The Future of Transportation

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Outline

• Introduction and Other transportation
• Battery Vehicles
• Fuel Cell Vehicles
• Biofuels
• Conclusions
Why the future will be different

• Less fossil fuels
• Energy security
• Sustainability
• Environment
• Population/Population density changes
• Technology changes
• Changes in political/social/community structures
Why does transportation matter to people of faith?

Many activities are enhanced by transportation, by either face-to-face contact or the movement of goods. Many of these are important to people of faith and or faith-based organizations.
Vehicle Requirements

- Ships and trains—Large cargo, long distance, large weight and volume capacity, lower speed
- Long-haul trucks, buses
- Commuting buses (trains)
- Automobiles—variable range. Size and weight of engine and fuel is important, very cost sensitive.
- Bicycles—etc. short range, lower speed, weight is critical
- Airplanes—variable range. Size and weight of engine and fuel is critical.

The function of the vehicle affects not only its design but also how well it fits with a particular fuel or engine technology.
Fuel/Energy Carrier Properties

• Batteries—low energy density, slow refill
• Hydrogen—moderate energy density, fast refill
• Methane (natural gas)
• Wood
• Coal—High CO2, mining damage, mercury etc.
• Ethanol (methanol, DME, butanol, propane)
• Gasoline/diesel/jet
Aircraft

- Long-range flight is most critical need for liquid fuels
- Many test flights of biofuels in jet engines

- Jet fuel properties are very specific
- Efficient—more than 100 passenger miles/gallon
Heavy Transport

• Have historically run on wind, wood, coal, coal gas, heavy oil.

• In the future?

  President Obama's plan is to invest federal money "in an efficient, high-speed passenger rail network of 100- to 600-mile [160- to 965-kilometer] intercity corridors that connect communities across America,"
  http://www.scientificamerican.com/article.cfm?id=high-speed-train-slideshow

• Renewable fuels—Electricity, biomass pyrolysis oil, hydrogen
How to reach 54.5 mpg on the road by 2025

- Degree of electrification (Power electronics & Energy Storage)
- Start/stop
- Regenerative braking
- Low rolling resistance tires
- Electric powered steering
- Electric infrastructure
- 8 speed transmissions
- Light weighting
- Variable cylinder mgmt
- Turbo-charging, direct fuel injection, advanced combustion
- Improved aerodynamics
- Diesel powered & or Alternative Fuels, H2 etc
Battery Electric Vehicle (BEV)
Examples of Light Duty Electric Drive Vehicles in the Market

- **Micro hybrids**
  - CITROËN C3
  - BMW ED
  - Smart
  - BMW 1&3

- **Mild hybrids**
  - Chevy Malibu
  - Saturn Vue
  - Saturn Aura

- **Medium hybrids**
  - Toyota Prius 3
  - Honda Insight

- **Full hybrids**
  - Ford Fusion
  - Mercedes S400

- **Plug-in hybrids**
  - GM Volt
  - BYD F3DM
  - Nissan Leaf

- **Electric**
  - Honda FCX
  - Toyota Prius 3
  - iMiev

Adapted and modified from "From Stop-Start to EV" by Derek de Bono presented at the SAE Hybrid Vehicle Technologies Symposium, San Diego, CA, February 2010
City Niche Market Vehicles

http://mobile.mit.edu/greenwheel/gallery

http://green.autoblog.com/2009/02/06/greenlings-what-is-a-neighborhood-electric-vehicle-nev/

http://www.segway.com/about-segway/previous-models.php
Sustainable Vehicle Charging

- Want to charge when vehicle not in use—at work
- Need local renewable chargers or very robust grid to provide connection to renewable energy
Is there enough lithium?

- Li supply does not appear to be a problem given today’s reserve and production quantities, even under aggressive expectations for EDV deployments
  - BEV’s offer the largest gasoline displacement capability
  - BEV’s are not always the best at CO$_2$ displacement - heavily dependent on electricity mix

- Were Li supply to become a concern under changing conditions in the short or long term...
  - HEVs offer the best ‘return-on-Li’ for both gas and CO$_2$ displacement, but mass deployment may be demand limited
  - Short range PHEVs may have the maximum impact in a Li limited market
Is battery life good enough?

**Life expectation in various thermal environments**

**Geographic Impact on Battery Life**

- Minneapolis
- Houston
- Phoenix

**Thermal Management Impact on Battery Life**

- No cooling
- Air cooling, low resistance cell
- Liquid cooling, chilled fluid

Compared with no cooling, the liquid-cooled battery can use 12% fewer cells and still achieve a 10-year life in Phoenix.
Fuel Cell Electric Vehicle (FCEV)

Hydrogen → FUEL CELL → ELECTRIC MOTOR → TRANSMISSION → ELECTRIC GENERATOR → BATTERY BANK → Regenerative Braking

Electricity flows through the system, with hydrogen fueling the fuel cell and electricity being generated and stored.
DOE Hydrogen and Fuel Cell Overview

U.S. Department of Energy
Fuel Cell Technologies Program
How Many Fuel Cells are in Use?

Megawatts Shipped, Key Countries: 2008-2010

Fuel cell market continues to grow
- ~36% increase in global MWs shipped
- ~50% increase in US MWs shipped

North American Shipments by Application

Various analyses project that the global fuel cell/hydrogen market could reach maturity over the next 10 to 20 years, producing revenues of:
- $14 – $31 billion/year for stationary power
- $11 billion/year for portable power
- $18 – $97 billion/year for transportation

Widespread market penetration of fuel cells could lead to:
- 180,000 new jobs in the US by 2020
- 675,000 jobs by 2035

FuelCells2000, Pike Research, Fuel Cell Today, ANL

Fuel Cell Advantages over Batteries:

- Less weight (56%)
- Less space in vehicle (56%)
- Lower greenhouse gases (44%)
- Lower estimated mass production cost ($6,700)
- Shorter refuel time

Longer Range
Hydrogen Safety

- Sensors are a key technology—Completed extensive life testing - 4,000 hrs and 10,000 thermal cycles - of a robust, ceramic, electrochemical Hydrogen safety sensor with exceptional baseline stability and resistance to H2 signal degradation.

- Detects 1% Hydrogen.

- Hydrogen a different kind of flammability hazard than gasoline.
  - Disperses more quickly so less sustained fires, ignites more easily.
  - Rises so need different ventilation.

- Nontoxic
How close to ready?

Real-world Validation

Vehicles & Infrastructure
- 155 fuel cell vehicles and 24 hydrogen fueling stations
- Over 3 million miles traveled
- Over 131 thousand total vehicle hours driven
- 2,500 hours (nearly 75K miles) durability
- Fuel cell efficiency 53-59%
- Vehicle Range: ~196 – 254 miles (430 miles on separate FCEV)

Buses (with DOT)
- H₂ fuel cell buses have a 42% to 139% better fuel economy when compared to diesel & CNG buses

Forklifts
- Over 45,000 refuelings at Defense Logistics Agency site

CHHP (Combined Heat, Hydrogen and Power)
- Achieved 54% (hydrogen + power) efficiency of fuel cell when operating in hydrogen co-production mode
- 100 kg/day capacity, renewable hydrogen supply
## How close to ready?

<table>
<thead>
<tr>
<th>Challenge</th>
<th>Requirement (target)</th>
<th>Status in Lab</th>
<th>DOE Demo status Vehicles + Stations</th>
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</thead>
<tbody>
<tr>
<td><strong>Fuel Cell Cost &amp; Durability</strong></td>
<td><strong>Cost:</strong> $30/kW, Durability: 5,000 hr (150,000 mi)</td>
<td><strong>Cost:</strong> $51/kW <em>(at 500,000 units/year)</em> Durability: Projected average &gt; 4,000 hr (max &gt; 5,000 hr)</td>
<td>2,500 hrs (75,000 mi)</td>
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<tr>
<td><strong>Hydrogen Production &amp; Delivery Cost</strong></td>
<td>$2 – $4/gge *(gge = gallon gasoline equivalent; 1 gge (H_2) = 1 kg (H_2))</td>
<td>High-volume projections: Achieved $3/gge (distributed natural gas to (H_2)) Renewables and other low carbon pathways range from ~$5/gge to &gt;$10/gge.</td>
<td>Low-volume (H_2) cost &gt;$10/gge</td>
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<tr>
<td><strong>Hydrogen Storage</strong></td>
<td>1.8 kWh/kg (6.5 MJ/kg) 1.3 kWh/L (4.7 MJ/L)</td>
<td><strong>Storage System Status:</strong> 350 bar: 1.8 kWh/kg, 0.6 kWh/L 700 bar: 1.7 kWh/kg, 0.9 kWh/L</td>
<td>Up to ~250 mile range (430 miles verified on Toyota FCEV)</td>
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</tbody>
</table>
Sustainability--Well-to-Wheels CO₂ Analysis

Analysis by Argonne National Lab, DOE Vehicle Technologies Program, and FCT Program shows benefits from a portfolio of options.

**Notes:**
For a projected state of technologies in 2035-2045. Ultra-low carbon renewable electricity includes wind, solar, etc. Does not include the lifecycle effects of vehicle manufacturing and infrastructure construction/decommissioning.

Analysis & Assumptions at: [http://hydrogen.energy.gov/pdfs/10001_well_to_wheels_gge_petroleum_use.pdf](http://hydrogen.energy.gov/pdfs/10001_well_to_wheels_gge_petroleum_use.pdf)

**H₂ from Natural Gas**
Even FCEVs fueled by H₂ from distributed NG can result in a >50% reduction in GHG emissions from today’s vehicles.

Use of H₂ from NG decouples carbon from energy use—i.e., it allows carbon to be managed at point of production vs at the tailpipe.

Even greater emissions reductions are possible as hydrogen from renewables enter the market.
Renewable Hydrogen Production

Reduced electrolyzer cost by 80% since 2001
- 15% cost reduction in just the last year
- Projected high volume capital cost of $350/kW (vs. 2012 target $400/kW) (Proton, Giner)

Autothermal Reforming of Pyrolysis Oil

- Increased hydrogen yield by 65%
- Reduced production cost to an estimated $4.65/gge delivered

Photoelectrochemical Conversion (PEC):
- Demonstrated potential to exceed 10% solar-to-hydrogen efficiency target >16% observed at lab scale (NREL)
Renewable Hydrogen Production

- The majority of biogas resources are situated near large urban centers—ideally located near the major demand centers for hydrogen for FCEVs.
- Hydrogen can be produced from this renewable resource using existing technology.

**SOURCE:** Wastewater Treatment, could provide enough $H_2$ to refuel **100,000 vehicles per day.**

- 500,000 MT per year of methane is available from wastewater treatment plants in the U.S.
- ~50% of this resource could provide ~**340,000 kg/day** of hydrogen.

**SOURCE:** Landfills, could provide enough $H_2$ to refuel **2–3 million vehicles/day.**

- 12.4 million MT per year of methane is available from landfills in the U.S.
- ~50% of this resource could provide ~**8 million kg/day** of hydrogen.
Biofuels
• Other organisms produce butanol or isobutanol
Diesel Biofuels from Biomass

- Green diesel is virtually identical to petroleum-derived diesel, can make a true jet fuel as well.
Thermochemical Pathways

Biomass Feedstocks

- Lignocellulosic Biomass (wood, agricultural, grasses)
- Agricultural Residues (stover, bagasse)

Intermediates

- Syngas
  - Gasification
  - Pyrolysis & Liquefaction
  - Pretreatment & Hydrolysis
- Bio-Oils
  - Hydroprocessing
- Lignin
  - Catalytic Upgrading
- Sugars
  - Catalytic Pyrolysis
  - Aq-Phase Reforming

Transportation Fuels

- Ethanol & Mixed Alcohols
- Diesel
- Methanol → MTG Gasoline
- Gasoline & Diesel
- Gasoline & Diesel
- Diesel
- Gasoline
- Hydrogen

- Gasification is high temperature with air or steam
- Pyrolysis is moderate temperature
Comparison of feeds and processes

• Biochemical is low temperature but long times
• Thermochemical is high-throughput but high temperature and sometimes high pressure
• Not enough sugar except perhaps sugar cane in Brazil
• Oil-seed yields too low for high impact
• Ligno-cellulosic feeds high yields but more difficult to process
• Algae has highest potential yields but many difficulties growing and processing
Sustainability of Cellulosic Ethanol

Requires Much Less Fossil Energy Than Gasoline from Petroleum or ethanol from corn

Total Btu spent for 1 Btu available at fuel pump

- Gasoline: 81% Efficiency
- Corn Ethanol: 57% Efficiency
- Cellulosic Ethanol: 45% Efficiency

Based on “Well to Wheels Analysis of Advanced Fuel/Vehicle Systems” by Wang, et. al. (2005)
Is there enough land?

• If biomass competes with food crops for farm land, then food prices will rise causing the poor to suffer
Have enough land to replace a large amount of oil but still need appropriate import and agriculture policies to prevent driving up fuel prices and getting too much fossil input into biofuels.
When will the fuels come?

- Corn ethanol and biodiesel are here now to some extent
- Cellulosic ethanol, mixed alcohols, and green diesel are rather near, 15% ethanol will be allowed in near future
- Hydrocarbons from biomass are further away
- Algal fuels are a long way off
- Approval of any new fuels is costly
Conclusions

• Batteries for short range
• Fuel cells for medium range
• Biofuels for long range, especially aircraft
• Look for changes such as small self driving cars in urban cores, high-speed electric inter-city trains, and personal aircraft
Acknowledgements

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