Title
Meeting the New CARB ZEV Mandate Requirements: Grid-Connected Hybrids and City EVs

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Requirements: Grid-Connected Hybrids and City EVs

Andrew Burke

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Meeting the New CARB ZEV Mandate Requirements: Grid-Connected Hybrids and City EVs

UCD-ITS-RR-01-02

Affiliate Program Workshop
Presentation Materials

May 15-16, 2001
Buehler Alumni Center, UC Davis

Organizer and Host
Dr Andrew Burke

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ITS-Davis Affiliate Program Workshop

Meeting the New CARB ZEV Mandate Requirements:
Grid-connected Hybrids and City EVs

May 15-16, 2001

Organizer: Dr. Andrew Burke

Scope and Focus

In January 2001, the California Air Resources Board adopted significant modifications to the ZEV Mandate. These changes affect the options available to large auto companies marketing cars in California that must meet the requirements of the Mandate starting in 2003. In the new regulations, up to 50% (2% of sales) of the ZEV requirement (4% of sales) may be met with grid-connected, plug-in hybrid vehicles having a 20-mile or longer all-electric range. In addition, city EVs that may or may not be freeway worthy are designated for full ZEV credit and can be used to meet the 4% ZEV requirement. In the case of both types of vehicles, there is much less information available concerning their design, cost, and marketing than for full function electric vehicles (FFEVs) -- which have in the past been the focus of meeting the ZEV Mandate. This two-day workshop will consider in-depth how the inclusion of the grid connected hybrids and city EVs in the Mandate may affect how it will be met in 2003-2006. In addition, each of the new technology options will be reviewed in terms of vehicle design, utility, cost, and marketing.

Agenda

Grid-connected Hybrid-electric Vehicles

MAY 15, Tuesday A.M. (8:30-12:00)

1. Welcome (8:30) (A Burke, ITS-Davis)

2. Review of the new ZEV Mandate requirements with emphasis on the role of plug-in hybrids (8:45-9:15) (C Childers, California Air Resources Board (CARB))

BREAK (15 min.)

3. Design options with emphasis on performance and cost (9:30-12:30)
   - Emissions and Performance Expectations (E. Kassoy, AD Little/EPRI)
   - ANL/DOE Study (D Santini, Argonne National Laboratory)
   - ITS-Davis EV/HEV Cost Study (M Delucchi/A. Burke, ITS-Davis)
- Auto Industry Perspective, Toyota Motor Company (D. Hermance, Toyota Technical Center, USA, Inc)
- Systems Design Options for Plug-in Hybrids (A. Frank, UC Davis/EPRI)

LUNCH (12:30-1:30)

MAY 15, Tuesday P.M. (1:30-5:30)

4. Batteries for plug-in hybrids with emphasis on cost and cycle life (1:00-2:45)
   - Nickel metal hydride (D. Corrigan, Ovonlic Battery Company)
   - Lithium-ion (K. Hironaka, Shin Kobe Electric Machinery Co., Ltd.)
   - Use of ultra caps with batteries (A. Burke, ITS-Davis)

BREAK (15 min.)

5. Marketing issues & prospects (3:00-4:00)
   - Commercialization/Market/Customer Issues (D. Taylor, Southern California Edison/EPRI)

   - Speakers from the previous sessions of the day (ARB, EPRI, ITS-Davis, auto industry)

RECEPTION (6:00-6:30) University Club Lounge

DINNER (6:30-9:00) University Club Dining Room

Talk: Electrifying Urban America - Is It Really Possible?
Robert Graham, Manager, Electric Transportation,
Electric Power Research Institute

City Electric Vehicles

MAY 16, Wednesday A.M. (8:30-12:15)

1. Welcome (8:30) (A. Burke, ITS-Davis)
2. Review of new ZEV Mandate requirements with emphasis in role of city EVs (8:35-9:00) (C. Childers, California ARB)

BREAK (15 min.)

3. City EV Products – Specification/utility, availability, cost (9:15-10:15)
   - Toyota e-com (D. Hermance, Toyota Technical Center, USA, Inc.)
• Nissan Hypermil (M. Teramoto, Nissan Technical Center)
• Ford Th'ink (D. Fabricatore, Th'ink City Project)
• NEVCO Gizmo (C. Watkins, NEVCO)

BREAK (15 min.)

4. Development of Small Full-Function EVs (10:30-12:00)
   • ATT Parade (H. Woo, ATT R&D) (20 min)
   • Solectria Force EV (V. Brachos, Solectria Corporation) (20 min)
   • Design Options and Simulation Results (A. Burke, ITS-Davis) (20 min)

Lunch (12:00-1:00)

May 16, Wednesday P.M. (1:00-4:30)

5. Battery issues for small EVs with emphasis on cycle, calendar life and cost (1:00-2:00)
   • Lead-acid (K. Snyder, Panasonic-Matsushita) (15 min.)
   • NaMtic Zebra Battery (C. Dustmann, MES-DEA S.A.) (15 min)

6. Marketing issues (2:00-3:00)
   • Marketing NEVs, CEVs, and Small FFEVs (K. Kuram, ITS-Davis) (20 min)
   • Car Sharing Possibilities for ZEV Credits (S. Shaheen, ITS-Davis) (20 min)

BREAK (15 min.)

7. Panel discussion and wrap-up; new insights (3:15-4:30)
   • Speakers from previous sessions of the day (ARB, ITS-Davis, battery and auto industry)
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Part 1: Hybrid EVs

May 15, 2001

Craig Childers
California Air Resources Board
Meeting the CARB ZEV Requirements
Grid-Connected HEVs and City EVs

Part I: Hybrid EVs

Craig M. Wallers
California Air Resources Board
May 15-16, 2011

California Environmental Protection
Air Resources

Why ZEVs?
- Emissions reduction
  - Zero tailpipe emissions
  - Durability- Emissions reduced as ZEV
- Efficiency improvement & CO2 reduction
- Transportation energy source diversity
- Potential Vehicle-to-Grid power generation and ancillary services
- "Secondary Benefits of the ZEV Mandate" (UCD/ ITS & WestStart-Calstart)

Daily VMT Increasing Faster Than Population

December ZEV Regulation Proposal Highlights
- Smoother transitions as requirement increases by incorporating phase multipliers
- New ATPZEV category created
- Reduction in long-term NEV credit
- Modification and phase-out of range credits
- Phase-in of efficiency credit multiplier
- In-service & under-warranty credit
- Require vehicle placement to earn multiple credits

ZEV Regulation Status
- January Board Meeting Key Directives
  - 2X ZEVs beyond Dec Staff Proposal in 2012+2
  - Phase in LDT2 when determining obligations
  - Modify treatment of Grid-HEVs (move to ATPZEV)
- Staff is presently developing changes in the regulation in response to the Board’s requests
- Proposed changes (15-Day Notice) estimated release in Mid June
Much of this presentation on proposed amendments to the ZEV regulation released 12/8/00 and considered at the January Board Hearing. This presentation judges assumptions regarding ZEV credit determination. Please consult regulations for actual determinations.

When possible, presentation includes changes reflecting the latest staff thinking in response to the Board's requests. These changes have not yet been finalized and will likely change further before they are released. In particular, staff is still working on:
- Advanced componentry credit for ATPZEVs
- Grid HEV, and Transportation System credit

Please withhold formal comment to ARB until after changes are formally released in June.

2003-2008 Manufacturer Obligation

- All PZEVs and ATPZEVs meet:
  - SULEV emission standards
  - "Zero" Fuel System Evap Standards
  - OBD II requirement for 150,000 miles
  - Emissions warranty extension to 15 years / 150,000 miles
- Staff Proposal: For all HEVs, battery must be included as a warranty item.

Why ATPZEVs?
- PZEVs achieve significant emission reduction, but will not necessarily assist with propagation of ZEV-related technologies
- Near-term ATPZEVs expected to be:
  - CNG
  - Mild HEVs
- Longer-term ATPZEVs
  - Grid-HEVs
  - Methanol reformer FCVs
  - Hydrogen ICE

ZEV Requirement Increase
- For example, in 2018 and beyond, ZEV requirement grows to 16%:
  - Up to 6% may be PZEV
  - Up to 5% may be ATPZEV, and
  - At least 5% must be Pure ZEV
- As ZEV requirement grows in 2009-2012, 6% PZEV cap remains frozen.
**PZEVs in 2006+**
- 6% is capped, and may not seem like much, but after phase-in (2006):
  \[ \frac{6\%}{0.2 \text{ credit per vehicle}} = 30 \]
- Estimated number of PZEVs = 380,000
  (large + intermediate mfgs)

**2003 Large Manufacturer ZEV Obligation**
- IF
  - PZEVs sold = maximum allowable (6%)
  - Large auto manufacturer California sales are 920,000
  - No ATPZEVs placed in service
  - Ignore ’01-’02 credit accumulations
  - FFBEV avg credit in ’03 is ~4
- THEN
  - ZEVs Required = 
    \[ \left\lceil \frac{0.04 \times (\text{CA sales})}{\text{ZEV credit}} \right\rceil \approx 8,800 \text{ FFEVs} \]

**ZEV Obligation**
(Combined Large Manufacturers)

**ZEV Credit Determination**
Initial ZEV Credit =
\[ \left\{ 1 + \left[ \frac{(\text{Range Mult} - 1) \times (\text{Range Mult Phase In})}{(\text{Transportation System Mult}) \times (\text{Early Intro Mult})} \right] \right\} \]

**In-Service/Under-Warranty Vehicle Power Source Credit**
- ZE Range (20+ mile) vehicles only
- Includes Grnd HEVs, NEVs excluded
- Applies to 4th year in service and beyond
- 1/10th original credit (without phase-in multiplier) is earned each year
- ZEV in service and under warranty for 13 years eventually accumulates in-service under-warranty credit equal to original ZEV credit

**Early Introduction Multiplier**
- Addresses "gap" in availability
- Rewards mfgs for early introduction
- "01 02 03 04 05 06"
- ZEV & NEV
- PZEV & ATPZEV
Range Multiplier

- Addresses concerns with range capability of early-year BEVs
- Encourages deployment of longer-range vehicles in early years of program
- As market matures, range is de-emphasized:
  - Phase down over 2004-2012 timeframe
  - Caps or max range used for credit determination
    - 225 miles in 2011
    - 175 miles in 2012
- Applies to ZEV and GHEV only
  - under consideration

Efficiency Multiplier

- Assumes power plant emissions proportional to ZEV energy use
- Also a factor in range performance
  - go further or reduce battery cost
- Applies to both ZEVs and ATPZEVs
  - but no phase-in for ATPZEVs
- Rewards most efficient and therefore lowest emissions vehicle designs

Efficiency Multiplier: CMPEG Determination

- Gasoline vehicles CMPEG = unadjusted combined EPA fuel economy
- For BEV & ATPZEV, CMPEG = [33,705 whr/gal / (55 * UDDS AC wh/mile) + (45 * HFEDS AC wh/mile)]
- Alt Fuel CMPEG = unadjusted combined EPA fuel economy
  - uncompensated by "fuel content" factor

Efficiency Multiplier

<table>
<thead>
<tr>
<th>VEHICLE CLASS</th>
<th>EFFICIENCY MULTIPLIER</th>
</tr>
</thead>
<tbody>
<tr>
<td>City (EV)</td>
<td>CMPEG / (1.5 x 45.9)</td>
</tr>
<tr>
<td>Subcompact PC</td>
<td>CMPEG / (1.5 x 29.6)</td>
</tr>
<tr>
<td>Compact PC</td>
<td>CMPEG / (1.5 x 33.1)</td>
</tr>
<tr>
<td>Midsize PC</td>
<td>CMPEG / (1.5 x 27.0)</td>
</tr>
<tr>
<td>Large PC</td>
<td>CMPEG / (1.5 x 25.6)</td>
</tr>
<tr>
<td>Small Truck</td>
<td>CMPEG / (1.5 x 25.0)</td>
</tr>
<tr>
<td>Medium Truck</td>
<td>CMPEG / (1.5 x 21.4)</td>
</tr>
<tr>
<td>Large Truck</td>
<td>CMPEG / (1.5 x 18.2)</td>
</tr>
</tbody>
</table>

ZEV Range Phase-out Efficiency Phase-in

<table>
<thead>
<tr>
<th>Year</th>
<th>Range</th>
<th>Efficiency</th>
</tr>
</thead>
<tbody>
<tr>
<td>'04</td>
<td>0</td>
<td>100</td>
</tr>
<tr>
<td>'05</td>
<td>0</td>
<td>90</td>
</tr>
<tr>
<td>'06</td>
<td>0</td>
<td>85</td>
</tr>
<tr>
<td>'07</td>
<td>0</td>
<td>80</td>
</tr>
<tr>
<td>'08</td>
<td>0</td>
<td>75</td>
</tr>
<tr>
<td>'09</td>
<td>0</td>
<td>70</td>
</tr>
<tr>
<td>'10</td>
<td>0</td>
<td>65</td>
</tr>
</tbody>
</table>

Range: 1
Efficiency: 0
2006 ZEV Credit Example.

RAV4 EV

- Cert Data
  - UDDS eff = 291.3 AC whr/mile
  - Highway eff = 374.1 AC whr/mile
- CMPEG = [33,705 whr/gal / (55 * UDDS AC whr/mile) + (45 * HFEDS AC whr/mile)]
  = 102.6
- EFF MULT = CMPEG / (1.5 x 25.0)
  = 2.74

2006 ZEV Credit Example.

RAV4 EV

Initial ZEV Credit =

\[ \frac{1 + [(\text{Range Mult} - 1) \times (\text{Range Mult Phase In})]}{1 + [(\text{Eff Mult} - 1) \times (\text{Eff Mult Phase In})]} \times \frac{(\text{Transportation System Mult})}{(\text{Early Intro Mult})} \times (\text{NEV/LSV discount}) \]

2006 ZEV Credit Example.

RAV4 EV

Initial ZEV Credit =

\[ \frac{1 + [(4.70 - 1) \times (0.60)]}{1 + [(2.74 - 1) \times (0.35)]} \times \frac{(\text{Transportation System Mult})}{(\text{Early Intro Mult})} \times (\text{NEV/LSV discount}) \]

= -5.17

Year 4+ In-Service/ Under-Warranty Credit

= -0.52 per year

2006 GHEV ATPZEV Credit

- GHEV credit determination methodology not yet final
- Staff is exploring the possibility of harmonizing GHEV credit determination with other ATPZEVs

Example- 2006 GHEV ATPZEV Credit

Per December 2000 Proposal
- GHEVs use 3.5 X actual Urban AEP
  - P 20 uses 70 mile range in determination
- Efficiency Multiplier
  - Favors GHEVs based on electric-mode only
  - Assume GHEV will attain -2.0 X
- P20 credit = -3.6 initial, plus 0.36/ year
  (>year 4)

Example- 2006 GHEV ATPZEV Credit

- This example uses method from December 2000 proposed amendments
- Phase-in multiplier has expired by now
- GHEV credit determination based on
  - (ZEV range multiplier) x
  - (efficiency multiplier), and
  - GHEVs also eligible for in-service/ under-warranty credit
GHEV VS Mild-HEV VS Year

- Assumptions
  - Mild HEV achieves 1.3 x efficiency multiplier
  - GHEV achieves 2 x efficiency multiplier

<table>
<thead>
<tr>
<th>Year</th>
<th>'01</th>
<th>'02</th>
<th>'03</th>
<th>'04</th>
<th>'05</th>
<th>'06</th>
</tr>
</thead>
<tbody>
<tr>
<td>Early Intro</td>
<td>4</td>
<td>4</td>
<td>4</td>
<td>2</td>
<td>133</td>
<td>1</td>
</tr>
<tr>
<td>Mild HEV</td>
<td>18</td>
<td>18</td>
<td>18</td>
<td>09</td>
<td>08</td>
<td>06</td>
</tr>
<tr>
<td>P20 GHEV</td>
<td>72</td>
<td>72</td>
<td>72</td>
<td>36</td>
<td>48</td>
<td>36</td>
</tr>
</tbody>
</table>

Grid-HEV Challenges

- Battery pack cost
- Battery pack lifetime
  - GHEV batteries subjected to more aggressive cycling limits than BEVs
- Battery pack warranty requirement
- OBD detailed requirements TBD
- HEV test protocols may need refinement
- Public perception (mild-HEV ads)

GHEV Credit Change Re-cap

- Move from “gold” to “silver” (ATPZEV) category
- Battery warranty requirement remains, but GHEVs rewarded for In-Service Under-Warranty credit along with ZEVs
- Exact basis for credit calculations TBD

GHEVs

- GHEV Prototypes
  - UCD Prototypes
  - GM Triax
  - Volvo HEV
  - Suzuki EV Sport
  - Audi Duo
  - Mitsubishi
  - Renault

EPRI GHEV Study

- ARB co-funded
- Series hybrids fell out of study early on due to poor performance
- Focus shifted to P0, P20, and P60
- Originally mid-size, but now considered in a variety of classes
- Examined performance, cost, consumer acceptance, and commercialization

Real-Life Range

P20 & P60 Nomenclature

- Nomenclature: Manufacturers may choose to refer to P20 and P60 with a different nomenclature
- Typical customer “drive cycle” with many batteries would likely provide less than 20-60 mile range
**Honda Insight**
- Emission Standards
  - '01 5 spd-ULEV (61 mpg city/ 50 highway)
  - '01 CVT- SULEV (57 mpg city/ 53 highway)
- Battery monitored by OBD
  - If battery "fails", NOx increase >15%
    will illuminate OBD MIL
  - Battery warranty voluntarily extended

**Toyota Prius**
- MY '00 Toyota Hybrid System/ SULEV emissions standards
- Battery
  - OBD monitored
  - Battery warranty also voluntarily extended

**Vision for the Future**
- Steady, sustainable increase in ZEVs
- Regulatory flexibility encourages diverse transportation technologies including GHEVs
- Clean and healthy air for all Californians

**Abbreviations Used**
- LS L Speed Vehicle
- NEV Neighborhood Electric Vehicle (zero-emission LS)
- CEV City Electric Vehicle
- ZEV Zero Emission Vehicle
- ZEM Zero Emission Motorcycle
- P2EV Partial Zero Emission Vehicles
- AT P2EV Advanced Technology Partial Zero Emission Vehicle
- SULEV Super Ultra Low Emission Vehicle
- vMT Vehicle Miles Traveled
- g/mi grams per mile
- BEV Battery Electric Vehicle
- HEV Hybrid Electric Vehicle
- GHEV Genetically Engineered HEV (same as conventional HEV)
- AER All Electric Vehicle
- OBD On Board Diagnostics
- MIL Malfunction Indicator Light
- EF EFFiciency Factor
- DOT Dept of Transportation
- CMPEG California Miles Per Equivalent Gallon
- LEV Low Emission Vehicle Regulations
- LEV II - 1998 amendments to LEV program

**EXTRA SLIDES**
*Provided for Reference*
Hybrid Electric Vehicle Performance and Emissions

May 15, 2001

Erin Kassoy
Arthur D. Little
Both Grid Connected and Non Grid Connected Hybrid Electric Vehicles were compared against conventional vehicles

- The results of modeling of HEVs by NREL and UC Davis were used to calculate vehicle performance, efficiency and emissions
- Three HEVs were studied
  - HEV 0 — Charge-sustaining HEV with no all-electric range
  - HEV 20 — Charge-depleting HEV with a 20 mile all-electric range
  - HEV 60 — Charge-depleting HEV with a 60 mile all-electric range
- Work is part of EPRI HEVWG project
- Final Report on Mid-size vehicles will be out in June

HEVs were designed to perform, look and feel like the equivalent conventional vehicle

- MY 2000 Chevrolet Lumina 3 1L was chosen as equivalent conventional vehicle
- All HEVs had the same aerodynamics, frontal area, glider and cargo mass, and accessory loads as the CV
- All HEVs were designed to have similar acceleration, top speed, range, and gradeability as the CV, with some exceptions

Some trade-offs were made in performance matching to reduce vehicle costs

- Sustained Top Speed - CV has a top speed of 120 mph, HEVs can maintain 120 mph for approximately 2 minutes, but sustain speeds of over 90 mph
- Gradeability - CVs generally can climb a 7.2% grade at 50 mph for 30 minutes, HEVs can climb 7.2% grade at 50 mph for 15 minutes and at 30 mph for 30 minutes. Can climb any highway grade in US at 50 mph
- Passing Performance - Acceleration times for 50 to 70 mph relaxed from 4.8 seconds for CV to 5.1 seconds for HEVs. All HEVs had better 0-30 mph and 0-60 mph acceleration times than CVs
- Engine on/off cycles - Constrained to 30 on/offs during FUDS cycle. Reduced fuel economy by about 15%, but results in better driveability and customer satisfaction

Engine and Motor power of HEVs was slightly less than that of CV, due to more efficient designs
Vehicle mass for the HEV 0 and HEV 20 less than CV due to use of CVT and smaller engine

NREL and UC Davis modeled HEV fuel economy using ADVISOR. Several fuel economy measures are defined:

- Gasoline Only - Fuel economy when the vehicle is in charge sustaining mode in mpg
- Electric Only - Fuel economy of Grid Connected HEVs when in charge depleting mode. Given in kWh/mi and converted to miles per equivalent gasoline gallon using 3.44 kWh/equivalent gasoline gallon
- Measured Weighted Probability Weighted - Measure of actual all-electric use. Determined from 1995 NPTS data
- Utility Factor Weighted - Discounted MWp factors determined by SAE for use in J1711. Assumes vehicle starts each day with a full charge
- SAE J1711 - Uses UF for all-electric usage determination and assumes the vehicle starts 50% of the time with a full charge and the other 50% of time with low SOC

All-electric operation for the HEV 20 and HEV 60 was derived from daily driving patterns. Based upon being able to drive 20 miles or 60 miles in all-electric operation, annual all-electric mileage was calculated for charging nightly.

<table>
<thead>
<tr>
<th>Vehicle Design</th>
<th>CV</th>
<th>HEV 0</th>
<th>HEV 20</th>
<th>HEV 60</th>
</tr>
</thead>
<tbody>
<tr>
<td>Acceleration Times in Seconds</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>0-30 mph</td>
<td>3.5</td>
<td>3.1</td>
<td>3.0</td>
<td>3.0</td>
</tr>
<tr>
<td>0-60 mph</td>
<td>9.3</td>
<td>8.7</td>
<td>8.9</td>
<td>8.9</td>
</tr>
<tr>
<td>40-60 mph</td>
<td>4.6</td>
<td>4.2</td>
<td>4.3</td>
<td>4.3</td>
</tr>
<tr>
<td>50-70 mph</td>
<td>4.5</td>
<td>5.2</td>
<td>5.2</td>
<td>5.2</td>
</tr>
<tr>
<td>Sustained Top Speed</td>
<td>mph</td>
<td>120</td>
<td>120</td>
<td>98</td>
</tr>
</tbody>
</table>

Daily driving patterns were determined through interviews of approximately 400 potential HEV owners (market survey)

- Battery life and replacement depends upon a number of factors:
  - Driving patterns
  - Vehicle electric fuel economy
  - Battery technology
  - Vehicle lifetime
  - Charging frequency
  - Battery controller logic

- Daily driving patterns were determined through interviews of approximately 400 potential HEV owners (market survey)
  - Purchased a vehicle in the last 5 years
  - Regularly parked within 25 feet of an electrical outlet
  - Results binned into three categories:
    - short commute
    - medium commute
    - long commute

Annual Miles | Commute Distance | Long
<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>HEV 20 AE</td>
<td>4,900</td>
<td>5,300</td>
</tr>
<tr>
<td>HEV 60 AE</td>
<td>5,900</td>
<td>10,100</td>
</tr>
<tr>
<td>Total Miles</td>
<td>7,700</td>
<td>15,800</td>
</tr>
<tr>
<td>City Portion</td>
<td>47%</td>
<td>49%</td>
</tr>
</tbody>
</table>
Real world fuel economy is generally less than fuel economy measured using standardized tests.

- Fuel economy is reduced due to the following factors:
  - Aggressive driving
  - Air conditioning use
  - Open windows
  - Others
- Real world fuel economy discounts are approximated by USEPA for fuel economy guide:
  - 10% increase in city fuel consumption
  - 22% increase in highway fuel consumption

Charge Sustaining HEVs have different discharge patterns than Charge Depleting HEVs.

Charge Sustaining HEVs charge and discharge batteries in a series of shallow discharges while Charge Depleting HEVs discharge batteries while in all-electric operation.

Charge Depleting

NIMH batteries in 2010 are assumed to last longer than today's batteries.

- Current NIMH batteries have cycle lives of 800 to 1200 deep discharge cycles before charge capacity drops to 80% of the original capacity.
- NIMH batteries have demonstrated 1500 to 2000 deep discharge cycles under controlled laboratory conditions.
- "Improvements in positive electrode composition have substantially increased NIMH battery charge acceptance and efficiency (especially at elevated temperature and near the end of charge), with the consequence that average battery operating temperatures will be significantly decreased" - Fritz Kuhlhammer
- 1750 deep discharge cycles (to 20% SOC) were assumed to be available in 2010.

Vehicle lifetimes were defined as 100,000 miles of total vehicle operation or 10 years, whichever came first. Actual vehicle life might be longer.

<table>
<thead>
<tr>
<th>Vehicle Lifetime</th>
<th>Commute Distance</th>
<th>Low</th>
<th>Average</th>
<th>High</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total Vehicle Miles</td>
<td>77,120</td>
<td>100,000</td>
<td>100,000</td>
<td></td>
</tr>
<tr>
<td>Years of Operation</td>
<td>10</td>
<td>7</td>
<td>5</td>
<td>6</td>
</tr>
</tbody>
</table>

No replacement is needed for HEV 60. HEV 20 might require battery replacement if user charges nightly and has an average or low commute distance.

<table>
<thead>
<tr>
<th>Commute Distance</th>
<th>Change nightly</th>
<th>Low</th>
<th>Average</th>
<th>High</th>
</tr>
</thead>
<tbody>
<tr>
<td>Total Energy, kWh</td>
<td>HEV 20</td>
<td>13,600</td>
<td>11,100</td>
<td>8,400</td>
</tr>
<tr>
<td>Deep Discharge Cycles</td>
<td>HEV 20</td>
<td>2,900</td>
<td>2,400</td>
<td>1,800</td>
</tr>
<tr>
<td></td>
<td>HEV 60</td>
<td>1,200</td>
<td>1,500</td>
<td>1,400</td>
</tr>
</tbody>
</table>

Several alternatives to battery replacement can be implemented:

- Smart controller
  - Limit all electric operation so that vehicle lasts 100,000 miles without need for battery replacement
  - Increases gasoline consumption (~40 additional gallons of gasoline per year on average driving scenario. Ordinarily, 220 gallons per year are used by HEV 20 on average driving scenario.)
- Upgrade all electric range
  - HEV 20 moves towards HEV 0
- Replace HEV 20 battery with an HEV 0 battery
  - HEV 20 becomes an HEV 0
- Use a larger battery
  - Increases vehicle weight, fuel consumption and initial vehicle cost
Since Grid-Connected Hybrids derive some or all of their energy from electricity, emissions comparisons between HEVs and CVs should include well-to-wheels emissions (both fuel cycle and vehicular).

- Fuel Cycle Emissions include emissions associated with the extraction, processing and distribution of the gasoline or electricity.
- Vehicular Emissions include tailpipe and evaporative emissions.
- Both smog precursor (NOx + HC) and greenhouse gas emissions were examined.

Fuel Cycle Emissions Assumptions
- Plug-in HEVs are charged primarily at night.
- Less efficient power generators, older coal and fuel oil power plants cannot readily be turned on and off and cannot satisfy marginal needs.
- Nuclear and hydroelectric power plants generally are already at capacity fulfilling the base load and would not be used for marginal needs.
- By 2010, many older fossil fuel power plants will have been replaced with new combined cycle turbines.
- New power plants and refineries in non-attainment areas will need to meet BACT without emission offsets.

HEV Performance and Emissions

For the Average Driving Pattern and Charging Nightly, greenhouse gas emissions are significantly lower for grid-connected hybrids.

- HEVs offer major efficiency improvements as well as substantial reductions in the consumption of petroleum-based fuels and emissions of air pollution precursors (NOx and HC) and carbon dioxide.
- Petroleum consumption of an HEV 60 (using gasoline/electricity) can be less than that of the PNGV diesel engine-battery HEV 0 concept vehicles without resorting to costly light-weight construction or body aerodynamics.
- HEV 0 technology is in the early commercial stage. Relative to mature combustion engines and state-of-the-art EV technology, HEV technology requires only evolutionary advances to meet technical requirements, with the possible exception of batteries.
N-MH batteries are technologically capable, but there are uncertainties regarding their life and costs, especially in plug-in HEV service.

Both the Honda Insight and the Toyota Prius are currently in production in Japan, the U.S., and Europe. Several other automobile manufacturers have announced upcoming models. The Renault Kangoo has been announced for launch in 2001 in Europe as a plug-in hybrid.

There are several issues that have been identified that need to be examined for successful commercialization including battery life and packaging.
Observations From a DOE HEV Technology Assessment

May 15, 2001

Dan Santini
Argonne National Laboratory
Observations From a DOE HEV Technology Assessment

S. Plotkin, D. Santini*, A. Vyas, J.L. Anderson, M. Wang, J. He, D. Bharathan†, L. Gaines, and F. An

(* Presenter)
Argonne National Laboratory
† National Renewable Energy Laboratory
CARB ZEV Workshop by
University of California at Davis, ITS
Sacramento, CA
May 15-16, 2001

Acknowledgment

The HEV technology assessment work presented here was sponsored by the U.S. Department of Energy (DOE), Office of Transportation Technologies (OTT)

Primary sponsor: Dr. Philip Patterson
OTT Planning

Partial support by: David Rodgers
Director, Office of Technology Utilization within OTT
Argonne National Laboratory (ANL) Conducted This HEV Technology Assessment

- Work started in 1996
  - Initial work covered full fuel cycle energy assessment
  - Expanded in 1998 to include cost
  - Some materials analysis conducted and recycling potential evaluated

- The assessment involved
  - Analysis of parallel and series, mild and full charge sustaining, and full charge depleting (grid-connected, 20 mile AER) HEVs
  - Use of National Renewable Energy Lab's ADVISOR model for vehicle performance simulations
  - Development of a cost estimation procedure
  - Use of ANL's GREET model for greenhouse gas analysis

- Publications/presentations
  - 8 presentations/papers
  - A report to be published soon

This Presentation Puts the ANL Study Into Context With Respect To:

- EPRI HEV Working Group analyses
- Effects of comparable performance rules on MPG gain estimates
- Comparison of conventional vehicle (CV) lifecycle costs to various HEV types
- GM-GAPC estimates of MPG gains via hybridization
- HEV type's impact on lifecycle costs vs. Fuel price
Mild and Full HEVs Differ by Share of Peak Power Provided Electrically

<table>
<thead>
<tr>
<th>Type</th>
<th>Battery Share of Peak Power (8 sec 0-60 cases)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Full Hybrid (Charge Sustaining)</td>
<td><img src="image" alt="Bar Graph" /></td>
</tr>
<tr>
<td>Grid Connected 20 mi Electric Range (Charge Depleting)*</td>
<td><img src="image" alt="Bar Graph" /></td>
</tr>
<tr>
<td>Full Hybrid (Charge Sustaining)*</td>
<td><img src="image" alt="Bar Graph" /></td>
</tr>
<tr>
<td>Mild Hybrid (Charge Sustaining)#</td>
<td><img src="image" alt="Bar Graph" /></td>
</tr>
<tr>
<td>Conventional Vehicle (CV)* #</td>
<td><img src="image" alt="Bar Graph" /></td>
</tr>
</tbody>
</table>

Denominator = ICE + Battery
* Type also in EPRI study
# Type also in GM study

Simulations Suggest Lower HEV In-use MPG Gains Than Certification Tests Imply

![Bar Graph](image)
Four Points Can Be Made From the Prior Slide, But Appearances Can Be Deceiving

1. Full hybrids can only double the fuel economy in very congested conditions
2. Mild hybrids provide a very large fraction of the full hybrid fuel economy gains, especially in congested driving
3. Deceptively, the percentage MPG gains of hybridization are greatest in city driving
4. Deceptively, the percentage MPG gains are lower in more aggressive or high-speed driving

(The next slide shows the extent of deception)

Examination Fuel Savings Per Hour of Driving Is More Instructive Than % Gain

<table>
<thead>
<tr>
<th>Driving Cycle (Avg MPH)</th>
<th>Gasoline Saved per Hr (Gallons)</th>
</tr>
</thead>
<tbody>
<tr>
<td>NYCC (7.3)</td>
<td>0.1</td>
</tr>
<tr>
<td>Japan 16-15 (14.1)</td>
<td>0.2</td>
</tr>
<tr>
<td>FTP cycle - city (21.2)</td>
<td>0.3</td>
</tr>
<tr>
<td>CAFE (29)</td>
<td>0.4</td>
</tr>
<tr>
<td>US06 (48)</td>
<td>0.4</td>
</tr>
<tr>
<td>HWY (48.2)</td>
<td>0.4</td>
</tr>
<tr>
<td>REPS (51.5)</td>
<td>0.4</td>
</tr>
</tbody>
</table>

ADVISOR simulation results for HEVs that accelerate 0-60 mph in 10 seconds
Per Hour Fuel Savings Give a Different Perspective

- Savings per hour are similar for all driving cycles
- Mild vs. full HEV and congested vs. high-speed driving differences become clearer
  - Mild HEVs are nearly as good as full HEVs in congestion
  - Full HEVs clearly save more fuel in high-speed driving
- Compared to CV, mild and full hybrid differences become clearer
  - Gains by mild hybrids are greatest in congested driving
  - Gains by full hybrids are greatest in high-speed driving
  - Gains by full hybrids in high-speed driving are larger for aggressive driving cycles

MPG Penalties For High Performance, Large In CVs, Can Be Small In HEVs

![Graph showing CAFE Fuel Economy (MPG) vs. 0-60 MPH Acceleration Time, Seconds]

- Parallel Full HEV
- Parallel Mild HEV
- Series HEV
- CV
Downsizing HEV's Engine Causes Reduced Continuous Gradeability (and Top Speed)

Note: gradeability design value for full HEVs was 6.5%

ANL/EPRI MPG Gain Estimates Are Consistent; Differ Notably From GM-GAPC
Making ANL HEVs 2 Sec Faster to 60 mph Than CVs Explains Some of the GM/ANL Gap

Adjusted ANL Results Show Consistency With GM-GAPC Results
(Confirmation of more MPG gain at higher performance)
ADVISOR Runs Imply Road Load Reduction Having Positive Synergism With HEV MPG

In Separate Analyses, GM and ANL Differ On Benefits of Hybridizing With SI and CI Engines
2000 Results Showed Relative Superiority of Full vs. Mild HEV to Depend On Fuel Price

![Graph showing net present value of hybrid based on speed and fuel price](graph1.png)

ANL Research Implies That Mild Hybrids Can Compete on Lifecycle Cost Basis

![Graph showing lifecycle costs at 150k volume](graph2.png)
The Desirable Proportion of Electric Power Rises With Rising Gasoline Price

Our Analysis Leads to the Following Conclusions

- At low U.S. gasoline prices, national research should focus on mild hybrids (and 42V systems)
- In comparisons, hybrids cannot be made performance equal, only performance comparable
- The high percentage MPG gains for hybrids in congested driving are deceptive – savings per hour is a better measure
- U.S. driving patterns are not the reason that HEVs will be difficult to market, low gasoline prices are
- GM-GAPC’s constraint of performance compatibility in simulating HEV MPG gains raises an issue of consumer valuation of top speed. How large is the market for HEVs with downsized engines?
An Electric-Vehicle Design Performance, And Life-Cycle Cost Model

May 15, 2001

Mark Delucchi
Institute of Transportation Studies, Davis
WHAT WE MODEL IN DETAIL

- Variable costs of manufacturing vehicles
- "Fixed" costs of making vehicles, as a function of production volumes
- Cost and performance of EV drivetrains and batteries
- Vehicle energy use
- Operating costs
- EV designed to meet range and performance requirements

"FIXED" COSTS

- Division costs
  - costs related to manufacturing cost
  - costs per unit
- Corporate costs
  - costs related to manufacturing+division costs
  - costs per unit
  - interest cost
  - corporate profit
- Dealer costs
  - costs related to factory costs
  - costs per unit
  - interest cost
  - warranty cost
- Shipping cost
  - function of vehicle weight
- Sales tax
  - function of vehicle retail price
**EV LIFECYCLE COST AND PERFORMANCE**

*Mid-size vehicle, advanced technology, high-volume production, FUDS*

<table>
<thead>
<tr>
<th></th>
<th>EV Pb/acid</th>
<th>EV Ni/m-h2</th>
<th>EV:</th>
</tr>
</thead>
<tbody>
<tr>
<td>Range (mi)</td>
<td>65</td>
<td>110</td>
<td></td>
</tr>
<tr>
<td>0 - 60, 0% grade (sec)</td>
<td>93</td>
<td>93</td>
<td>93</td>
</tr>
<tr>
<td>vehicle wt (kg)</td>
<td>1,635</td>
<td>2,354</td>
<td>1,361</td>
</tr>
<tr>
<td>fuel economy (mpg)</td>
<td>95.5</td>
<td>73.9</td>
<td>87.5</td>
</tr>
<tr>
<td>vehicle price ($)</td>
<td>24,553</td>
<td>29,422</td>
<td>28,034</td>
</tr>
<tr>
<td>battery price ($/kWh)</td>
<td>259</td>
<td>202</td>
<td>475</td>
</tr>
<tr>
<td>battery price ($)</td>
<td>3,482</td>
<td>6,003</td>
<td>9,675</td>
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<tr>
<td>lifecycle cost (c/mi)</td>
<td>38.31</td>
<td>44.12</td>
<td>53.39</td>
</tr>
<tr>
<td>present value ($)</td>
<td>11,632</td>
<td>18,955</td>
<td>21,369</td>
</tr>
<tr>
<td>breakeven $/gal</td>
<td>2.64</td>
<td>4.14</td>
<td>4.19</td>
</tr>
</tbody>
</table>

*Present value of gasoline lifecycle costs, difference between gasoline and EV present value*

**EXTERNAL COST OF EVs vs. GASOLINE VEHICLES**

(cents/mile)

<table>
<thead>
<tr>
<th></th>
<th>Battery EVs</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>low</td>
</tr>
<tr>
<td>Noise1</td>
<td>0.00</td>
</tr>
<tr>
<td>Externalities of oil use2</td>
<td>0.02</td>
</tr>
<tr>
<td>Climate change3</td>
<td>0.00</td>
</tr>
<tr>
<td>Air pollution4</td>
<td>0.02</td>
</tr>
<tr>
<td>TOTAL</td>
<td>0.05</td>
</tr>
</tbody>
</table>

1 Assumes range of damages on collectors and principal arterials
2 Assumes 25 mpg
3 Use lifecycle CO2-equivalent emissions at 25 mpg
4 Uses Delucchi $/kg damage estimates, adjusted for estimated differences in exposure

**SOCIAL COST OF EVs vs. GASOLINE VEHICLES**

(cents/mile)

<table>
<thead>
<tr>
<th></th>
<th>Difference in costs</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>low</td>
</tr>
<tr>
<td>Private lifecycle costs</td>
<td>0.00</td>
</tr>
<tr>
<td>Noise1</td>
<td>0.00</td>
</tr>
<tr>
<td>Externalities of oil use2</td>
<td>-0.20</td>
</tr>
<tr>
<td>Climate change3</td>
<td>-0.00</td>
</tr>
<tr>
<td>Air pollution4</td>
<td>-0.17</td>
</tr>
<tr>
<td>Total externalities</td>
<td>-0.37</td>
</tr>
<tr>
<td>Social cost</td>
<td>-4.00</td>
</tr>
</tbody>
</table>

1 Assumes range of damages on collectors and principal arterials
2 Assumes 25 mpg
3 Use lifecycle CO2-equivalent emissions at 25 mpg
4 Uses Delucchi $/kg damage estimates, adjusted for estimated differences in exposure
Hybrid Electric Vehicles

*Myth versus Reality*

May 15, 2001

Dave Hermance
Toyota Technical Center, USA, Inc.
Hybrid Electric Vehicles
Myth versus Reality

Toyota Technical Center, USA, Inc
Dave Hermance

May 15 2001

What Does the Market Want?

A significant and growing percentage of customers indicate a willingness to buy an environmentally friendly vehicle, if and only if, all other attributes are equal.

May 15 2001

Myth #1

All "power assist hybrids" are the same

Power assist HEV Variations

- Architecture
- Performance
- Cost
- Emissions
- Fuel Economy
- Electric Operation

May 15 2001

EEA Analysis

<table>
<thead>
<tr>
<th>Type</th>
<th>Cost</th>
<th>FE Benefit</th>
</tr>
</thead>
<tbody>
<tr>
<td>Starter/Alternator</td>
<td>$500-700</td>
<td>22%</td>
</tr>
<tr>
<td>Motor Assist</td>
<td>$1450</td>
<td>33%</td>
</tr>
<tr>
<td>Integrated</td>
<td>$2900-4000</td>
<td>50-52%</td>
</tr>
<tr>
<td>Separate 4wd</td>
<td>$2800</td>
<td>28%</td>
</tr>
</tbody>
</table>

Note: Costs and Benefits are Drivetrain Only

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Argonne Labs Analysis

Performance-Capability CAFE MPG gains from engine downsizing and hybridization (Steps 6 & 7; also fuel reduction measures e.g. from Prius II to Prius HEV)

Performance-Capability CAFE MPG Gain

Argonne National Laboratory
Transportation Technology ASD Center

May 15 2001
**Myth #2**

Prius could easily be made into a grid-connected HEV

**Reality #2**

The unique Prius drivetrain (THS) is not appropriate for a grid-connected application

- Motor is much too small
- Battery energy and power are too small
- No way to carry required battery mass or volume
- Engine is too large
- THS transmission design is inappropriate

**Probable Attributes of Grid-Prius**

- Markedly reduced performance in EV mode
  - Slower 0-60
  - Lower top speed
  - Reduced passing performance
- Drastically reduced battery life
- Loss of ICE fuel economy due to mass
- Significantly higher cost

**Vehicle Performance**

Comparison of performance for Prius and Grid Prius

<table>
<thead>
<tr>
<th></th>
<th>Current Prius/THS</th>
<th>Grid Prius (Prius with e-com battery (Simulation))</th>
<th>RAV4EV</th>
</tr>
</thead>
<tbody>
<tr>
<td>Usable Energy</td>
<td>~500 Wh</td>
<td>~8 of ~4 kWh</td>
<td>~29 kWh</td>
</tr>
<tr>
<td>Motor/Generator</td>
<td>Max power 33kW</td>
<td>Max power 40kW</td>
<td>Max power 56kW</td>
</tr>
<tr>
<td>Vehicle Weight</td>
<td>1255 kg</td>
<td>1255 + 150 kg</td>
<td>1560 kg</td>
</tr>
<tr>
<td>0 - 60 mph (ICE+EV)</td>
<td>12.5 sec</td>
<td>19.2 sec (EV)</td>
<td>18.6 sec</td>
</tr>
</tbody>
</table>

**Battery life/durability**

*LIFE OF EV BATTERY*
**Myth #3**

An HEV-20 will have significant EV use

**Reality #3**

- AER ≠ Real World (RW) range
- Even 20 mile RW is only ~ 20% VMT substitution if re-charged daily

**Sierra Analysis of EPA Data**

**Myth #4**

UC Davis Vehicles Are Viable Under Current Regulations

**Reality #4**

- Control strategy is probably a "defeat device" under EPA/ARB rules
- Emissions claims require averaging EV and ICE emissions
- Performance claims are simulation based, actual is far different
- Published cost estimates neglect critical components
UCD Control Strategy

Technical Issues for Grid-HEVs
- Real world control strategy
- Vehicle Performance
- Real world EV/VMT fraction
- Battery Technology
- Cost
- Emissions
- Test Procedure

Regulatory Issues for Grid-HEVs
- 15/150,000 Battery Warranty
- Credit Structure
- Test Procedures

UCD Cost Estimates

EV Performance
EV operation in Grid-HEV depends on architecture
- Slower 0-60
- Lower top speed
- Reduced passing performance

Test Procedure for Grid-HEV
Issues to be addressed:
- Defeat device treatment for EV operation
- Emissions for ICE-on In/Off mode
- Safety/system protection issues
- Determination of DF for emission control system
- Evaporative emission during EV operation
- OBD requirements
Hybrid Electric Vehicle Technology
from
No Plug to Plug-In to Plug-out
Hardware & Control
EPRI-HEV WG/UCDavis-HEV Center

May 15, 2001

Andrew Frank
University of California, Davis
Department of Mechanical & Aeronautical Engineering
Hybrid Electric Vehicle Technology
from
No Plug to Plug-in to Plug-Out
Hardware & Control
EPRI-HEV WG / UCDavis-HEV center

Andy Alfonso Frank – "The Fonzi"
Director HEV Center
Mech Aero Eng
Univ of Ca – Davis
530 752 8120
aafrank@ucdavis.edu

Hybrid Electric Vehicle Technologies
Addressed by the HEV WG

- Series or Parallel configurations—Only Parallel because of efficiency
- Technology and hardware solutions and system configurations
- Plug to electric company or no plug—Both vehs are considered to evaluate F/E and Emissions - tail pipe and well to wheels
- Control policies and options—discussed
- Energy from the Electric Companies or energies back to the Electric companies can be done How to control? New item to study for the next phase

Other points of design and discussion among HEV WG members include

- A single traction motor/Gen or 2 units?—1 EMG selected
- Battery location for HEV 20 and 60? SUV ok, smaller vehicles harder to find a place
- "Turtle Light" and performance limit allowance
- Cabin cooling and heating techniques. Low cost soin
- Auxiliary power concepts. Mechanical, unless electric is cheaper
- Zero Evaporation concepts—canister or pressurized tank?
- Simplified and low cost emission control concepts
- Battery cooling and heating
- Battery life replacement management and policies

Hybrid Vehicle Technology
ZEV (Criteria Emissions) No Plug Type

Conventional Gasoline Powertrain Vehicle
--CV--

Hybrid with Zero All Electric Range
0 mile AER

Conventional Gas
Hybrid Plug-In with 20 mile AER

Hybrid Electric Vehicle HEV 20

Hybrid Plug-In with 60 mile AER

Hybrid Electric Vehicle HEV 60

Conventional Auto transmission Parts

Standard Auto Transmission Number of parts are over 700!

Conventional CVT cutaway

UCDavis HEV Center
CVT Control System Simplification
UCDavls HEV Center
550 hp Continuously Variable Transmission
Parts Count less than 60

UCD HEV Center
Hybrid 350 hp-CVT Chevrolet Suburban Powertrain

UCDavls Hybrid Center HEV 60 Future Truck
Electric operation @ GM proving grounds

UCDavls Hybrid Center HEV 60's with CVT's
The HEV-1 and Coulomb

Mid size Fuel Economy Calculations Std construction HEV WG

<table>
<thead>
<tr>
<th>Component</th>
<th>HEV 60</th>
<th>HEV 4</th>
<th>HEV 2</th>
</tr>
</thead>
<tbody>
<tr>
<td>Engine</td>
<td>5.7</td>
<td>4.8</td>
<td>3.9</td>
</tr>
<tr>
<td>Gearbox</td>
<td>0.7</td>
<td>0.6</td>
<td>0.5</td>
</tr>
<tr>
<td>Chassis</td>
<td>6.9</td>
<td>5.9</td>
<td>5.0</td>
</tr>
<tr>
<td>Electrical</td>
<td>0.9</td>
<td>0.8</td>
<td>0.7</td>
</tr>
<tr>
<td>Total</td>
<td>13.2</td>
<td>11.3</td>
<td>9.7</td>
</tr>
</tbody>
</table>

EPRI-10% reduced mass, 30% lower rolling resistance and 40% improved Aero — all less than 1/2 of PNGV cars HEV WG
From the Technology Slides HEV WG Conclude That HEV's Have the following Properties

1. No engine idle and Torque Converter—Electric motor Launch
2. Regenerative Braking is enough to sustain charge in the City with the appropriate engine "turn - on" speed
3. Allows ideal engine operation at 30% efficiency on gasoline today and opens the door to design much higher efficient gasoline engines over 40% efficient that are much simpler than current designs—Toyota Prus-38%
4. Replaces Mechanical complexity with Electronic controls for much higher overall efficiency reliability and lower costs
5. Much lighter powertrain for the same performance—HEV 80 powertrain is 1/3 the weight of CV
6. Total vehicle weight of the HEV 60 can be the same as the CV with the use of some better materials
7. With PNGV materials and aerodynamics a 5-6 passenger sedan such as the Lumina can achieve over 100 mpg within today's cost range for these vehicles

Infrastructure—The Achilles Heel of All Alternative Fuel Vehicles

1. Small and midsize 5 passenger Plug-in HEV vehicles and SUV's can use today's gasoline stations and 120v electric plugs with GFI to fill tanks and charge batteries at 15kw No Infra Prob
2. Large SUV's could use 220v GFI plugs or special 120v plugs with GFI at 3 kw Rapid charge is not required since it's an overnight charge and a partial charge does not affect performance or range in all plug-in HEV's
3. Completely automatic charging systems are easy to design at these low powers Standards needed for all manufacturers No action required of user!
4. Research area for the future HEV WG

General Control Philosophy for parallel HEV's

1. Use E/M/G and batteries for low speed driving and vehicle acceleration and deceleration performance
2. Use gasoline Eng for Steady State speeds and loads
3. These cars are ZEV at low speed city driving but clean efficient highway cruisers with up to 2X or better MPG
4. Gasoline is used at highway speeds with E/M/G for better acceleration, deceleration and engine regulation for minimum fuel and lowest emissions for SS power
5. Parallel HEV's provide opportunities for optimization of many other parameters simultaneously

HEV WG identified 12 control strategy items

- 3 techniques for engine Turn On-T/O, speed, 45, 60, 80 mph
- Ramp down Engine T/O speed/SOC for increased range on electric energy
- Driver interaction allowance for better electric use
- Smart-car trip planning capabilities
- Enhanced electric modes to increase AER
- Better engine Start algorithm development
- CVT optimization for gasoline-EV-regen operation
- Minimize battery replacement strategies
- Mountain mode strategies
- The highlights are discussed in the next few slides

WG Control for battery management of zero AER small batteries HEV 0 to HEV 20

Objective

- Use batteries and EMG to enhance downsized eng for vehicle performance and launch up to about 5 to 10 mph
- Use batteries to collect regenerative braking energy. There is enough energy in "normal" city driving to maintain battery SOC
- Aggressive driving for a few minutes will cause "turtle light" to come "on", limiting performance. Larger batteries reduce the frequency of the "T"

WG Control of batteries for plug-in long AER, HEV 20 to HEV 60

- Batteries are used for low speed city driving w/o eng. (ZEV) unless the batteries are depleted to a certain state then ZEV up to 25 mph ZEV performance 0 to 80 mph in 8 to 9 seconds or less
- Up to 60mph eng "off" until 20 to 60 miles are driven. then batteries will be maintained at about 20% SOC
- Engine controlled to always come "on" above 60 mph
- With Eng "on" EMG and batteries are used to enhance performance like the HEV 0
- Larger battery pack leads to a longer time to "turtle light" HEV 60 may only see Turtle light when driving faster than 100 mph for 20 minutes
### Control System to manage the battery SOC as the car is driven
- Can be done by engine "turn on (T/O)" speed - The lower the T/O the more gasoline used and the less electric energy used in city driving
- For highway cruise, one way is to require the engine to make slightly more power than needed to maintain a given speed then to use the EMG to generate enough to keep the batteries at the minimum SOC - about 20% SOC. Then wait for the vehicle to park to plug-in before charging to "full" SOC. Gasoline is not used to charge to 100%—only to maintain SOC
- T/O concept allows battery charging to be automatic
- Driving habits can be used to determine adaptive or predictive control strategy Controls are simpler when batteries are larger

### Control of daily energy use to increase battery life
- Can be done by taking less energy per day from the batteries by sustaining at a higher SOC. Therefore, the driver goes fewer AE miles per day and covers more miles using gasoline—Depreciates HEV 20 to HEV 15 etc
- Battery End of Life (EOL) was defined as 80% capacity for HEV 0 to HEV 20 batteries. For HEV 20 to HEV 60 plug-in vehicle batteries EOL can be extended to lower capacity thus extending replacement range. Control to extend battery life may be done only after 100,000 miles has been covered
- 150,000 vehicle mile battery life can be accomplished requiring fewer pure electric miles toward the battery end of life

### Conclusions
- Technology is now possible but not yet completely developed
- The heart of the Technology is the mechanical CVT which has been demonstrated by UCDavis HEV Center, more efficient than manual transmissions
- The larger the battery pack, the more efficient the Plug-in HEV up to a range of about 60 miles. The optimum range will increase as battery technology improves
- There are numerous control strategies that the technology can be used to optimize the many parameters not now possible with CV's
- It is possible to integrate Plug-in HEV's with the Electric power grid to improve the system efficiency and lower the electric energy costs to all
- Complete automatic control of the vehicle is expected and thus the vehicle is transparent to CV's
- User control of energy management may not be advisable until the public is better informed
- Fleet energy management control is a natural and can greatly reduce fleet operating costs
- All emissions and CO2 can be greatly reduced
- Fuel economy can be further increased by advance gasoline engine design with efficiencies up to 45%
- A shift in the use of fuel (G to E) can mean higher profits to Energy Companies. Car companies also Gain $ !
- Plug-in HEV's can lead eventually to advanced alternative power such as FCE and others after infrastructure and technologies are developed
Ovonic Nickel-Metal Hydride Batteries For ZEV-Range HEVs

May 15, 2001

Dennis Corrigan
Ovonic Battery Company
OVONIC NICKEL-METAL HYDRIDE BATTERIES FOR ZEV-RANGE HEVs

Dennis A. Corrigan
Ovonics Battery Company
Troy, Michigan

NiMH Production EV/HEVs

- GM EV1
- Chevrolet S10 Truck
- Ford Ranger Truck
- DaimlerChrysler EPIC Minivan
- Honda EV Plus
- Honda Insight
- Toyota RAV4-EV
- Toyota Prius

Ovonics NiMH Powered EV1

Performance Compared to Goals

- Range doubled vs PbA
  221 miles @ 45 mph
  140 miles @FUDS
- Meets EVA performance goals

GM Ovonics → Texaco Ovonics Pilot Production Facility
(Troy, MI)

Ovonics Energy Systems Production Facility
(Kettering, OH)
BARRIERS TO EV MARKET

1. Limited range
2. Slow recharge time
3. Cost

ADVANTAGES OF ZEV-RANGE HEVS

1. Range comparable to conventional ICE vehicle
2. Rapid refueling like conventional ICE vehicle
3. Lower battery cost with smaller battery
4. Emissions reduction similar to EV

Power Performance of Ovonic NiMH Batteries for Charge-Depletion HEV Applications

Ovonic NiMH Battery Products

EV Batteries
At 70+ Wh/kg

HEV Batteries
500-1000 W/kg

ZEV-Range
HEV Batteries
65+ Wh/kg
500+ W/kg

Ovonic Family of Batteries 20Ah to >100Ah

UC Davis 1st Place 1997 FutureCar

Ford Taurus Conversion, Charge-Depletion HEV
Powered by 90 Ah Ovonic NiMH EV Batteries

UC Davis "Joule"

Mileage 49 mpg
vs. 25 mpg Taurus

65 mile ZEV range
340 mile total range
UC Davis 2000 Future Truck

Chevy Suburban Conversion, Charge-Depletion HEV "Sequoia"
Powered by 90 Ah Ovonic NiMH HEV Batteries
2X mileage, 70 mi ZEV range, 450 mi total range

High-Performance Charge-Depletion HEV
Powered by 60 Ah Ovonic NiMH HEV Batteries

Charge-Depletion HEV Performance Summary

<table>
<thead>
<tr>
<th>Vehicle</th>
<th>Joule</th>
<th>Coulomb</th>
<th>Sequoia</th>
</tr>
</thead>
<tbody>
<tr>
<td>Battery Type</td>
<td>EV90</td>
<td>HEV60</td>
<td>HEV90</td>
</tr>
<tr>
<td>Battery Capacity (Ah)</td>
<td>90</td>
<td>60</td>
<td>90</td>
</tr>
<tr>
<td>Battery Voltage (V)</td>
<td>172</td>
<td>317</td>
<td>317</td>
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<tr>
<td>Battery Energy (kWh)</td>
<td>15.5</td>
<td>19.0</td>
<td>28.5</td>
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<tr>
<td>Battery Wgt Fraction</td>
<td>0.15</td>
<td>0.23</td>
<td>0.16</td>
</tr>
<tr>
<td>Battery Power (kW)</td>
<td>49</td>
<td>161</td>
<td>213</td>
</tr>
<tr>
<td>Motor Power (kW)</td>
<td>48</td>
<td>75</td>
<td>150</td>
</tr>
<tr>
<td>Acceleration Time (s)</td>
<td>14</td>
<td>11</td>
<td>9</td>
</tr>
<tr>
<td>ZEV Range (mi)</td>
<td>65</td>
<td>80</td>
<td>70</td>
</tr>
<tr>
<td>ICE Mileage (mpg)</td>
<td>25</td>
<td>25</td>
<td>13</td>
</tr>
<tr>
<td>HEV Mileage (mpg)</td>
<td>49</td>
<td>62</td>
<td>26</td>
</tr>
<tr>
<td>Improvement Factor</td>
<td>2</td>
<td>2.5</td>
<td>2</td>
</tr>
</tbody>
</table>

BATTERY LIFE ISSUES FOR ZEV-RANGE HEVS

<table>
<thead>
<tr>
<th>ZEV Range (miles)</th>
<th>Cycle Life (cycles)</th>
<th>Total Lifetime ZEV Mileage (miles)</th>
</tr>
</thead>
<tbody>
<tr>
<td>100</td>
<td>1200</td>
<td>120,000</td>
</tr>
<tr>
<td>60</td>
<td>1200</td>
<td>72,000</td>
</tr>
<tr>
<td>40</td>
<td>1200</td>
<td>48,000</td>
</tr>
<tr>
<td>20</td>
<td>1200</td>
<td>24,000*</td>
</tr>
</tbody>
</table>

*Increased cycle life possible via incomplete recharge strategies
### BATTERY SIZE OPTIONS FOR ZEV-RANGE HEVS

<table>
<thead>
<tr>
<th>Range (miles)</th>
<th>Capacity (Ah)</th>
<th>Voltage (V)</th>
<th>Energy (kWh)</th>
</tr>
</thead>
<tbody>
<tr>
<td>100</td>
<td>100</td>
<td>300</td>
<td>30</td>
</tr>
<tr>
<td>60</td>
<td>60</td>
<td>300</td>
<td>18</td>
</tr>
<tr>
<td>40</td>
<td>40</td>
<td>300</td>
<td>12</td>
</tr>
<tr>
<td>20</td>
<td>20</td>
<td>300</td>
<td>6</td>
</tr>
</tbody>
</table>

### Ovonic NiMH 12-HEV-12
Water-Cooled Monoblock Battery

- Voltage 12 V
- Capacity 12 Ah
- Specific Power 1000 W/kg
- Reduced Parts Count
- Reduced Hardware Cost
- Enables lower costs for smaller batteries

### OTHER BATTERY SIZE OPTIONS FOR ZEV-RANGE HEVS

<table>
<thead>
<tr>
<th>Range (miles)</th>
<th>Capacity (Ah)</th>
<th>Voltage (V)</th>
<th>Energy (kWh)</th>
</tr>
</thead>
<tbody>
<tr>
<td>100</td>
<td>100</td>
<td>300</td>
<td>30</td>
</tr>
<tr>
<td>60</td>
<td>100</td>
<td>180</td>
<td>18</td>
</tr>
<tr>
<td>40</td>
<td>100</td>
<td>120</td>
<td>12</td>
</tr>
<tr>
<td>20</td>
<td>100</td>
<td>60</td>
<td>6</td>
</tr>
</tbody>
</table>

(enables lower battery costs proportional to energy)

### SUMMARY AND CONCLUSIONS

- ZEV-Range HEVs mimic EV emissions advantages best with 60+ mile ZEV range
- Significantly better cycle life with 60-mile ZEV range HEV than with 20-mile ZEV range HEV
- 60 mile ZEV range HEV may have lower life cycle cost than 20-mile ZEV range HEV
Manganese-type Lithium Ion Battery for City EVs

May 15, 2001

Kensuke Hironaka
Shin-Kobe Electric Machinery Co., Ltd.
Manganese type lithium ion battery for city EVs

Kensuke Hironaka
Shin-Kobe Electric Machinery Co., Ltd.

May 15, 2001
Meeting the New CARB ZEV Mandate Requirements
Grid-connected Hybrids and City EVs
Shin-Kobe Electric Machinery Co., Ltd.

Outline

- Features of Mn type Li ion Battery
- Developments of Mn type Li ion Battery
  Topics: Improvement of cycle life
- Specifications and Characteristics for City EVs
- Summary

Shin-Kobe Electric Machinery Co., Ltd. 1

Features of Mn Type Li ion Battery

Comparison of 3 Positive Electrode Materials

<table>
<thead>
<tr>
<th>Type</th>
<th>Composition</th>
<th>Thermal Decomp T. (°C)</th>
<th>Max Li deposition (mg/g)</th>
<th>Raw Material</th>
</tr>
</thead>
<tbody>
<tr>
<td>Co</td>
<td>LiCoO₂</td>
<td>225</td>
<td>35</td>
<td>8</td>
</tr>
<tr>
<td>Ni</td>
<td>LiNiO₂</td>
<td>180</td>
<td>20</td>
<td>110</td>
</tr>
<tr>
<td>Mn</td>
<td>LiMn₂O₄</td>
<td>150</td>
<td>4</td>
<td>3,500</td>
</tr>
</tbody>
</table>

Merits for Mn Type Li ion Battery

- Safety (Thermal Stability, Li Deposition)
- Low Cost (Large Abundance, Low Price)

Weak Point for Mn Type Li ion Battery

- Insufficient Cycle Life Characteristics

Shin-Kobe Electric Machinery Co., Ltd.
Improvement of Cycle Life (Positive Electrode)

- **Strategy**: To decrease the volume change
- **Optimization of [Li]/[Mn] ratio**
- **Li-rich spinel**

![Graph showing volume change of LiMn₂O₄](image)

- **Fig. 1** Volume change of a unit cell of LiMn₂O₄.
  - Shin-Kobe Electric Machinery Co., Ltd.

---

Improvement of Cycle Life (Negative Electrode)

- **Before cycling**
- **After cycling**
- **Strategy**: To keep the electric conductive network
- **Add a conductive fiber additive**

![Graph showing cycle life characteristics](image)

- **1/3C rate Charging**
- **Electric conduction network was destroyed in negative electrode**
- **Isolated active mass increased (capacity fade)**

- **Charge potential of Negative electrode**

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---

**Charge/discharge cycle life characteristics**

- **1C rate, DOD40%, 50°C**

![Graph showing cycle life characteristics](image)

- **Conventional Spinel**
- **Li-rich Spinel**

---

**Charge/discharge cycle life characteristics**

- **1C rate, DOD40%, 50°C**

![Graph showing cycle life characteristics](image)

- **Non Additive**
- **Conductive Fiber Additive**

Shin-Kobe Electric Machinery Co., Ltd.
for City EVs

<table>
<thead>
<tr>
<th>Battery construction</th>
<th>Single cell</th>
<th>Module</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>—</td>
<td>8 cylindrical cells in series</td>
</tr>
<tr>
<td>Dimensions / mm</td>
<td>Φ67 x L410</td>
<td>L440 x W290 x 186</td>
</tr>
<tr>
<td>Weight / kg</td>
<td>3.2</td>
<td>30</td>
</tr>
<tr>
<td>Capacity / Ah</td>
<td>90</td>
<td>90</td>
</tr>
<tr>
<td>Nominal voltage / V</td>
<td>3.8</td>
<td>30</td>
</tr>
<tr>
<td>Energy density / Wh·kg⁻¹</td>
<td>107</td>
<td>93</td>
</tr>
<tr>
<td>Energy density / Wh·dm⁻³</td>
<td>237</td>
<td>114</td>
</tr>
<tr>
<td>Power density / W·kg⁻¹</td>
<td>470 (DOD85%)</td>
<td>350 (DOD85%)</td>
</tr>
</tbody>
</table>

Outside view of a single cell and battery module.
Shin-Kobe Electric Machinery Co., Ltd.

Charge/discharge characteristics for a single cell at 25°C

Charge Voltage
Discharge Voltage
Charge Current

Surface temperature for a single cell at various discharge rates.

Shin-Kobe Electric Machinery Co., Ltd.
Output power and internal D.C. resistance for the battery module at 25°C.

- **Output Power Density**
- **D.C. Resistance**

![Graph showing output power and internal D.C. resistance](image)

Shin-Kobe Electric Machinery Co., Ltd.

---

30A Discharge performance for a single cell at various temperatures.

- **50°C**
- **25°C**
- **0°C**
- **-15°C**
- **-30°C**

![Graph showing 30A discharge performance](image)

Shin-Kobe Electric Machinery Co., Ltd.

---

Charge/discharge cycle life characteristics for a single cell at various temperatures.

- **1C rate, DOD40%**
- **40°C**
- **25°C**
- **10°C**

![Graph showing charge/discharge cycle life characteristics](image)

---

Application of 8-cell module to City EV

- **8-cell module**
- **(90Ah-30V)**
- **x 4**

Shin-kobe

**Nissan Hypermini**

(2-seat compact car)

Mn type Li ion Baterry

---

Shin-Kobe Electric Machinery Co., Ltd.
Summary

● We developed manganese type lithium ion battery.
  - Energy density 93Wh/kg, 114Wh/dm³ : module
  - Power density 350W/kg (at DOD85%) : module
  - Cycle life more than 1000 cycles (at 25°C)

● These batteries are already used in commercial vehicles "Nissan Hypermini" and are proving their practical applicability.

● Manganese type lithium ion battery will be very promising in future for City EVs which will make large market.

  - Cost, Resources, Performance and Management

Shin-Kobe Electric Machinery Co., Ltd.
Cost-effective Combinations of Ultracapacitors and Batteries for Hybrid Vehicle Applications

May 15, 2001

Andrew Burke
Institute of Transportation Studies, Davis
Cost-effective Combinations of Ultracapacitors and Batteries for Hybrid Vehicle Applications

Andrew Burke
Institute of Transportation Studies
University of California-Davis
Davis, California 95616

Paper presented to Meeting the ZEV Mandate Requirements Grid-connected Hybrids and City EVs May 15-16, 2001

Outline of the Presentation

- Introduction
- Ultracapacitors vs. Batteries
- Reasons for combining batteries and ultracapacitors
- Combinations studied
- Ultracapacitor characteristics
- Battery characteristics
- Applications studied
- Results
- Conclusions

Ultracapacitors vs. Batteries

**Ultracapacitors**
- High power and low resi stance (2kW/kg, 95%)
- Long cycle life (>100K cycles)
- Cycle life independent of the pattern of SOC
- Long shelf life (>10 years)
- Relatively low energy density (<10Wh/kg)
- Power characteristics independent of SOC

**Batteries**
- High energy density (30-150 Wh/kg)
- Moderate power (< 5 kW/kg)
- Short shelf life (<1 year w/o recharge)
- Relatively short cycle life (<1k cycles, deep discharge)
- Cycle life can dependent on the pattern of SOC
- Variation of power characteristics with SOC

Reasons for combining Batteries and Ultracapacitors

- In order to get high power in both motoring (discharge) and regenerative braking (charge) the batteries are maintained at an intermediate SOC (approx. 50%)
- Dual high power requirements result in only a fraction of stored energy being available for use
- Ultracapacitors can provide the power when the power density of the battery is less than needed permitting the battery to be discharged over a wide SOC range
- The total energy stored in the battery can be reduced because a greater fraction of the energy is available for use
- The maximum power of the combination is greater for both motoring and regenerative braking
- In some applications, use of a battery with a higher energy density than possible when the battery must meet the maximum system power requirements for both motoring and braking
Combinations studied
- Ultracapacitors with lead-acid batteries
- Ultracapacitors with nickel-metal-hydride batteries
- Ultracapacitors with lithium-ion batteries

Ultracapacitor Characteristics
- Carbon-based, organic electrolyte
- 2.5-3 V/cell
- Energy density 3-5 Wh/kg
- Power density 1.5-2 kW/kg, 95% efficiency

Applications studied
- Mild hybrids (42V)
- Power assist hybrids (200V)

<table>
<thead>
<tr>
<th>Device</th>
<th>V (V)</th>
<th>C (F)</th>
<th>R (mOhm)</th>
<th>DRR</th>
<th>Wh/kg (1)</th>
<th>W/kWh (2)</th>
<th>W/kg Match Impact</th>
<th>W/kg Match</th>
<th>Wgt (kg)</th>
<th>Vol lit</th>
</tr>
</thead>
<tbody>
<tr>
<td>Skeleton</td>
<td>3</td>
<td>47</td>
<td>5.2</td>
<td>24</td>
<td>10</td>
<td>9735</td>
<td>&gt;80k</td>
<td>0.005</td>
<td>0.003</td>
<td></td>
</tr>
<tr>
<td>Techn R4*</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Maxwell</td>
<td>3</td>
<td>2700</td>
<td>5</td>
<td>135</td>
<td>4.8</td>
<td>713</td>
<td>6428</td>
<td>76</td>
<td>62</td>
<td></td>
</tr>
<tr>
<td>Ness</td>
<td>3</td>
<td>2630</td>
<td>2.5</td>
<td>65</td>
<td>5.1</td>
<td>1556</td>
<td>13880</td>
<td>65</td>
<td>534</td>
<td></td>
</tr>
<tr>
<td>Panasonic (2000)</td>
<td>3</td>
<td>1200</td>
<td>1.0</td>
<td>135</td>
<td>4.2</td>
<td>741</td>
<td>6618</td>
<td>34</td>
<td>215</td>
<td></td>
</tr>
<tr>
<td>Montana</td>
<td>3</td>
<td>1800</td>
<td>10</td>
<td>18</td>
<td>5.6</td>
<td>632</td>
<td>5625</td>
<td>40</td>
<td>30</td>
<td></td>
</tr>
</tbody>
</table>

*unpackaged
(1) Energy density based on E=1/2C/2V2, Vrated=2V
(2) Power based on P=9/16*(1-EF)V2/R, EF=efficiency of discharge, V=3V
Figure 3 Photograph of the Ness 23 V, 2500 F Capacitor

**Principal Specification / EC-HV1225**

<table>
<thead>
<tr>
<th>Specification</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Height</td>
<td>175 mm</td>
</tr>
<tr>
<td>Width</td>
<td>110 mm</td>
</tr>
<tr>
<td>Length</td>
<td>200 mm</td>
</tr>
<tr>
<td>Weight</td>
<td>11.4 kg</td>
</tr>
<tr>
<td>Nominal Voltage</td>
<td>12 V</td>
</tr>
<tr>
<td>Nominal Capacity</td>
<td>3W</td>
</tr>
<tr>
<td>Specific Power (W)</td>
<td>1,000 W/kg</td>
</tr>
</tbody>
</table>

Output/Input Power Performance

Ragone Curve

Energy / Power Plot for NiMH cells with different design
### Table 1 Automotive Lion Cell Characteristics

<table>
<thead>
<tr>
<th>Cell Type</th>
<th>Diameter (mm)</th>
<th>Length (mm)</th>
<th>Mass (kg)</th>
<th>Max Operating Voltage (V)</th>
<th>C/3 Capacity (Ah)</th>
<th>Total Energy @ E/2/3 (W/kg)</th>
<th>Max Power (W/kg)</th>
<th>Discharge Power</th>
<th>Charge Power</th>
</tr>
</thead>
<tbody>
<tr>
<td>HE40</td>
<td>64</td>
<td>106</td>
<td>2.05</td>
<td>4.0</td>
<td>41.66</td>
<td>140</td>
<td>220</td>
<td>280</td>
<td>280</td>
</tr>
<tr>
<td>NR35</td>
<td>54</td>
<td>95</td>
<td>1.65</td>
<td>4.0</td>
<td>39.9</td>
<td>135</td>
<td>260</td>
<td>415</td>
<td>415</td>
</tr>
<tr>
<td>NR41</td>
<td>54</td>
<td>88</td>
<td>0.95</td>
<td>4.0</td>
<td>29.9</td>
<td>115</td>
<td>241</td>
<td>360</td>
<td>360</td>
</tr>
<tr>
<td>HP20</td>
<td>54</td>
<td>126</td>
<td>1.65</td>
<td>3.9</td>
<td>31.9</td>
<td>106</td>
<td>234</td>
<td>1190</td>
<td>600</td>
</tr>
<tr>
<td>HP21</td>
<td>54</td>
<td>126</td>
<td>0.96</td>
<td>3.9</td>
<td>16.0</td>
<td>86</td>
<td>167</td>
<td>105</td>
<td>105</td>
</tr>
<tr>
<td>NR56</td>
<td>47</td>
<td>106</td>
<td>0.28</td>
<td>3.9</td>
<td>8.0</td>
<td>75</td>
<td>150</td>
<td>760</td>
<td>760</td>
</tr>
</tbody>
</table>

The maximum voltage of high energy and medium range cells is specified at 4.0 V, while 3.9 V is used for high power cells. Lower voltage (3.9 V) results in lower energy (about 10%) but may be needed for HEV due to operating cycle.

**Note 1:** Nominal voltage under 1.5 second pulse @ 30°C (50°C for HP 21). 25°C base cell.

**Note 2:** Nominal voltage range quoted by voltage source.

**Note 3:** Data from HP23 cell sample (6.0 Ah) Valid only.

**Note 4:** Nominal power calculated as follows:
- Discharge Power: $P_{max} = V_{max} \times I_{max}$ with $I_{max} = \frac{V_{max} \times V_{rel}}{R}$
- Charge Power: $P_{max} = V_{max} \times I_{max}$ with $I_{max} = \frac{V_{max} \times V_{rel}}{R}$

**Note 5:** Short-range spikes can reach 4.0 V, resulting in power acceptance increase of more than 10% at high state of charge.

**Note 6:** Higher end voltage (below 2.7 V) especially at low temperatures is possible, leading to increased discharge power.
Ultracapacitor - Nickel Metal Hydride Battery

- 200V, 10 Ah
  - NiMHydr Bat 2 kWh
  - 10 Ah
- Weight: 40 kg
- Cost: $2 \times $600 = $1200
- 50 Wh/kg, 625 W/kg, $600/kWh

- 200V, 5 Ah
  - NiMHydr Bat 1 kWh
  - 5 Ah
- Weight: 20 + 25 = 45 kg
- Cost: $1 \times 3 \times 500 + $1200 = $1850
- 65 Wh/kg, 250 W/kg, $500/kWh

Ultracapacitor - Lithium-ion Battery

- 200V, 10 Ah
  - Lithium-ion Bat 2 kWh
  - 10 Ah
- Weight: 27 kg
- Cost: $2 \times $700 = $1400
- 75 Wh/kg, 1300 W/kg, $700/kWh

- 200V, 5 Ah
  - Lithium-ion Bat 1 kWh
  - 5 Ah
- Weight: 15 + 25 = 40 kg
- Cost: $1 \times 2 \times 600 + $1200 = $1920
- 85 Wh/kg, 1 kW/kg, $600/kWh

Ultracapacitor - Lead-acid Battery

- 200V, 10 Ah
  - Lead-acid Bat 2 kWh
  - 10 Ah
- Weight: 80 kg
- Cost: $2 \times $200 = $400
- 25 Wh/kg, 315 W/kg, $200/kWh

- 200V, 5 Ah
  - Lead-acid Bat 2 kWh
  - 5 Ah
- Weight: 28 + 25 = 53 kg
- Cost: $1 \times 150 + $1200 = $1350
- 35 Wh/kg, 200W/kg, $150/kWh
### Summary of the Characteristics of Various Batteries with Ultracapacitors

<table>
<thead>
<tr>
<th>Battery Type</th>
<th>Weight (kg)</th>
<th>Useable Energy (Wh)</th>
<th>Max. Power (kW)</th>
<th>Cost ($)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Lead-acid w/o caps</td>
<td>80</td>
<td>400</td>
<td>25</td>
<td>400</td>
</tr>
<tr>
<td>Lead-acid with caps</td>
<td>53</td>
<td>800</td>
<td>50</td>
<td>1350</td>
</tr>
<tr>
<td>Nickel metal hydride w/o caps</td>
<td>40</td>
<td>400</td>
<td>25</td>
<td>1200</td>
</tr>
<tr>
<td>Nickel metal hydride with caps</td>
<td>45</td>
<td>1000</td>
<td>50</td>
<td>1850</td>
</tr>
<tr>
<td>Lithium-ion w/o caps</td>
<td>27</td>
<td>400</td>
<td>35</td>
<td>1400</td>
</tr>
<tr>
<td>Lithium-ion with caps</td>
<td>40</td>
<td>960</td>
<td>50</td>
<td>1920</td>
</tr>
</tbody>
</table>

### Conclusions

- All the battery/ultracapacitor systems are heavier and more expensive than those with the battery alone.
- All the battery/ultracapacitor systems are higher power and have more useable energy than those with the battery alone.
- The use of capacitors with batteries permits the batteries to be used over their complete SOC.
- The use of capacitors results in the same power for vehicle acceleration and braking independent of battery SOC.
- Lead-acid batteries benefit most of the use of ultracapacitors and lithium-ion the least.
- The lead-acid battery/ultracapacitor combination is particularly attractive in terms of performance and cost.
- The use of capacitors should significantly improve the cycle life of lead-acid batteries in charge sustaining hybrids, but the effect on the cycle life of the other types of batteries is not known.
Hybrid Electric Vehicle Commercialization, Market Potential, Customer Preferences

May 15, 2001

Dean Taylor
Southern California Edison
Overview of Customer Preference Study

- Two teams of the WG worked with ADA to design the format, questions, and education slides of the study
  - Customer Preference team (involved two automakers)
  - Modeling team (included one automaker UCSD NREL ADA others
- 8 Focus Groups
- 1 Pilot Interview
- 400 + Quantitative interviews
- 9 independent attributes tested first in trade-off questions
- Then linked to describe HEV 0 HEV 20 and HEV 60 in full profile trade off questions
- About 100 direct assessment questions tested other benefits demographics attitudes etc.
Customer Based Market Model

Examples of Trade-Off and Direct Assessment Questions

Trade off question example if you had to replace your current Ford Taurus which would you prefer?

| Fuel costs $60 per month (25% less than current costs) | Fuel costs $6 per month (90% less than current costs) |
| Costs $600 per month for 36 months with $3000 down (Total $23,000) | Costs $650 per month for 36 months with $3000 down (Total $24,700) |

Demographics and direct assessments provide context for the preference results (attitudes sex income education etc) and can also be useful in their own right. For example, respondents were asked directly which factors would be most influential in the purchase decision. These questions also provided the model to compute the fuel usage and the gas station preferred way of purchasing (cash lease etc) and other custom inputs for each respondent.

Focus Groups and Quantitative Study Assumptions

- HEVs have been available in the market for about 10 years
- The technology is safe and reliable
- Skilled mechanics are available
- Performance, interior roominess convenience comfort features, and resale value is comparable to the equivalent conventional vehicles
- HEVs are produced by many manufacturers in a wide range of styles such that any model can be purchased as an HEV
- Information about HEVs is widely available from the Internet magazines, automakers government, consumer groups and other sources
- The intent was to focus respondents on their preferences with respect to their choice of well-established power train (conventional or several hybrid) options, not on any other differences in the vehicle itself.
Market Preference Versus Vehicle Price for Mid-size HEVs

Scenario 1 - Simple Market (HEV 0 vs CV HEV 20 vs CV HEV 60 vs CV)

<table>
<thead>
<tr>
<th>Market Preference for HEV vs CV</th>
<th>HEV 0</th>
<th>HEV 20</th>
<th>HEV 60</th>
</tr>
</thead>
<tbody>
<tr>
<td>60%</td>
<td>[1]</td>
<td>[1]</td>
<td>[1]</td>
</tr>
<tr>
<td>50%</td>
<td>[1]</td>
<td>[1]</td>
<td>[1]</td>
</tr>
<tr>
<td>40%</td>
<td>[1]</td>
<td>[1]</td>
<td>[1]</td>
</tr>
<tr>
<td>20%</td>
<td>[1]</td>
<td>[1]</td>
<td>[1]</td>
</tr>
<tr>
<td>0%</td>
<td>[1]</td>
<td>[1]</td>
<td>[1]</td>
</tr>
</tbody>
</table>

HEV Market Potential at Constant Price

<table>
<thead>
<tr>
<th>Vehicle Retail Price Equivalent</th>
<th>HEV 0</th>
<th>HEV 20</th>
<th>HEV 60</th>
</tr>
</thead>
<tbody>
<tr>
<td>$24,000</td>
<td>[1]</td>
<td>[1]</td>
<td>[1]</td>
</tr>
<tr>
<td>$27,500</td>
<td>[1]</td>
<td>[1]</td>
<td>[1]</td>
</tr>
</tbody>
</table>

Mid-size Car Component Based Case Costs (Without Mark-ups) or ANL Costs (With Partial Mark-ups on 3 items)

<table>
<thead>
<tr>
<th>Component</th>
<th>Battery Module Costs to OEM</th>
<th>Battery Power/Energy (kW/h)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Battery</td>
<td>NiMH</td>
<td>HEV 0</td>
</tr>
<tr>
<td>Power</td>
<td>ANL</td>
<td>HEV 20</td>
</tr>
<tr>
<td>Capacity</td>
<td>ANL</td>
<td>HEV 60</td>
</tr>
</tbody>
</table>

Mid-size Car Specifications
Summary of the Base and ANL Methods

Vehicle Fully Loaded Cost Estimates for the Mid-size Car

Vehicle RPE for the HEV 0 is from $2,500 to $4,000 higher than the HEV 20 from $4,000 to $5,000 and the HEV 60 from $7,400 to $10,000 than the comparable CV

Market Preference Versus Vehicle Price for Mid-size HEVs

Low Price Scenario

"Significant uncertainty exists regarding HEV retail price. Even if the early commercialization stage because of the willingness of major automobile manufacturers to subsidize this promising new automotive product. While new technology will cost more to produce, final retail pricing will be a function of competition, government incentives, cost market demand, benefits of ZEV and CAFE compliance, battery leasing, and other factors the WG did not know how to quantify."

Desire to capture new markets (such as fleets or young buyers) and desire to improve the corporate image (technological or environmental) are examples of how competition result in cross product line subsidies.

Federal incentives and Tax Credits Applicable to HEVs

Tax Credits and Other Incentives Conclusions

Tax credits and other incentives could offset much of the purchase and life cycle cost difference between HEVs (especially plug-in HEVs) and conventional vehicles that remain after allowing for the lower energy and maintenance costs of HEVs. However, the applicability of most of the existing incentives to the different HEV types is not clear, but should be made clear. Generally, there appears to be justification for larger incentives going to those HEV types that have greater all electric range because of the larger environmental and energy security benefits associated with all electric vehicle operation.
HEV Reductions in Smog-Forming Gases
CO2, Energy Use and Petroleum Consumption

"While desirable reductions of about 15% in smog-forming gases and 25% in CO2 emissions, energy use and petroleum consumption can be expected for a properly designed HEV 0, a 50% reduction in smog precursors CO2 and energy use as well as a 75% reduction in petroleum consumption, is predicted for the HEV 60. This is compared to a CV meeting the very clean SULEV emissions standard. Specifically ADVISOR simulations show that the petroleum consumption of an HEV 60 (using gasoline/electricity) can be less than that of the PNGV diesel engine-battery HEV 0 concept vehicles and attain the equivalent of 80 mpg without resorting to costly light-weight construction or body aerodynamics."

Draft Final
CBM Model Constructed to Be Extremely Flexible

- Market preferences can be predicted for any vehicle described by the attributes
- Market preferences can be roughly estimated for other HEVs with similar prices and attributes e.g. hybrid pick-up trucks
- The model can be re-run with a different base case vehicle and new sensitivities
- The model can also estimate complex markets where more than one HEV is offered by OEMs in a market segment. Base case was also run to show the (HEV 0 vs HEV 20 vs HEV 60 vs CV) but it is a very aggressive case for 2010 and more likely for 2015 or later.

Preference for HEVs When Choosing 1 Vehicle from all Configurations (2015 Possible Scenario)

Detail on Linked Assumptions and Attributes

<table>
<thead>
<tr>
<th>Vehicle Configuration</th>
<th>CV</th>
<th>HEV 0</th>
<th>HEV 20</th>
<th>HEV 60</th>
</tr>
</thead>
<tbody>
<tr>
<td>Price</td>
<td>20,000</td>
<td>25,000</td>
<td>30,000</td>
<td>35,000</td>
</tr>
<tr>
<td>Battery Capacity (kWh)</td>
<td>200</td>
<td>250</td>
<td>300</td>
<td>350</td>
</tr>
<tr>
<td>Fuel Efficiency (mpg)</td>
<td>40</td>
<td>50</td>
<td>60</td>
<td>70</td>
</tr>
<tr>
<td>CO2 Emissions (g/mi)</td>
<td>200</td>
<td>150</td>
<td>100</td>
<td>50</td>
</tr>
<tr>
<td>Electric Range (mi)</td>
<td>300</td>
<td>400</td>
<td>500</td>
<td>600</td>
</tr>
<tr>
<td>Other Features</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
<td>Yes</td>
</tr>
</tbody>
</table>

Sensitivities: Market Potential for HEV 0 versus Conventional Vehicle

- Fuel price also had a significant effect on market potential. If gasoline prices rose from $1.65 per gallon (baseline assumption) to $3.00 per gallon (an 82% increase), market potential for an HEV 0 would increase about 30%, an HEV 20 would increase about 35%, and an HEV 60 would increase about 65%.
- On the other side if batteries need to be replaced at 5 years or 50,000 miles, market potential for the HEV 0 is reduced by about two-thirds and the HEV 20 and HEV 60 by about half. Battery replacements at 80,000 miles or 120,000 miles were not tested and should not be inferred.

HEV Market Sensitivities for Fuel Price and Battery Replacement

Draft Final
Sensitivities

Market Potential for HEV 60 versus Conventional Vehicle

<table>
<thead>
<tr>
<th>Sensitivity</th>
<th>HEV 60</th>
<th>Conventional</th>
</tr>
</thead>
<tbody>
<tr>
<td>Vehicle Price</td>
<td>$30,000</td>
<td>$25,000</td>
</tr>
<tr>
<td>Battery Cost</td>
<td>$5,000</td>
<td>$5,000</td>
</tr>
<tr>
<td>Gridded Price</td>
<td>$1,000</td>
<td>$1,000</td>
</tr>
<tr>
<td>Battery Replacement</td>
<td>N/A</td>
<td>N/A</td>
</tr>
<tr>
<td>Maintenance Savings</td>
<td>N/A</td>
<td>N/A</td>
</tr>
<tr>
<td>Electrical Upgrades</td>
<td>N/A</td>
<td>N/A</td>
</tr>
<tr>
<td>Environmental Benefits</td>
<td>N/A</td>
<td>N/A</td>
</tr>
</tbody>
</table>

| Fuel Tank Size                     | 25 gal | 25 gal       |

Key Assumption: Plug in each night.

Note: this cannot be added.

Other Sensitivities

Extra Features Option (Pre heat / Pre-cool for $300 and 120 V outlet for recreational work or home applications for $300)

- For the HEV 20 and HEV 60 that can use these features with the engine off (using battery power alone) 41% would select both; 26% would select only the pre-cool and 33% would select none.
- For the CV and HEV 20 which use these features with the engine on 62% would select both; 18% would select one feature and 1% would select neither features.

If electricity prices rose 66% to 10 cents per kWh the HEV 60 fuel cost savings would decrease by $1.65 per year. This is equivalent to a gasoline price of $1.40 per gallon which has little impact on market potential. A similar example for the HEV 20 is equivalent to a gasoline price of $1.83 per gallon. Because of the high efficiency of HEVs even expensive electricity is expected to have only a small impact on market potential (in the above example).

If seven incentives (e.g., carpool lane access and free or reserved parking) are available, the HEV 20 market potential would increase from 35% to 50% and the HEV 60 would increase from 17% to 30%.

Why Pay More for HEVs? Ranking of HEV Benefits

<table>
<thead>
<tr>
<th>HEV Benefit</th>
<th>CV Rank</th>
<th>HEV 20 Rank</th>
<th>HEV 60 Rank</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fuel cost savings</td>
<td>2%</td>
<td>2%</td>
<td>2%</td>
</tr>
<tr>
<td>Responding more effectively (fuel and personal time)</td>
<td>8%</td>
<td>7%</td>
<td>7%</td>
</tr>
<tr>
<td>50% longer range</td>
<td>8%</td>
<td>7%</td>
<td>7%</td>
</tr>
<tr>
<td>Less worry about running out of charge</td>
<td>8%</td>
<td>7%</td>
<td>7%</td>
</tr>
<tr>
<td>Less need for an additional vehicle</td>
<td>8%</td>
<td>7%</td>
<td>7%</td>
</tr>
<tr>
<td>Reducing dependence on foreign oil</td>
<td>8%</td>
<td>7%</td>
<td>7%</td>
</tr>
<tr>
<td>Less variation and changes in speed</td>
<td>8%</td>
<td>7%</td>
<td>7%</td>
</tr>
<tr>
<td>Unhurried daily travel</td>
<td>8%</td>
<td>7%</td>
<td>7%</td>
</tr>
<tr>
<td>Pre-heated, pre-cooled</td>
<td>8%</td>
<td>7%</td>
<td>7%</td>
</tr>
<tr>
<td>Lower emissions (fuel and personal time)</td>
<td>8%</td>
<td>7%</td>
<td>7%</td>
</tr>
<tr>
<td>Avoiding exposure to fumes at gas stations</td>
<td>8%</td>
<td>7%</td>
<td>7%</td>
</tr>
<tr>
<td>Higher personal status</td>
<td>8%</td>
<td>7%</td>
<td>7%</td>
</tr>
<tr>
<td>More personal security (less risk of gas stations)</td>
<td>8%</td>
<td>7%</td>
<td>7%</td>
</tr>
</tbody>
</table>

| More sophisticated CBMM results for willingness to purchase an HEV 20 and HEV 60 (based on plugging them in each night) show market potential that is generally lower because it factors in vehicle price and cost to upgrade electrical systems.

Plugging In Versus Going to the Gas Station

Participants were asked about their preferences for vehicle options on the basis of pluging in versus going to the gas station on a ranking scale of 1 to 9 where 1 = strongly prefer to plug my vehicle with gas at the gas station and 9 = strongly prefer to plug it in at home.

<table>
<thead>
<tr>
<th>Ranking</th>
<th>Results</th>
</tr>
</thead>
<tbody>
<tr>
<td>1-3</td>
<td>1%</td>
</tr>
<tr>
<td>4-8</td>
<td>35%</td>
</tr>
<tr>
<td>7-9</td>
<td>60%</td>
</tr>
</tbody>
</table>

More sophisticated CBMM results for willingness to purchase an HEV 20 and HEV 60 (based on plugging them in each night) show market potential that is generally lower because it factors in vehicle price and cost to upgrade electrical systems.
Draft Final Conclusions

1. HEV 0 technology is in the early commercial stage. Relative to mature combustion engines and state-of-the-art EV technology, HEV technology requires only evolutionary advances to meet technical requirements with the possible exception of batteries. NiMH batteries are technologically capable, but there are uncertainties regarding their life and costs, especially in plug-in service.

2. All HEVs will cost more to produce than their CV equivalent. Estimated increases in the retail price equivalent (RPE) are from $2,500 to $4,000 for an HEV 0, from $4,000 to $6,000 for an HEV 20, and from $7,400 to $10,000 for an HEV 60. Battery costs are the primary reason for this incremental cost.

3. Total energy (motor fuel and electricity) and maintenance costs plug-in HEVs will be less than that for CVs, partially offsetting the impact of battery costs. Incentives to buyers of HEVs could produce additional cost offsets, but more analysis is necessary to confidently quantitate and compare life cycle costs.

4. The Customer Preference study indicates definite market potential for all HEVs. That potential is large if cost equivalence with conventional vehicles can be achieved, but even at higher costs there is likely to be significant market potential.

5. People are willing to pay more for an HEV 60 than an HEV 20; more for an HEV 20 than an HEV 0; and more for an HEV 0 than a CV. It is not clear why so many people prefer medium HEVs over their CV counterparts. However, ten HEV benefits have a high to strong influence on the purchase decision for most consumers, especially for those who prefer HEVs. This refers to a broad package of benefits that could be marketed.

6. The majority of the people surveyed preferred plugging in a vehicle to fueling at the gas station.

Draft Final Conclusions (continued)

7. There are some issues that have been identified that need to be examined for successful commercialization, including battery cost and packaging. Real-world testing must be done regarding life battery costs. It is difficult to estimate, appear to be attainable based on what we know today.

8. HEV 0 vehicles are in the early commercialization stage because of the willingness of major automobile manufacturers to subsidize this promising new automotive product. However, there is an unclear commercialization path for plug-in hybrid electric vehicles despite their substantial societal benefits because, in particular, there are no corresponding automakers initiatives presumably because of battery cost and battery replacement concerns. However, HEV 0s could be a stepping stone to plug-in hybrids.

9. The incremental costs for all HEVs are very significant in low and medium volume production (higher than the numbers in this report). Yet there are also very large societal benefits if HEVs are commercialized. And the infrastructure issues for HEVs are few compared with alternative fuel vehicles. (Even for plug-in HEVs, the survey found 86% had relatively easy overnight access to a plug with 120 V systems being relatively hassle free.)
Part 2: City and Neighborhood EVs

May 16, 2001

Craig Childers
California Air Resources Board
Meeting the CARB ZEV Requirements: Grid-Connected HEVs and City EVs

Part II: City and Neighborhood EVs

Crag Methods
California Air Resources Board
May 15-16, 2010

Challenges for BEVs
- Near-term costs are higher than CV
- Establish appropriate incentives
- Develop necessary infrastructure
- Increase public awareness
  - BEV VS HEV

Emerging Small BEV Classes
- City EVs (CEVs)
- Neighborhood EVs (NEVs)
- Zero emission motorcycles (including enclosed 3-wheel motorcycles)
- e-bikes, scooters, etc

Cost Reduction
- Volume production
  - Vehicle, or
  - Componentry
    - shared components
- Additional battery developments
- Mission-specific BEVs
  - Neighborhood EVs
  - City EVs
- Niche Applications- Shared platforms
  - Postal Delivery Trucks, etc

Range-Speed Graph
Examples of City EVs

- Nissan Hypermini

Examples of City EVs

- Ford Think City

Examples of City EVs

- Honda CityPal

Examples of City EVs

- Toyota e com

Examples of NEVs

- Ford Think Neighbor

Examples of NEVs

- DC GEM
Examples of NEVs

- Dynasty "IT"

Examples of ZEMs

- Gizmo

Examples of ZEMs

- CityEl

- Corbin Sparrow

Neighborhood EVs (NEVs)

- USDOT established new Low Speed Vehicle (LSV) category in 1996.
- LSV created due to increasing conflicts between state and federal law.
- Rulemaking initiated in response to Bombardier, Inc. in 1996.

Neighborhood EVs (NEVs)

- DOT considered 3 options:
  - Raise motor vehicle threshold to 33 mph
  - Bombardier original request
  - No change
  - Create new LSV category
  - LSVs in-between Passenger Car and Golf Carts
- Further DOT Information on LSV development:
Neighborhood EVs (NEVs)

US DOT Low Speed Vehicle definition:
- 4-wheel motor vehicle
- Minimum 20 mph
  - Attainable in 1 mile
  - 20 mph selected as "driving line"
- Maximum 25 mph
- No powerplant definition, so
  - NEVs = LSVs that are zero emission
  - LSVs= Any vehicle meeting DOT regulation

California Vehicle Code Definition:
- 4-wheel
- Min 20 mph Max 25 mph
- <1800 lbs unladen weight
- Vehicle disclosure to purchaser
- Modifications prohibition
- Not allowed on roads posted >35 mph
- Local restrictions

NEV Treatment in ZEV Regulation
- Original 1990 ARB ZEV Regulation
  - NEVs not yet proposed or considered
- 1998
  - NEVs now part of newly expanded definition of "passenger vehicle" that included LSVs
  - Would become eligible for full ZEV credit
- Revised ZEV Regulation (January 2001)
  - NEVs treated separately (credit discounted)

ARB-Certified NEVs
- GEM (DC) (1999, 2000)
- Dynasty IT (2001)
- (Ford Think Neighbor)
- (Iacocca?)

City EVs
- No concrete definition of CEV
- Usually 2 seat
- ~60 mph range
- ~60 mph top speed
- Battery capacity ~1/3-1/2 of full function BEV or ~9-15 kwhr
  (NEVs usually carry less, typ 8.6 kwhr)
- Must meet all standards applicable to motor vehicles
  - Will most likely be designed and built by large automakers

CA ZEV Credit Earned by NEVs:

<table>
<thead>
<tr>
<th>Year</th>
<th>Early</th>
<th>Intro Multiplier</th>
<th>NEV discount</th>
<th>Resulting NEV Credit</th>
</tr>
</thead>
<tbody>
<tr>
<td>'00</td>
<td>4</td>
<td>1</td>
<td>1</td>
<td>4</td>
</tr>
<tr>
<td>'01</td>
<td>4</td>
<td>1</td>
<td>1</td>
<td>4</td>
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<tr>
<td>'02</td>
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<td>1</td>
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<td>4</td>
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<td>'03</td>
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<td>1.25</td>
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<td>'04</td>
<td>1.25</td>
<td>1.25</td>
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<td>1.25</td>
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<tr>
<td>'05</td>
<td>1.25</td>
<td>1.25</td>
<td>1</td>
<td>1.25</td>
</tr>
<tr>
<td>'06</td>
<td>1.25</td>
<td>1.25</td>
<td>5</td>
<td>6.25</td>
</tr>
</tbody>
</table>

Early

- No concrete definition of CEV
- Usually 2 seat
- ~60 mph range
- ~60 mph top speed
- Battery capacity ~1/3-1/2 of full function BEV or ~9-15 kwhr
  (NEVs usually carry less, typ 8.6 kwhr)
- Must meet all standards applicable to motor vehicles
  - Will most likely be designed and built by large automakers
City EVs

- Usually intended for city (not freeway) travel
- Usually fit Japanese microcar class limits
  - Length < 3400 mm (some < 2500 mm)
  - Width < 1480 mm
- NOTE: some NEVs are larger than City EVs
- Most manufacturers targeting shared or station car applications

ZEV Credit Determination

Initial ZEV Credit =

\[ \{1 + ([\text{Range Mult} - 1] \times [\text{Range Mult Phased}])\} \times \{1 + ([\text{Eff Mult} - 1] \times [\text{Eff Mult Phase In}])\} \times [\text{Transportation System Mult}] \times [\text{Early Intro Mult}] \times [\text{NEV/LSV discount}] \]

Efficiency Multiplier

<table>
<thead>
<tr>
<th>VEHICLE CLASS</th>
<th>EFFICIENCY MULTIPLIER</th>
</tr>
</thead>
<tbody>
<tr>
<td>City (EV)</td>
<td>CMPEG/ (1.5 x 45.9)</td>
</tr>
<tr>
<td>Subcompact PC</td>
<td>CMPEG/ (1.5 x 16)</td>
</tr>
<tr>
<td>Compact PC</td>
<td>CMPEG/ (1.5 x 30)</td>
</tr>
<tr>
<td>Midsized PC</td>
<td>CMPEG/ (1.5 x 27)</td>
</tr>
<tr>
<td>Large PC</td>
<td>CMPEG/ (1.5 x 25.6)</td>
</tr>
<tr>
<td>Small Truck</td>
<td>CMPEG/ (1.5 x 25.0)</td>
</tr>
<tr>
<td>Medium Truck</td>
<td>CMPEG/ (1.5 x 21.4)</td>
</tr>
<tr>
<td>Large Truck</td>
<td>CMPEG/ (1.5 x 18.2)</td>
</tr>
</tbody>
</table>

2006 ZEV Credit Example: Typ. City EV

Initial ZEV Credit =

\[ \{1 + ([1.4 - 1] \times [0.60])\} \times \{1 + ([1.85 - 1] \times [0.35])\} \times [\text{Transportation System Mult}] \times [\text{Early Intro Mult}] \times [\text{NEV/LSV discount}] \]

\[ \approx 1.6 \]

Year 4+ In-Service/ Under-Warranty Credits:

\[ \approx 0.16 \text{ per year} \]

City EV Proposed changes

- Station car credit multiplier for CEVs
- Enhances usability of mass transit
- Freeway capability and long range often unnecessary
- Amount of additional credit may increase from December proposed revisions (2x)
- New class for eff credit determination
### ZEV (Initial) Credit Comparison

<table>
<thead>
<tr>
<th></th>
<th>'01</th>
<th>'02</th>
<th>'03</th>
<th>'04</th>
<th>'05</th>
<th>'06</th>
<th>2012</th>
</tr>
</thead>
<tbody>
<tr>
<td>High FFEV Credit</td>
<td>19</td>
<td>19</td>
<td>5</td>
<td>87</td>
<td>5</td>
<td>87</td>
<td>5</td>
</tr>
<tr>
<td>Typ CEV Credit</td>
<td>5</td>
<td>6</td>
<td>1</td>
<td>8</td>
<td>1</td>
<td>8</td>
<td>1</td>
</tr>
<tr>
<td>NEV Credit</td>
<td>4</td>
<td>4</td>
<td>1.25</td>
<td>625</td>
<td>625</td>
<td>0.15</td>
<td></td>
</tr>
</tbody>
</table>

### Vision for the Future

- Clean & healthful air
- Steady, sustainable increase in ZEVs
- Mission-specific BEVs may play a role

### SPARES

### ZEV Obligation (All Manufacturers)

![Graph showing ZEV Obligation over time]

### NEVs & CEVs

**Estimated number of vehicles in 2003:**

- Without ATPZEVs
- ZEVs: 9,300
- If 100% Full Function EVs: 23,500
- If 100% City EVs: 30,900
- If 100% NEVs: 94,500
- PZEVs: 94,500
- ATPZEVs: 10,700

### Manufacturer Obligation

![Graph showing manufacturer obligations]

**Current Regulation**
- Battery EV
- H2 Fuel Cell
- Grid-Connected HEV
- Medium Fuel Cell
- BEV
- CNG
- 0.2 Credit PZEV

**Staff Proposal**
**Abbreviations Used**

- **LSV** - Low Speed Vehicle
- **NEV** - Neighborhood Electric Vehicle (zero-emission LSV)
- **CEV** - City Electric Vehicle
- **ZEV** - Zero Emission Vehicle
- **ZEM** - Zero Emission Motorcycle
- **PZEV** - Partial Zero Emission Vehicles
- **AT PZEV** - Advanced Technology Partial Zero Emission Vehicle
- **SULEV** - Super Ultra Low Emission Vehicle
- **VMT** - Vehicle Miles Traveled
- **GGE** - grams per mile

- **BEV** - Battery Electric Vehicle
- **HEV** - Hybrid Electric Vehicle
- **GHEV** - Green Hybrid HEV (same as extended range HEV)
- **AEV** - all electric vehicle
- **OBD** - On Board Diagnosis
- **MIL** - Malfunction Indicator
- **EFF MULT** - Efficiency Multiplier
- **DOT** - Dept. of Transportation
- **CMPEG** - California Miles Per Equivalent Gallon
- **LEV** - Low Emission Vehicle
- **LEV II** - 1028 amendments to LEV program
Toyota
EV Commuter (e-com)

May 16, 2001

Dave Hermance
Toyota Technical Center, USA, Inc.
**Toyota EV Commuter (e-com)**

Toyota Technical Center, USA, Inc
Dave Hermance

---

**e-com - Features**
- 2-door, 2-passenger mini-car
- Local personal transportation concept
- NiMH batteries ~8.4 kW-hr, 320 pounds
- Regenerative braking
- High efficiency permanent magnet motor
- 60 mph top speed
- 50 mile range (FTP city)

---

**e-com Battery Pack**
- 24 12-volt NiMH batteries
- ~8.4 kW-hr capacity

---

**e-com Battery Pack Location**
- Center mounted under vehicle floor pan in a resin carrier
- Maintenance-free
- 1/3 the weight of RAV4-EV battery pack

---

**e-com Placements**
- 103 worldwide, 15 in CA
- Demonstrations only
- Japan demos include integrated ITS elements

---

**e-com Motor**
- Front-wheel drive transaxle
- Three-shaft, single-speed reduction gear unit
- Maximum output = 19kw at 2200-3500 rpm

---

**e-com - Retail Potential**
- Limited retail potential due to cost, range, top speed, utility of design
- Not equal to conventional gasoline
Crayon Project (e-com)

City EV Regulatory Issues
- Credits relative to FFEV
- Cost per credit

City EV Technical Issues
- FMVSS compliance
- Real-world safety
- Acceleration performance
- Top speed
- Battery choice
- Range
- Recharge time

City EV Marketing Issues
- Americans don't buy small cars
- Buyer expectations

What Does the Market Want?
A significant and growing percentage of customers indicate a willingness to buy an environmentally friendly vehicle,
if and only if, all other attributes are equal
The Demonstration Test
of ITS/EV City car System with “Hypermini”

May 16, 2001

Masahiko Teramoto
Nissan Motor Co., Ltd.
The Demonstration Test of ITS/EV City car System with “Hypermini”

Masahiko Teramoto
NISSAN MOTOR CO., LTD.

Outline of the Project

Fig 1, Concept
Seamless transportation system
= Door to door
Residential area

Yokohama Minato Mirai 21
*850 Companies in 1Km square
*50,000 business persons
*Parking capacity 10,000 cars
*Company car 3000’s
*New business area since 1983

Fig 2, How to use the system
Control center
EV station

Remote control
Vehicle status monitoring
Messaging service
Voice service

Member
Yokohama
Minato Mirai 21
Round trip
Unmanned service
Authorization/return door lock/unlock
One way trip

Information service
Navigation
Battery level warning
Call button

EV stations

Fig 3, System Components

Fig 4, ITS function
Battery level warning
Call button in trouble

Battery level is low
Please return to a station immediately

Emergency message please confirm

Fig 5, ITS new function-2
Eco-friendliness indicator

Your eco-friendliness index
Saving weight of CO2 431g-C
this value is equivalent to
378CC volume of gasoline
Fig 14. Development of New ITS system

Control Center

Packet Communications (Cellular phone line mode)

Reservation
Authorization
Permission
Door
Backface
charging fee

*Hands free telephone

EV station A
(crowded)

Available vehicle number

Announcement of charge fee

EV station B
(vacant)

Relocation
Cheaper price

Fig 15. Self growth model (YOKOHAMAXINAGA)

 Worcester

Control center
YOKOHAMA

Participate in from anywhere services

New member

FX

Generation 2

Yokohama

Chief

Broker

Mutual use
Th!NK

May 16, 2001

David Fabricatore
Th!nk City Project
THINK City Project Coordinator

Our Vision
- Create a new sustainable business enterprise
- Connect with customers in fun & innovative ways

Our Mission
- Provide innovative solutions for personal mobility
- Incubate leading edge technologies

Fresh approaches
Caring for the environment

Environmental Trends
- "Most cars are used for short trips"
- 70-80% live in cities and close communities
- Approx. 70% of all car driving is in these areas
- 1.2-1.3 people per car on average
- With only little or some luggage

Most cars are larger than needed.

Conclusion
- Best selling vehicles in US are SUV's and trucks
- Big disconnect between customer needs vs purchase decision
- Many consumers have multi-vehicle fleets - in which vehicles have different utilization patterns
- Opportunity to provide specialized vehicles & mobility services that replace regular vehicles
**Pilot Program**

**Goals**
- Develop the market for the new city-class electric vehicle
- Test the THINK city in new niche marketing programs suited to urban vehicles
- Provide understanding of city-class customers prior to launch in 2002
- Generate positive PR/awareness
- ZEV credits - 4 48

**General Specifications**

**Seating Capacity** 2

**Body Dimensions**
- length 9 8 ft.
- width 5 25 ft.
- height 5 1 ft.
- luggage 12 4 cu. ft.

**Curb weight** 2,075 lbs

**GVW** 2,490 lbs.

**Top Speed** 66 mph

**Acceleration** 0-30 mph in 7 secs

**Range, city driving** 53 miles (est.)

**Frame and Body**

**Lower Frame** Steel frame, 90% high strength steel w/ cold coated

**Upper Frame** Extended and welded aluminum

**Bodywork** Thermoplastic (polyethylene)

**Roof** ABS plastic

**Electrical Systems, Motor & Chassis**

**Propulsion** Nickel Cadmium batteries, 550 lbs, water cooled

**Power Storage** 15.5 kWh, 100 Ah

**Charger** Conductional internal 100-240V - 16A (3.21 kW) air cooled

**Charge Time** 4 - 6 hours at 16A

**Motor Type** Three Phase A/C induction Motor water cooling

**Max. Output** 27 kW

**Voltage** 114 volts

**Drive** Front Wheel Drive

**Tires** 155/70 R13

**Brakes** front disc brakes

**Safety**

- Low Center of Gravity
- Steel and Aluminum Safety Frame
- Side Impact Beams in the Doors
- Driver Front Air Bag
- Sashbelts with pre tensioners
- Battery Separated from Passenger Compartment
- Headrests and Rear Window
- Child Seat Tether Anchor
Standard Equipment

- Tinted Glass
- 3kW Electric Heater
- Pro Cabin Heating/Cooling
- AM/FM/CD Radio with 2 speakers
- 12V Auxiliary Outlet
- 13 5-spoke aluminum wheels
- Regenerative Braking

95%+ of Vehicle is Recyclable

Customer Profile

- Fleet Customers (private/government)
  - Local driving
  - Auto-paused fixed routes
  - Stop & Go style of driving

- Urban based, second car
- Substitute for an older second-hand car
- Environmentally aware
  - Personal priorities
  - Opinion Leaders and innovators

For more information

www.thinkmobility.com
NEVCO Gismo

May 16, 2001

Carl Watkins

NEVCO
Presentation by Carl Watkins, Neighborhood Electric Vehicle Company, at:

Meeting the New CARB ZEV Mandate Requirements Conference

The objective of the Air Resources Board is to produce cleaner air. There is an urgent need to reduce the use of gasoline by replacing ICE vehicles with zero emission vehicles or ZEVs. Fossil fuels should not be used for local transportation where alternative fuels will accomplish the task. Electric Vehicles, if designed for specific uses, are entirely capable of accomplishing local, in-town trips. Incentives are an effective tool to get ZEVs into use as quickly as possible. Any ZEV that eliminates the use of a gasoline vehicle for a large segment of the market should receive equivalent government incentives as other ZEVs.

Three wheeled enclosed electric motorcycles can eliminate a large segment of the vehicle miles traveled in ICE vehicles. In some ways, they have a better chance of accomplishing this substitution than other types of ZEVs or AFVs. Such vehicles as the Gizmo, from NEVCO, and the Sparrow, by Corbin Motors, deserve the same incentives as other EVs. They are capable of having at least as much impact as more car-like EVs, and sooner than other EVs that have incentives, because they are more affordable priced and currently available, and they meet large segments of the market.

More than 75 percent of all travel can be accomplished by the Gizmo. Demographic and statistical information show that most travel is one person traveling alone, and going fewer than 25 miles in a day with a small amount of cargo. Most of these trips do not include freeway travel. With other considerations of cost and congestion, small single person EVs offer an excellent option for future urban transportation.

Demographic Data

In 1990, the National Personal Transportation Survey indicated that 50 percent of all car trips took fewer than 10 minutes. Sixty-five percent of all trips are non-work trips, which account for 59 percent of all vehicle miles traveled. It also showed

<table>
<thead>
<tr>
<th>Non-work Activity</th>
<th>Average Distance</th>
</tr>
</thead>
<tbody>
<tr>
<td>Social/Recreational (Incl. Vacation)</td>
<td>11.8</td>
</tr>
<tr>
<td>Other Family/Personal Business</td>
<td>7.4</td>
</tr>
<tr>
<td>Shopping</td>
<td>5.1</td>
</tr>
</tbody>
</table>

This type of trip can easily be accomplished in a Gizmo or other similar vehicles.

Commuter Travel

The Bay Area Commute Profile 2000 revealed the following facts.
Over 70 percent of area commuters traveled less than 40 miles
Forty-five percent traveled fewer than 20 miles
The average speed was 30 miles per hour
The average time was 34 minutes
Sixty-seven percent of all commuters travel alone

The Gizmo can accomplish this type of travel at a reasonable price

Because of the limitations in range of EVs, they will almost always be a second or third vehicle. This means they will be added to the existing vehicles that a family owns. Where a second or third car is concerned, the 1998 Alameda Exposition survey shows that the mileage requirements are even less stringent, requiring a median distance of only 20 miles. This type of application is especially appropriate for the Gizmo.

See Attached Graph

Energy Efficiency

The Bureau Of Transportation Statistics keeps records on vehicle "energy intensity" in terms of BTUs per passenger-mile. This allows us to make a comparison of vehicles' average efficiency. The less energy used per mile, the less pollution is generated. Better energy efficiency should be encouraged. The Gizmo is designed to accomplish the required driving as efficiently as possible.

1996 Energy Intensity by Vehicle Type

<table>
<thead>
<tr>
<th>Type</th>
<th>BTUs per passenger mile</th>
</tr>
</thead>
<tbody>
<tr>
<td>Automobile</td>
<td>3700</td>
</tr>
<tr>
<td>Light truck</td>
<td>4529</td>
</tr>
<tr>
<td>Amtrak Trains</td>
<td>2400</td>
</tr>
<tr>
<td>Airlines</td>
<td>4100</td>
</tr>
<tr>
<td>Transit Bus</td>
<td>4500</td>
</tr>
<tr>
<td>Inter-city Bus</td>
<td>1000</td>
</tr>
<tr>
<td>Current AFVs</td>
<td></td>
</tr>
<tr>
<td>Hybrid (50 mi/gal)</td>
<td>2280</td>
</tr>
<tr>
<td>Honda Plus EV</td>
<td>1300</td>
</tr>
<tr>
<td>Gizmo</td>
<td>650</td>
</tr>
</tbody>
</table>
Speed

The first Gizmos were designed to have a top speed of only 30 miles per hour to simplify licensing. Our experience was that this was not fast enough to travel on neighborhood arterial roads that feed traffic from one area to another. These are the roads that commuters use, and are the same roads that people use when traveling around town. At 30 mph, the driver feels uncomfortable because of the actions of other drivers when encountering a delay. In order to blend comfortably with normal traffic, a vehicle must be able to attain a speed of 40 mph or more. We completely redesigned the Gizmo to meet this requirement.

Replacing gasoline vehicles

The type of gas cars that are in most need of replacing are older, more polluting vehicles. These are generally driven by people who are less able to pay more for a vehicle. That is why a low-priced EV is essential for replacing gas vehicles in large numbers.

Congestion

For most city planners, increasing congestion is a bigger problem than pollution. By building electric vehicles that are smaller, a better long-term solution is possible. Bumper-to-bumper stop-start traffic and continual idling are major sources of pollution, which the Gizmo eliminates by being electric, but also by taking up less space and parking easily.

Conclusion

If you want to get a large number of ZEVs on the road, you have to make it as easy as possible for people to buy them. Because these will all be niche market vehicles, you will need to have a variety of options to meet many people’s needs.

The effort to get people to switch to ZEVs is about competition between gas vehicles and ZEVs, not among ZEVs themselves.

There are millions of cars sold every year. CARB is just trying to get a small percentage of those to be clean.

The better each manufacturer does, the better we all will do. We all need credibility. We all need to help people learn a new way of getting around. It is tremendously difficult to get people to change. The auto industry is spending billions of dollars trying to convince people to buy SUVs. We need to build momentum by having thousands of people switch to ZEVs every month.

All EVs, whatever the type, need all the incentives they can get.
Commute Distance over Time (by mileage)

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>0-5 Miles</td>
<td>29.0%</td>
<td>36.3%</td>
<td>33.8%</td>
<td>32.7%</td>
<td>25.1%</td>
<td>27.6%</td>
<td>27.8%</td>
</tr>
<tr>
<td>6-10 Miles</td>
<td>18.3%</td>
<td>18.1%</td>
<td>18.6%</td>
<td>20.0%</td>
<td>20.2%</td>
<td>19.8%</td>
<td>17.2%</td>
</tr>
<tr>
<td>11-20 Miles</td>
<td>26.0%</td>
<td>23.4%</td>
<td>24.9%</td>
<td>24.6%</td>
<td>27.5%</td>
<td>26.1%</td>
<td>25.9%</td>
</tr>
<tr>
<td>21-40 Miles</td>
<td>20.4%</td>
<td>16.8%</td>
<td>15.2%</td>
<td>16.1%</td>
<td>20.7%</td>
<td>19.0%</td>
<td>22.0%</td>
</tr>
<tr>
<td>41+ Miles</td>
<td>6.3%</td>
<td>5.4%</td>
<td>7.6%</td>
<td>6.6%</td>
<td>6.5%</td>
<td>7.5%</td>
<td>7.1%</td>
</tr>
<tr>
<td>n</td>
<td>1,600</td>
<td>3,201</td>
<td>400</td>
<td>3,188</td>
<td>1,171</td>
<td>3,572</td>
<td>3,608</td>
</tr>
</tbody>
</table>

Commute Distance and time

<table>
<thead>
<tr>
<th>Miles Per Hour</th>
<th>Average Minutes</th>
<th>One-Way Miles</th>
</tr>
</thead>
<tbody>
<tr>
<td>1992</td>
<td>1993</td>
<td>1994</td>
</tr>
</tbody>
</table>
QUESTION 7 – APPROXIMATELY HOW MANY MILES DOES EACH CAR TRAVEL PER DAY?

Exhibit 11 shows the average number of miles driven per day for the vehicles in the household. The median value is also shown. The minimum number of miles for all vehicles was 1 mile per day while the maximum varied between 100 and 200 miles per day.

Exhibit 11
Average and Median Miles Driven per Day
Development of Affordable Electric Vehicles

May 16, 2001

Hyungpyo Woo
ATT R&D
Parade, an affordable Electric Vehicle

OUTLINES

I What People Want or Expect From Electric Vehicle
   - Right Balance of Performance & Price
   - Attractive Styling, Economics & Ergonomics
   - Safety as the First Priority

II New Approach to Vehicle Design
   - New Vehicle Platform Development
   - New Manufacturing Method
   - New/Carry-over Components Development
Parade, an affordable Electric Vehicle

III Reducing Development Cost
- Use All the Available Resources
- Geographical Advantages
- In-house Engineering Capability
- Outsourcing

IV Current Status
- Financing for Building 40 prototypes for Test
- Discussing with US cities for Manufacturing Facility Setup
- Developing Low Speed Electric Vehicles
parade

Ideation Sketches

Interior color sketches for MPV

parade

Final Model

Exterior
Base Camp in Korea for EV Development

- **Cost Advantage of Local Services & Parts**
  - US
  - Japan
  - Germany
  - France
  - Korea

- **Availability of Technology & Parts of Small Vehicles**

- **Over-supply of Talented Human Resources in Korea**
  - 4 Korean Auto Makers (Out of 7) were Merged Since 1996
  - More Than 30% of Experienced Design Engineers Changed Career Since 1998
  - Early Retirement Programs of Auto Makers Encourage Talented Engineers to Leave
# Parade EVs vs. Other EVs in Market

<table>
<thead>
<tr>
<th>Body</th>
<th>EV50 / EV150</th>
<th>Honda EV+</th>
<th>GM EV1</th>
</tr>
</thead>
<tbody>
<tr>
<td>Construction</td>
<td>Aluminum Monocoque</td>
<td>Steel Monocoque</td>
<td>Aluminum Monocoque</td>
</tr>
<tr>
<td></td>
<td>Rear Wheel Drive</td>
<td>Rear Wheel Drive</td>
<td>Front Wheel Drive</td>
</tr>
</tbody>
</table>

## Dimensions/Weights

<table>
<thead>
<tr>
<th>Seating Capacity (Passengers)</th>
<th>4</th>
<th>2</th>
<th>2</th>
</tr>
</thead>
<tbody>
<tr>
<td>Exterior Dimensions (LxWxH in mm)</td>
<td>3,595 x 1,680 x 1,270</td>
<td>4,146 x 1,775 x 1,53</td>
<td>4,102 x 1,755 x 1,520</td>
</tr>
<tr>
<td>Wheelbase (in mm)</td>
<td>2,460</td>
<td>2,550</td>
<td>2,615</td>
</tr>
<tr>
<td>Tread (Front/Rear)</td>
<td>1,415 mm / 4,415 mm</td>
<td>1,415 mm / 4,415 mm</td>
<td>1,430 mm / 4,430 mm</td>
</tr>
<tr>
<td>Curb Weight (kg)</td>
<td>250</td>
<td>270</td>
<td>275</td>
</tr>
<tr>
<td>Number of Doors</td>
<td>4</td>
<td>3</td>
<td>3</td>
</tr>
</tbody>
</table>

## Performance

<table>
<thead>
<tr>
<th>Range by EPA City Mode</th>
<th>155 miles</th>
<th>177 miles</th>
<th>9 miles</th>
</tr>
</thead>
<tbody>
<tr>
<td>Top Speed</td>
<td>26 mph</td>
<td>124 mph</td>
<td>90 mph</td>
</tr>
<tr>
<td>Carrying Capacity</td>
<td>323 kg</td>
<td>325 kg</td>
<td>325 kg</td>
</tr>
</tbody>
</table>

## Purchase/Lease Terms

<table>
<thead>
<tr>
<th>Stick Price</th>
<th>$10,000</th>
<th>$10,000</th>
<th>$10,000</th>
</tr>
</thead>
<tbody>
<tr>
<td>Monthly Lease Price</td>
<td>$454</td>
<td>$424</td>
<td>$424</td>
</tr>
</tbody>
</table>

## Body-in-White (Summary)

### Platform X

<table>
<thead>
<tr>
<th>Primary Material</th>
<th>Aluminum/Air</th>
<th>Steel</th>
</tr>
</thead>
<tbody>
<tr>
<td>Primary Forming Process</td>
<td>Stamping</td>
<td>Stamping</td>
</tr>
<tr>
<td>Preferred Joint Process</td>
<td>Riveting</td>
<td>Spot Welding</td>
</tr>
</tbody>
</table>

### Manufacturing Cost

<table>
<thead>
<tr>
<th>Platform X</th>
<th>Conventional</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>$8,000</td>
</tr>
<tr>
<td></td>
<td>$6,000</td>
</tr>
<tr>
<td></td>
<td>$4,000</td>
</tr>
<tr>
<td></td>
<td>$2,000</td>
</tr>
<tr>
<td></td>
<td>$0</td>
</tr>
</tbody>
</table>

### Design Cost

<table>
<thead>
<tr>
<th>Platform X</th>
<th>Conventional</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>$500,000</td>
</tr>
<tr>
<td></td>
<td>$500,000</td>
</tr>
<tr>
<td></td>
<td>$500,000</td>
</tr>
<tr>
<td></td>
<td>$500,000</td>
</tr>
<tr>
<td></td>
<td>$500,000</td>
</tr>
</tbody>
</table>

### Delivery of Testing

- 12-18 months
Vehicle Safety Crashworthiness

Before Crash

After Crash

Meets or Exceeds: FMVSS 208, US NCAP, Euro NCAP
Overall Rating: ★★★★★

Chassis Design Resources

- Modern Design Tools:
  - Full CAE Ability from Concept to Production
  - CATIA for CAD operation
  - ADAMS, DADS, MATLAB for vehicle dynamics analysis
  - NASTRAN, ANSYS for finite element analysis

- World-Class Manpower:
  - Highly Qualified Engineers
    - Able to handle both design and analysis
    - Over 10 years experience each in automotive industry
  - Design Cycle Experience
    - All of drawing, analysis and test correlation work steps
    - Average 3 model-car program carried out

- Slim & Effective Organization:
  - Tightly Combined Workflow
    - Design, analysis, development and outsourcing within one team
  - Well Developed Information Flow
    - Wide knowledge on outsourcing and prototyping
    - Full awareness of simultaneous engineering about production

ATT R&D Co., Ltd.
Auto Venture Tower #121, Yongsan-gu, Seoul, Korea
Tel: +82 31 907 5333 Fax: +82 31 907 5344
Email: att@att.co.kr
Chassis Working Process

Dynamic Behavior

Kinematics → Elastic Kinematics

Various Quasi-Static Analyses

Simulation

Dynamic Boundary Condition

Flexible Bodies Information

Strength & Stiffness

Conceptual Stiffness → Model Analysis → Detailed Analysis → Optimization

ATT R&D's Chassis Design Capability

Resource to Develop New Chassis Platform

ATT R&D

5 Months

Other

Prototyping 8 Months

Automakers

ATT R&D

25 Man-Months

Other

Prototyping 60 Man-Months

Automakers

ATT R&D

10-20%

Other

Expense

Automakers

100%
Suspension

Suspension Front:
- MacPherson Strut Type
- Aluminum Knuckle
- Aluminum Lower Arms
- Weight: 13.5 kg
- System Purchase Cost: $276
- Testing Cost: $500

* For Left & Right

Suspension Rear:
- MacPherson Strut Type
- Light Alloy Multi-Link
- Aluminum Knuckle
- Weight: 19.4 kg
- System Purchase Cost: $164
- Testing Cost: $550

Lighting Devices

Rear Lamp Cluster:
- Custom Tailoring for the U.S. & EU
- Development & Testing Cost: $520.00
- System Purchase Cost: $518 (Per Left & Right Units)

Head Lamp Cluster:
- One-time Tailoring for the U.S. & EU
- MFR-Type Left & Right Beams
- Development & Testing Cost: $915.00
- System Purchase Cost: $578 (Per Left & Right Units)

* U.S. only
** EU only
Heating & Air-Conditioning System

**Mechanism for Enclosure Parts**

- **Mechanism Total**
  - Weight: 33.2 kg
  - Material Cost: $256
  - Tooling Cost: $303,500

- **Front Door Mechanism**
  - Weight: 33.2 kg
  - Material Cost: $287
  - Tooling Cost: $122,000

- **Rear Door Mechanism**
  - Weight: 33.2 kg
  - Material Cost: $91
  - Tooling Cost: $122,000

---

**Target System Weight**: 28 kg
**System Purchase Cost**: $500 (Target)
**Development & Tooling Cost**: $700,000

---

ATT RAD Co. Media Venture Tower #215 Senapang 775 1 Han, Keung, Bundang, Gungnam 411 937 Tel. +82 31 907 5333 Fax. +82 31 907 5344 Strictly Confidential
### Advantages of ATT R&D's Technology

<table>
<thead>
<tr>
<th>Development</th>
<th>Production</th>
<th>Use &amp; Disposal</th>
</tr>
</thead>
</table>
| Styling & Engineering Cost  
(10-15 man-hours) | EV Manufacturing Cost  
(5000 units) | Expected Life Of Vehicle Body  
(30-40 years) |
| $10-$15 million | $100-$300 million | 30-40 years |
| Testing Investment For Body Parts  
(4 Door Passenger Car Model) | | Value Of Recycled Body  
($200-$300) |
| $2-$3 million | $30-$50 million | 30-40 years |
| Parade | Parade | 30-40 years |
| (minimum R&D) | (minimum R&D) | (minimum R&D) |
| | | 30-40 years |

### Current Status of Parade EV Project

- Financing for Building 40 prototypes for Test
- On Going Discussion with US cities for Manufacturing Facility Setup
- Developing Low Speed Electric Vehicles
The Force EV- Solectria’s Path to Emerging as a Premier Electric and Hybrid Electric Drive System Component Developer and Manufacturer

May 16, 2001

Vasilios Brachos
Solectria Corporation
Solectria Corporation

The Solectria Force Electric Sedan and Technology Spin-Offs
By Vasilios Brachos

ITS UC Davis
May 16, 2001

Force Customers

- Electric utilities – SCE, SMUD, Boston Edison, PEPCO, PP&L, etc.
- Universities
- EV demonstration programs – Massachusetts, New Jersey, Connecticut, Vermont, etc.
- Battery Companies – GP, EVonyx
- Individuals nationwide

Solectria is NOT a car company

- Solectria Force introduced to market in 1991
- Geo Metro platform – high MPG, produced domestically
- 300 on the road
- over 3,000,000 miles

Force – Proven Design

- Dynomometer tested
- EV America tested
- CARB certified
- Crash tested to meet FMVSS – frontal, side, roof
Force Technology Development

- Constant revision and refinement of Force drive system & ancillary components
- Extensive on-road experience with these systems
- All-digital electronics
- Rugged motor-gearbox system

Strategic Partnerships

- Solectria proved it was able to deliver automotive standard quality production
- Manufacturing partners established
- General Motors supplied gliders for last 50 Forces produced

Force as Test Bed

- Battery chemistries - Lead acid, Zinc bromine, Zinc air, Nickel cadmium, Nickel metal hydride
- Fuel Cells - NJ DOT
- SuperCaps - technology from Maxwell, testing by EVermont

Quality Issues

- Many of Solectria's suppliers now ISO qualified
- Solectria’s Quality Plan in place
Spin-off Technology

- AC motors - 20kW to 150kW
- DSP motor controller
- DSP battery chargers - 3kW to 9kW
- Hybrid controller - ICE/generator, APU's, microturbines, fuel cells, ultracapacitors
- Grid connected and independent power generation systems

Motors & Transaxles

- Robust, efficient products
- Proprietary designs
- Motors utilize established motor technologies for low cost even at low volumes
- Optimized for OEM customer system requirements

Electric Drive Systems

- EV, Hybrid, Fuel Cell
- Wide range of power levels
- Scalable architecture
- Cost-effective design approach
- Proven products (millions of miles)

Power Electronics

- DSP-based Motor Controllers (Inverters)
- DC-DC Converters
- Battery Chargers
- Auxiliary Systems
- Proprietary & Patented Technologies, Software & Algorithms
Advanced Energy Systems

- Power management for various energy sources (generators, storage)
- Inverters/Generator Controllers
- DSP based technology
  - DC-DC Converter
    (shown at right)
- Specialists in AC motor control theory & power factor correction for high quality power
- High reliability for quality power market

Numerous Niche Vehicle Applications Exist

- Resurface Collect - Ice Resurfacer
- Canada Post - LLV
- New York USPS - CitiVan
- Advanced Vehicle Systems - Shuttle Bus

Component Kits

- Canada Post - LLV
- Advanced Vehicle Systems - 22' shuttle buses
- SuperSteel - CitiVan delivery trucks for US Postal Service
- Resurface - ice resurfacing machines

Solectria Drive Systems in Use

- GM S-Car
- Suzuki Wagon-R
Design Options and Simulation Results for Small Full-Function EVs

May 16, 2001

Andrew Burke
Institute of Transportation Studies, Davis
Design Options and Simulation Results for Small Full-function EVs

Andrew Burke
Institute of Transportation Studies
University of California-Davis
Davis, California 95616

Paper presented to:
Meeting the ZEV Mandate
Requirements Grid-connected
Hybrids and City EVs
May 15-16, 2001

Outline of the Presentation

- Introduction
- Types of EV designs
- Design Considerations for Small FFEVs
- Characteristics of small ICE passenger cars
- Characteristics of electric passenger cars
- EV design parameters
- Simulation approach (SIMPLEV)
- Simulation results
- Cost considerations and estimates
- Comparisons with grid-connected hybrids
- Conclusions

Types of EV Designs

- **Full-function EVs** - designed to operate on interstate highways and freeways at speeds up to 75-80 mph (ex: EVI)

- **City EVs** - designed to operate on city arterials at speeds up to 50 mph (ex: E-com and T'Wink)

- **Neighborhood EVs** - designed to operate on city streets at speeds up to 25 mph (ex: Dynasty)

Design Considerations for a Small Full-function EV

- **Minimum vehicle length** that is marketable in large numbers
- **Safety** - must satisfy the FMVSS tests and be perceived as safe by public and insurance industry
- **Have sufficient acceleration performance** for merging on freeways and interstate highways (sets power requirement)
- **Sufficient range** for regional use (probably about 100 miles at highway speeds)
Characteristics of Small/Compact Passenger Cars Using Engines and Gasoline

<table>
<thead>
<tr>
<th>Model</th>
<th>Curb Weight (lbs)</th>
<th>Length (inches)</th>
<th>Width (inches)</th>
<th>Height (inches)</th>
<th>Max. Hp</th>
</tr>
</thead>
<tbody>
<tr>
<td>CRX</td>
<td>1600</td>
<td>144</td>
<td>—</td>
<td>58</td>
<td></td>
</tr>
<tr>
<td>Geo Metro</td>
<td>1895</td>
<td>149</td>
<td>63</td>
<td>55</td>
<td>79</td>
</tr>
<tr>
<td>Aspre</td>
<td>2060</td>
<td>153</td>
<td>66</td>
<td>35</td>
<td>63</td>
</tr>
<tr>
<td>Insight</td>
<td>1856</td>
<td>155</td>
<td>67</td>
<td>53</td>
<td>75</td>
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<tr>
<td>Prun</td>
<td>2728</td>
<td>168</td>
<td>67</td>
<td>59</td>
<td>85</td>
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<tr>
<td>Civic</td>
<td>2359</td>
<td>164</td>
<td>67</td>
<td>54</td>
<td>106</td>
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<tr>
<td>Echo</td>
<td>2150</td>
<td>162</td>
<td>65</td>
<td>59</td>
<td>109</td>
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<tr>
<td>Focus</td>
<td>2715</td>
<td>175</td>
<td>67</td>
<td>56</td>
<td>107</td>
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<tr>
<td>Escort</td>
<td>2478</td>
<td>175</td>
<td>67</td>
<td>53</td>
<td>114</td>
</tr>
</tbody>
</table>

Small Full-function EV Design Parameters

- **Minimum size parameters** – length 140-150 inches, width 60-65 inches, height 55-60 inches
- **Speed and acceleration** – cruising speed of 70-75 mph and 0-60 mph time of 12-15 seconds
- **Highway range** – 100-125 miles at 65 mph
- **Vehicle utility** – batteries should be placed outside the passenger compartment and trunk, probably under the vehicle
- **Safety** – vehicle must pass insurance industry crash tests with excellent rating (not just acceptable)
- **Cost** – materials selection and manufacturing done to minimize (control) cost consistent with battery selection to meet the range requirement

Characteristics of Electric Passenger Cars

<table>
<thead>
<tr>
<th>Model</th>
<th>Curb weight (lbs)</th>
<th>Length (inches)</th>
<th>Width (inches)</th>
<th>Height (inches)</th>
<th>Max. Hp</th>
</tr>
</thead>
<tbody>
<tr>
<td>EVI</td>
<td>2970</td>
<td>170</td>
<td>70</td>
<td>51</td>
<td>137</td>
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<tr>
<td>Daimler A-Class</td>
<td>3043</td>
<td>109</td>
<td>52</td>
<td>49</td>
<td>67</td>
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<tr>
<td>Think</td>
<td>2112</td>
<td>118</td>
<td>63</td>
<td>61</td>
<td>36</td>
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<tr>
<td>E-com</td>
<td>1694</td>
<td>110</td>
<td>58</td>
<td>63</td>
<td>25</td>
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<td>Hyperm</td>
<td>1812</td>
<td>105</td>
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<td>32</td>
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<tr>
<td>Parade</td>
<td>2050</td>
<td>140</td>
<td>—</td>
<td>—</td>
<td>58</td>
</tr>
<tr>
<td>Dynasty</td>
<td>1450</td>
<td>140</td>
<td>60</td>
<td>63</td>
<td>20</td>
</tr>
</tbody>
</table>
Safety for Small, Light Vehicles is Possible

The Insight's safety engineering is quite extensive. Its aluminum body and frame, which incorporate front and rear crumple zones, help protect the occupants in impacts such as full-frontal, offset-frontal, side and rear. Dual front airbags; 3-point seat belts and built-in head restraints are all standard equipment.

As you can see, the Honda Insight really is different. It's smarter. A car that takes care of your needs as it takes care of the environment. The kind of car you'd expect from Honda.

### Vehicle Parameters

<table>
<thead>
<tr>
<th>Model</th>
<th>Weight (kg)</th>
<th>Voltage (V)</th>
<th>Capacity (Ah)</th>
</tr>
</thead>
<tbody>
<tr>
<td>GMG-1</td>
<td>177</td>
<td>43</td>
<td>69</td>
</tr>
<tr>
<td>GMO-2</td>
<td>174</td>
<td>43</td>
<td>69</td>
</tr>
<tr>
<td>HEV-1</td>
<td>175</td>
<td>43</td>
<td>69</td>
</tr>
<tr>
<td>HEV-2</td>
<td>172</td>
<td>43</td>
<td>69</td>
</tr>
</tbody>
</table>

Simulations done using SIMPLEV.

Vehicle parameters selected to be appropriate for a small full-function EV.

Powertrain power (motor and inverter) selected to meet the acceleration and speed requirements at highway speeds.

Battery sized to meet the range requirement at highway speeds.

Simulations done for advanced batteries—nickel-metal hydride, lithium-ion, and sodium metal chloride (Zebra) technologies.
Simulation Results

**Concept Full-function Small EV**
(Cd=.25, Af=2.1 m², fr=0.08)

<table>
<thead>
<tr>
<th>Battery Type</th>
<th>Battery Weight (kg)</th>
<th>Energy Stored (kWh)</th>
<th>Vehicle Test Weight (kg)</th>
<th>Driving Cycle</th>
<th>Range (miles)</th>
<th>Energy Use (Wh/mi)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Nickel metal hydride</td>
<td>239</td>
<td>20</td>
<td>1100</td>
<td>FUDS</td>
<td>150</td>
<td>146</td>
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<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Highway</td>
<td>148</td>
<td>139</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>65 mph</td>
<td>113</td>
<td>174</td>
</tr>
<tr>
<td>Sodium metal chloride</td>
<td>218</td>
<td>22</td>
<td>1080</td>
<td>FUDS</td>
<td>159</td>
<td>144</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Highway</td>
<td>150</td>
<td>138</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>65 mph</td>
<td>110</td>
<td>173</td>
</tr>
<tr>
<td>Lithium ion</td>
<td>192</td>
<td>22</td>
<td>1054</td>
<td>FUDS</td>
<td>143</td>
<td>170</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Highway</td>
<td>165</td>
<td>136</td>
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<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>65 mph</td>
<td>124</td>
<td>172</td>
</tr>
</tbody>
</table>

**Insight EV**
(Cd=.25, Af=1.86 m², fr=.007)

<table>
<thead>
<tr>
<th>Battery Type</th>
<th>Battery Weight (kg)</th>
<th>Energy Stored (kWh)</th>
<th>Vehicle Test Weight (kg)</th>
<th>Driving Cycle</th>
<th>Range (miles)</th>
<th>En (W)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Nickel metal hydride</td>
<td>188</td>
<td>16</td>
<td>1095</td>
<td>FUDS</td>
<td>118</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Highway</td>
<td>126</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>65 mph</td>
<td>98</td>
<td></td>
</tr>
</tbody>
</table>

**Acceleration Performance**: 18 kW motor/inverter, 204 V
0-30 mph 4 sec, 0-60 mph 11.5 sec, top speed > 70 mph

Cost Considerations

- Cost estimates made for a small full-function EV
- Electric drive power - 45 kW
- Battery energy storage – 22 kWh
- Motor/inverter cost to OEM - $40/kW, $20/kW
- Battery costs to OEM - $350/kWh, $250/kWh, $150/kWh
- Differential OEM costs between EV and ICE cars
- Batteries assumed to last the lifetime of the car

![Cost Considerations Graph](Cost%20Considerations%20Graph.png)
Estimated OEM Cost Differentials between the Small FFEV and ICE Car for Various Battery and Motor/Inverter Costs

<table>
<thead>
<tr>
<th>Motor/inverter Unit Cost ($/kW)</th>
<th>Battery Cost ($/kWh)</th>
<th>Motor/Inverter Cost ($)</th>
<th>Battery Cost ($)</th>
<th>OEM EV driveline cost ($)</th>
<th>OEM differential cost ($)</th>
</tr>
</thead>
<tbody>
<tr>
<td>40</td>
<td>350</td>
<td>1800</td>
<td>7700</td>
<td>9500</td>
<td>8300</td>
</tr>
<tr>
<td></td>
<td>250</td>
<td>1800</td>
<td>5500</td>
<td>7300</td>
<td>6100</td>
</tr>
<tr>
<td>20</td>
<td>900</td>
<td>3300</td>
<td>5100</td>
<td>3900</td>
<td></td>
</tr>
<tr>
<td></td>
<td>250</td>
<td>900</td>
<td>5500</td>
<td>6400</td>
<td>5200</td>
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<tr>
<td></td>
<td>150</td>
<td>900</td>
<td>3300</td>
<td>4200</td>
<td>3000</td>
</tr>
</tbody>
</table>

- ICE car has a 60 kW engine costing $20/kW to the OEM

Cost Estimate Comparisons for battery-powered Electric and Plug-in Hybrid Vehicles

<table>
<thead>
<tr>
<th>Vehicle</th>
<th>Engine Power (kW)</th>
<th>Engine/100m cost ($/kW)</th>
<th>Electric Motor Power (kW)</th>
<th>Motor/Inverter Cost ($/kW)</th>
<th>Battery kWh</th>
<th>Battery Cost ($/kWh)</th>
<th>Manufacturing Cost ($)</th>
</tr>
</thead>
<tbody>
<tr>
<td>ICE</td>
<td>67</td>
<td>1154 ($/kW)</td>
<td>45</td>
<td>1980</td>
<td>5</td>
<td>2475 ($/kWh)</td>
<td>1154 ($/kWh)</td>
</tr>
<tr>
<td>HEV</td>
<td>25</td>
<td>602 ($/kW)</td>
<td>65</td>
<td>3200 ($/kW)</td>
<td>21</td>
<td>754 ($/kWh)</td>
<td>10371 ($)</td>
</tr>
<tr>
<td>Insight</td>
<td>49</td>
<td>685 ($/kW)</td>
<td>27</td>
<td>1188 ($/kW)</td>
<td>17.5</td>
<td>6248 ($)</td>
<td>10354 ($)</td>
</tr>
<tr>
<td>Insight</td>
<td>126</td>
<td></td>
<td>50</td>
<td>2200 ($/kW)</td>
<td>17.5</td>
<td>6248 ($)</td>
<td>13448 ($)</td>
</tr>
</tbody>
</table>

Delta-manufacturing cost compared to an ICE car
- Hybrid (range 25-40 miles) $4400-$5300
- EV (range 130-165 miles) $8400-$9500

Fuel Economy of Small Plug-in Hybrid Vehicles using Lithium-ion Batteries

<table>
<thead>
<tr>
<th>Vehicle</th>
<th>Battery Weight (kg)</th>
<th>All-electric Range on the FUDS (mi)</th>
<th>Driving Cycle</th>
<th>Fuel Economy (mpg)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Concept FFEV</td>
<td>59</td>
<td>38</td>
<td>FUDS</td>
<td>61.7</td>
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<tr>
<td></td>
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<td>Highway</td>
<td>64.4</td>
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<tr>
<td>Insight</td>
<td>59</td>
<td>41</td>
<td>FUDS</td>
<td>67.3</td>
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<td></td>
<td></td>
<td></td>
<td>Highway</td>
<td>71.6</td>
</tr>
</tbody>
</table>

Conclusions
- Performance - no problem
- Packaging - no problem
- Safety - probably no problem with good engineering
- Cost - this is the problem, especially battery costs, need to be about $150/kWh
High Power, Long-Life Advanced VRLA for Cycling Application

May 16, 2001

Kent Snyder
Naoto Hoshihara
Panasonic-Matsushita
High-power, Long-Life Advanced VRLA for Cycling Application

Kent Snyder
Naoto Hoshihara
Panasonic-Matsushita

Long Cycle Life Advanced VRLA Battery for Vehicle Applications

<table>
<thead>
<tr>
<th></th>
<th>EV-VRLA</th>
<th>SV-VRLA</th>
<th>HV-VRLA</th>
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</thead>
<tbody>
<tr>
<td>Utilization</td>
<td>PEV</td>
<td>NEV</td>
<td>HEV</td>
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<tr>
<td>Characteristics</td>
<td>High Power</td>
<td>High Energy</td>
<td>High Regenerative Power</td>
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<tr>
<td>Type</td>
<td>EC-EV1260</td>
<td>EC-SV1266</td>
<td>EC-HV1255</td>
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<tr>
<td></td>
<td>EC-EV1238</td>
<td>( EC-SV1242 )</td>
<td>EC-HV1235</td>
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<tr>
<td></td>
<td>EC-EV1228</td>
<td>EC-SV1230</td>
<td>( EC-HV1225 )</td>
</tr>
</tbody>
</table>

Principal Specifications EV-VRLA

- Dimensions
  - Height: 175 mm
  - Width: 116 mm
  - Length: 388 mm
- Weight: 21.0 kg
- Nominal Voltage: 12 V
- Nominal Capacity: 3HR 60 Ah
- Specific Power (25°C): DOD80% 200 W/kg

Characteristics of EV-VRLA Batteries

- ✔️ Long Cycle Life
  - 1000 Cycles (DST120)
- ✔️ High Specific Power
  - 200 W/kg at DOD80%
- ✔️ Rapid Charge Acceptance
  - 10 min. recovery from DOD80% to 20%

Panasonic
Development Technology of EV-VRLA Batteries

✓ Grid Surface Treatment
   Double layer structure of Lead-alloy Sheet
✓ High Power Design
   Optimized grid design for high power
   Thin plate structure and product technology
✓ Long Cycle Life Design
   High compression retention performance

Rapid Charge Performance

DST120 Performance & Charge Method

DST120 Discharge Performance
- Discharge Capacity: 55.6 Ah
- Discharge Energy: 632 Wh
- Maximum Current
  - Discharge: 305 A
  - Charge: 110 A
- Temperature Rise: 4 °C

Charge Method (5-step CCC)
- 1st-4th Step charge: charge current
  - I_{1} = 12.0 A
  - I_{2} = 6.0 A
  - I_{3} = 3.0 A
  - I_{4} = 1.5 A
- Switching voltage: V_{s} = 14.4 V + 0.03 V(25-T)
- T: battery temperature (°C)
- 5th Step charge:
  - Charge current: I_{5} = 1.5 A
  - Charge time: t_{5} = 2.5 h

Cycle Life Performance in Vehicle Pack

Test Conditions
- # of Batteries: 18 Module series-conn
- Discharge: DST120/600 Wh (25 °C)
- Charge: 2step constant current
- Capacity check: every 50cycles (25 °C)
**Our VRLA Battery Characteristics**

- **High Energy Density**
  - 100Wh/liter

- **High Capacity**
  - 10% greater capacity in comparison with EV-VRLA

- **Long Cycle Life**
  - Improvement in 1/3C cycle life

---

**DST120 Cycle Life Performance**

- **Cycle Conditions**
  - Discharge: DST120/500 Wh (25 °C)
  - Charge: 5-step constant current
  - Capacity check: every 50 cycles (25 °C)

---

**Discharge Performance**

- **Test Conditions**
  - Discharge Current: 20 A
  - Cut-off Voltage: 9.9 V
  - Ambient Temperature: -20 °C ~ 45 °C

---

**Panasonic**
**Development Technology of HV-VRLA Batteries**

- **Optimization of Additives**
  Improved negative electrode active material characteristics

- **Optimization of Grid Design**
  Super fine mesh grid for negative plate

- **Decreased Internal Resistance**
  Improvement of terminal component, etc.

---

**Cycle Life Performance**

![Graph showing cycle life performance with discharge capacity percentage over cycle number.](Image)

**Cycle Conditions**
- Discharge: 1/3C-DOD60% (25 °C)
- Charge: Sstep constant current
- Capacity check: every 50 cycles (25 °C)

---

**Characteristics of HV-VRLA Batteries**

- **High Regenerative Power**
  (Output power)/(Input power) ratio = 1

- **High Specific Power**
  Over 10C discharge capability

- **Long Cycle Life**
  Improved cycle life on HEV(PNGV) pattern

---

*Panasonic*
Summary

We are developing long life VRLA batteries for PEV, NEV, and HEV applications. We believe our work will contribute to the developing EV market and to the reduction of environmental and energy problems.

Output/Input Power Test Profile

- Current: 5C-A
- Temperature: 25°C
- R(0): 5C-A
- V(t): 15.3 V
- T: 5 s
- DOD: every 10%
- Regeneration: V(t): 15.3 V

Example

PNGV Cycle Life Test Profile

- Test Conditions: PNGV 100 Wh Slow response
- Test conditions: 10 V or 70°C
- Voltage limits: 10 V or 70°C

PNGV Cycle Life Performance

- Ambient Temp.
- Battery Temp.
- Minimum Voltage
- Maximum Voltage
- (Cycle no.)
ZEBRA Battery

May 16, 2001

Cord-H. Dustmann
MES-DEA
ZEBRA Battery

Cord - H Dustmann

ZEBRA, Best Available High Energy Battery

1 Basic battery chemistry
2 Cell Design
3 Battery Design
4 Battery System Components
   - BMI (Battery Management Interface)
   - MBS (Multy Battery Server)
   - BC (Battery Charger)
5 Safety, durability, recycling
6 ZEBRA powered vehicles
7 Production, conclusion
### Periodisches System der Elemente

<table>
<thead>
<tr>
<th>Periode</th>
<th>Zeile der Elemente in Pериode</th>
<th>Gruppe I a</th>
<th>Gruppe I a</th>
<th>Gruppe II a</th>
<th>Gruppe II a</th>
<th>Gruppe III a</th>
<th>Gruppe IV a</th>
<th>Gruppe V a</th>
<th>Gruppe VI a</th>
<th>Gruppe VII a</th>
<th>Gruppe VIII a</th>
</tr>
</thead>
<tbody>
<tr>
<td>K</td>
<td>1. Periode</td>
<td>1 H</td>
<td>2 Li</td>
<td>3 Be</td>
<td>4 B</td>
<td>5 C</td>
<td>6 N</td>
<td>7 O</td>
<td>8 F</td>
<td>9 Ne</td>
<td>10 Na</td>
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<tr>
<td>L</td>
<td>2. Periode</td>
<td>11 Na</td>
<td>12 Mg</td>
<td>13 Al</td>
<td>14 Si</td>
<td>15 P</td>
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<td>18 Ar</td>
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<td>20 Ca</td>
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<td>W</td>
<td>3. Periode</td>
<td>21 Ti</td>
<td>22 V</td>
<td>23 Cr</td>
<td>24 Mn</td>
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<td>O</td>
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<td>32 Se</td>
<td>33 Br</td>
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<td>38 La</td>
<td>39 Ce</td>
<td>40 Pr</td>
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<td>P</td>
<td>5. Periode</td>
<td>41 Nd</td>
<td>42 Pm</td>
<td>43 Sm</td>
<td>44 Eu</td>
<td>45 Gd</td>
<td>46 Tb</td>
<td>47 Dy</td>
<td>48 Ho</td>
<td>49 Er</td>
<td>50 Tm</td>
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<tr>
<td>O</td>
<td>6. Periode</td>
<td>51 Yt</td>
<td>52 Lu</td>
<td>53 Hf</td>
<td>54 Ta</td>
<td>55 W</td>
<td>56 Re</td>
<td>57 Os</td>
<td>58 Ir</td>
<td>59 Pt</td>
<td>60 Au</td>
</tr>
</tbody>
</table>

Davis 15/16 5 2001 (3)

---

**R Keramik = \Sigma (interface1 + Knstall + KG + Interface2) + f (Orientierung)**

**R Keramik ca 6 \Omega \text{cm bei 300}^\circ\text{C} - bei Raumtemperatur > 20 \text{K}^2 \text{cm**}

Davis 15/16 5 2001 (4)
ZEBRA Technology - Basic Electrochemistry

Charge

\[
\text{Ni + 2NaCl} \rightarrow 2\text{Na} + \text{NiCl}_2
\]

Load

\[
\text{2NaCl} + \text{Ni} \rightarrow \text{NiCl}_2 + 2\text{Na}
\]

OCV 2.58 at 300°C,
Operating Range
270°C to 350°C,
Typical capacity 32Ah

Cell Reaction
Cell Voltage [V]

- 3.05
- 2.58
- 1.58

Status of Charge [%]

100
0

Cell Reaction at 300°C

ML1 cell cross section
β"- Alumina Electrolyt

β"- Ceramic with TCB
Ni + 2NaCl $\rightarrow$ 2Na + NiCl₂

<table>
<thead>
<tr>
<th>unit</th>
<th>ML3</th>
<th>ML4</th>
<th>ML8</th>
</tr>
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<tbody>
<tr>
<td>Capacity Ah</td>
<td>32</td>
<td>26</td>
<td>20</td>
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<tr>
<td>OCV V</td>
<td>2.58</td>
<td>2.58</td>
<td>2.58</td>
</tr>
<tr>
<td>Normal charge voltage V</td>
<td>2.67</td>
<td>2.67</td>
<td>2.67</td>
</tr>
<tr>
<td>Fast charge voltage V</td>
<td>2.85</td>
<td>2.85</td>
<td>2.85</td>
</tr>
<tr>
<td>Max Regen Voltage V</td>
<td>3.1</td>
<td>3.1</td>
<td>3.1</td>
</tr>
<tr>
<td>Peak power W</td>
<td>185</td>
<td>155</td>
<td>125</td>
</tr>
</tbody>
</table>

(80% DOD, 2/3 OCV, 30s, 335°C)

Max current A | +12/-60 | 90 | 70 |

Weight g | 705 | 605 | 500 |

Length mm | 232 | 198 | 146 |

Specific energy Wh/kg | 117 | 110 | 103 |

Specific power W/kg | 262 | 256 | 250 |

β*-Ceramic with TCB

Heating/cooling System of the ZEBRA Battery
Up to 16 battery units in parallel (285 kWh / 510 kW)

ZEBRA Battery System

Cooling Plates
### Z5 standard Battery with main data

<table>
<thead>
<tr>
<th>Type</th>
<th>ZS-278-ML-64</th>
<th>ZS-557-ML-32</th>
</tr>
</thead>
<tbody>
<tr>
<td>Capacity (Ah)</td>
<td>64</td>
<td>32</td>
</tr>
<tr>
<td>Rated Energy (kWh)</td>
<td>17.8</td>
<td>17.8</td>
</tr>
<tr>
<td>Open Circuit Voltage</td>
<td>278</td>
<td>557</td>
</tr>
<tr>
<td>0-15% DOD (V)</td>
<td>224</td>
<td>112</td>
</tr>
<tr>
<td>Max discharge current (A)</td>
<td>ML3 / 216</td>
<td></td>
</tr>
<tr>
<td>Cell Type/N° of cells</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Weight with BMI (kg)</td>
<td>195</td>
<td></td>
</tr>
<tr>
<td>Specific energy (Wh/kg)</td>
<td>94</td>
<td></td>
</tr>
<tr>
<td>Energy density (Wh/l)</td>
<td>148</td>
<td></td>
</tr>
<tr>
<td>Specific power (W/kg)</td>
<td>169</td>
<td></td>
</tr>
<tr>
<td>Power density (W/l)</td>
<td>255</td>
<td></td>
</tr>
<tr>
<td>Peak power (kW)</td>
<td>32</td>
<td></td>
</tr>
<tr>
<td>80% DOD 20°C 30s 3.35°C</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Ambient temperature (°C)</td>
<td>-40 to +50</td>
<td></td>
</tr>
</tbody>
</table>
| Thermal loss (W) 270°C internal temperature | < 110
Fast charge 1 h rating

Z5C Normal Charge in 7.5h

Integrated booster
Ragone Diagram for traction batteries

ZEBRA Battery System Design
BMI – Battery Management System

MBS – Multi Battery Server
### Technical data (Preliminary)

<table>
<thead>
<tr>
<th>Type</th>
<th>BC-278-Z-3-A</th>
<th>BC-557-Z-3-A</th>
</tr>
</thead>
<tbody>
<tr>
<td>Output voltage</td>
<td>240 to 305</td>
<td>480 to 610</td>
</tr>
<tr>
<td>DC output power</td>
<td>3300</td>
<td></td>
</tr>
<tr>
<td>Input current AC</td>
<td>- 15.5</td>
<td>95%/3 3 kW, 90%/400W</td>
</tr>
<tr>
<td>Efficiency / load</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Protection class</td>
<td>IP 6 5</td>
<td>170-253VAC, 47-63 Hz</td>
</tr>
<tr>
<td>Input voltage</td>
<td>170-253VAC, 47-63 Hz</td>
<td></td>
</tr>
<tr>
<td>Control</td>
<td>PWM by BMI</td>
<td></td>
</tr>
<tr>
<td>Cooling</td>
<td>Air</td>
<td></td>
</tr>
<tr>
<td>Ambient temperature</td>
<td>-25°C to 40°C</td>
<td>40°C to 70°C derated</td>
</tr>
<tr>
<td>EMC</td>
<td></td>
<td>95/54/EG</td>
</tr>
<tr>
<td>Weight</td>
<td>ca 8</td>
<td></td>
</tr>
</tbody>
</table>

**Battery Charger**

**Can Display**
ZEBRA Battery Safety Concept

ZEBRA Battery Type Z12 – Crash test at 50 Km/h
Materials of ZEBRA Battery Type Z5 (Weight 195 kg)

- BMI: 2%
- SS: 6%
- Steel: 3.5%
- Thermal Insulation SiC: 4%
- Mica: 4%
- Miscellaneous: 2%

Cells: 78%

Calendar Life

- Discharge 22-23 March 1993
- Discharge 50-22 June 2000
- Discharge 19 June 1991

This battery has been on test for 9 years periodically, electrically and thermally cycled with no cell failure, no

Completed 8 thermal cycles in total
Requirements of the Automotive Industry

PW "soft" Hybrid, 42 V, 1-2 kWh, 10-20 kW
"power assist" Hybrid, 300 V, 2-4 kWh, 25-40 kW
"range extender" Hybrid, 300 V, 20-30 kWh, 40-60 kW

Transporter
(+ minibuses) 300 V, 30-50 kWh, 40-60 kW

Buses EV, 300 oder 600 V, 90-285 kWh, 80-120 kW
HEV with EV, 600 V, 35-70 kWh, 60-120 kW
HEV without ZEV, 600 V, 10-30 kWh, 60-120 kW
<table>
<thead>
<tr>
<th>Feature</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Payload</td>
<td>600 kg</td>
</tr>
<tr>
<td>Drive</td>
<td>Asynchronous Motor</td>
</tr>
<tr>
<td>Drive Power</td>
<td>40kW at 2000-5000/min</td>
</tr>
<tr>
<td>Type of Battery</td>
<td>2 x Z5C</td>
</tr>
<tr>
<td>Energy Content</td>
<td>35.6 kWh</td>
</tr>
<tr>
<td>Battery Voltage (OCV)</td>
<td>278V</td>
</tr>
<tr>
<td>Weight of Battery</td>
<td>400 kg</td>
</tr>
<tr>
<td>Maximum Speed E</td>
<td>120 km/h</td>
</tr>
<tr>
<td>Range</td>
<td>120-170 km</td>
</tr>
</tbody>
</table>

Vito 108E of DaimlerChrysler with ZEBRA
### Microvett 15t - Imola, Italy

<table>
<thead>
<tr>
<th>Payload</th>
<th>9 t</th>
</tr>
</thead>
<tbody>
<tr>
<td>Drive</td>
<td>Continuous Power 38 kW</td>
</tr>
<tr>
<td>Drive Power</td>
<td>Peak Power 83 kW</td>
</tr>
<tr>
<td>Type of Battery</td>
<td>6 x Z5</td>
</tr>
<tr>
<td>Energy Content</td>
<td>102 kWh</td>
</tr>
<tr>
<td>Battery Voltage (OCV)</td>
<td>278V</td>
</tr>
<tr>
<td>Weight of Battery</td>
<td>1200 kg</td>
</tr>
<tr>
<td>Maximum Speed E</td>
<td>70 km/h</td>
</tr>
<tr>
<td>Range</td>
<td>150 km</td>
</tr>
</tbody>
</table>

### AUTODROMO City Bus in Bologna, Italy - In Service

<table>
<thead>
<tr>
<th>Hybrid</th>
<th>Electric</th>
</tr>
</thead>
<tbody>
<tr>
<td>Capacity</td>
<td>10 + 1 Seating</td>
</tr>
<tr>
<td></td>
<td>29 Standing</td>
</tr>
<tr>
<td>Drive</td>
<td>Brushless DC</td>
</tr>
<tr>
<td>Drive Power</td>
<td>50kW</td>
</tr>
<tr>
<td>Type of Battery</td>
<td>2 x Z5C</td>
</tr>
<tr>
<td>Energy Content</td>
<td>35 6 kWh</td>
</tr>
<tr>
<td>Battery Voltage (OCV)</td>
<td>279 V</td>
</tr>
<tr>
<td>Weight of Battery</td>
<td>400 kg</td>
</tr>
<tr>
<td>Maximum Speed E</td>
<td>50 km/h</td>
</tr>
</tbody>
</table>

**Images:**
- Microvett 15t - Imola, Italy
- AUTODROMO City Bus in Bologna, Italy
Capacity: 34 Seating, 68 Standing
Drive: 2 Asynchron Hub Motors
Drive Power: 150 kW
Type of Battery: 2 x 2 x Z5 A/B
Energy Content: 68 kWh
Battery Voltage (OCV): 2 x 284 = 568 V
Weight of Battery: 806 kg
Maximum Speed: 60 km/h
E-Range per Charge: 40 - 70 km

40ft Hybrid Bus from EvoBus operate in Oberstdorf, Germany and in Leiden, Holland

Energiebilanz von Hybridbussen mit ZEBRA Batterie
Marketing Neighborhood, City, and Small Highway-capable Electric Vehicles

May 16, 2001

Ken Kurani
Institute of Transportation Studies, Davis
Marketing Neighborhood, City, and Small Highway-capable Electric Vehicles

16 May 2001

Ken Kurani
Institute of Transportation Studies
University of California, Davis

Types of small EVs
Some things we've learned
Market Segments
  - Who?
  - Where?
Market Segment Size
  - How many?
  - What next?

Highway-capable EV Market Studies
  - 1991 to 1997
  - Household markets for vehicles and electricity
Neighborhood Electric Vehicle Studies
  - 1993 to 1995
  - Multi-objective
Secondary Benefits of ZEVs Report
  - Summer 2000

City EV Station Car User Evaluation
  - 1997
Consumer Benefits of EVs and Plug-in HEVs
  - 1998
Consumer Markets for EVs
  - Green Car Institute, 2000

New Types of Vehicles
  - NHTSA Low Speed Vehicle definition
    - Four wheels, 20 to 25mph max speed
    - FMVSS No. 500 (49 CFR 571.500)
      - head lamp turn signal, and tail lamps, reflectors parking
        brakes, rear view mirrors windshield, seat belt and
        VINS
  - Examples
    - GEM Neighborhood EV, THINK Neighbor

New types of vehicles
  - City EVs
    - not quite highway-capable
      - top speeds varying from 36 to 62mph
      - are not yet certified to FMVSS for light duty
        motor vehicles
    - two-seats (so far)
  - Examples
    - Toyota eXcursion, Nissan Hyperman, THINK City
What vehicles have we studied?

<table>
<thead>
<tr>
<th>Type</th>
<th>Seating</th>
<th>Speed</th>
<th>Range</th>
</tr>
</thead>
<tbody>
<tr>
<td>Golf car</td>
<td>2</td>
<td>18 to 20</td>
<td>15 to 35</td>
</tr>
<tr>
<td>Case study</td>
<td>NEVs</td>
<td>1 to 4</td>
<td>35 to 75</td>
</tr>
<tr>
<td>Household</td>
<td>NEVs</td>
<td>1 to 2</td>
<td>35 to 40</td>
</tr>
<tr>
<td>Household</td>
<td>CEVs</td>
<td>1 to 2</td>
<td>35 to 40</td>
</tr>
<tr>
<td>CA Survey</td>
<td>NEVs</td>
<td>1 to 4</td>
<td>40</td>
</tr>
<tr>
<td>CA Survey</td>
<td>CEVs</td>
<td>1 to 4</td>
<td>40</td>
</tr>
<tr>
<td>City EV</td>
<td>CEVs</td>
<td>2</td>
<td>40</td>
</tr>
</tbody>
</table>

A Few Things we learned:

- Vehicle "choice" shifts
- The effects of constraints on travel decisions
- How far a household can travel in a NEV
- Mode shifts within households
- All places are not equal
- User valuation of vehicle characteristics

Vehicle Choice Shifts

<table>
<thead>
<tr>
<th>Type Choice</th>
<th>Non-EV</th>
<th>EV Style</th>
</tr>
</thead>
<tbody>
<tr>
<td>Neighborhood EV</td>
<td>6</td>
<td>12</td>
</tr>
<tr>
<td>Community EV</td>
<td>5</td>
<td>21</td>
</tr>
<tr>
<td>Regional EV</td>
<td>37</td>
<td>81</td>
</tr>
<tr>
<td>Range-extend HEV</td>
<td>15</td>
<td>27</td>
</tr>
<tr>
<td>Natural Gas</td>
<td>33</td>
<td>52</td>
</tr>
<tr>
<td>Garohne</td>
<td>53</td>
<td>96</td>
</tr>
</tbody>
</table>

The Effects of Constraints

<table>
<thead>
<tr>
<th>Serve Passenger</th>
<th>Could trip be made another time?</th>
<th>Total</th>
</tr>
</thead>
<tbody>
<tr>
<td>No</td>
<td>No</td>
<td>387</td>
</tr>
<tr>
<td>No</td>
<td>Yes</td>
<td>128</td>
</tr>
<tr>
<td>Total</td>
<td></td>
<td>515</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Trips</th>
<th>Percent</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mean</td>
<td>41 1 4</td>
</tr>
<tr>
<td>High</td>
<td>72 7 4</td>
</tr>
<tr>
<td>Low</td>
<td>10 1 4</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Miles</th>
<th>Percent</th>
</tr>
</thead>
<tbody>
<tr>
<td>Mean</td>
<td>19 4 6</td>
</tr>
<tr>
<td>High</td>
<td>43 4 6</td>
</tr>
<tr>
<td>Low</td>
<td>6 4 6</td>
</tr>
</tbody>
</table>
NEV Mode Shift within Households

- NEVs can displace many trips and much VMT in households
- Household travel mode splits during NEV tests depend on prior behavior
  - determined in part by local land use and transportation options
- NEVs can displace environmentally superior options for some trips

User Valuation of Characteristics

- Less-than-highway-capable vehicles
  - Users start to group vehicle characteristics
    - Range and Top Speed
    - Passenger Seating and Cargo Capacity
    - Top Speed, Vehicle Size, Handling, and Safety
- A word about Plug-in Hybrids
  - Benefits based on three systems
    - Environmental, Recharging, Drivetrain

Market Segments

- Small vehicles
  - One or two seats, regardless of range or speed
- Hybrid households
  - City EVs, Small Highway-capable EVs
- LSV-amenable places

Small Vehicles

- Pro
  - One-person households?
    - Over 25 percent of US households (2000 Census)
- Con
  - Small car sales historically tiny
    - Two-seats 11 percent of new car sales
    - Automotive News "budget" and "small" cars 21.2 percent of cars
    - Based on the wrong question

Hybrid Households

- Guestimate from 1995 ITS
  - 2 percent combined Neighborhood/Community EV market share
    - Only small and compact sedans, sports car, and compact pickup truck body styles
    - Not LSVs/CEVs
- Guestimate from 2000 GCI
  - Interested?
    - 24 percent LSV, 43 percent CEV
    - 1 percent new LDV market share
Markets for LSVs defined
- primarily by characteristics of the use environment
- secondarily by characteristics of the user

Places can be dynamic too
- do LSVs fit the place, and the plans for the place?

Infrastructure includes roadway, vehicle maintenance, electricity distribution,

Whose We?
- Broad coalitions of stakeholders
  - Government
  - Industry
  - Issue Advocates
  - Independent Researchers

Marketing Green and Social
- Market Research based on multiple methods, multiple types of exposures

Build market segments
- Motivate consumers and producers
- Facilitate expression of a wider set of household lifestyle goals and values

Transform Markets

Avoid gaming of regulations

City EVs, Small Highway-capable EVs and Hybrid EVs
- Users will figure them out

LSVs and City EVs
- Users are constrained as to where they can use such vehicles
  - Market in those places that are suitable
  - Building and retrofitting
    - Palm Desert, PASStown, New Urbanism
Shared-Use Fleets: Lessons Learned

May 16, 2001

Susan Shaheen, Ph.D.
Honda Distinguished Scholar
University of California,
New Mobility Center & PATH
SHARED-USE FLEETS: OVERVIEW

- Carsharing and CarLink Defined
- CarLink I Findings & Management Issues
- Market Opportunities
- Pilot Project Recommendations

WHAT IS CARSHARING?
- Individuals Gain the Benefits of Private Cars without the Costs and Responsibilities of Ownership
- Individuals Access a Fleet of Cars
- Generally, Participants Pay a Usage Fee Each Time a Vehicle Is Used

ROOTS IN EUROPE
- Sefage (1948) of Zurich, Switzerland
- Recent developments began in 1980s
- Over 200 fleets active in 400 cities
- Claim over 125,000 participants
- Mobility (Switzerland, 1987) and StadtAuto (Bremen, 1990)

U.S. TRENDS: 1998 TO PRESENT
- 8 Carsharing Programs
- 2 Station Car Programs
- 2 Pilot Research Programs
- 9 Planned Programs
- Advanced Technologies
- Partnership Management
- Pioneering -> Growth & Volume Phase

WHAT IS CARLINK?
- A Commuter-Based Carsharing Program, Linked to Transit
- Public-Private Partnership
- Smart Technologies
- Three User Groups: Homebased Users, Workbased Commuters, and Day Users
CARLINK I: USER GROUPS

- **Homebased Users**: $200/Month (Per Vehicle)
- **Workbased Commuters**: $60/Month (Minimum of Two Participants Per Vehicle)
- **Day Users**: $1.50/ Hour and $.10/Mile

CARLINK I: PROGRAM FINDINGS

- 54 Participants
  - 67% Male and 69% Married
  - 81% Homeowners and All Employed
  - 81% Average Yearly Income of $50,000
  - 36% — 24 to 40 Years of Age
  - 59% — 41 to 64 Years of Age
  - 75% Bachelor's Degree or Higher

CARLINK I: KEY FINDINGS

- Environmental Concern High
- Reduced Cost & Increased Convenience Key Usage Factors
- Users Wanted More Mixed Fleet (e.g., Pickup Truck)
- Members Would Share Rides More Frequently, If Communication Facilitated

CARLINK I: KEY FINDINGS

- If a Permanent Service, Several Homebased Users Would Sell Personal Vehicles
- Net Reduction in Vehicle Miles Per Day (~20 Miles) for CarLink Commuters
- At Least 20 New BART Trips Generated Per Day
CARLINK I: MANAGEMENT ISSUES

ISSUE ONE
Vehicle Maintenance & Emergencies

RESOLUTION
- Personnel Provide Quick Response
- 24-Hour Roadside Assistance
- Local Dealership for Servicing/Repairs
- Hide-A-Keys in Emergency

ISSUE TWO
Clean-Fuel Vehicle Refueling

RESOLUTION
- Guidelines for Refueling—1/4 Tank
- Fueling Cards
- Anticipate Demand
- Refueling Training
- High-Quality & Multiple Refueling Sites

ISSUE THREE
Vehicle Cleanliness

RESOLUTION
- Guidelines for Cleaning Own Trash
- Personnel or Detailing Company to Service (Wash & Vacuum)
- Economic Penalties

ISSUE FOUR
Vehicle Insurance

RESOLUTION
- Umbrella Policy Through Organizations
- Specialized in Shared Fleets (e.g., Insurance One & VPSI)

ISSUE FIVE
- Scheduling & Billing
- Smart Access & Vehicle Tracking Technologies

RESOLUTION
- Develop or Purchase Advanced Technology
- Integrate Systems, Where Possible
- Test Prior to Launch

ISSUE SIX
Parking & Lot Assignment

RESOLUTION
- Partner to Access Subsidized/Donated Premium Parking
- Flexibility with Customers in Identifying Lots
- Employ Wireless Management System
CARLINK I: MANAGEMENT ISSUES

ISSUE SEVEN: Roadside Service
RESOLUTION: Contract with 24-Hour Provider for Emergency Service

ISSUE EIGHT: Guaranteed-Ride Service
RESOLUTION:
- Provide Guaranteed Taxi or Shuttle Service
- Partner with Region, If Possible, To Access Free, Ride-Home Services (Demand-Management Strategy)

ISSUE NINE: Lost & Found System
RESOLUTION: Provide Lost & Found Center for Retrieving Items Left in Fleet Vehicles

MARKET OPPORTUNITIES
- Incentives: Parking & Policy
- Media: Marketing & Social Tool
- Data: Feedback & Customer Understanding

CARLINK II: MAY 2001
- Public-Private Partnership: UC Davis, PATH, Caltrans, Honda, and Caltrain
- 27 ULEV Civics Based Out of Caltrain Station
- Homebased Users and Business Subscribers
- Advanced Seamless Technology

INCENTIVES
- ZEV Mandate Credits for Shared Use Systems
- Parking, Where Limited is Huge Incentive
- Reduced Fares (e.g., Transit)
- Discounts at Local Stores
- Frequent Flyer Miles
- Access to HOV or HOT Lanes
MEDIA: A MARKETING TOOL

- Can Increase Program Interest
- Subsidize Marketing Costs
- Promote Social & Environmental Benefits of Program

AUTOMATED DATA

- Instant Feedback on System Functionality
- Key Information to Improve Service Logistics
- Understanding of Underlying Market Forces

PILOT PROJECTS: RECOMMENDATIONS

- Outline Project Purpose & Design
- Maintain Flexible Partnership Management
- Integrate Smart Technologies
- Employ Economic Signals
- Trial & Reduced User Fees

PILOT PROJECTS: RECOMMENDATIONS

- Adjust User Guidelines As Necessary
- Deploy Top-Notch Clean Fuel Infrastructure
- Apply for Demonstration Grants
- Conduct Nonmonetary Benefits Research

ACKNOWLEDGMENTS

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- Lawrence Livermore National Laboratory
- INVERS and Teletrac
- UC Transportation Center
- National Science Foundation
- CarLink II Team Londa Novack, John Wright, Dimitri Loukakos, Nihar Gupta, and Barbara Bower