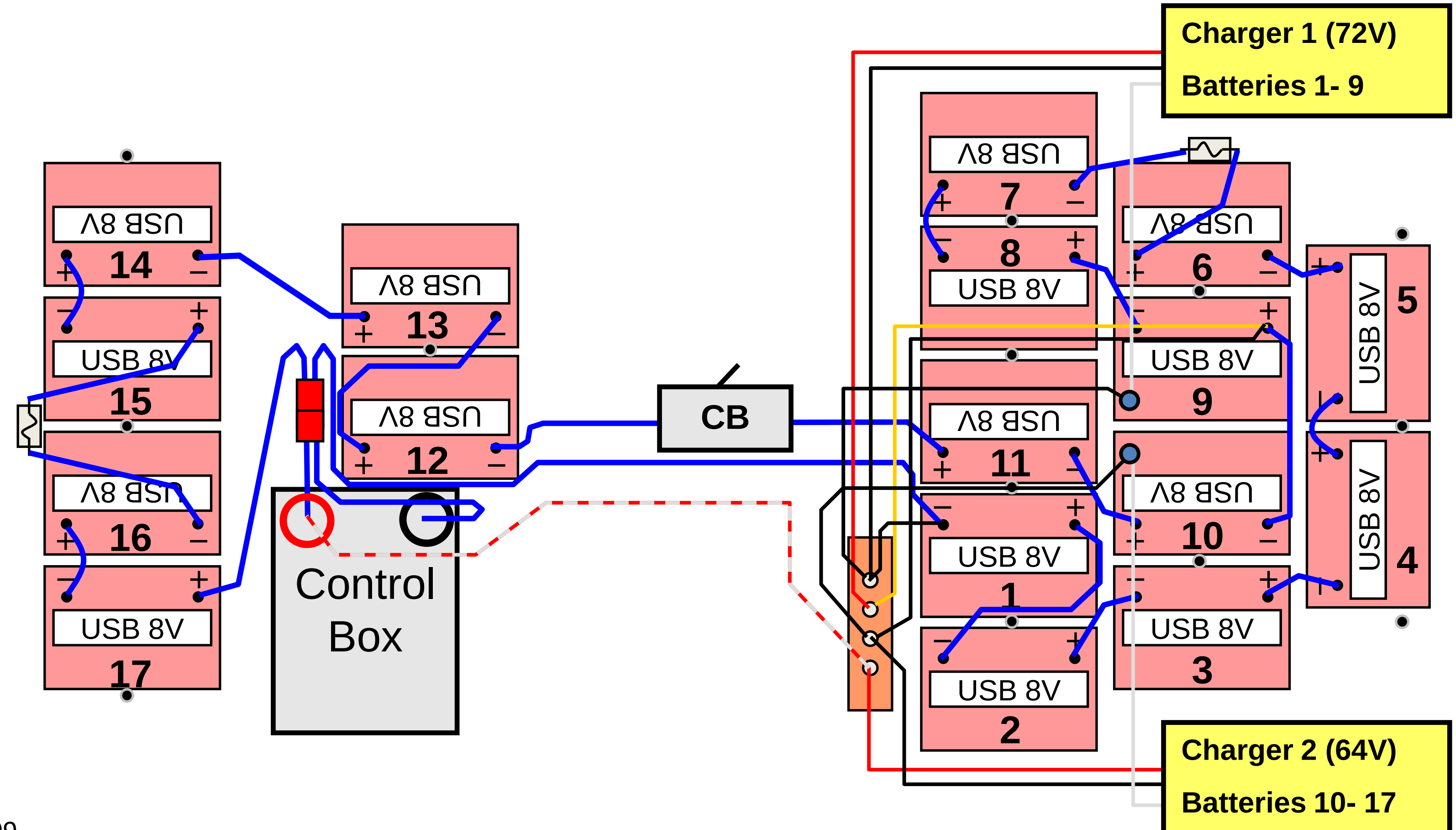
Batteries



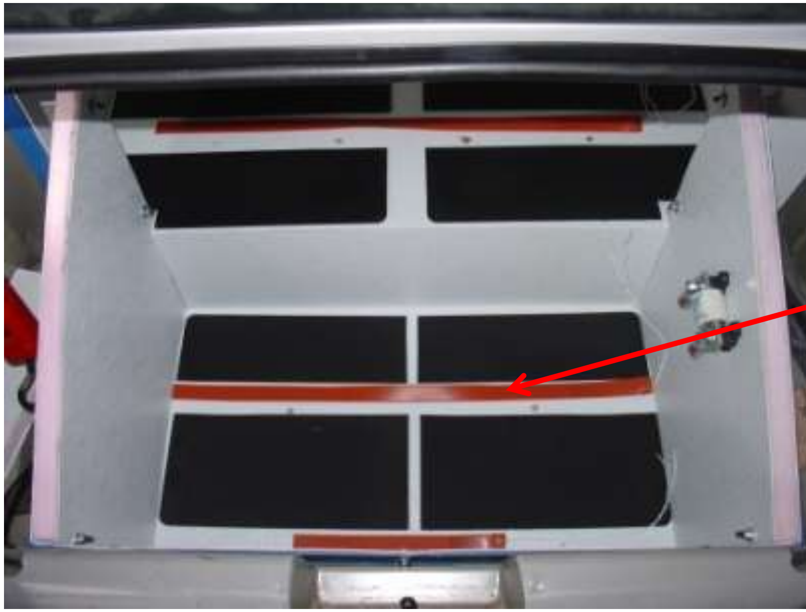
Electric Motor

Battery Connections

- Batteries are connected in series with 00 gauge stranded copper cable
- Use automotive style lead battery posts with copper terminals for low resistance connections
- Keep the wiring short for lower resistive losses (and lower cost!)
- Minimize the loop area of the current (up to 500A pulse width modulated at 15 KHz)
- Circuit breaker in the middle of the pack – emergency shut-off accessible by the driver

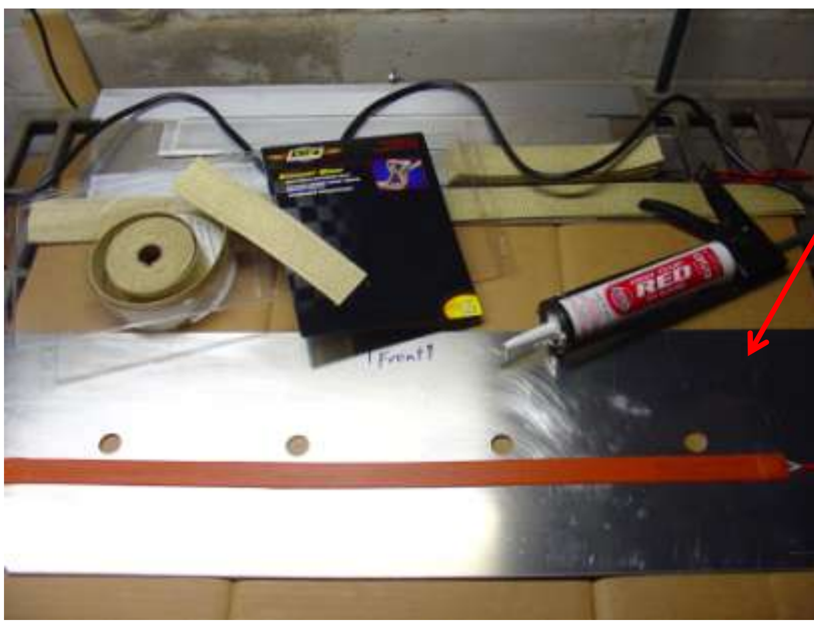


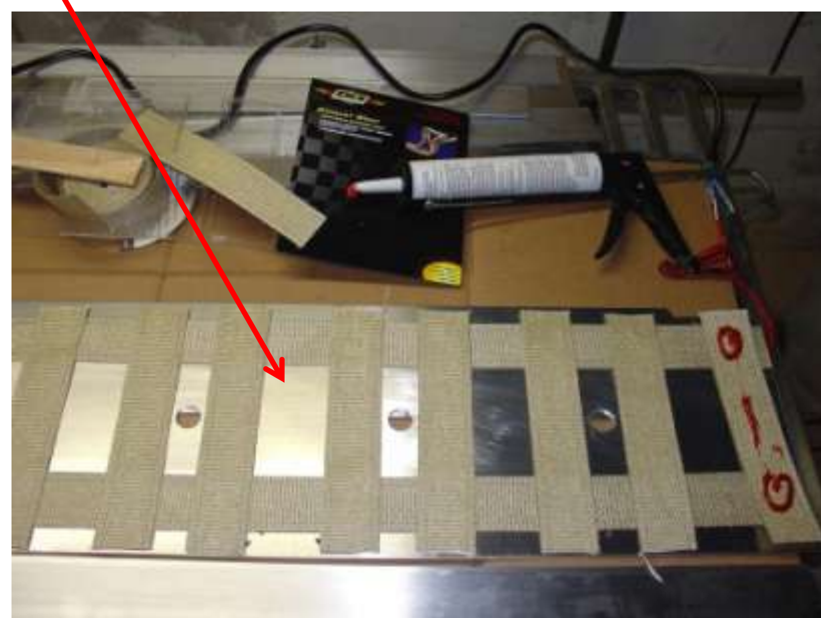
Battery Heaters



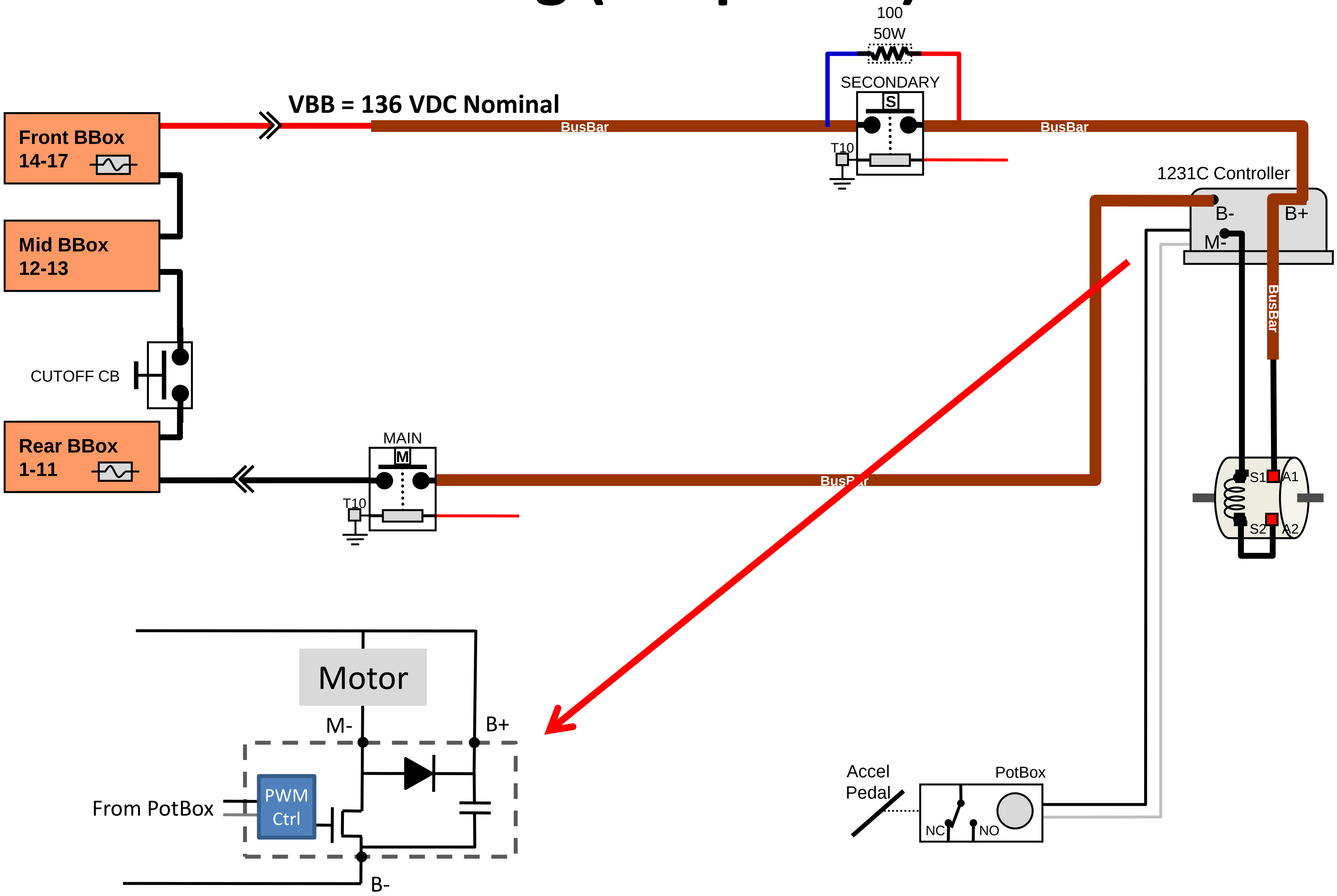
While charging 110 VAC heating elements are plugged in. There are thermostats for each set of batteries. It took me three tries to get it right.

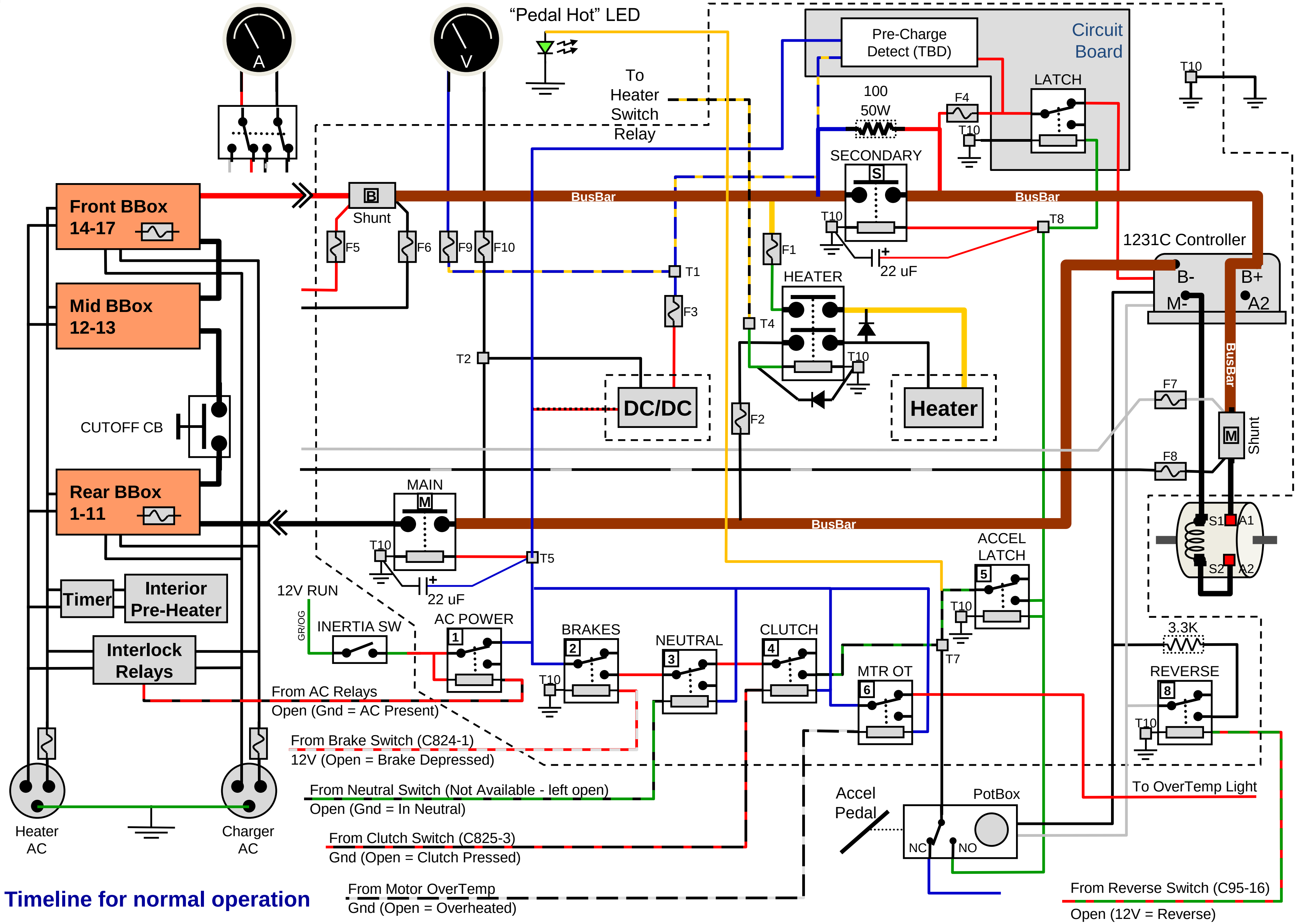
- Attempt 1 – Bad smells and discolored fiberglass
- Attempt 2 – Another EV converter burned up his heater strips and melted through his batteries
- Attempt 3 – Success! Gently warming the batteries using an aluminum heat-spreader





Wiring (Simplified)





Timeline for normal operation

Key ON	Caps charged	Pedal depressed	Pedal released	Brake depressed
MAIN on, Pre-charge, DC/DC on	PH LED on	KSI on, ACCEL Latch on, SECOND on		ACCEL Latch off, KSI off, SECOND off

Wiring as Implemented

EV Control

MAIN contactor = Key on & Inertia Switch OK & No AC POWER

SECONDARY contactor = MAIN cont & No BRAKES & No CLUTCH & ACCEL Latch

• AC POWER relay path will be closed when neither the chargers or the heaters are connected to AC power.

• BRAKES relay path will be closed when the brake pedal is not depressed.

• CLUTCH relay path will be closed when the clutch pedal is not depressed.

• Purpose of ACCEL Latch relay: Prevent the SECONDARY contactor from opening and closing with the ACCEL pedal (when coasting, for example.) Instead it will close when the ACCEL pedal is first pressed and open when the BRAKES or CLUTCH are applied.

Bat Pack = 17 x 4 cells = 68 cells (136 VDC)

• Depleted Bat Pack Voltage (0% SoC) =	68 x 1.91 V = 130 VDC
• Minimum Bat Pack Voltage (40% SoC) =	68 x 1.99 V = 135 VDC
• Maximum Bat Pack Voltage (100% SoC) =	68 x 2.12 V = 144 VDC

FocusEV Parts List (1 of 2)

Item	Qty	Cost Each	Weight each (lbs)	Description	Total Cost	Total Weight (lbs)	Source
Battery Pack	17	$104.00	63	US Battery USB8VGC with SAE posts	$1,768	1,071.0	Northern Battery
Motor	1	$1,535.00	143	ADC FB1-4001A, Aux shaft	$1,535	143.0	www.kta-ev.com
Controller	1	$1,380.00	16	Curtis 1231C-8601 500A - to 144V	$1,380	16.0	www.kta-ev.com
Charger	2	$460.00	12.1	Delta-Q Quiq, 72V, 12A, 110/220 VAC	$920	24.2	http://www.etecevs.com
Flywheel Hub	1	$500.00	6.2	Steel, custom	$500	6.2	Ames Mechanical Development
Transaxle adaptor	1	$300.00	6.2	6061 Aluminum, custom	$300	6.2	Ames Mechanical Development
Motor spacer	1	$300.00	6.2	6061 Aluminum, custom	$300	6.2	Ames Mechanical Development
QD Bushing	1	$14.00	1	Dayton, SH series, 1 1/8 inch bore	$14	1.0	Grainger
Battery Monitor	0	$500.00	0.4	Home built - 3 Monitor Assy's, Display	$0	0.0	
Vacuum Pump	1	$362.00	2.86	MES-DEA 70/6E	$362	2.9	www.metricmind.com
Battery Boxes	3	$126.67	25	Home built using angle iron, fiberglass panels and foam	$380	75.0	Gerlich Steel, Ambles, Menards
Main Contactor	2	$139.00	0.5	Tyco Kilovac 500A EV200AAANA	$278	1.0	www.evsource.com
DC/DC converter	1	$189.00	5.0	IOTA 55A DLS-110-55	$189	5.0	www.evsource.com
Copper wire	50	$3.25	0.5	2/0 cable black	$163	25.0	www.kta-ev.com
Motor Mount - rear	1	$150.00	5.0	KTA M009, black	$150	5.0	www.kta-ev.com
Kill Switch	1	$150.00	5.0	Eaton Heinemann Breaker, 250A, 160V	$150	5.0	www.evsource.com
Interior Heater	1	$127.50	2.0	Solid State with contactor and fuses, 1500W	$128	2.0	www.kta-ev.com

FocusEV Parts List (2 of 2)

Battery Heaters	5	$23.00	0.1	Strip heating elements, 1"x12" and 1"x30"	$115	0.5	www.mcmaster.com
Thermostats	4	$8.00	0.1	Stancor STC-65 Bimetalic temperature switch	$32	0.4	www.mouser.com
Battery clamps	32	$3.00	0.2	Battery Clamp, Magna 2/0	$96	5.0	www.kta-ev.com
Fuse	2	$42.00	0.6	Ferraz 500A 300V	$84	1.2	www.kta-ev.com
Accelerator Pot	1	$75.00	0.8	Throttle PB-6 0-5K Lever	$75	0.8	www.kta-ev.com
Safety Disconnect	2	$28.50	0.2	Anderson connector, 350 A	$57	0.4	www.kta-ev.com
Controller heatsink	1	$49.00	2.0	Aluminum with 12V fan	$49	2.0	Surplus Sales
Controller fan	2	$12.00	0.2	12V, blowers	$24	0.4	Axman
Interior heater	1	$50.00	1.0	1500W Ceramic Heater Element, 110 VAC	$50	1.0	www.kta-ev.com
Voltage Gauge	1	$48.00	0.1	Westberg Voltmeter, 80-180V	$48	0.1	www.kta-ev.com
Current Gauge	1	$48.00	0.1	Westberg Ammeter 0-500A	$48	0.1	www.kta-ev.com
Shunt	2	$22.50	0.4	50mV = 500A, Deltec MKB-500-50	$45	0.8	www.kta-ev.com
Battery Fans	3	$15.00	0.2	Brushless, 110VAC	$45	0.6	Axman
Battery clamp covers	36	$0.79	0.0	18 red, 18 black (include spares)	$28	0.4	www.evsource.com
3/8" lugs	14	$2.00	0.1	3/8" lugs, 2/0 wire	$28	1.0	www.evsource.com
DPDT Relay	1	$20.00	0.1	for interior heater/battery heater	$20	0.1	Axman
Relay 12V	4	$5.00	0.1	Relay, SPDT, 12V coil	$20	0.4	Axman
Fuseholder	4	$5.00	0.3	Stud block insulator	$20	1.2	www.kta-ev.com
Plastic tubing	20	$1.00	0.0	Cheap tubing to go over cables	$20	0.0	ACE Hardware
5/16" lugs	8	$2.00	0.1	5/16" lugs, 2/0 wire	$16	0.8	www.evsource.com
Heatshrink	4	$2.00	0.0	3/4" read and black	$8	0.0	www.evsource.com

Driving an EV

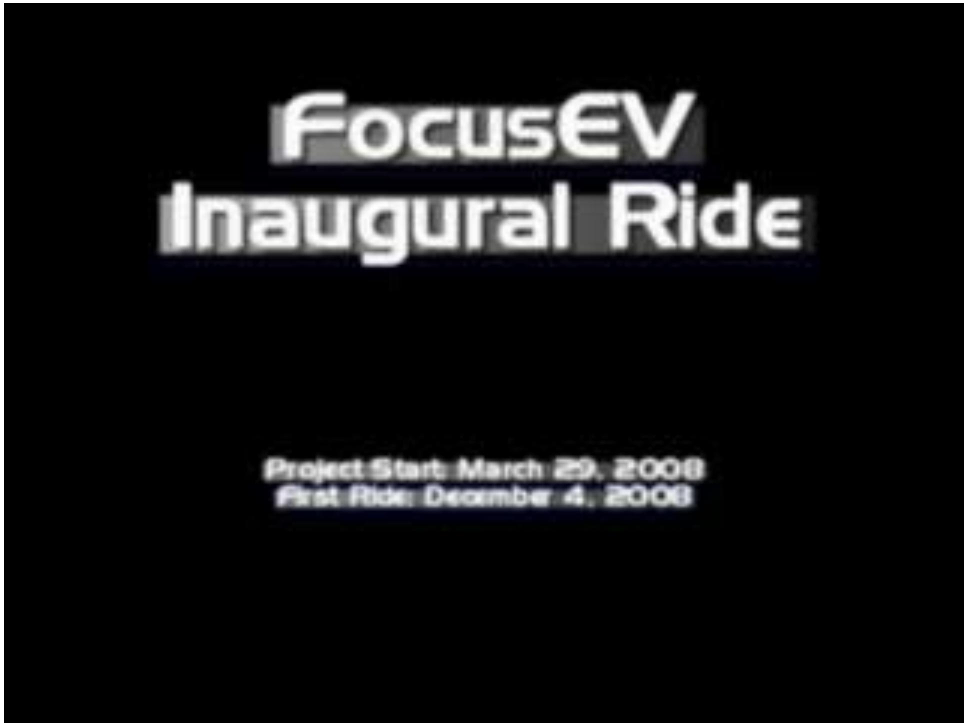
- Lots of torque when starting from a stop (at the expense of large current draw from the batteries)
  - Torque falls off as RPMs increase – the opposite of a modern small engine
- The motor stops spinning when you release the accelerator pedal – no wasted energy in stop-and-go traffic
- Range is affected very much by driving style, as compared to an ICE powered car
  - Avoid prolonged time on freeways (air resistance is proportional to velocity^2)
  - Avoid quick starts
  - Anticipate stoplights and traffic slowing to avoid braking
  - Keep the motor RPMs in the most efficient range (~4000 RPM for a series-wound DC electric motor)
  - These are all basic “hypermiling” techniques

How Some People Drive an EV

- **Acceleration in an EV is less than with an ICE**
  - **Unless your required range is ¼ mile** http://www.plasmaboyracing.com/videos.php

- **Electric 1972 Datsun 1200 vs 2005 Corvette**

FocusEV First Drive



http://www.youtube.com/watch?v=EcNZ5QoW7Yk

Cost for Energy

Internal Combustion Engine vs. Electric Vehicle

ICE Powered Car

- 1 gallon of gas has approximately 36 KW-Hr of energy
- The energy that goes to moving a car down the road is about 20% (~80% is lost as heat)
- For a car that gets 25 MPG and gasoline at $2.00 per gallon, fuel cost is

  $2.00/25 = **$0.08 per mile**

FocusEV

- The FocusEV battery pack has approximately 23 KW-Hr of energy, with about 12.5 KW-Hr usable (before degrading batteries)
- That's ~1/3 of a gallon of gas!
- The energy that goes to moving a car down the road is about 80% (~20% is lost as heat)
- For a car that uses 400 Wh per mile and electricity at $0.10 per KW-Hr, fuel cost is

  0.4 x $0.10 = **$0.04 per mile**

400 Wh/mile is energy equivalent to ~90 MPG

Greenhouse Gasses

Internal Combustion Engine vs. Electric Vehicle

ICE Powered Car

- 19.5 lbs of CO_2 for every gallon of gas consumed in an ICE
- Assume 800 miles per month at 25 MPG (32 gallons)
- CO_2 released into the atmosphere:

  19.5 lbs/gallon x 32 gallons

  = **624 lbs** CO_2 per month
- Additional CO_2 is released in the extraction and refinement of crude oil
  - CO_2 per gallon is increasing as oil is recovered from undesirable sources such as oil sands

FocusEV

- 1.4 lbs*of CO_2 for every kW-hr of electricity generated in the US
- Assume 800 miles per month at 400 W-hr/mile (320 KW-Hr)
- CO_2 released into the atmosphere:

  1.4 lbs/kW-Hr x 320 kW-Hr

  = 448 lbs CO_2 per month
- This will improve as we generate more electricity from solar, wind, and geothermal sources.

** U.S. Environmental Protection Agency estimate, November, 2004*

Considerations for an EV Conversion

Were the goals met?

1 -> 10	
6	Range that allows for my daily commute (Greater than 35 miles at 40 MPH, even in winter)
10	Use of an American donor car
10	A donor car with a manual transmission
8	Maximize the life of the batteries, which is the largest ongoing expense with an EV.
6->9	Ease of use (A vehicle that anyone can drive, with self-management of battery charging)
8	All components extendable to higher range and performance when better batteries become available)
9	Parts that are "Made in USA" where possible (Easier to deal with the suppliers if there's a problem.)
8	A design that prioritizes higher range over faster acceleration.
8	Quiet operation
4	Keep the weight down – stay close to the GVWR (Gross Vehicle Weight Rating)
10	Top speed of at least 65 MPH
9	Minimize initial cost of battery pack
7	Total conversion project cost less than $10,000 (not counting donor car)
6	Include heater and defroster for comfort through the Minnesota winter.
7	Flexible battery layout (not size specific) to allow an upgrade at a later date.
5 -> 9	Suspension modified to compensate for additional weight of the batteries.
9	Brakes must operate as before conversion using a quiet vacuum pump.

FocusEV vs. “the Competition”

Which car would you drive for your daily commute?

	Tesla Roadster	Zenn NEV	FocusEV Home-built
Drive Motor	185 KW AC Induction	5.7 KW 3-phase AC	50 KW Series Wound DC
Battery Pack	53 KW-Hr Li-Ion 375V	5 KW-Hr Lead-Acid 72V - Gel	12.5 KW-Hr Lead-Acid 136V – Wet Cell
Top Speed	125 MPH	25 MPH	70 MPH
Acceleration	3.9 seconds (0 to 60)	Never (0 to 60)	~22 seconds (0 to 60)
Range	220 miles	35 miles	35 miles
Seats	2	2	5

Tesla http://www.teslamotors.com/performance/tech_specs.php
Zenn http://www.zenncarsabq.com/pdf/zenn_2008specs.pdf

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Top Speed	125 MPH	25 MPH	70 MPH
Acceleration	3.9 seconds (0 to 60)	Never (0 to 60)	~22 seconds (0 to 60)
Range	220 miles	35 miles	35 miles
Seats	2	2	5
Cost	$109,000	$15,995	~ $16,000
Hours of labor	None	None	You don't want to know

Tesla http://www.teslamotors.com/performance/tech_specs.php
Zenn http://www.zenncarsabq.com/pdf/zenn_2008specs.pdf

Resources

- The FocusEV Website (includes FAQs) http://www.simonfamily.us/FocusEV

- The Electric Auto Association (with links to local chapters) http://www.eaaev.org

- The EV Album – over 2,000 examples of vehicle conversions (skateboards, bikes, Porches, a Delorean, a Land Rover, etc.) http://www.evalbum.com/