Electric Mobility
Unanswered Questions Regarding the Future of the Automobile
Stanford University – December, 2010

Sven A. Beiker, Executive Director CARS, December 2010
Individual Mobility in the 21st Century

Driver Assistance

Mobile Society

Connected Mobility

Alternative Energy
Automotive Competences at Stanford University

- Driver Assistance
- Alternative Energy
- Connected Mobility
- Mobile Society

Technology
Design
Economics
Business
Psychology
Sociology
Resources
Environment
Politics
Policies

- Competence of CARS core labs
- Competence of other labs
- Competence w/ limited applicability
Would you Like / Drive / Buy an Electric Car?

A recent U.S. survey [1] shows:
70% think expanded use of EVs is vital part to reduce use of fossil fuels
66% support EV recharging infrastructure investment by electric utilities
54% believe EVs will account for about 20% of new vehicles sold in 15-20 years
52% would like to see utilities taking leadership to encourage shift to EVs
43% could see themselves driving EV in 10 years
13% “very likely” to buy EV in 10 years

Challenges consumers see regarding electric vehicles
28% range and battery life
20% availability of charging stations
17% total cost/affordability
9% high [purchase] cost of vehicles

Analysts expect EVs to have 2% to 3% share of the new-car market by 2020 [2]

1,168 interviews U.S. nationwide, October 14-25, 2010
<table>
<thead>
<tr>
<th><strong>Public Discussion and Research Facts</strong></th>
<th></th>
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</thead>
<tbody>
<tr>
<td><strong>EVs are the solution, because...</strong></td>
<td><strong>But did you consider that...</strong></td>
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<tr>
<td>EVs don’t generate tailpipe emissions</td>
<td>EVs simply move the emissions from tailpipe to smokestack</td>
</tr>
<tr>
<td>With the present electricity mix, EVs still leads to less GHG</td>
<td>With particles, $SO_2$, $NO_x$ from power plants, EVs are not cleaner</td>
</tr>
<tr>
<td>EVs help gaining independence from foreign oil</td>
<td>EVs will create new dependence on lithium producers, resources</td>
</tr>
<tr>
<td>Li: Chile world’s largest producer, batteries don’t need that much</td>
<td>Considering the battery mass, EVs are inefficient</td>
</tr>
<tr>
<td>EVs are modular, simpler, cheaper than conventional vehicles</td>
<td>The range of EVs does not meet consumer demands</td>
</tr>
<tr>
<td>50% of people drive less than 25mls a day (80% less than 50mls)</td>
<td>Charging takes too much time and requires behavioral change</td>
</tr>
<tr>
<td>Most consumers will never need to go to filling station again</td>
<td>The electricity infrastructure is not ready for electric vehicles</td>
</tr>
<tr>
<td>The transformation of mobility sector will take time</td>
<td>EVs cost more than conventional vehicles</td>
</tr>
<tr>
<td>Tax breaks offset the higher purchase price of an EV</td>
<td>Once the tax breaks are used up the real cost of EVs will surprise</td>
</tr>
<tr>
<td>Energy cost of EVs is lower than conventional vehicle</td>
<td>Operating cost of EVs will increase with more renewable energy</td>
</tr>
<tr>
<td>Oil price will increase operating cost of conventional vehicle</td>
<td>Batteries from EVs will create a new waste problem</td>
</tr>
<tr>
<td>Recycling lithium batteries is well understood</td>
<td>EVs are too quiet and will lead to new accident pattern</td>
</tr>
<tr>
<td>EVs will improve significantly over time</td>
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</table>
Electric Vehicles – Facts and Hopes

‘Published’ Level of Detail

‘Perceived’ Sustainability of EVs

Lifetime Damages from Life Cycle Emissions

Impact of EVs on GHGs

Technology Potential for Reducing CO2

Published Level of Detail

Perceived Sustainability of EVs

Center for Automotive Research at Stanford

December 2010

S. Beiker, Executive Director
Lifetime Damages from Life Cycle Emissions

Lifetime Emissions Damages w/ Sensitivity Analysis

Source: J. Michalek et al, CMU, 2010
Impact of EVs On GHGs

Source: L. Schewel et al, UC Berkeley, 2010
Stanford Proposal to Research Electric Mobility

- Integrate existing studies, assessments, forecasts
- Create concise scenarios for the transition of the mobility sector
- Understand sensitivities of different influences, boundary conditions
- Provide background for more educated assessments and decisions
Electric Mobility Touching all Disciplines

Technology Design
- Development of charging infrastructure
- Improvement of batteries

Economics Business
- Cost of ownership and operation
- Industry business models

Politics Policies
- Connections to politics
- Appropriateness of incentives

Sociology Psychology
- Unlimited mobility needs
- Adapt to new vehicle operation

Resources Environment
- Assessment of environmental impact
- Availability of resources

Environment
- Availability of resources

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A Closer Look at the Car

Technology
Design

Economics
Business

Politics
Policies

Sociology
Psychology

Resources
Environment

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EV – Just a Car with a Motor instead of an Engine?

![Diagram of electric vehicle components](http://www.allcarselectric.com/image/100318171_bosch-ev-powertrain)

Source: http://www.allcarselectric.com/image/100318171_bosch-ev-powertrain
EV – Just a Car with a Motor instead of an Engine?

1. **MOTOR CONTROLLER**
   Monitors the motor's position, speed, power consumption and temperature. It uses these inputs along with driver throttle input to enable an inverter to convert DC voltage from the battery into three precisely timed signals that drive the motor.

2. **HIGH-VOLTAGE ELECTRIC HVAC COMPRESSOR**
   Is specifically designed for electric vehicle applications, drawing energy directly from the main battery pack.

3. **ELECTRIC WATER PUMPS**
   Circulates coolant for the traction motor, inverters, battery and heater.

4. **TRACTION MOTOR**
   Performs the conversion between electrical and mechanical power. Electric motors have efficiencies three times higher than that of a standard gasoline engine, minimizing energy loss and heat generation.

5. **ELECTRIC POWER STEERING**
   Is tuned to deliver the same driving dynamics as the gasoline-powered Focus.

6. **TRANSMISSION**
   Has the identical role as in a gasoline vehicle; however, it has different design considerations due to the higher rpm range available from the electric motor and increased emphasis on efficient and silent operation. It is a single-speed unit.

7. **MODULAR POWERTRAIN CRADLE**
   Enables the entire propulsion system to be inserted as one piece within the engine compartment and isolated from the vehicle body.

8. **ELECTRIC VACUUM PUMP**
   Supplies vacuum to the brake system for power assist.

9. **HIGH-VOLTAGE ELECTRIC COOLANT HEATER AND CONTROLLER**
   Specifically designed for electric vehicle applications, using energy-efficient technology to heat and circulate coolant. Heat also may be circulated to the battery to optimize performance.

10. **VEHICLE CONTROL UNIT**
    Monitors and controls each vehicle system, and manages energy and mechanical power being delivered to the wheels to maximize range.

11. **BATTERY PACK**
    Uses total of 23 kWh of power and liquid coolant for thermal management, and includes an electronic monitoring system that manages temperature and state of charge.

12. **AC CHARGER**
    Converts the AC electricity from the power grid to DC voltage required by the battery, enabling full state of charge in a matter of hours when plugged in. The vehicle will accommodate both 120V and 240V power sources.

13. **DC-DC CONVERTER**
    Allows the vehicle's main battery pack to charge the on-board 12V battery to power various vehicle accessories (headlights, etc.).

**FOCUS ELECTRIC FACTS**
- **Final assembly location:** Michigan Assembly Plant
- **Battery cell manufacturer:** Compact Power Inc., Holland, Mich.
- **Battery system:** Lithium-ion, liquid-cooled/heated, recyclable
- **Total battery capacity:** 23kWh
- **Estimated cost to fully charge vehicle:** $2 to $3 (based on nationwide average cost of $0.10 per kWh)
- **Cost of 240v charging station:** TBD
- **Tire size:** 17-inch
- **0-60 acceleration:** TBD, similar to gas-powered base model
- **Braking distance:** TBD, similar to gas-powered base model
- **Passenger room and cargo room:** TBD
- **Price range:** TBD

Many of the Current Electric Vehicles are Conversion

Vehicle layout optimized for conventional powertrain
Breaking, steering, air-condition systems need to be adapted
Manufacturing, distribution, service not scaled to large volume

A Completely New Vehicle Concept not a Conversion

Weight: 900 kg
Top speed: 120 km/h
Motor: 32kW, direct drive
Battery: Na-S, 19 kWh, 200kg
Range: 160 km in city, 265 km max
Charging: 6-8 hrs at 220V home outlet

BMW E1, 1991 Frankfurt Automobile Show

# Why We Drive What We Drive – A Case Study

## 1990’s

<table>
<thead>
<tr>
<th>Technology Design</th>
<th>Super Computing ➔ Engine / Chassis Control</th>
</tr>
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<tbody>
<tr>
<td>Economics Business</td>
<td>Booming Economies, Pre-Burst ➔ Consumer spending high</td>
</tr>
<tr>
<td>Resources Environment</td>
<td>Andrew ’92, El Niño, Cheap Oil ➔ …</td>
</tr>
<tr>
<td>Psychology Sociology</td>
<td>Individualism, Counter-Culture ➔ Individual freedom essential</td>
</tr>
<tr>
<td>Politics Policies</td>
<td>Gulf War, ZEV Mandate ➔ …</td>
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## 2000’s

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<th>Mobile Computing ➔ High Performance Batteries</th>
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<td>Economic Crisis, High Oil Price ➔ Consumer spending low</td>
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<tr>
<td>Katrina / Rita ‘05, Glaciers, Peak Oil? ➔ Oil Usage more considerate</td>
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<tr>
<td>Grass Root Movements, CO2 Movies ➔ Green becomes mainstream</td>
</tr>
<tr>
<td>Iraq / Afghanistan, HOV for HEV ➔ “Dependence on Foreign Oil”</td>
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**Automobiles Defining the Decade**

![Automobiles](image1.png) ![Automobiles](image2.png) ![Automobiles](image3.png)
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