The Bumpy Road to Hydrogen

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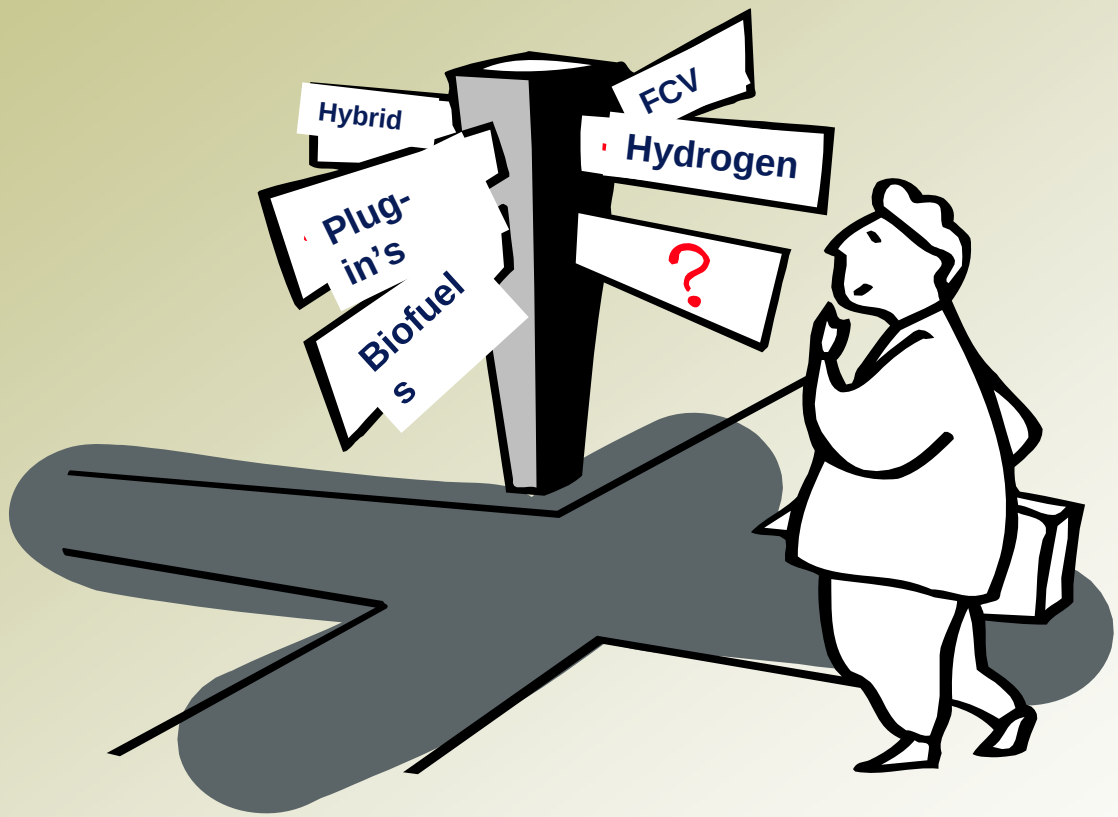
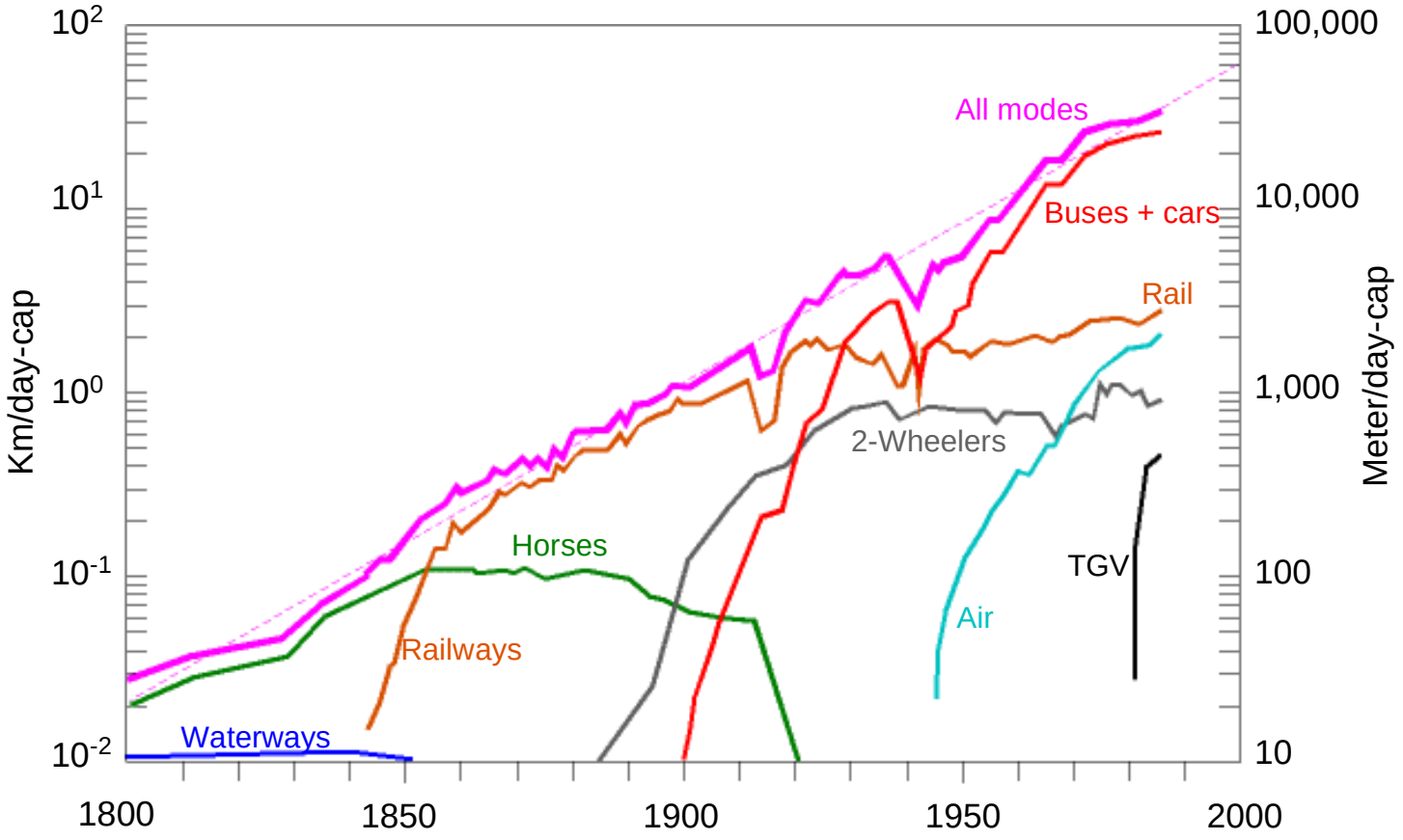


WHEC
15 June 2006

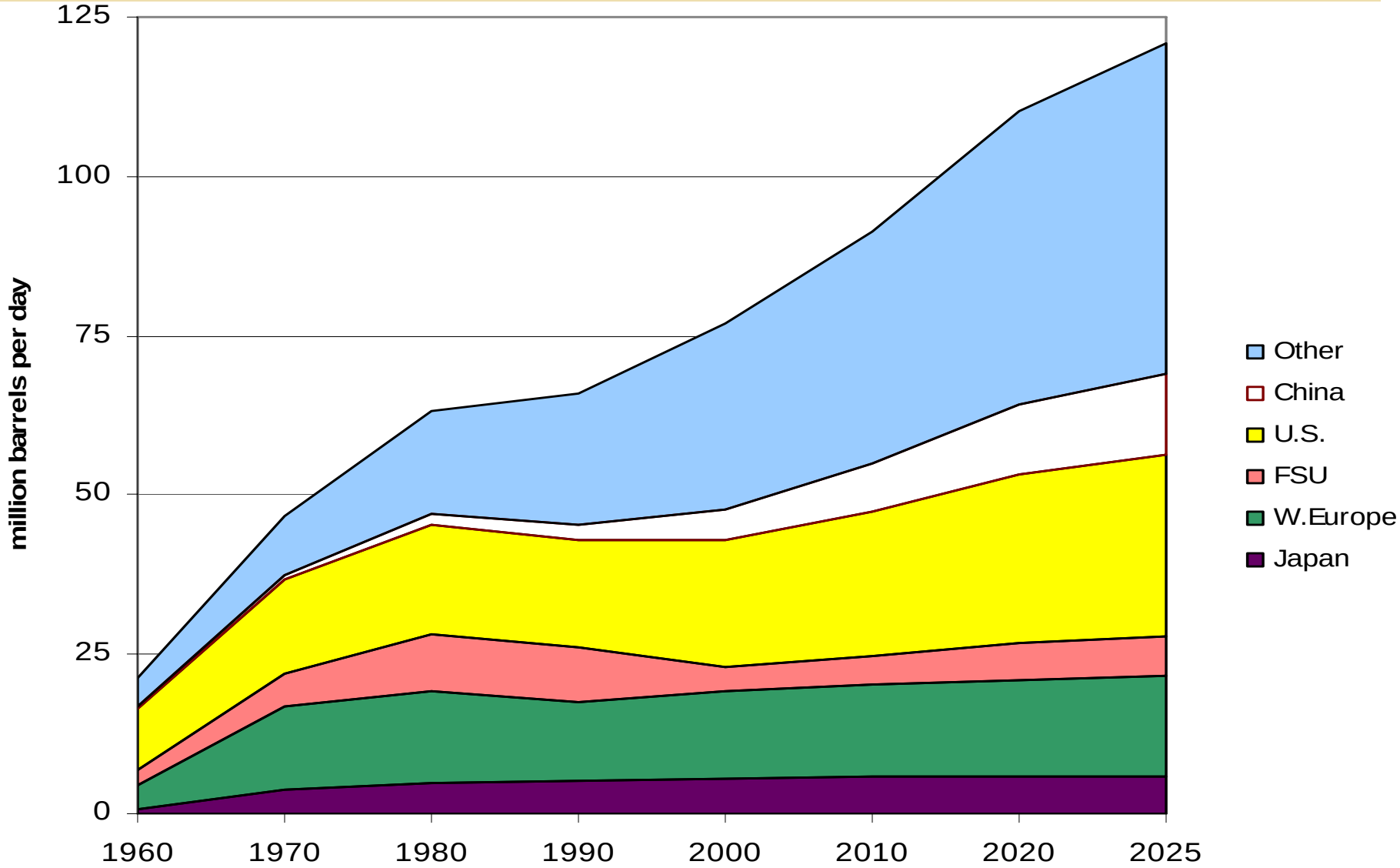
#1. Under almost any scenario, vehicle use will continue to increase

Exponential Growth in Mobility
(passenger-km per day per capita in France)

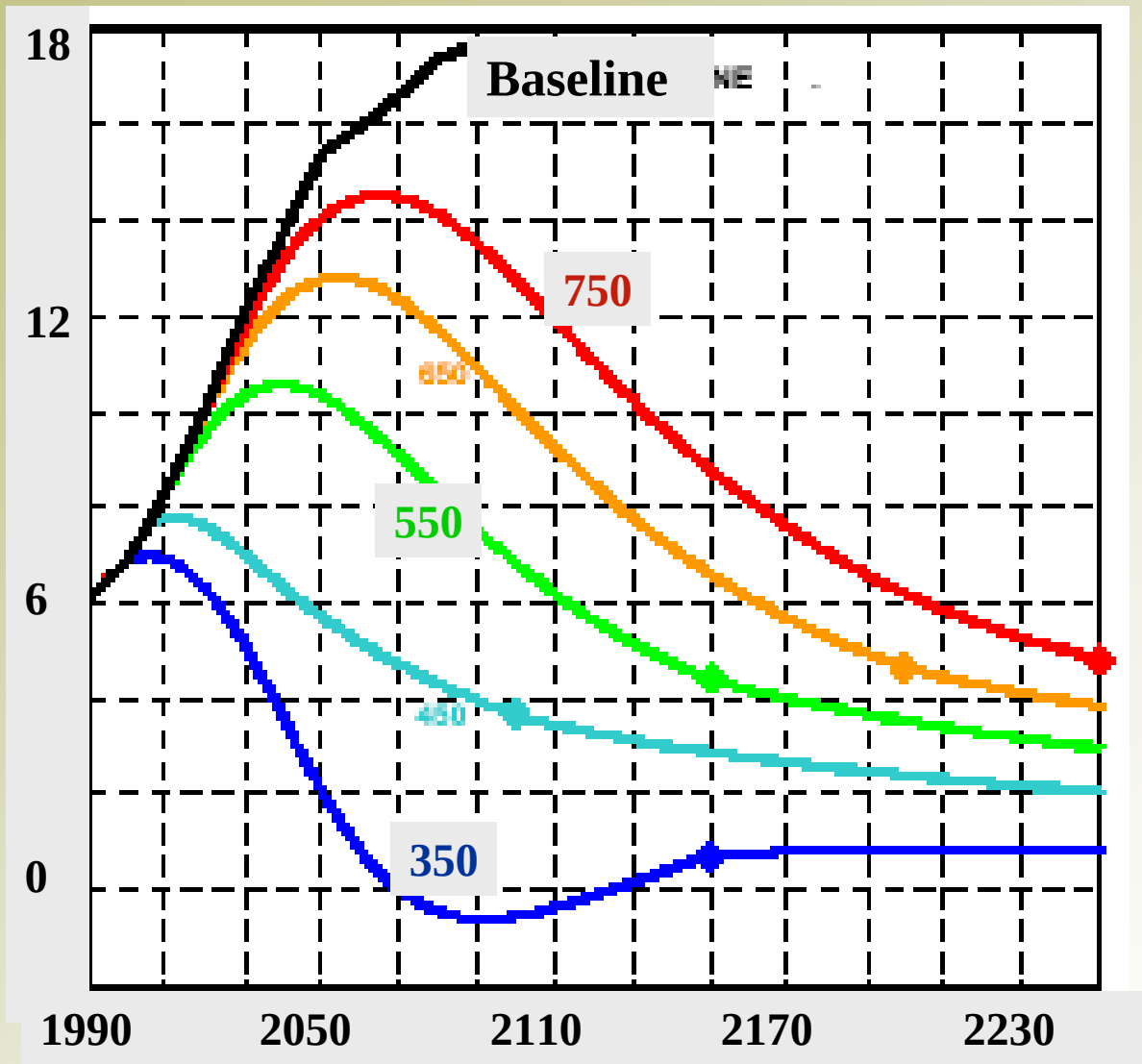


More Vehicles and Travel Means Continuing Increases in World Petroleum Consumption

2/3 is for transport in US; ½ worldwide



To reach stable carbon levels of 450-550 ppm, world emissions need to decline dramatically – by as much as 90% from projected levels by 2100.

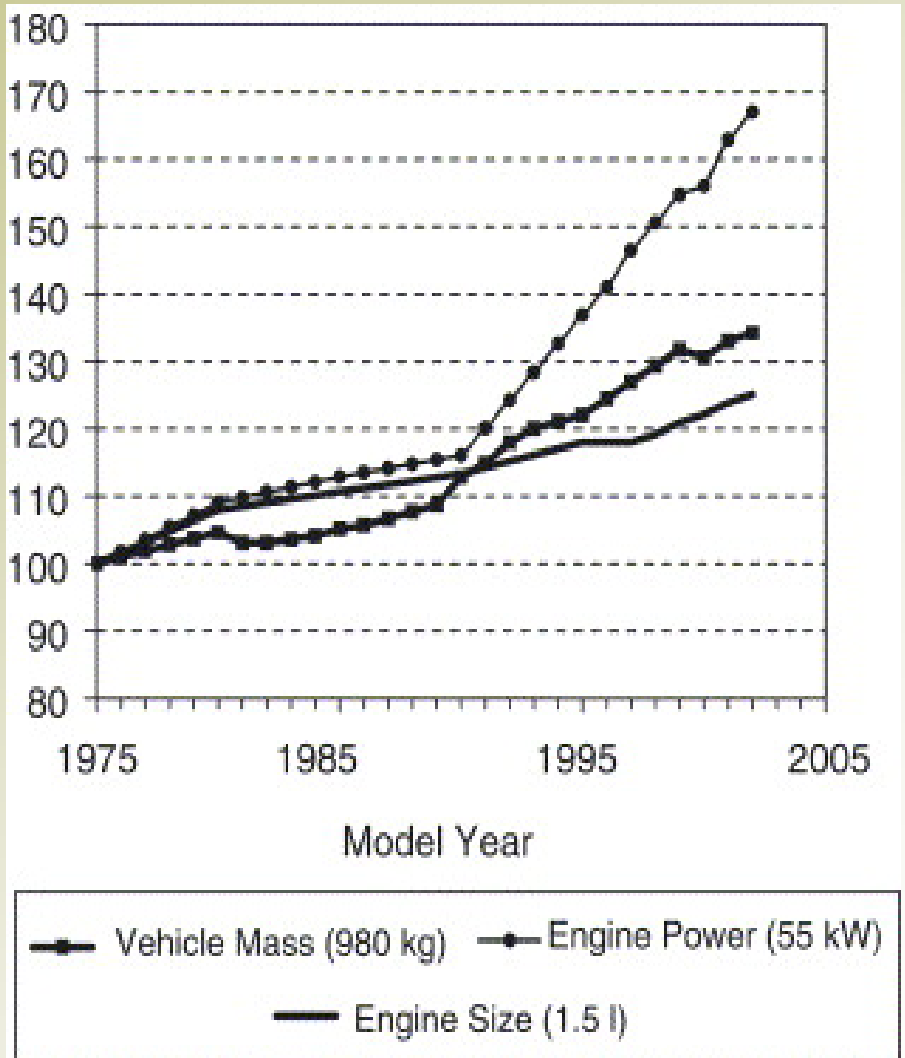


UK has goal of 60% reduction by 2050

California (Schwarzenegger) has goal of 80% reduction by 2050

The “best” strategy to reduce oil use and GHGs is to reduce travel and improve vehicle efficiency, but these will likely fall far short of GHG and energy reduction goals.

Vehicle efficiency is a critically important strategy, but even in Europe, where fuel prices are high, vehicles are getting bigger and more powerful



Theodoros Zachariadis, *Energy Policy*, Sept 2006

Principal Long Term Energy Options for Vehicles

- **Petroleum-like fuels from unconventional fossil**
  - Made from tar sands, heavy oil, remote gas, coal, and oil shale
  - High GHGs. *Re-carbonizing energy systems!*
- **Electricity**
  - **BEVs and plug-in hybrids**
- **Biofuels**
  - **Lignicellulose (crop wastes, grasses, trees)**
  - **Starch and sugar (corn, sugar cane, etc)**
- **Hydrogen**
  - **Used in fuel cells**

#2: Momentum is toward unconventional fossil fuels, and thus aggressive efforts will be needed to shift toward clean fuels.

e.g., Tar sands solves oil problem but exacerbates GHGs

Tar sands production (Canada) (million b/d):

2005: 1.1 mm b/d

2015: 2 to 4 mm b/d

GHG emissions (gasoline made from tar sands vs made from petroleum):

+37% (surface mining)

+50% (in situ)

New technologies and new fuels have potential for huge GHG reductions

GHGs per Km, Relative to Gasoline-Powered ICE, Full Energy Cycle

Fuel/Feedstock	**% Change**
Fuel Cells, H2 with Solar Power	-90 to -80
Cellulosic Ethanol/Liquids	-90 to -40
Fuel Cells, H2 from NG	-50 to -15
Gasoline Hybrid Vehicle	-35 to -10
Diesel	-25 to -15
BEVs, current U.S. power mix	-30 to 0
Corn ethanol	-30 to 0
Gasoline	0

Actual impacts could vary considerably. These estimates reflect a large number of assumptions and should be treated as illustrative.

Liquid Biofuels

Gaining popularity because…

- Easy to implement (vehicles, fuel distribution)
- Regulatory benefits to automakers (in US)
- Powerful political alliance of enviros, farm interests, and national security

BUT …

- Brazil is unique
- Corn etoh has limited supply potential (<5% of gasoline) and minimal energy/enviro benefits
- Cellulose etoh technology is far from commercialization
- Little potential outside Brazil, US, and a few other places

#3: Biofuels will be used in many regions, but will probably not dominate anywhere (except maybe Brazil)

Plug-in hybrids

Gaining popularity (in US) because…

- Seems easy to implement (to some)
- Large energy/environmental improvements are possible
- Attractive to electric utilities

BUT …

- High vehicle/battery cost -- because of need for larger, heavier, more durable batteries than gasoline HEVs (to handle deep-discharges)
- Automakers skeptical due to battery challenges and need for changes in consumer behavior (plugging in)
- No business model for oil industry
- It took gasoline hybrids 6 years to get to 1.5% in US; Plug-in hybrids will be much slower due to cost, recharging

#4. Time Frame for Cellulosic Biofuels and Plug-in Hybrids is About Same as for H2

- H2/FCVs have many obstacles but are championed by (some) automakers
- Plug-in hybrids do not have industrial champions, have fundamentally high costs, and require behavioral changes by consumers
- Cellulosic biofuels need scientific breakthroughs in processing, do not have industrial champions, require large amounts of land, and require transformation of agricultural industries

So why are biofuels and plug-in hybrids gaining momentum in US?

- Backlash against hydrogen
  - Enviros hostile/skeptical to Bush Administration proposals (plus concerned about “black” hydrogen)
  - Jealousy by competing interests (energy efficiency, renewables) – ZERO sum game?
- Impatience with Bush Administration initiatives on energy
- Heightened concern about oil due to high gasoline prices, Middle East tension, and increasing concerns about global warming – “need to do something now”
- Popular perception that plug-in hybrids and cellulosic ethanol are easy to implement and ready to commercialize
- Farm lobby exploiting economic and political opportunity
- Alliance of farm, enviro, and national security interests

FCVs (and other EVs) are superior to biofuels and ICEs in many important ways

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

#5: Key choice is between electricity and H2. Victory between BEVs/PHEVs and FCVs will depend upon…

- Consumer preference (image of H2, range, etc)
- Improvements in batteries
- Improvements in fuel cell costs (and durability) and on-board H2 storage
- Enthusiasm (and timing) of oil companies in building H2 infrastructure
- Enthusiasm of automakers for fuel cells

In the end, both are likely to thrive, with BEVs used for smaller and lower performance vehicles.

#1. Under almost any scenario, vehicle use will increase

#2. Momentum is toward unconventional fossil fuels; thus, aggressive efforts will be needed to shift toward clean fuels.

#3. Biofuels will succeed in many regions, but will probably not dominate anywhere (except maybe Brazil)

#4. Time frame for cellulosic biofuels and plug-in hybrids is about same as for H2

#5: Key choice is between electricity and H2. Uncertain which will dominate. My personal judgment is that both will thrive, with BEVs used for smaller and lower performance vehicles, and hydrogen fuel cells for other applications

Thank You

Merci