Electric Vehicles:
Transportation Without Petroleum

Symposium on Electric Vehicles
Center for Information Technology
Research in the Interest of Society
University of California, Santa Cruz
March 10, 2007

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AC Propulsion, Inc.
http://www.acpropulsion.com
Petroleum: A Hierarchy of Value

1. Aviation
2. Petrochemicals
3. Maritime shipping
4. Long haul trucks
5. Rail transport
6. Long trips by car
7. Commuting
8. Picking up the kids
9. Driving a Hummer
US Gasoline Addiction: Undeniable

Annual Per Capita Gasoline Consumption

gallons per person per year

<table>
<thead>
<tr>
<th>Country</th>
<th>Consumption</th>
</tr>
</thead>
<tbody>
<tr>
<td>China</td>
<td>10</td>
</tr>
<tr>
<td>India</td>
<td>2</td>
</tr>
<tr>
<td>EU</td>
<td>102</td>
</tr>
<tr>
<td>US</td>
<td>453</td>
</tr>
<tr>
<td>Japan</td>
<td>124</td>
</tr>
<tr>
<td>Rest of world</td>
<td>31</td>
</tr>
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source: Population Reference Bureau
Energy Information Administration
Urban Dynamometer Driving Schedule (UDDS)

505 sec

UDDS:
11.0 miles
31.3 minutes
21.2 mph
Acceleration Consumes Most Energy

Urban Driving Cycle Net Energy Requirement

- **Acceleration**
- **Aero**
- **Tires**

Conventional Car
Vehicle Weight Determines MPG

Fuel Consumption vs. Weight
2007 EPA Data

- Exotics
- Guzzlers
- LDVs
- Hybrids
Vehicle Weight Determines MPG

Fuel Consumption vs. Weight
2007 EPA Data

1000 lbs = 150 gal/year

pounds

gal per 100 mi

0 2 4 6 8 10

2000 3000 4000 5000 6000 7000

10 mpg 12 mpg 14 mpg 16 mpg 20 mpg 24 mpg 28 mpg 34 mpg 42 mpg 60 mpg

LDVs
line
Regenerative Braking Recovers Energy

Urban Driving Cycle Net Energy Requirement

![Bar chart comparing energy consumption between Conventional Car and With Regen. The chart shows a significant reduction in energy consumption with regenerative braking.]
US Gasoline Addiction: Unsustainable

Annual Per Capita Gasoline Consumption - If Every Light Vehicle Is A Prius

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<th>Country</th>
<th>Gallons per Person per Year</th>
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Source: Population Reference Bureau
Energy Information Administration
Fuel Substitution in Addition to Conservation

- Electricity
- Natural gas
- Ethanol
- Methanol
- Bio-diesel
- Hydrogen
Electricity: The Best Alternative to Gasoline

- Off-peak capacity
- Diverse energy resources – without oil
- Low emissions
- Suitable for most driving
- Proven vehicle technology
- Established and available infrastructure
Electricity

Off-Peak Capacity

CAISO Daily Outlook - March 2, 2007

12 AM to 6AM
44,000 MWh
40 mi/EV/day
13 kWh/EV/day
3,400,000 EVs

available resources

actual demand
### Diverse Energy Resources – Without Oil

<table>
<thead>
<tr>
<th>Source</th>
<th>CA</th>
<th>US</th>
</tr>
</thead>
<tbody>
<tr>
<td>Natural Gas</td>
<td>37%</td>
<td>17%</td>
</tr>
<tr>
<td>Large Hydro</td>
<td>16%</td>
<td>7%</td>
</tr>
<tr>
<td>Coal</td>
<td>21%</td>
<td>51%</td>
</tr>
<tr>
<td>Nuclear</td>
<td>15%</td>
<td>20%</td>
</tr>
<tr>
<td>Eligible Renewables</td>
<td>11%</td>
<td>2%</td>
</tr>
<tr>
<td>Petroleum</td>
<td>0%</td>
<td>3%</td>
</tr>
</tbody>
</table>

100% 100%

Source: CEC, EIA

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**Plug-In Vehicles:**

**Transportation Without Petroleum**
Low Emissions

Electricity

Joint NRDC/EPRI Environmental Analysis
Preliminary National CO2 Results

Source: NRDC, EPRI
Electricity

Suitable for Most Driving

Vehicle Travel Log
11/16/05 - 12/4/05

Family Car
33 months old
65,000 Miles
66 mi/day average

This data:
19 days
5.7 trips/day
68.7 mi/day
Electricity

Proven Vehicle Technology

1994

1997

2007

ACP Civic EV
- First AC150
- Still in use
- Brake pads ½ worn
Established and Available Infrastructure

8,000,000 Plug-in Vehicles In US
Recreational vehicles access grid power at over 16,000 RV parks nationwide

- Safe, simple, reliable hookups
- Up to 12 kW at each hookup
- More RVs than FFVs + NGVs + HEVs
- Over 30 million people with RV experience

source: RVIA
Electricity: The Best Alternative to Gasoline

- Off-peak capacity
- Diverse energy resources – without oil
- Low emissions
- Suitable for most driving
- Proven vehicle technology
- Established and available infrastructure

All we need is electric cars
eBox by AC Propulsion

Urban Utility Vehicle
Spacious, efficient, comfortable, unique, sporty, versatile, zero emission.
Electric.

Performance

- Range: 120 – 150 miles
- Acceleration: 0-60 mph < 7 sec
- Top speed: 95 mph
- Charge rate: 30 minutes for 20 to 50 miles
- Charge time: 2 hours (fast), 5 hours (normal)
- Grid connection: Bi-directional, V2G-capable
Li Ion Battery Allows Practical EV Conversions

**Li Ion (eBox)**
- 35 kWh
- 270 kg
- 130 Wh/kg

**NiMH (RAV4 EV)**
- 25 kWh
- 475 kg
- 52 Wh/kg
Commodity Cells Offer Price and Performance

Li Ion 18650 cell
2.0 Ahr, 3.7 V, 45 g

53P2S modules
106 Ahr, 7.4 V, 5.7 kg
BMS - Maintains Critical Battery Parameters

**eBox Pack**
- 5088 cells
- 96 blocks in series
- 96 volt and temp measurements
- 24 LVTM's

**LVTM**
- 4 volts and temps
- Synchronized sampling
- Optically isolated
- Serial communication
Motor Moves Car, and Stops It

**AC150 Motor**
- AC Induction
- 120 kW (160 hp)
- 200 Nm (165 ft-lbs)
- 13,000 rpm
- 3-phase
- 4-Pole
- 50 kg (110 lbs)
- Air-cooled
Inverter Smooths Torque Response Efficiently

AC150 Inverter
- Up to 180 kW
- 350V to 440V
- Smooth
- Quiet
- Efficient
- Air-cooled
Charger Saves Time, Increases Convenience

AC150 Charger
• Up to 20 kW
• 110V or 220V
• Quiet
• Efficient
• Fast - Charge rate in mi/hr:
  • 30A – 25 mi/hr
  • 50A – 40 mi/hr
  • 80A – 65 mi/hr
New Instruments and Controls Aid Driver

- Modified cluster
- Drive selector
- Multi-function display
- Regen control
- Cruise Control
- MFD control
Modified Instrument Cluster

Charge port location

Ammeter
- 200A charge
- 400A discharge

SOC meter
- Voltage-based
- Linearized
Electronic Drive Selector Saves Weight

Column-mounted
Finger control
DOT compliant
Regen Control

- Regen on accel pedal
- Adjustable on the fly
- Brake light indicator
Cruise Control

Accurate
Stable
Easy to use
MFD Control

- Controls screens and menu selections on MFD
- Easy to reach
- Push to select
- Turn to scroll
Charge Control Screen

- Line current limit
- Cell voltage limit
- Charging status
Onboard Charger Is Bidirectional

Power can flow to or from vehicle

- Stand-alone or grid-tied
- Unity power factor
- Sine wave current draw
- GFI compatible
- Discharge to grid for batt test
Plug-in vehicles serve as distributed energy resource (DER)
Plug-In Vehicles = “A Battery on the Grid”

AC Propulsion Demonstration Projects

☑ Grid regulation (automatic generation control - AGC)
☑ Extra power during demand peaks

Other Possible V2G Functions

★ Energy buffer for variable renewables
  – Spinning reserves
  – Uninterruptible power source for businesses and homes
  – Active stability control of transmission lines
  – Standby power for interruptible customers
Grid Regulation With an EV

• Project Sponsors – CARB, CAISO
• Contractor – AC Propulsion
• Vehicle – “Plug Bug” VW Beetle EV conversion
• Duration – October 2001 to December 2002
• Results
  – Vehicle driven normally, plugged in when parked
  – Vehicle automatically maintains battery state of charge to comply with driver usage requirements
  – Vehicle dispatches +/- power to grid upon remote command
  – Value of service provided estimated at $100 - $500/mo
Vehicles Regulate Area Control Error

Load

Area Control Error (ACE)

Time

24 Hour Cycle - Driving, Charging, Regulation
A Small Fleet of V2G Cars Buffers Renewables

100 kW peak power, variable output

10 to 15 kW dispatchable power from each car

= Higher reliability from renewable resources
# Plug-in Cars for V2G

<table>
<thead>
<tr>
<th>Battery</th>
<th>Li Ion</th>
<th>Li Ion</th>
</tr>
</thead>
<tbody>
<tr>
<td>35 kWh</td>
<td>9 kWh</td>
<td></td>
</tr>
<tr>
<td>600 lb</td>
<td>145 lb</td>
<td></td>
</tr>
<tr>
<td>Charger</td>
<td>20 kW</td>
<td>1.5 kW</td>
</tr>
<tr>
<td>onboard</td>
<td>onboard</td>
<td></td>
</tr>
<tr>
<td>bi-directional</td>
<td>charge only</td>
<td></td>
</tr>
</tbody>
</table>
**eBox : V2G-Ready**

- 35 kWh battery
- 20 kW charger (80 A)
- Two-way current flow
- Onboard metering
eBox: Efficient Package

<table>
<thead>
<tr>
<th>Curb weight</th>
<th>Gasoline</th>
<th>2750 lbs</th>
</tr>
</thead>
<tbody>
<tr>
<td>2400 lbs</td>
<td>Electric</td>
<td>3550 lbs</td>
</tr>
<tr>
<td>3050 lbs</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
eBox: Available Now
**eBox** : How to Get One

- Have $70,000 to $80,000 to spend
- Place deposit with AC Propulsion - $10,000 per car
- Buy Scion xB 5spd - $17,000 new, $15,000 used
- Deliver Scion to AC Propulsion
- Wait while AC Propulsion converts your car
  - Current backlog is three to four months
  - Conversion takes about one month
- Pay balance due - $45,000 plus options and tax
- Drive away in your eBox electric
AC Propulsion Next Steps

• Continue eBox conversions to end of 2007 at least
• Plan to replace xB with new platform
  – Another conversion
  – Fully-certified vehicle
  – Joint venture with an OEM
• Cost reduction
  – Drive system manufacture in Shanghai
  – Joint effort with battery supplier
  – Higher production volume
• Sales to other manufacturers