FCs and $H_2$ for Transportation
Strategic Assessment and Research Priorities

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Overview

• Context (Intellectual, Political)

• Using Pathways as an Organizing Framework, Focusing on Transportation – beyond “dumb engineers”

• Key Elements and Research Questions for a Transition to H₂
  - Basic research for FCs, H₂ storage, renewable H₂
    *But very important and complementary research needed on ....*
  - New approaches to vehicle markets
  - New energy system formats
Intellectual Context of My Remarks

• Addressing process of change (which defies disciplinary boundaries)

• Rich systems thinking needed to tackle design of entirely new systems
  ▪ traditional disciplines have limited explanatory power; systems have huge empirical complexity; large public engagement implied because of externalities

• Need to mesh insights and methods that address …
  ▪ Pathways of technological innovations
  ▪ Economics of new technologies: “buydowns,” market dynamics, anticipated non-market attributes and values, experience curves
  ▪ Market research for entirely new vehicle attributes
  ▪ Organizational behavior and policy theory to understand transformation of industries and public-private relationships

• Strategic assessment of change processes is key to prioritizing basic and applied research agendas
Empirical/Political Context

Public Debate is Already Underway

- UK: *Cut carbon dioxide emissions by 60% by 2050* (2003 gov’t energy “white paper”)
- Japanese gov’t: *5 million FCVs on road by 2020*
- GM: *1 million FCVs by 2010*
- Toyota and GM: *“Widespread availability” of FCVs by 2010*
- President Bush (US) and Prodi (EU) express great enthusiasm for H₂ economy, though they have different visions of what that means.
High Priority Basic R&D

• **FCs:** Several car companies believe that costs are on track to be competitive, but huge amounts of engineering and science R&D is needed. Entirely new FC designs “better” than PEM? New PEM architectures? New materials? Low-temperature low-cost catalysts? (Note: Basic research on ICEs is still continuing after 100+ years of mass commercialization – and after hundreds of billions of dollars of R&D.)

• **H₂ storage:** Massive basic research still needed for solid, liquid, and gaseous storage.

• **Renewable H₂:** No current processes seem to lead to cost-competitive H₂ from renewable sources. Need entirely new approaches and methods?!
Principal Research Areas at ITS-Davis

Environmental Impacts
Air Quality, Energy, GHG

Advanced Environmental Vehicle Research

Travel Behavior and New Mobility

ITS-Davis Today
• 40 faculty, 70 grad students (research assistants), 10 administrative/technical staff
• Houses interdisciplinary grad program on “Transport Technology & Policy” (IGERT)
• Awarded DOE GATE Center for Fuel Cell Vehicles
Advanced Environmental Vehicle and Fuels Research at ITS-Davis (2003)

- H₂ Pathway Program *(building upon research programs below)*
- FCV Systems Modeling
  - Direct Hydrogen, Indirect and Direct Methanol, Indirect Hydrocarbon, Hybridization
- Basic Science and Engineering Studies of FCs
- FCV Market Research and Marketing
  - Demand for “future” attributes
- Fuel Cell APUs in Trucks *(system engineering, modeling, market assessment, environmental effects, economics)*
  - PEM & SOFC
- Analysis and Modeling of Hydrogen ICE and FC Buses
- Toyota FCHV Demo and Evaluation
- Lifecycle Emissions and Cost Models
- ... and various Battery EV, HEV, and Diesel Studies
Hydrogen Fuel Pathways –

an intellectual and organizing framework for research and analysis. But …
Texaco: “Possible Paths to FCV Commercialization” (2000)

- Methanol Reformer Development
- Methanol Infrastructure
- Hydrocarbon Fuel Processor Development
- Fischer Tropsch Fuels
- Re-tool Refineries for Lower S Gasoline
- Compressed / Liquid H2 at Service Stations
- Service Station Hydrogen Generation?
- Advanced H2 Storage Technology
- “Personal” H2 FCVs
- Production Methanol FCVs
- Direct Methanol FCVs (??)
- Indirect-Hydrocarbon FCVs
- Hydrogen Pipeline Networks
- Direct Hydrocarbon FCVs (??)

Texaco, 2000
GM: “POSSIBLE FUTURE PATHWAYS TO HYDROGEN”

**Fuel Source**
- Hydrocarbons

**Refueling Station**
- Hydrocarbon Fuel Storage

**Vehicle Technology**
- Existing ICEs
  - Gasoline FCVs
- H₂-fueled ICEs
  - H₂-fueled FCVs

**H₂ Production**
- Renewables
- Fossil Fuels (with C-sequestration)

GM, 2003
Technological Path: BEVs $\rightarrow$ HEVs $\rightarrow$ FCVs

**Prius**

**FCHV**

**ICE Hybrid Vehicle (Prius)**

- Engine
- Power Control Unit
- Motor
- Secondary Battery

**Toyota Fuel Cell Hybrid Vehicle**

- Fuel Cell
- Power Control Unit
- Motor
- Secondary Battery
ITS-Davis Hydrogen Pathways Program
Focusing on Temporal, Spatial, and Organizational Transitions

“Pilot Demonstrations”
“Pilot Expansion”
“Market Introduction”

Process/Step
Feedstock
Production
Distribution
Storage/Dispensing
Application

Phase I
Phase II
Phase III

Present
Future

Framework for my insights about H₂ research priorities
ITS-Davis H₂ Pathways Program
Framework for Formulating Key Research Issues

• Multi-year, multi-disciplinary, multi-partner program addressing how to get from “here to there.”
• Focus on transportation sector and US.
• Two goals: research and public “engagement” (OEMs, energy firms, government, environmental community)
• Key issues:

1. How to simultaneously grow a H₂ vehicle market and H₂ fuel supply infrastructure -- creating a business case for private investment that takes into account scaling and public policy?

2. It appears that extrapolation of current system formats to H₂ are a dead end. Need entirely new ways of building and marketing vehicles, and entirely new ways of designing and operating energy distribution systems.

• Initial industry members: Toyota, ExxonMobil, Nissan, Shell Hydrogen, BP, Honda, ConocoPhillips
H₂FCVs Could Be Very Different
(take note, Jay Keller)

- Zero emission, quiet, smooth driving feel
- Mobile electricity -- new accessories and services (and lifestyle uses)
  - One implication: New relationship between driving range and non-travel use of energy
- Home refueling
- Emergency power, V2G
- New design possibilities (eliminate hydraulic and mechanical subsystems)
- Easily reconfigurable ("skateboard" design)
- New mfg possibilities to reduce cost – fewer platforms, modular designs, no emission technology (R&D, certification, testing)
- New vehicle power concepts (eg, fuel cell APUs) – beyond cars and trucks?!
H₂ FCVs will not compete on cost with ICEVs for decades. To succeed, they must be positioned as a “New Product.”

- On board electricity and new lifestyle uses
- Mobile electronics, tools & appliances
- Emergency electricity
- Low emissions, energy use
- Vehicle to grid power
- New vehicle designs
- Electric-drive feel
Implications of “New Product” Concept

• Revolutionize organization and structure of automotive industry
  - vehicle design
  - cost structure (modular design, materials, emission certification and monitoring)
  - vehicle manufacturing industry (upstream)
  - vehicle marketing (downstream)

• Large effect on lifestyles

• Large effect on energy systems
  - Home refueling
  - Connections with electricity grid, microgrids, and distributed energy systems
H₂ Economy Also Implies Very Different Energy System Attributes

- Connections between mobile and stationary energy
- Connections between electricity and liquid/gaseous fuels (“hydricity”)
- More geographically diffuse source of energy production facilities (coal minemouth, “small” distributed biomass, NG pipelines, nuclear plants, imported LNG)
- More diverse resources and fuel production processes
- More difficult and more diverse means of transport (more feedstock types and more energy carriers)
- More difficult and more diverse means of storage (solid, liquid, gas)
Research on Energy Distribution Systems

Observations:

1. If the petroleum production and distribution system were designed from scratch now, it would look very different. Today’s petroleum distribution system is far from “optimal” – it evolved *ad hoc* over past 100+ years in response to shifting oil production sites, import/export patterns, and spatial shifts in population.

2. Today’s petroleum systems will have very different attributes and designs than tomorrow’s H$_2$ energy system (production, distribution, end use).

3. H$_2$ would probably “never” be competitive with petroleum if it were superimposed on the current petroleum system structure and patterns (according to most ongoing studies).

Conclusion:

*It seems apparent that a very different system format is needed for H$_2$ (upstream and downstream). Need new research and innovative thinking.*
Some H₂ infrastructure is in place, but is it the base to build on?
H₂ investments will build out regionally – all types of niche situations. What are key investments and technological needs, and what are key system design attributes, and how will it vary regionally and temporally?
Relative Attractiveness for Hydrogen Station Siting

GIS can be used to integrate research and findings on environment, economics, user behavior, codes/standards, and infrastructure siting.

Sacramento County

An important tool:
GIS Analysis for Energy System Design
System Tools and Thinking

- Costs of H₂ production and distribution (for new system formats, new renewable processes, carbon sequestration)
- Costs of FCVs:
  - Methods to estimate long-term production costs of H₂ and FCVs: *Experience curves?*
  - Fuel cell components and systems – for innovative modular and Autonomy-type designs (consider new mfg processes and industrial structures)
  - Lifecycle cost models for different vehicle types and applications: APUs in heavy-duty vehicles, etc.
  - Future production costs of hydrogen from renewables (using innovative new processes)
- Environmental accounting
  - Lifecycle AQ and GHG emission models are good (but need to be enhanced)
  - Sequestration is biggest uncertainty (and highest priority?)

*Sensitive and responsive to niche opportunities and situations*
Some Closing Thoughts on Research Agendas

• Virtually unlimited topics of intellectual interest.
• Yes, there is a justification for curiosity-driven basic research.
• But clever and strategic analysis -- combining physical, biological, and social sciences -- will provide strong clues about which scientific and technological thrusts are likely to be most “promising.” What will society value? What will customers value? Where are greatest and most important opportunities for reductions in private and social costs, and creation or enhancement of consumer benefits?
• Which vehicle attributes are most compelling, how can they be achieved, and what are the implications for energy supply?
• Which energy attributes are most compelling, how can they be achieved, and what are implications for vehicle technology?
Thank You