Plug In Vehicle Technology
The Case for a Multi-Technology Approach

COMPETE Coalition
Washington DC

Bill Reinert
Advanced Technology Group,
Toyota Motor Sales, USA, INC
October 5, 2010
On One Hand: Growing Megacities (>10M)

Today – 2

New York, NY
18.65M

Los Angeles, CA
12.22M

4 Additional by 2050

Atlanta, GA

Chicago, IL

Dallas – Fort Worth, TX

Miami, FL
Urban Mass Transport Solutions

Light Rail

Personal Rapid Transit
Developing Solutions For The Last Mile Problem

- iReal
- Winglet
- CityCar
On the Other Hand: Populations are Spreading

2/3 of US jobs, 3/4 economic output, are within 35 mi of 98 largest central business districts (CBD). Increasingly, they are moving to a ring 10-35 mi from CBD. (Brookings Inst.)
Most Commutes Are Suburb to Suburb

Metropolitan Flow Map (Millions of Commuters)

Source Brookings Inst.
Unique US Urbanization and Transportation Trends

- US Vehicle Miles Traveled grows with US economy
- Jobs and housing are decentralizing (despite efforts to do the opposite)
- Commute distance increasing (often between suburbs of metro area)
- Highway car remains critically important to US

One-way Commute Distance

Fifty-year US Travel and Economic Trends


Oil Prices Strongly Influenced by Excess Capacity

Oil Production Forecast

Oil Price Forecast

Platform Design

- Cheap Oil
- Expensive Oil
- Scarce Oil

Source: Neftex (Dr. Peter Wells)
<table>
<thead>
<tr>
<th>Fuel source</th>
<th>Transportation energy displacement</th>
<th>Acres$^b$</th>
<th>Fraction of U.S. cropland</th>
<th>gallons of fuel per acre</th>
<th>MMBTU$^e$ of fuel per acre</th>
<th>Water use (gallons)</th>
<th>BTU input per BTU of fuel</th>
<th>Energy ratio</th>
<th>CO$_2$ emissions$^a$</th>
<th>Land use</th>
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<tbody>
<tr>
<td>Conventional gasoline</td>
<td>0-100%</td>
<td>a few thousand</td>
<td>very low</td>
<td>-</td>
<td>-</td>
<td>5</td>
<td>45</td>
<td>0.05</td>
<td>175</td>
<td></td>
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<tr>
<td>Conventional diesel</td>
<td>0-100%</td>
<td>a few thousand</td>
<td>very low</td>
<td>-</td>
<td>-</td>
<td>10</td>
<td>80</td>
<td>0.08</td>
<td>175</td>
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<tr>
<td>Coal-to-liquid</td>
<td>10%</td>
<td>4,100</td>
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<td>~4.4 M</td>
<td>~500,000</td>
<td>3</td>
<td>24</td>
<td>~0.5</td>
<td>~380</td>
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<tr>
<td></td>
<td>25%</td>
<td>10,300</td>
<td>very low</td>
<td>~20 M</td>
<td>~65,000</td>
<td>~6</td>
<td>~45</td>
<td>~0.1$^d$</td>
<td>~150</td>
<td></td>
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<tr>
<td></td>
<td>50%</td>
<td>20,600</td>
<td>very low</td>
<td></td>
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<td></td>
<td></td>
<td></td>
<td></td>
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<td>CNG</td>
<td>0-100%</td>
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<td>-</td>
<td>-</td>
<td>n/a</td>
<td></td>
<td>~10$^d$</td>
<td>~0.1$^d$</td>
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<tr>
<td>Heavy crude</td>
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<td>a few thousand</td>
<td>very low</td>
<td>-</td>
<td>-</td>
<td>~10</td>
<td>~80</td>
<td>~0.25</td>
<td>~200</td>
<td></td>
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<tr>
<td>In situ oil shale</td>
<td>10%</td>
<td>7,500$^c$</td>
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<td>~3 M</td>
<td>~350,000</td>
<td>~5</td>
<td>~38</td>
<td>~0.25</td>
<td>~180</td>
<td></td>
</tr>
<tr>
<td></td>
<td>25%</td>
<td>19,000$^c$</td>
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<td>~20 M</td>
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<td>~6</td>
<td>~45</td>
<td>~0.15</td>
<td>~240</td>
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<tr>
<td></td>
<td>50%</td>
<td>37,000$^c$</td>
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<td>~45</td>
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<tr>
<td>Tar sands</td>
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<td>very low</td>
<td>-</td>
<td>-</td>
<td>~10</td>
<td>~80</td>
<td>~0.25</td>
<td>~180</td>
<td></td>
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<tr>
<td></td>
<td>10%</td>
<td>48,000$^c$</td>
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<td>~20 M</td>
<td>~65,000</td>
<td>~6</td>
<td>~45</td>
<td>~0.15</td>
<td>~240</td>
<td></td>
</tr>
<tr>
<td></td>
<td>25%</td>
<td>120,000$^c$</td>
<td>very low</td>
<td>~20 M</td>
<td>~65,000</td>
<td>~6</td>
<td>~45</td>
<td>~0.15</td>
<td>~240</td>
<td></td>
</tr>
<tr>
<td></td>
<td>50%</td>
<td>240,000$^c$</td>
<td>very low</td>
<td>~20 M</td>
<td>~65,000</td>
<td>~6</td>
<td>~45</td>
<td>~0.15</td>
<td>~240</td>
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Source: Kreider and Associates
### Finding replacements part 2

<table>
<thead>
<tr>
<th>Fuel source</th>
<th>Transportation energy displacement</th>
<th>Acres&lt;sup&gt;b&lt;/sup&gt;</th>
<th>Fraction of U.S. cropland</th>
<th>gallons of fuel per acre</th>
<th>MMBTU&lt;sup&gt;e&lt;/sup&gt; of fuel per acre</th>
<th>Water use (gallons)</th>
<th>Energy ratio</th>
<th>CO&lt;sub&gt;2&lt;/sub&gt; emissions&lt;sup&gt;a&lt;/sup&gt;</th>
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<tbody>
<tr>
<td>Conventional gasoline</td>
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<td>-</td>
<td>-</td>
<td>5</td>
<td>0.05</td>
<td>175</td>
</tr>
<tr>
<td>Conventional diesel</td>
<td>0-100%</td>
<td>a few thousand</td>
<td>very low</td>
<td>-</td>
<td>-</td>
<td>10</td>
<td>0.08</td>
<td>175</td>
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<tr>
<td>Corn-based ethanol</td>
<td>10%</td>
<td>65 M</td>
<td>20%</td>
<td>370</td>
<td>28</td>
<td>170</td>
<td>0.98</td>
<td>350</td>
</tr>
<tr>
<td></td>
<td>25%</td>
<td>160 M</td>
<td>51%</td>
<td>370</td>
<td>28</td>
<td>180</td>
<td>0.98</td>
<td>350</td>
</tr>
<tr>
<td></td>
<td>50%</td>
<td>337 M</td>
<td>103%</td>
<td>360</td>
<td>28</td>
<td>220</td>
<td>0.98</td>
<td>350</td>
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<tr>
<td>Cellulosic ethanol</td>
<td>10%</td>
<td>46 M</td>
<td>15%</td>
<td>515</td>
<td>39</td>
<td>146</td>
<td>0.92</td>
<td>330</td>
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<tr>
<td></td>
<td>25%</td>
<td>112 M</td>
<td>35%</td>
<td>515</td>
<td>39</td>
<td>146</td>
<td>0.92</td>
<td>330</td>
</tr>
<tr>
<td></td>
<td>50%</td>
<td>228 M</td>
<td>72%</td>
<td>510</td>
<td>39</td>
<td>149</td>
<td>0.92</td>
<td>330</td>
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<td>Soybean biodiesel fuel</td>
<td>10%</td>
<td>253 M</td>
<td>80%</td>
<td>57</td>
<td>7</td>
<td>900</td>
<td>0.76</td>
<td>240</td>
</tr>
<tr>
<td></td>
<td>25%</td>
<td>380 M</td>
<td>120%</td>
<td>57</td>
<td>7</td>
<td>900</td>
<td>0.76</td>
<td>240</td>
</tr>
<tr>
<td></td>
<td>50%</td>
<td>1.2 B</td>
<td>390%</td>
<td>57</td>
<td>7</td>
<td>900</td>
<td>0.76</td>
<td>240</td>
</tr>
<tr>
<td>Algae culture</td>
<td>10%</td>
<td>2.5 M</td>
<td>&lt; 1%</td>
<td>6000</td>
<td>800</td>
<td>50</td>
<td>0.2</td>
<td>absorbs CO&lt;sub&gt;2&lt;/sub&gt; waste</td>
</tr>
<tr>
<td></td>
<td>25%</td>
<td>6.5 M</td>
<td>2%</td>
<td>6000</td>
<td>800</td>
<td>50</td>
<td>0.2</td>
<td></td>
</tr>
<tr>
<td></td>
<td>50%</td>
<td>13 M</td>
<td>4%</td>
<td>6000</td>
<td>800</td>
<td>50</td>
<td>0.2</td>
<td></td>
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<tr>
<td>MSW-based ethanol</td>
<td>0-100%</td>
<td>tens of thousands</td>
<td>very low</td>
<td>-</td>
<td>-</td>
<td>5</td>
<td>0.6</td>
<td>~105</td>
</tr>
</tbody>
</table>

Source: Kreider and Associates
PHV Role: EV Mode For Short Distance HV Mode for Longer Trips

U.S. Driving Patterns

Source: 1990 Nationwide personal transportation survey

Cumulative percentage of personal automobile trips

Cumulative percentage of travel distance energy

Approx. 20%

Approx. 35%

80% Trips

Average Daily Travel Distance per Vehicle (miles)
Toyota’s PHV Development
### Operation Specifications

<table>
<thead>
<tr>
<th>Max. Output</th>
<th>Engine</th>
<th>98 HP (73 kW)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>MG2</td>
<td>80 HP (60 kW)</td>
</tr>
<tr>
<td>In EV Driving Mode</td>
<td>Max. Speed</td>
<td>Approx. 62 mph (100 km/h)</td>
</tr>
<tr>
<td></td>
<td>Range</td>
<td>Approx. 13 miles (21 km)</td>
</tr>
<tr>
<td>Power Source</td>
<td></td>
<td>Household Electrical Outlets</td>
</tr>
<tr>
<td>Charging Time</td>
<td></td>
<td>Approximately 3 hrs (110 V)</td>
</tr>
</tbody>
</table>
HV Battery Cooling

- Additional fans
- New ductwork
- 42 Temperature Sensors

Intake Air Ducts

HV Battery Temperature Sensors
(for HV Battery Pack)

HV Battery Temperature Sensors
(for Intake Air Duct)

DC/DC Converter
Cooling Blower

Sub 2 Main
HV Battery
Cooling Blowers
Toyota’s PHV Introduction Scenario

Step by Step approach, dependent on Battery Development

Field Test Phase

- Test car (10)  
  - Field Data

Understand market potential

- Small demo (150)
- Accumulate Field data

Medium volume (~25K)
- Accumulate Field data

Mass volume

Battery

- NiMH
- Li
- Li (Revised)
- Li (Adv)
Last Century Urban Mobility Projects

Toyota e-Com shared-use ‘community’ EVs for employees

Crayon System pay-as-you-go public EV rentals
New Urban Mobility – EV Concept

- Range: 50 miles
- Charge Time: ~2.5hr/7.5hr (220V/110V)
- 2012
Transition in Personal Mobility

Transition will require:

1. Real-time Communication from Vehicle
   a) to customer (web portal, Smart Phone)
   b) to utilities

2. Shift to other modes of personal transportation

3. Partnerships

Mobility based on Multiple Modes
- Car Sharing
- Personal Rapid Transit
- Mass Rapid Transit
Technology Enables New Possibilities

Wireless Technology Promotes Modal Diversity

Convergence of:
- Wireless Computing
- Consumer Electronics
- Transportation
- Energy Management
- Eco-impact Metrics

Eco Technology Conserves Energy, Reduces CO₂

PEV ENABLERS

Smart Grid

Locate Mass Transit

Locate Charge Station

Smarter Charging Stations

Monitor Charge Status

Vehicle to Grid

Recommend optimal mode to minimize price & travel time

Zipcar Available?

Reserve Phoenix

Name: Phoenix
Model: Toyota Prius
Hourly Cost: $9.25
Car Sharing is Growing

Currently at 70+ U.S. college campuses

U.S. Car Sharing Growth Forecast

Members (000s)

0
1,000
2,000
3,000
4,000
5,000
6,000
7,000
8,000

2007
~2020

Fox Business 2008 (70 Campuses); Innovative Mobility Research 2007 (current members), CNW Research 2008 (8 million forecast)
Car Sharing Opens New Market Opportunities

Two Basic Models, OEM Owner and Independent

- **OEM Owned Example: Mercedes Smart Car To Go**
  - Two Locations, Austin, Texas and Ulm Germany
  - Charge $.35/minute or $70 for all day
  - Insurance (and future charging) Provided
  - Mercedes Retains Control of Vehicle
  - Municipality Provides Free Parking
  - Income Stream From Services not From Sales
    - Enabled by Smart Phone Applications

- **Independent Owner Example: Zip Car**
  - 350,000 Subscribers and Climbing
  - 6000 Vehicles, 70 Different Models
  - Largest Car Sharing Operation in the World
  - Estimated to be $1 Billion Company in 5 years (Fortune Magazine)
  - iPhone App Finds the Car, Reserves the Car and Unlocks the Car
  - Municipalities Provide Dedicated Parking and Charging
Key Infrastructure Issues Remain

Vehicle to Grid Communications

- Electric Utilities have excess electricity *generation* capacity during off-peak hours – typically at night
- Even during off-peak times, however, there is insufficient electricity *distribution* capacity for many PEVs to charge at the same time

Communication between vehicle and “grid” is necessary to avoid negative impacts to distribution system (such as local outages)

Level 2 Charging Equipment

- The majority of customers, particularly larger-capacity BEVs (50+ miles), will need/want L2 (220V) charging at home and business
- The installation of L2 charging equipment is extremely challenging: high cost, lengthy time period, complex interactions among City, Utilities, Contractor, Customer, OEM and Dealer

Resolving L2 installation issues will be critical for EV market adoption

Last Mile Grid System not Developed

- Old Transformers Cannot Accommodate Multiple EVs Charging in One Neighborhood
- Night Time Charging Limits Charging Hours
- Public Charging Not Assured
“What the Market will Bear”

2008 Midsize Car Prices

Mass Market

Prius

Prius PHV

Source: PIN
The U.S. market is primed for light PHVs . . . .

if oil prices play along

Source: Lux Research
The Obama administration has made EVs an agenda item...

Energy Plan from Campaign - Key Points

- Put 1 million plug-in hybrid and/or electric vehicles on the road by 2015
- Ensure 10% of energy comes from renewable sources by 2012 and 25% by 2025
- Implement economy-wide cap-and-trade program to reduce greenhouse gas emissions 80% from 1990 levels by 2050

Progress vs. Campaign Promises

- Congress passed energy legislation in 2009 to reduce U.S. emissions below 2005 levels (Senate has not voted on legislation)
  - 17% reduction by 2020
  - 83% reduction by 2050
- American Recovery and Reinvestment Act included $2.4 billion in funding for battery development and electric vehicle component
...backed by significant financial commitments

**Advanced Tech Vehicles Manufacturing Loan Program**
Measured in USD Millions

**American Reinvestment & Recovery Act Awards**
Measured in USD Millions

ATVM provides loans for the cost of re-equipping, expanding, or establishing manufacturing facilities in the United States to produce advanced technology vehicles or qualified components, and for associated engineering integration costs.

ARRA provides funding for U.S.-based manufacturers to:
- Produce batteries and components
- Produce electric drive components such as electric motors and power electronics

Source: U.S. Department of Energy
However, past presidential agenda items such as solar power have struggled once funding was cut.

![Estimated Department of Energy Solar Funding](chart1)

- **Photovoltaic**
- **Concentration**

1977 - 1979: President Carter makes multiple speeches touting solar power and installs panels on roof of White House.

President Reagan cuts funding for solar development.

![Shipments of Solar Thermal Collectors](chart2)

- **Medium-Temp**
- **Low-Temp**

CARB expects **BEV/FCV sales volume to surpass conventional gas** by 2035 and reach **30% of mix** by 2040.

However, the above vision does not achieve the 80% reduction in GHG emissions from 1990 levels by 2050; **ZEVs will need to reach 100% of vehicle sales by 2040, to meet the 80% goal**.
Outside Voices: Evaluation of PHVs, Duke University

Duke University, *Plug-in and regular hybrids: A national and regional comparison of costs and CO₂ emissions.*
## Comparison of Vehicle Powertrain Technologies

<table>
<thead>
<tr>
<th></th>
<th>Lifetime emissions</th>
<th></th>
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<th>Lifetime energy use</th>
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<tr>
<td></td>
<td>CO2 equiv</td>
<td>SOx</td>
<td>NOx</td>
<td>Hg</td>
<td>MMBTU</td>
</tr>
<tr>
<td></td>
<td>lb</td>
<td>lb</td>
<td>lb</td>
<td>lb</td>
<td></td>
</tr>
<tr>
<td>Gasoline (30mpg Sentra)</td>
<td>140,000</td>
<td>150</td>
<td>160</td>
<td>0.00084</td>
<td>721</td>
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<tr>
<td>EV-40 (Current US Grid)</td>
<td>110,000</td>
<td>430</td>
<td>210</td>
<td>0.00190</td>
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<tr>
<td>PHEV-20 (Reduced Volt)</td>
<td>100,000</td>
<td>270</td>
<td>160</td>
<td>0.00120</td>
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<tr>
<td>HEV (2010 Prius)</td>
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<td>140</td>
<td>120</td>
<td>0.00071</td>
<td>472</td>
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<td>Fuel Cell (70mi/kg)</td>
<td>76,000</td>
<td>4,100</td>
<td>53</td>
<td>0.00047</td>
<td>626</td>
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# Comparison of Vehicle Powertrain Technologies

<table>
<thead>
<tr>
<th></th>
<th>FC</th>
<th>HEV</th>
<th>PHEV-20</th>
<th>EV-40</th>
<th>Gas</th>
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<tr>
<td><strong>Lifetime energy use breakdown</strong></td>
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<tr>
<td>Material production</td>
<td>17%</td>
<td>17%</td>
<td>20%</td>
<td>25%</td>
<td>11%</td>
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<tr>
<td>Vehicle assembly</td>
<td>3%</td>
<td>3%</td>
<td>4%</td>
<td>5%</td>
<td>2%</td>
</tr>
<tr>
<td>Fuel production / transport</td>
<td>10%</td>
<td>10%</td>
<td>9%</td>
<td>5%</td>
<td>12%</td>
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<tr>
<td>Vehicle operation</td>
<td>63%</td>
<td>63%</td>
<td>59%</td>
<td>54%</td>
<td>71%</td>
</tr>
<tr>
<td>Vehicle maintenance</td>
<td>3%</td>
<td>3%</td>
<td>3%</td>
<td>4%</td>
<td>2%</td>
</tr>
<tr>
<td>Vehicle disposal</td>
<td>4%</td>
<td>4%</td>
<td>5%</td>
<td>7%</td>
<td>3%</td>
</tr>
<tr>
<td>Total</td>
<td>100%</td>
<td>100%</td>
<td>100%</td>
<td>100%</td>
<td>100%</td>
</tr>
</tbody>
</table>
Roles of EV/PHEV/FCV

- **Vehicle Size**
  - High-Speed, Long-Distance Driving
  - Highway driving between cities
  - Med-to-High Speed, Med-Distance Driving
  - Lower-Speed, Short-Distance Driving
  - Low-Speed, Inter-City Driving

- **Driving distance**
  - High-Speed, Long-Distance Driving
  - Highway driving between cities
  - Med-to-High Speed, Med-Distance Driving
  - Lower-Speed, Short-Distance Driving
  - Low-Speed, Inter-City Driving

- **Roles of EV/PHEV/FCV**
  - Mobility-based
  - Vehicle-based

- **Electrical Sources**
  - Electricity
  - Gasoline, Diesel, Biofuel, etc.
  - Hydrogen
Apply existing technologies in new ways

Most of the technologies mentioned already exist, just not yet in the mobility space

For now smaller battery approaches are more cost effective

Implies multiple charge periods throughout the day

At the end of the day, customer is king

All solutions must solve customers problems without creating new ones

Charging solutions to manage the grid may be at odds with customer expectations.