Driving to Net Zero *with full performance*

Bob Simpson - founder and CTO of EVDrive Inc

My History

- 1977 – AS degree in Electronics, LBCC
- 1990 – BSEE from Oregon State University
- June 1977 - June 2011 – Tektronix Inc., Senior HW Design Engineer
- Decades of racing, wrenching, fabrication, and tuning on motorcycles and automobiles
- Life-long passion with woodworking, metalworking, automotive technology, and electrical engineering

With the convergence of these life experiences, and with a passion for performance AND reduction of fossil fuel use,

An electric conversion project is conceived in late 2007

Inspiration

The AC powered Tesla

Electric Vehicle Project goals

- Make an electric vehicle by conversion for daily 40 mile commute
- Choose an ideal and competent sports car platform
- Meet or exceed original performance
- Match the weight and its distribution
- Generate the annual energy consumed using grid tied solar array for net zero energy consumption

Platform Choice

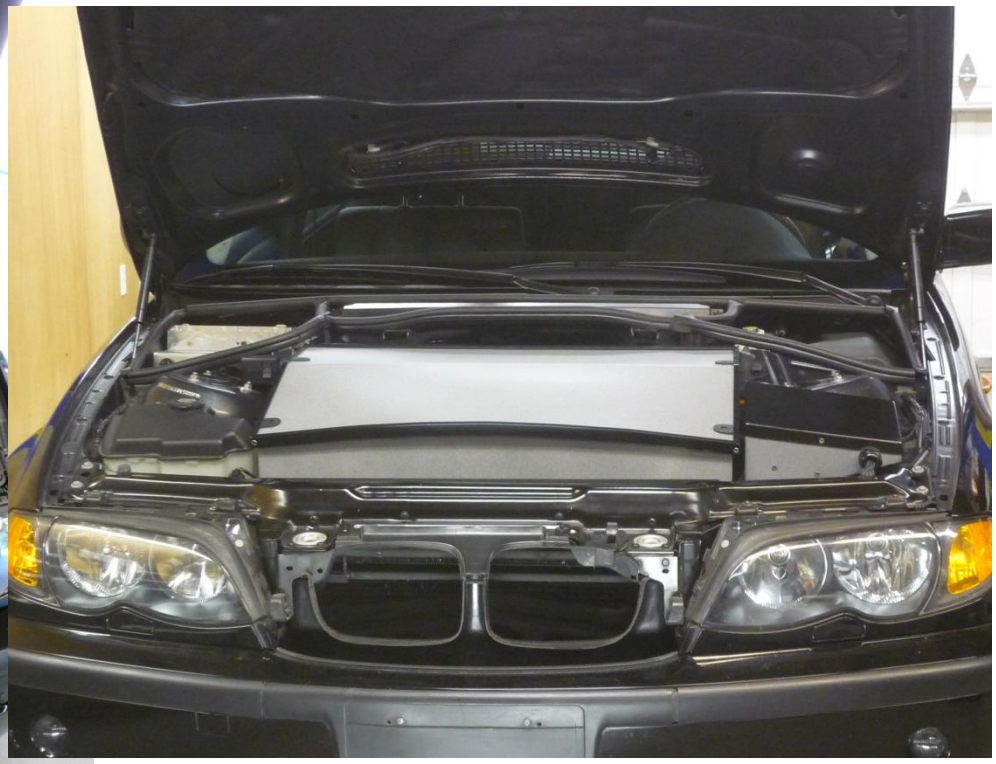
BMW 325i

performance and fuel use measured and documented

Ready for conversion

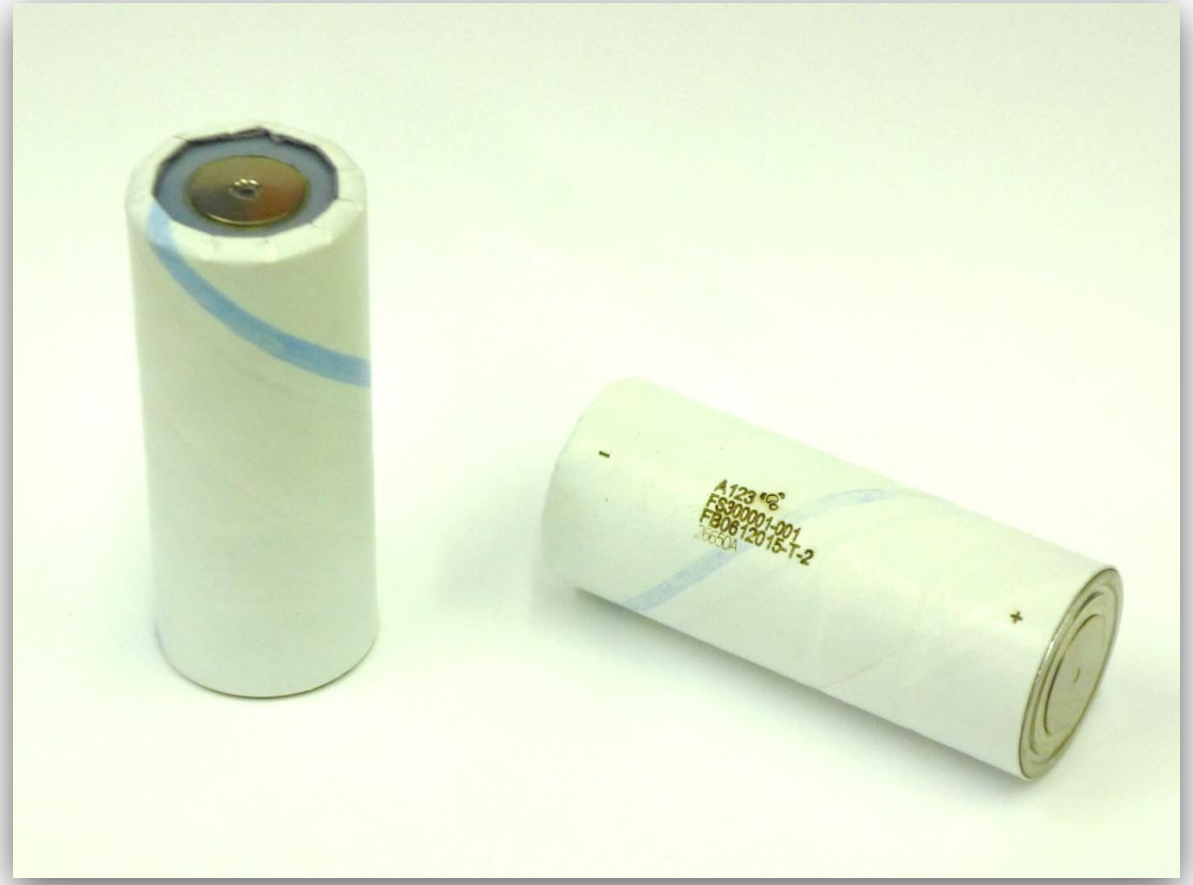
The Upgrade

ICE is pulled at 38k miles



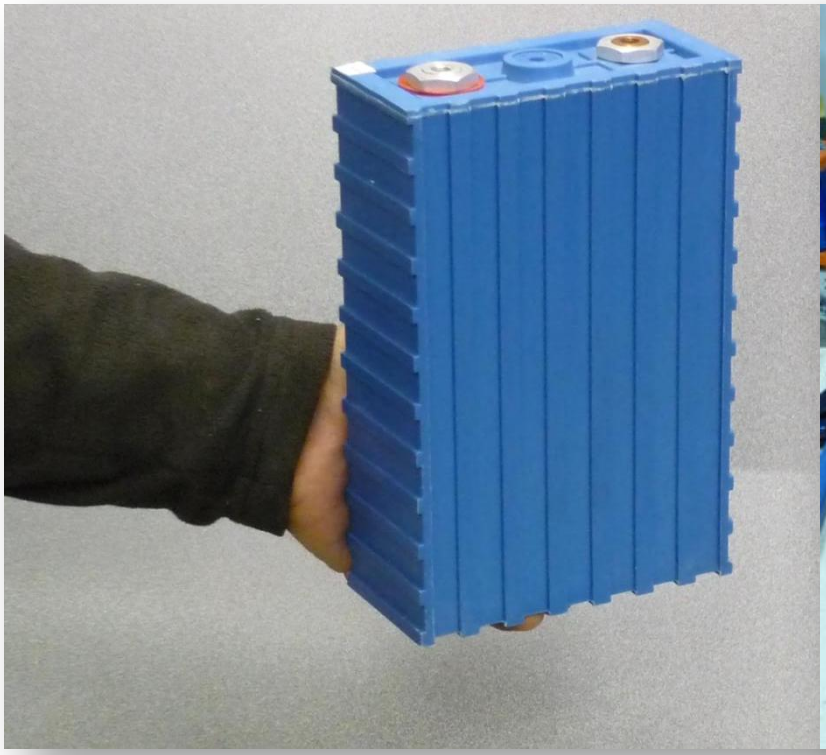
Electric Drive with 45 mile range under the hood

The Performance Enabler

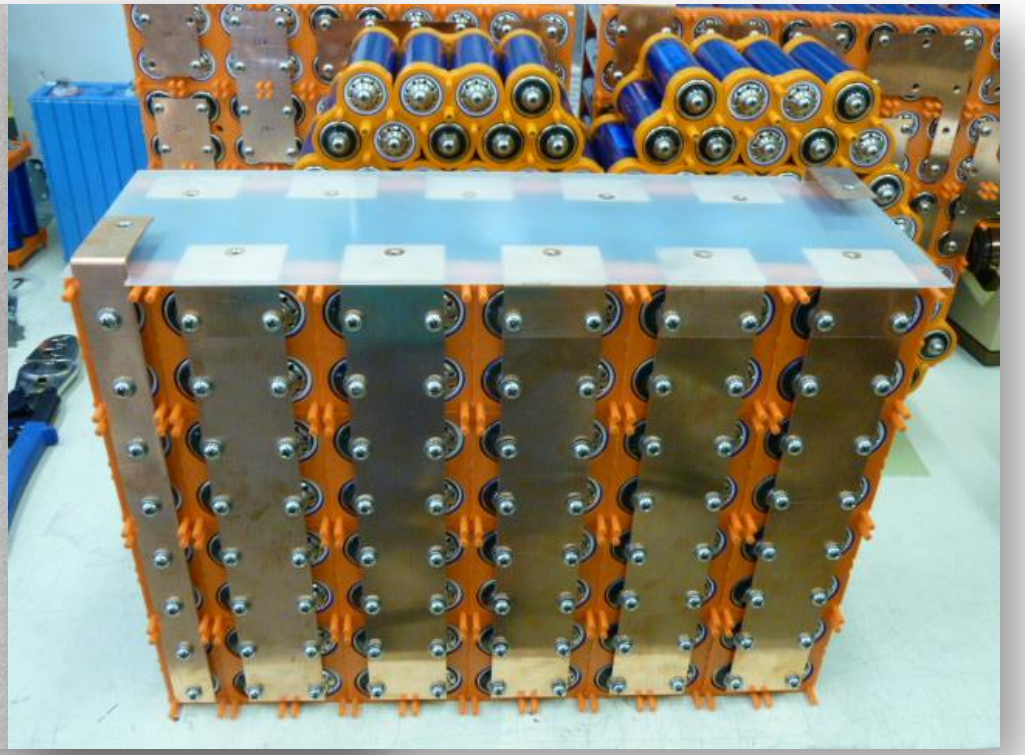


A123 Systems 2.3Ah 26650 cells
Robust and Capable for high performance EV's

Larger Format Lithium Ion

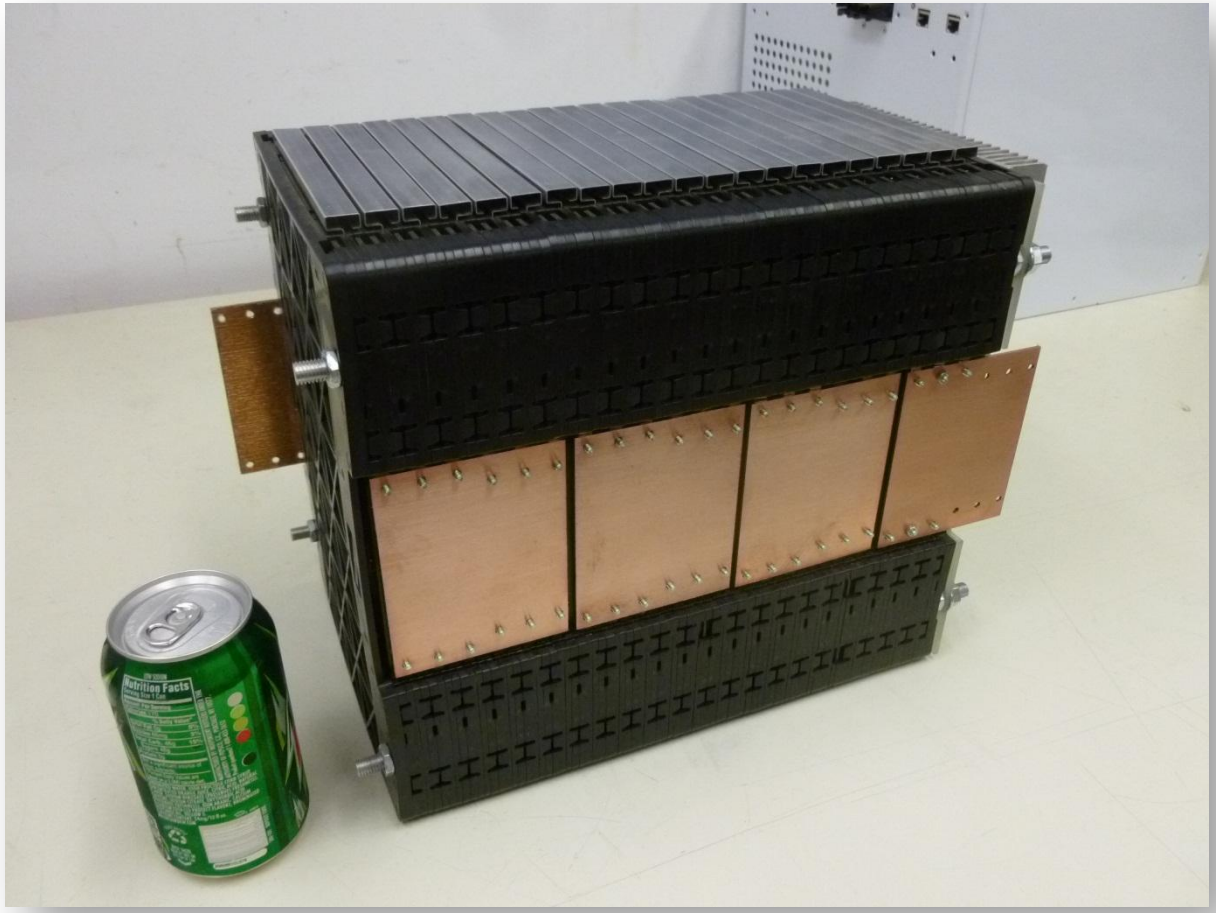


100Ahr cell



10Ahr cells

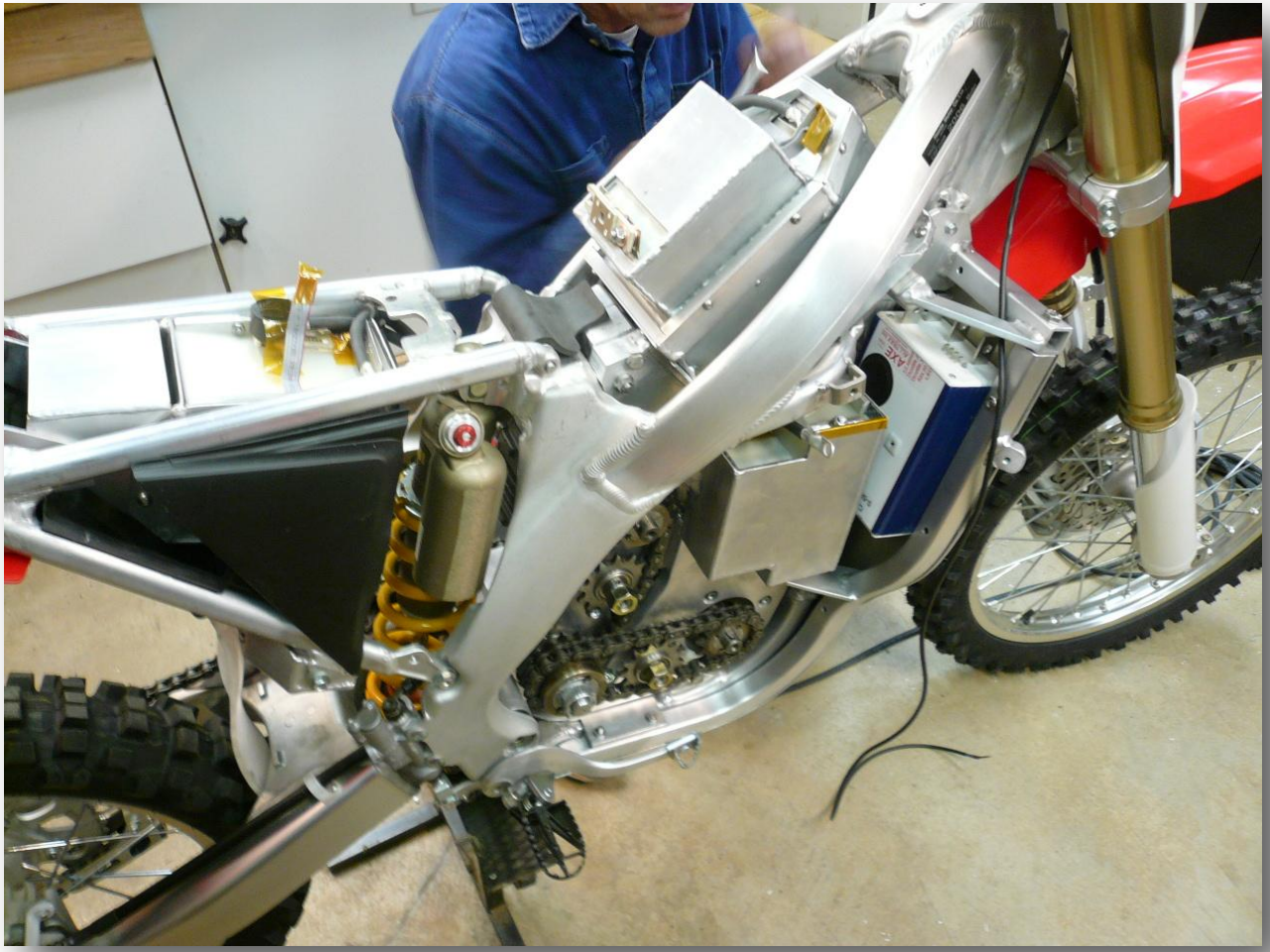
Automotive Format Lithium Ion



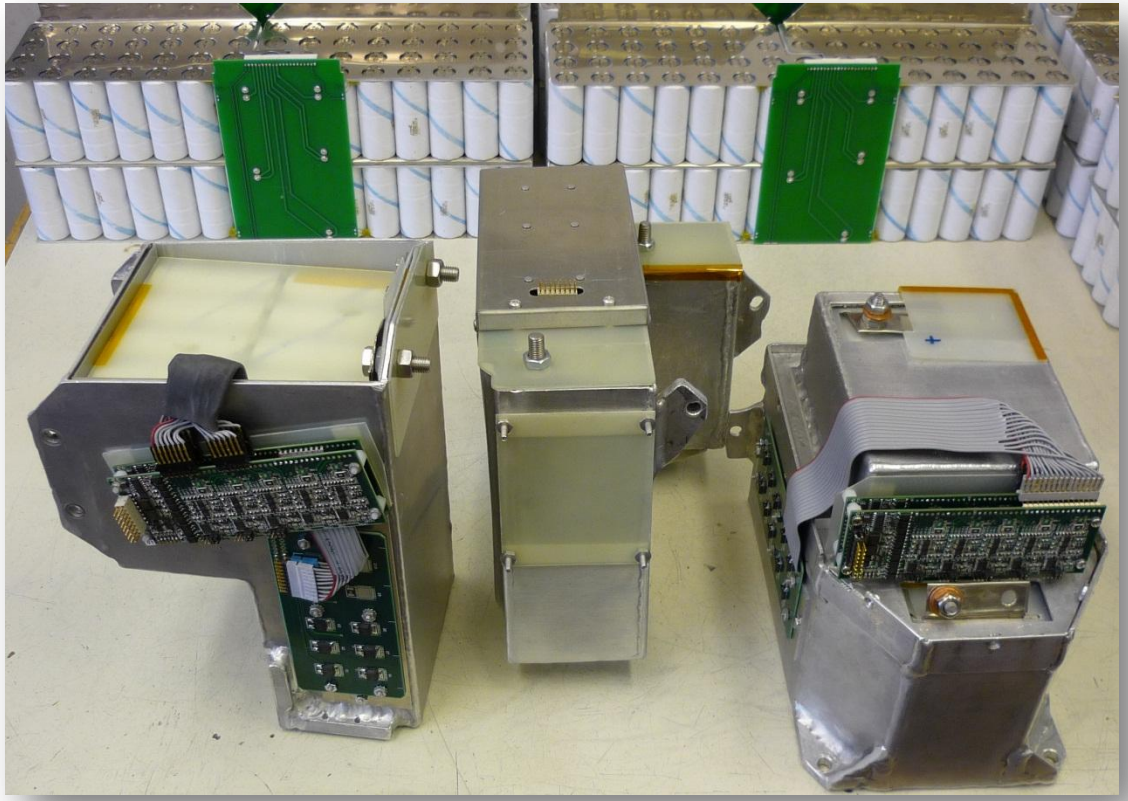
One of many modules, this configuration delivers 1500 Amps

Warm Up Projects

Cell packaging training



Packaged, monitored, and controlled



Air box Motor area Gas tank

A rather complex set of packages indeed, but great for training.

These (A123 Systems) cells in this arrangement can deliver up to 960 Amps @ 72V (90 HP)

Result: Full performance!

Cells are no longer the limiting element

Dynamic Testing

More Testing

More Testing…

BMW Battery pack

This 700 Volt pack can deliver 1200 amps peak (10sec).
Under full acceleration, the load on the pack is only 13% of that.

Inside the pack

15.5kWhr capacity, Configurable for:

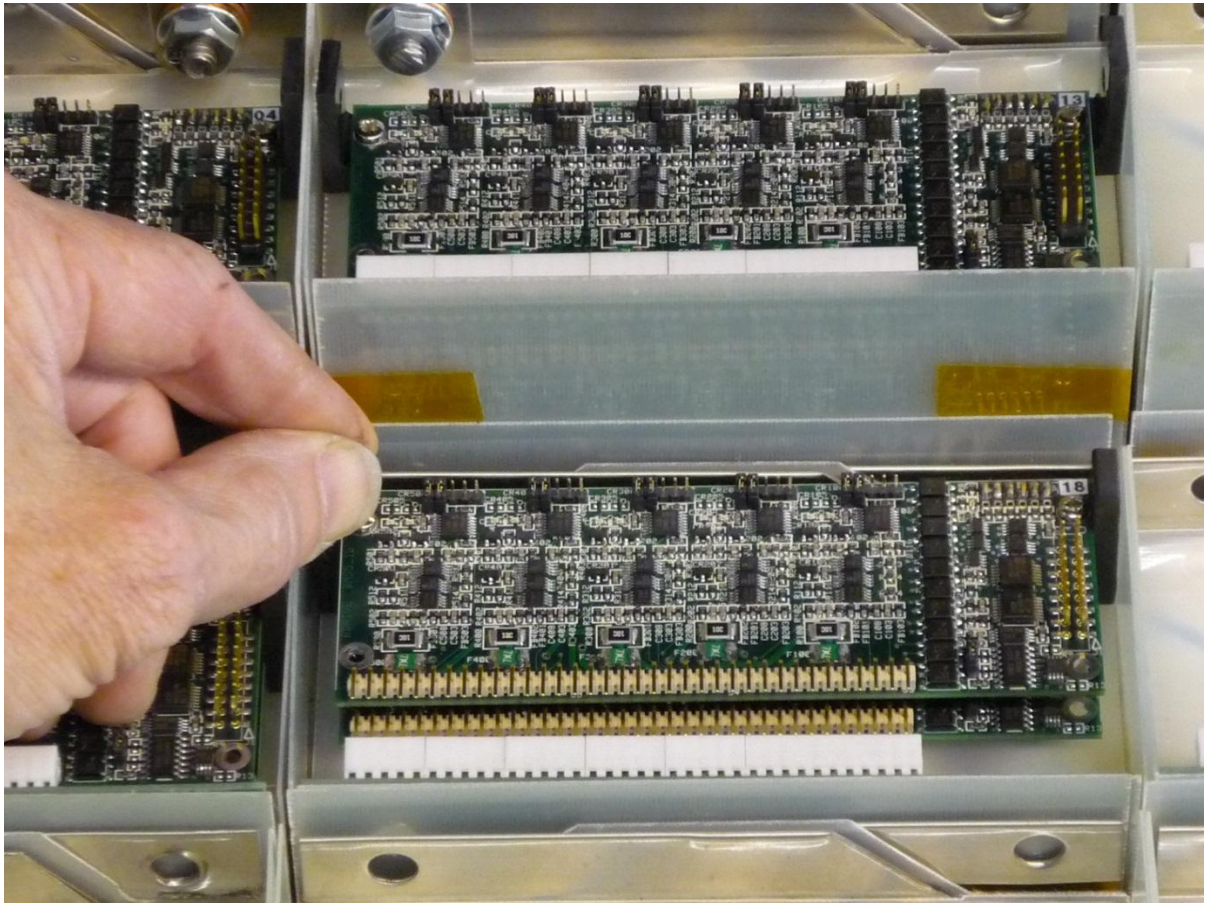
700V @ 23Ahr

350V @ 46Hhr

Modular Format

Safe voltage levels with modules, 30 total in this 45 mile pack

Battery Management System



With proper management, these cells can last for decades

Lithium Ion End of Life

- Batteries are considered at end of life at 80%
- Automotive cells have second life with Uninterruptable Power Systems for backup power.
- After another decade, cells are recycled with Lithium Ion recovery rate of 95% that can go back into new cells.
- No hazardous materials in this chemistry

Electric Vehicle Life cycle impact

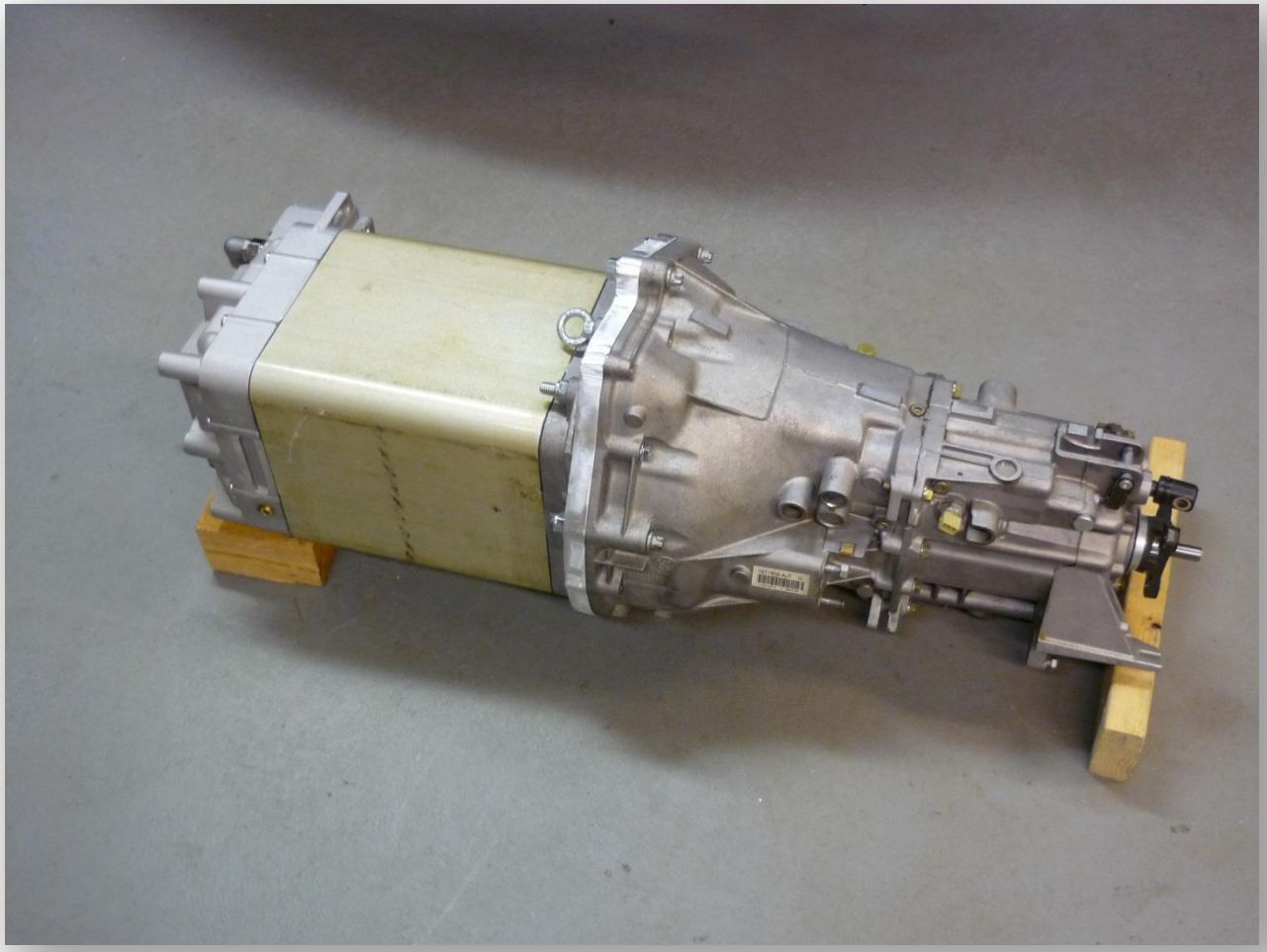
- Over typical 10 year life or 100,000 miles, an EV reaches payback at ~40,000 miles – with current production levels

- With the improvements from economy of scale, the payback point reached even sooner

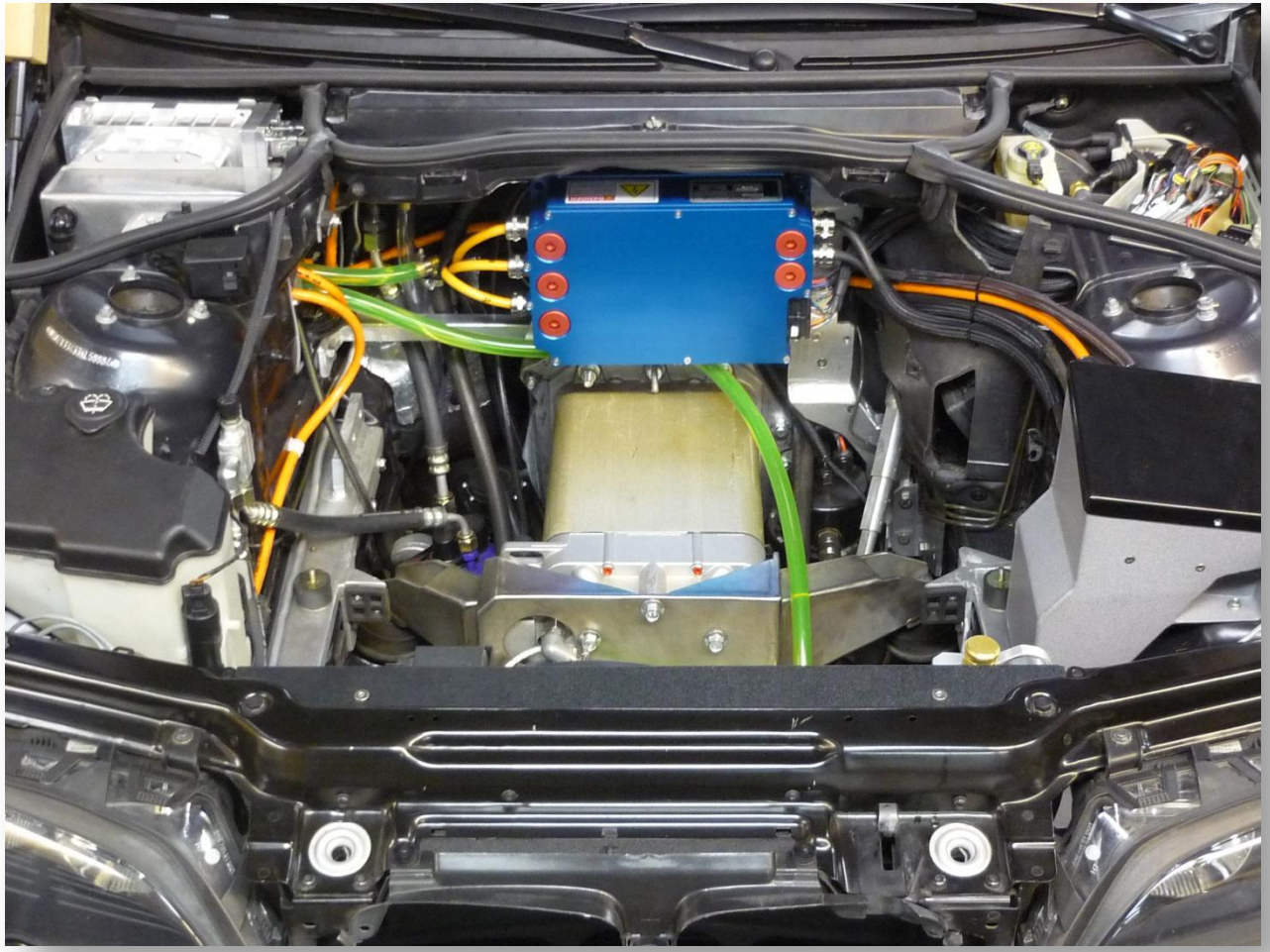
Comparison with current generation ICE

	ICE	Electric – AC Induction
Torque	175 ft-lb	265 ft-lb
Power	185 HP	200 HP

Siemens AC Induction motor
Mated to 5 speed transmission



100kW (134HP) Drive System



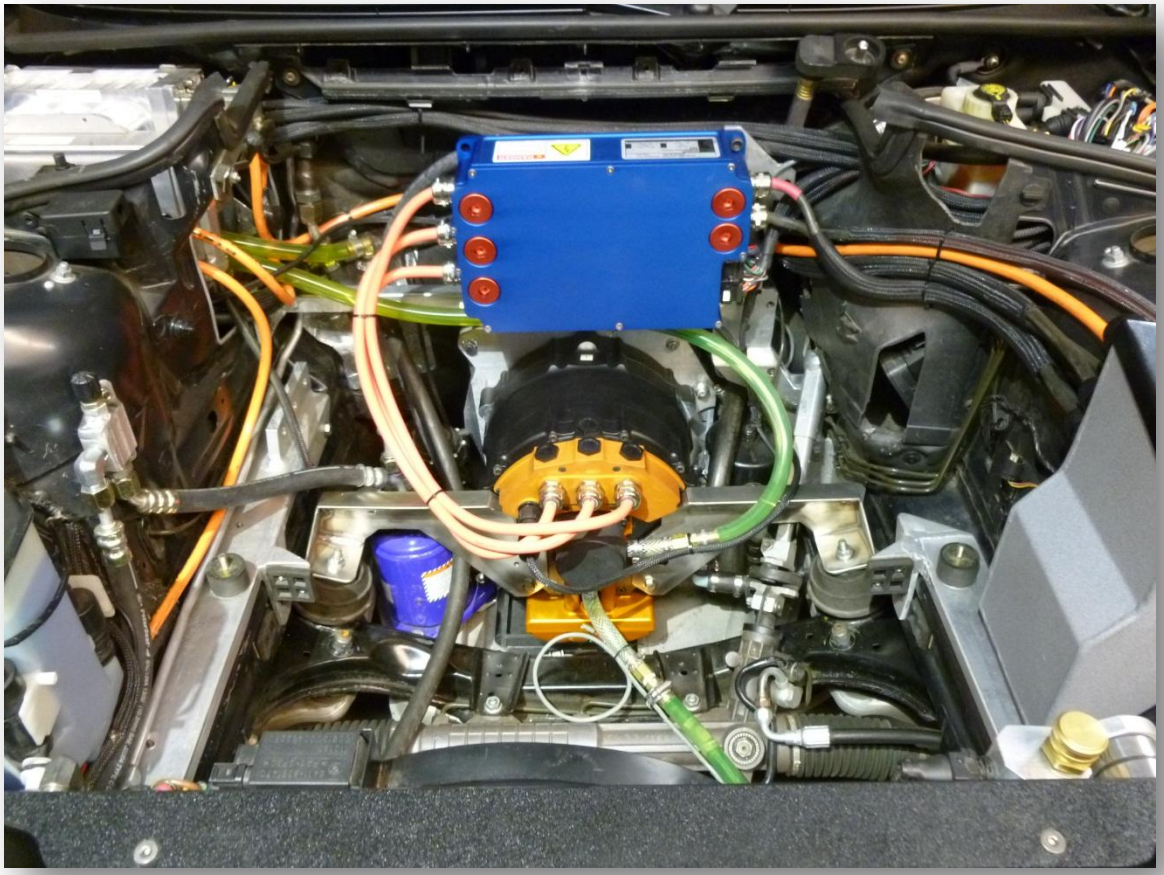
Performance matches the original BMW 325i

Completed IPM motor package

Power density **doubles** compared to original Siemens AC Induction motor

This IPM motor is half the weight: 101 lbs. vs. 200 lbs. with AC Induction

BMW Upgrade to IPM motor technology



150kW (200HP) peak, >100HP continuous

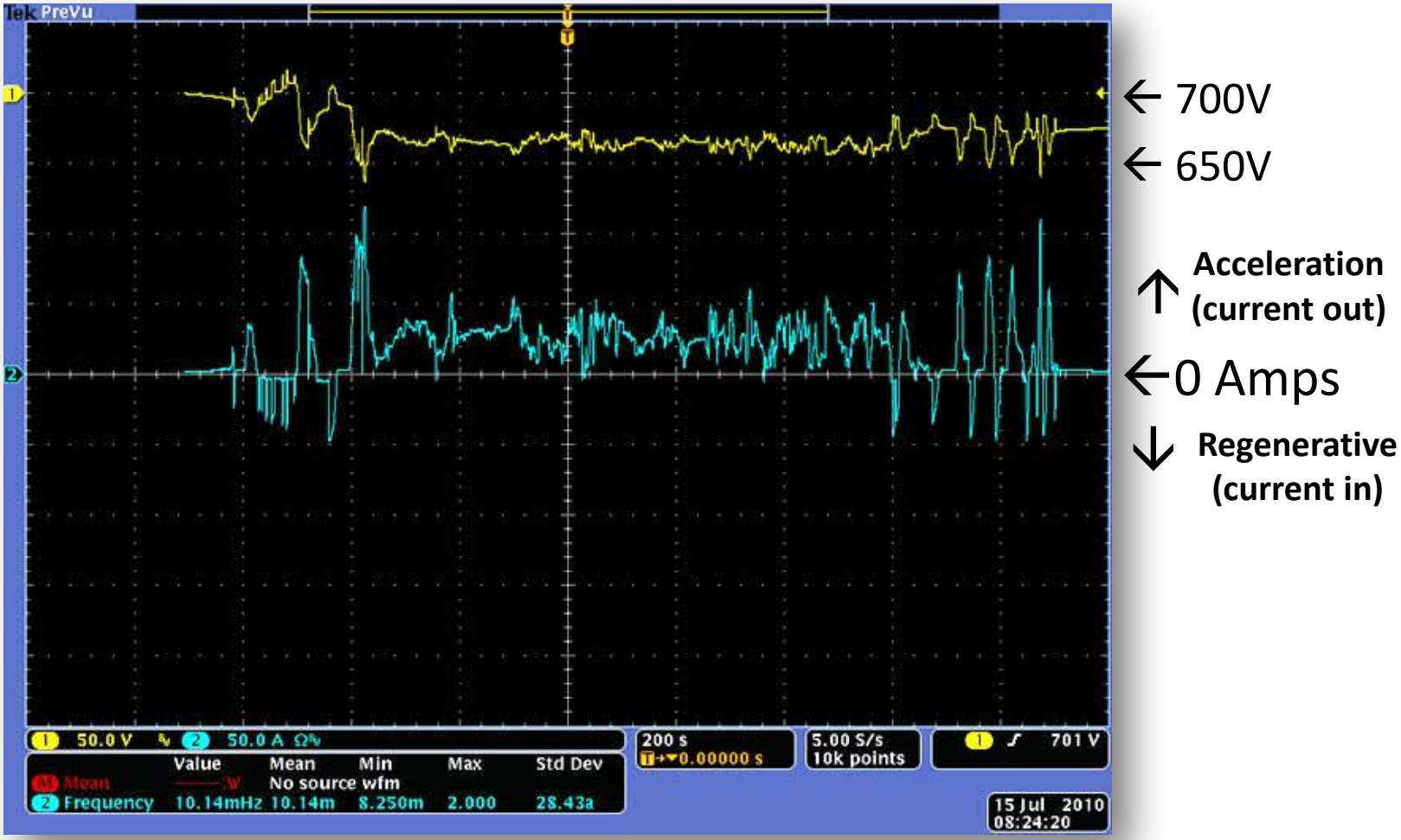
Performance now **exceeds original** BMW 325i ICE drive

The Result

Fun, Fast and efficient

Over 21000 miles logged as of Aug 2013

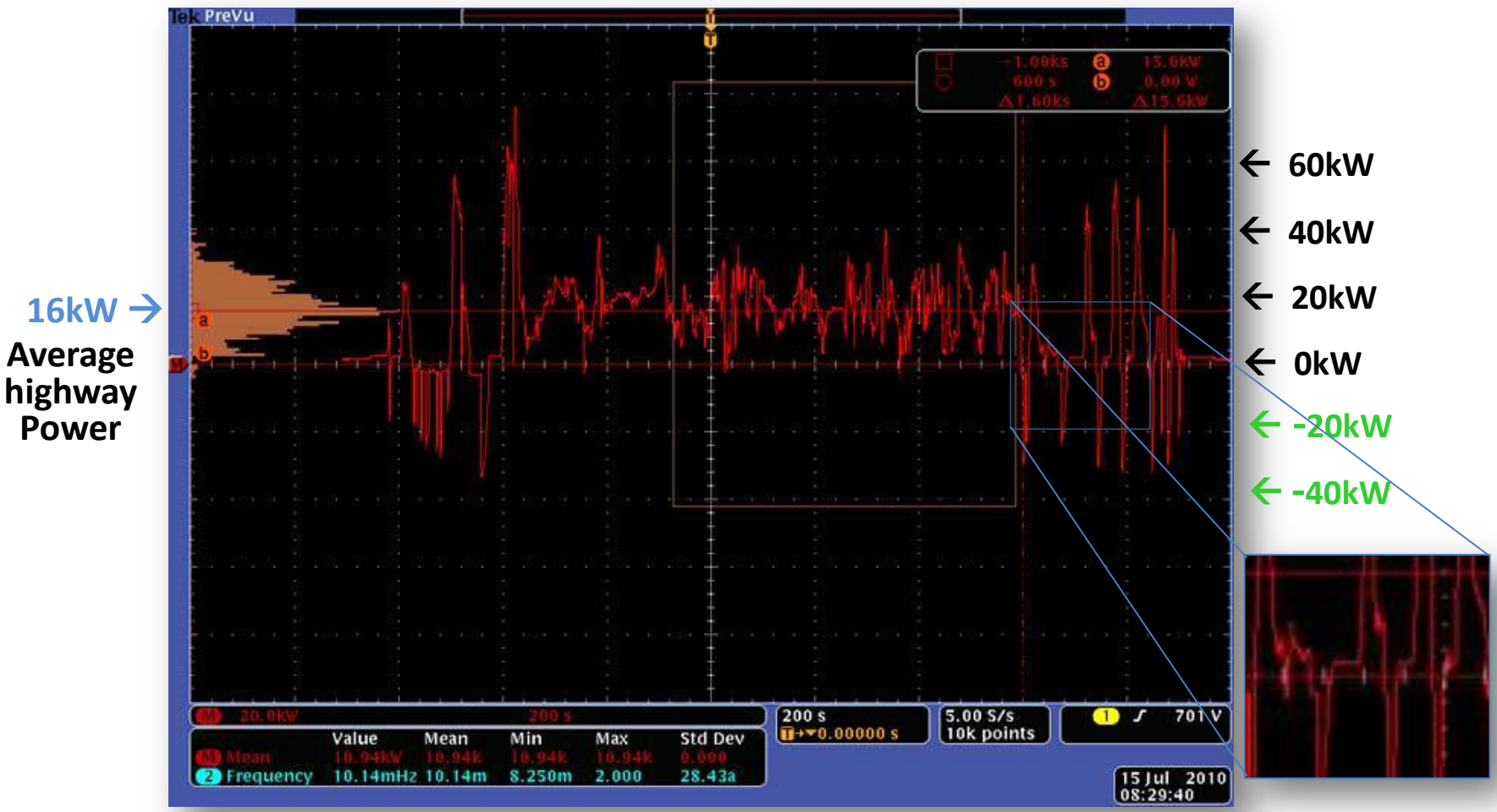
Voltage and current Waveforms of 20 mile drive



Yellow trace is pack Voltage

Blue trace is pack Current

BMW Power profile – 20 mile drive



The true power being consumed and generated

Power Sources

- Enormous grid capacity during off peak time
- Most charging can be done at home, overnight
- Allows driving from local &renewable energy
- 5.6kW Grid-tied Solar array generates over 18,000 miles of driving annually in Portland area

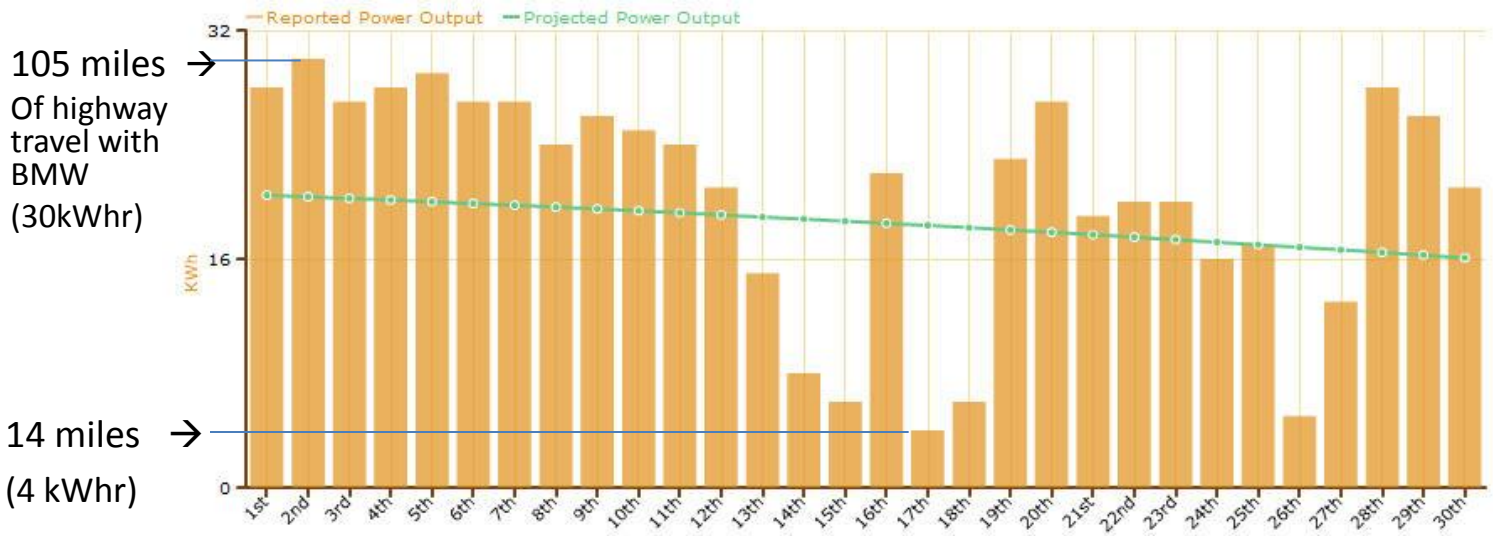
continued

Grid-Tied Solar array example

Out of the way and tied to the grid, this 24 panel array will quietly generate power for decades. The only maintenance is glass cleaning.

5.6kW Array generated **5.3MWhr** this year → >18,000 miles of BMW driving

Solar array power to Grid – First full month



September 2011

Annual Cost Comparison: Gas vs. Electric

BMW Drive source	Miles per year	Fuel Effeciency	Annual fuel/energy use/source	Average fuel/energy price	Annual fuel/energy cost	Cents per mile	
Gasoline	12000	28 miles / gal	428 gal	$4 / gal	$1,712.00	**14.2**	
Electric w/std. rate	12000	3.5 miles /kWhr	3428 kWhr	10¢ / kWhr	$342.80	**2.8**	→ 5.1 Times better than gas
Electric w/TOU	12000	3.5 miles / kWhr	3428 kWhr	7.7¢ / kWhr	$264.00	**2.2**	→ 6.5 Times better than gas
5.6kW Solar array			4800 kWhr	-13.7¢ / kWhr	-$656.00		
Electric w/TOU	12000	3.5 miles / kWhr	3428 kWhr	7.7¢ / kWhr	$264.00	**-3.3**	→ makes 3.3 cents/mile **profit**

TOU = Time Of Use metering:

On-Peak time → 16.6 cents / kWhr

Mid-Peak time → 10.7 cents / kWhr

Off-Peak time → 7.7 cents / kWhr

With solar array and TOU metering, I make money driving my BMW electric sports car!

continued

Fossil fuel Power Sources

- If 100% of this EV power comes from coal, it still reduces C02 emissions by >27% **considering only the 19.2 lbs of CO2 per gallon of gasoline!**
- The energy used to refine 1 gallon of gasoline can directly drive my BMW ~25 highway miles
- The government is subsidizing fuel by $2.50/gallon just to police the oil delivery

Impact to grid

- Jim Piro, President of PGE: “Portland area is ready for 170,000 electric vehicles over the next decade.” This would represent 2% of base load.
- Nationally, 10 Million EV’s represent 0.8% of existing grid demand
- Increases the efficiency of the grid infrastructure by adding demand during times of excess capacity
- When V2G is standardized, the EV becomes a resource for grid stabilization, by *sourcing* power.
- Distributed solar removes load from mains during peak times (7.5% transmission losses eliminated)

Benefits - Cost

- Impact on home power bill: over 6 times less cost than gasoline at current $4 /gal (with flat rate power)
- Time of use metering makes driving cost even lower by further reducing the home's monthly power bill
- V2G participation will make the charging power even cheaper for EV users
- History shows utility power much more stable than oil

Other benefits

- Service and Maintenance reduced to:
  - Tires
  - Wiper blades
  - Brake pads (very little use now with regen braking)
- Emissions no longer around humans – huge benefit in high density population areas.
- Pre-HVAC conditioning via phone now practical
- Silence is now an option!

The only problem…. Range.

The answer to “range anxiety”

- Start with ~100 mile range - pure electric drive
- Add a Range EXtender:
  - Small ICE with very high power/weight & volume
  - Deliver enough power for continuous highway speeds

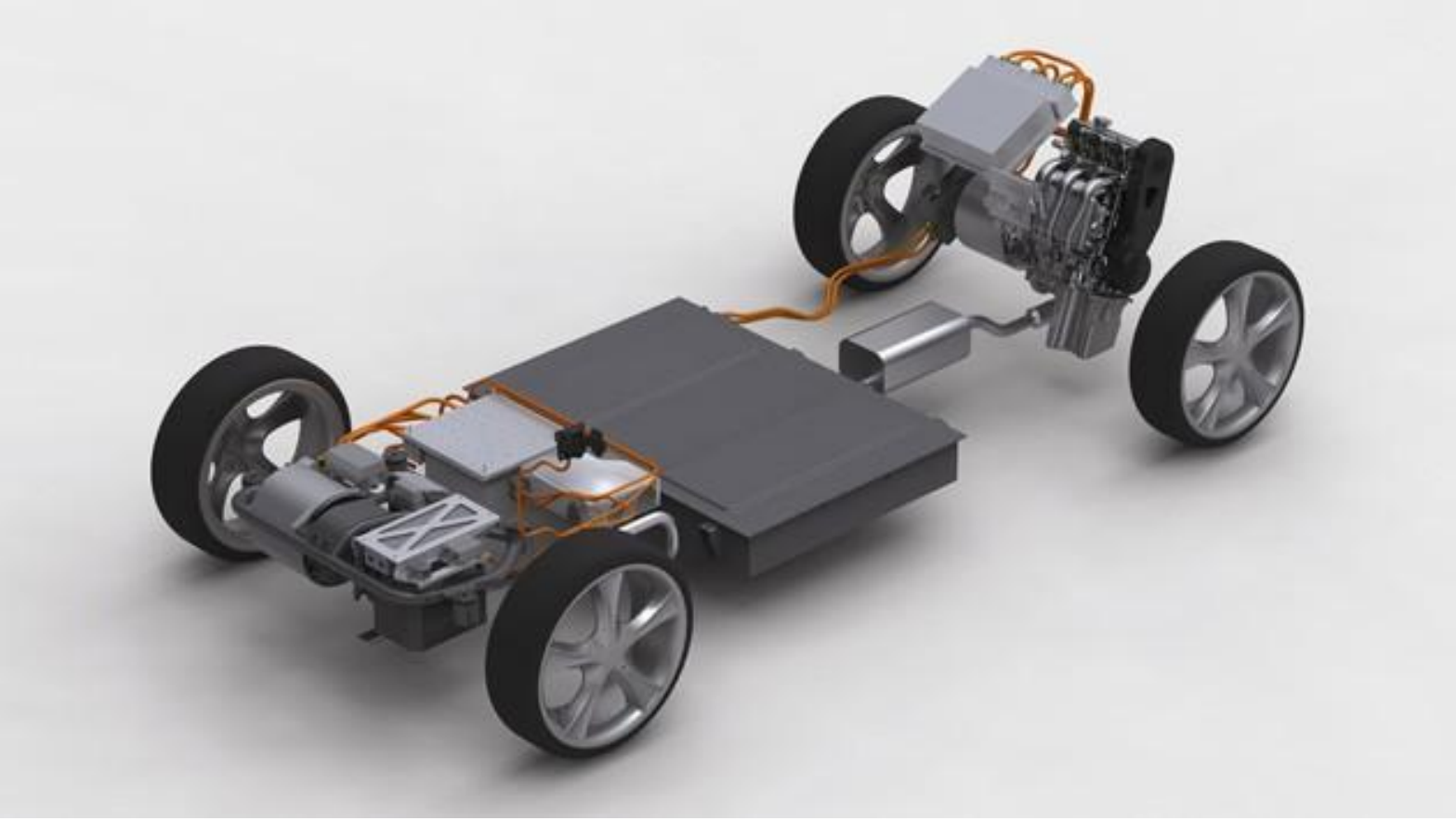
- The Key is deliver the *Average* power, not peak

- Fixed RPM for tuned efficiency, low emissions & noise

REX for BMW

25kW Generator

Other Examples

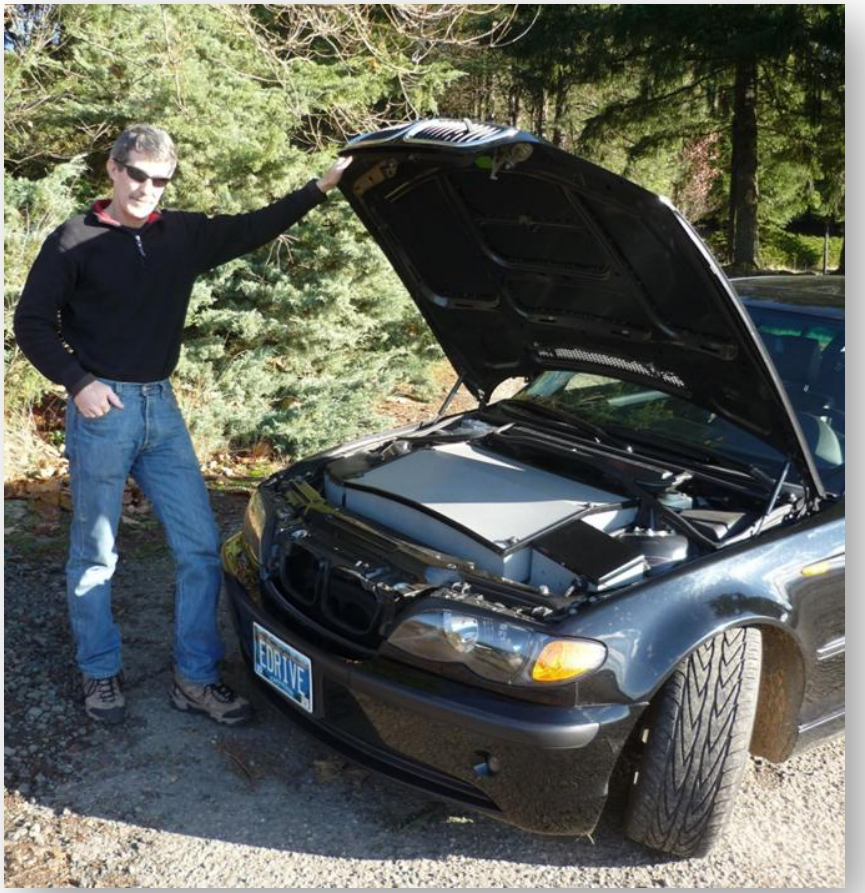


Lotus

Other Examples

35kW REX

Going strong at over 21000 miles



After hundreds charge cycles,
the cells are performing flawlessly.

Driving to Net Zero *with full performance*

For more detail on this and other projects

www.evdrive.com