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

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...
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

<table>
<thead>
<tr>
<th></th>
<th>ICE</th>
<th>Electric – AC Induction</th>
</tr>
</thead>
<tbody>
<tr>
<td>Torque</td>
<td>175 ft-lb</td>
<td>265 ft-lb</td>
</tr>
<tr>
<td>Power</td>
<td>185 HP</td>
<td>200 HP</td>
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</table>
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

700V
650V
0 Amps
Acceleration (current out)
Regenerative (current in)
BMW Power profile – 20 mile drive

The true power being consumed and generated

Average highway Power

16kW

60kW

40kW

20kW

0kW

-20kW

-40kW
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

105 miles →
Of highway travel with BMW (30kWhr)

14 miles →
(4 kWhr)

September 2011
## Annual Cost Comparison: Gas vs. Electric

<table>
<thead>
<tr>
<th>Drive Source</th>
<th>Miles per year</th>
<th>Fuel Efficiency</th>
<th>Annual fuel/energy use (source)</th>
<th>Average fuel/energy price</th>
<th>Annual fuel/energy cost</th>
<th>Cents per mile</th>
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</thead>
<tbody>
<tr>
<td>Gasoline</td>
<td>12000</td>
<td>28 miles / gal</td>
<td>428 gal</td>
<td>$4 / gal</td>
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<td>Electric w/Std. Rate</td>
<td>12000</td>
<td>3.5 miles / kWhr</td>
<td>3428 kWhr</td>
<td>10¢ / kWhr</td>
<td>$342.80</td>
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<td></td>
<td></td>
<td>5.1 Times better than gas</td>
</tr>
<tr>
<td>Electric w/TOU</td>
<td>12000</td>
<td>3.5 miles / kWhr</td>
<td>3428 kWhr</td>
<td>7.7¢ / kWhr</td>
<td>$264.00</td>
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<td>6.5 Times better than gas</td>
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<tr>
<td>5.6kW Solar array Electric w/TOU</td>
<td>12000</td>
<td>3.5 miles / kWhr</td>
<td>4800 kWhr</td>
<td>-13.7¢ / kWhr</td>
<td>-$656.00</td>
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</tbody>
</table>

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!
If 100% of this EV power comes from coal, it still reduces CO2 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