Drivers of change in the Auto Industry

Global development of industry & technology in the 21st century

Accelerated consumption of fossil fuels

Dramatic increase in
• Population
• Vehicles

Drivers for Change
1. Energy & Fuel Diversification
2. CO₂ reduction
3. Lower exhaust emissions
4. Urban congestion
The Planning Process

4~5 Year Process, increasing definition towards end

Customer Analysis:
• Size
• Performance
• Cost/Price Targets

Powertrain:
• Size
• Performance
• Cost/Price Targets

Fuels:
• Cost
• Carbon Content
• Availability
• Infrastructure

Regulatory:
• CAFE
• ZEV
• CO2
• Fuels

Competitors Actions:

Customer Acceptance/Market Size

Compliance Strategy

Alternative Fueled Vehicles
Sustainable Mobility – More than vehicles

A system approach

Vehicles, Energy, Environment, Partnerships

Required to bring these products to market

to power the product

in which the product “lives”
Hybrid is our Core Technology

**Annual Sales** (1000 units)

- **1 million units per year**
- **Cumulative sales of 1 million worldwide**
- **Cost reduction, Downsizing, Battery development**

Further evolution of HV and expansion plan to more models
Fuel Cell Hybrid Vehicle
Inside the FCHV\textsubscript{ADV}

- Toyota Proprietary Fuel Cell stack (90kw)
- Power Control Unit
- NiMH Battery Pack (21kW)
- Hydrogen Storage Tanks (10,000 psi)
- Toyota-Developed Electric Motor (90kw, 260n-m torque)
## TOYOTA FCHV Progress

### Vehicle
<table>
<thead>
<tr>
<th>Present</th>
<th>2015</th>
</tr>
</thead>
<tbody>
<tr>
<td>'02 FCHV (lease model) Dec. 2002 ~</td>
<td>Improved FCHV FCCJ* Target</td>
</tr>
<tr>
<td>'05 FCHV (lease model) Jul. 2005 ~</td>
<td></td>
</tr>
</tbody>
</table>

### Technical Challenges

1. **Cold Start / Driving Capability**
   - 32degF ~
2. **Actual Cruising Range**
   - 125 miles
3. **FC Stack Durability**
   - 15 years or more
4. **Cost reduction**
   - 1/10 or less (design / materials)

- 135 miles
- 300 miles or more
- -22degF ~
Plug-in Hybrid Electric Vehicles ("PHEV")
PHEV Types: EV vs. HV Based

**EV-based PHV**
- Electric flow
- Traction flow
- Engine
- Generator
- Battery
- Motor

**HV-based PHV (Toyota PHV)**
- Electric flow
- Traction flow
- Battery
- Generator
- Motor
- Engine
# PHEV Comparison

<table>
<thead>
<tr>
<th>Feature</th>
<th>EV (EV-based)</th>
<th>PHV (HV-based)</th>
<th>HV</th>
</tr>
</thead>
<tbody>
<tr>
<td>CO₂</td>
<td>◎</td>
<td>◎</td>
<td>◎</td>
</tr>
<tr>
<td>Air quality</td>
<td>◎</td>
<td>◎</td>
<td>◎</td>
</tr>
<tr>
<td>Driving range</td>
<td>✗</td>
<td>◎</td>
<td>◎</td>
</tr>
<tr>
<td>Recharging time</td>
<td>✗</td>
<td>△</td>
<td>—</td>
</tr>
<tr>
<td>Special recharging infrastructure</td>
<td>✗ (Necessary)</td>
<td>✗ (Necessary)</td>
<td>—</td>
</tr>
<tr>
<td>Cost</td>
<td>✗</td>
<td>△~×</td>
<td>○</td>
</tr>
</tbody>
</table>

© = Excellent  ○ = Good  △ = Passable  ✗ = Unacceptable

Unnecessary

Unnecessary, but could be used

Necessary

(End of table)

(End of page)
Finding an *Optimal* Solution

<table>
<thead>
<tr>
<th></th>
<th>Gasoline</th>
<th>Diesel</th>
<th>HV</th>
<th>PHEV (EV based)</th>
<th>PHEV (Blended)</th>
<th>EV</th>
<th>FCHV</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>CO2 (vehicle only)</strong></td>
<td>✠</td>
<td>☀</td>
<td>☀</td>
<td>☀</td>
<td></td>
<td>☀</td>
<td>☀</td>
</tr>
<tr>
<td><strong>CO2 (Full fuel cycle)</strong></td>
<td>☒</td>
<td>✠</td>
<td>☀</td>
<td>☀ → ☀</td>
<td>☀ → ☀</td>
<td>☀ → ☀</td>
<td>☀ → ☀</td>
</tr>
<tr>
<td><strong>Air Quality (vehicle only)</strong></td>
<td>✠</td>
<td>☒</td>
<td>☀</td>
<td>☀</td>
<td></td>
<td>☀</td>
<td>☀</td>
</tr>
<tr>
<td><strong>Air Quality (Full fuel cycle)</strong></td>
<td>☒</td>
<td>☒ → ☒</td>
<td>☀</td>
<td>☒ → ☒</td>
<td>☒ → ☒</td>
<td>☒ → ☒</td>
<td>☒ → ☒</td>
</tr>
<tr>
<td><strong>Energy Diversity</strong></td>
<td>☒</td>
<td>☒</td>
<td>☀</td>
<td>☀</td>
<td></td>
<td>☀</td>
<td>☀</td>
</tr>
<tr>
<td><strong>Single Fill Range</strong></td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
<td>☐ → ✠</td>
<td>☐ → ☐</td>
<td>☐ → ☐</td>
<td>☐ → ☐</td>
</tr>
<tr>
<td><strong>Refuel Time</strong></td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
<td>☒</td>
<td>☐ → ☐</td>
<td>☒ → ☒</td>
<td>☐ → ☒</td>
</tr>
<tr>
<td><strong>Special Fueling Infra.</strong></td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
<td>☐ → ✠</td>
<td>☐ → ☐</td>
<td>☐ → ☒</td>
<td>☐ → ☒</td>
</tr>
<tr>
<td><strong>Cost</strong></td>
<td>☐</td>
<td>☐</td>
<td>☐</td>
<td>☐ → ✠</td>
<td>☐ → ☐</td>
<td>☐ → ☒</td>
<td>☐ → ☒</td>
</tr>
</tbody>
</table>
PHEVs – the promises

Customer
– Lower fuel costs
  • Less gasoline usage
  • Gasoline price per mile < electricity cost per mile
  • Nighttime electricity discounted rate

Environment
– Lower CO2
  • Future electricity generation will be “cleaner”
– Local air quality
  • Move emissions from tailpipe to power plant

Electric Utilities
– Ability to level electric load with nighttime charging
– Sufficient spare capacity to charge large # of vehicles
Oil Use Reduction with PHEVs

This highly aggressive scenario assumes 100% HEV sales from 2010 and 50% PHEV40 sales from 2020 onwards…

Source: NREL
**CO₂ Reduction**

### Electric power mix

- **USA**: 100% Fossil, 0% Hydro, 0% Nuclear
- **Japan**: 70% Fossil, 30% Nuclear
- **France**: 50% Fossil, 50% Nuclear

### Well-to-wheel CO₂ emissions

- **Prius**: USA = 1.0, Japan = 0.7, France = 0.5
- **Plug-in hybrid vehicle**: N.A. mode

*Toyota estimate*
Battery Pack Size

Prius (MY '98 vs. '01)

Plug-in Prius?

Prius (MY '04)

Battery pack

cargo space
PHEVs – the reality

Customer
– ??? Lower fuel costs
  • Less gasoline usage
  • ??? Gasoline price per mile < electricity cost per mile
  • ??? Nighttime electricity discounted rate

Environment
– ??? Lower CO2
  • ??? Future electricity generation will be “cleaner”
– Local air quality
  • Move emissions from tailpipe to power plant

Electric Utilities
– ??? Ability to level electric load with nighttime charging
– ??? Sufficient spare capacity to charge large # of vehicles
PHEVs – more reality

“Customers will charge their vehicles at night”

Based on assumption of 30-40 mile range

“Nearly all vehicles were regularly charged during daytime business hours.”
  – UC Davis study of early plug-in hybrid users

“That assumption doesn’t necessarily take into account human nature.”
  – Oak Ridge National Lab study on hybrid effect on power distribution, March 2008
Challenges for New Technologies

Most customers are unwilling to accept compromises for the sake of new technology or environmental benefit

To be successful, new automotive technologies must be

- Transparent to the user
- As reliable and as durable as current vehicles
- Offer consistent performance
- Offer value

For positive environmental impact, must also

- Sell in mass market quantities
Sustainable Mobility – More than vehicles

A system approach

Vehicles to power the product
Energy in which the product “lives”
Environment Required to bring these products to market
Energy Density

Volumetric energy density (Gasoline=10)

- **Batteries**
  - Lithium-ion battery

- **Gaseous fuels**
  - Hydrogen absorbing alloy (2wt%)
  - CNG

- **Liquid fuels**
  - Ethanol
  - Gasoline
  - Diesel fuel

Energy Density

Toyota estimate
Issues for Fuel Cell Vehicles and Hydrogen Fuel

Production
- Solar / Biomass
- Coal
- Petroleum
- Natural gas
- Electricity

Transport / Storage / Supply
- H₂, etc.

Issues
- Transportation storage method
- Infrastructure development
- Codes & standards
- H₂ cost (transportation, infrastructure)

Vehicle
- Stack durability
- Compactness & high power density
- Freeze start capability
- Cruising range
- Vehicle cost

Government, Fuel Industries
Car-makers
Electric Capacity Growth

Regions with large increases in capacity are also regions of growing water concerns.

Future Electricity Generation

EIA Annual Energy Outlook 2008
“Clean Coal”

“CO2 sequestration faces economic and political hurdles”
June 2008

“Sequestration is Running Late and Short of Funds”
April 2008

“Governments, Utilities Face Hefty Sequestration Costs”
April 2008

“EPRI Discusses Economic, Technological Challenges Facing Carbon Capture”
March 2008
Sustainable Mobility –
More than vehicles

A system approach

Sustainable Mobility

Vehicles  Energy  Environment  Partnerships

to power the product  in which the product “lives”  Required to bring these products to market
Measuring Sustainability – Life Cycle Assessment

INPUT

- Natural Resources
- Energy

OUTPUT

- Vehicle Emissions
- Greenhouse Gases
- Waste Water
- Waste Solids
- Air Pollutants

- Materials Production
- Vehicle Production
- Driving
- Maintenance
- Disposal
World Population Growth and Urban Congestion

- Africa
- Asia
- Europe
- Latin-America
- North America
- Oceania
Urban Mobility Projects

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

Crayon System
pay-as-you-go public EV rentals
Sustainable Mobility – More than vehicles

A system approach

Sustainable Mobility

Vehicles

Energy

Environment

Partnerships

to power the product
in which the product “lives”
Required to bring these products to market
University Partners

Shared Use Station Car program, in partnership with University of California Irvine (UCI)

University of California at Berkeley and Toyota

MEETING OF THE MINDS
THE INNOVATIONS WE NEED FOR MORE SUSTAINABLE CITIES

Conference on sustainable cities, in partnership with University of California Berkeley (UCB)
Sustainable Galapagos
Electric plant on Santa Cruz island showing ground water contamination from diesel fuel and PCBs leaking from discarded transformers.
Baltra . . . before
• Electricity Generation
• Transportation
• Fishing
• Tourism
Baltra . . . after
Oil Recycling

- 100,000 gallons recycled to date
- Previously dumped directly into the ecosystem
- Created sustainable employment opportunity for local fisherman
- Will be used as a model for other islands
Integrated Waste Mgt
So what is our message?

→ We must agree on the goals and priorities

→ We must align transportation, energy and climate change policy

→ We cannot ignore primary resources

→ Societal preparation for increased energy costs and lifestyle changes are key for carbon reduction plans

→ The greatest near-to-mid term opportunity lies in EFFICIENCY!
Thank you!