SUSTAINABLE TRANSPORTATION ENERGY PATHWAYS
INSTITUTE OF TRANSPORTATION STUDIES

# Envisioning Sustainable Transportation Systems: Near and Long Term Options


## Prof. Joan Ogden*

### University of California, Davis


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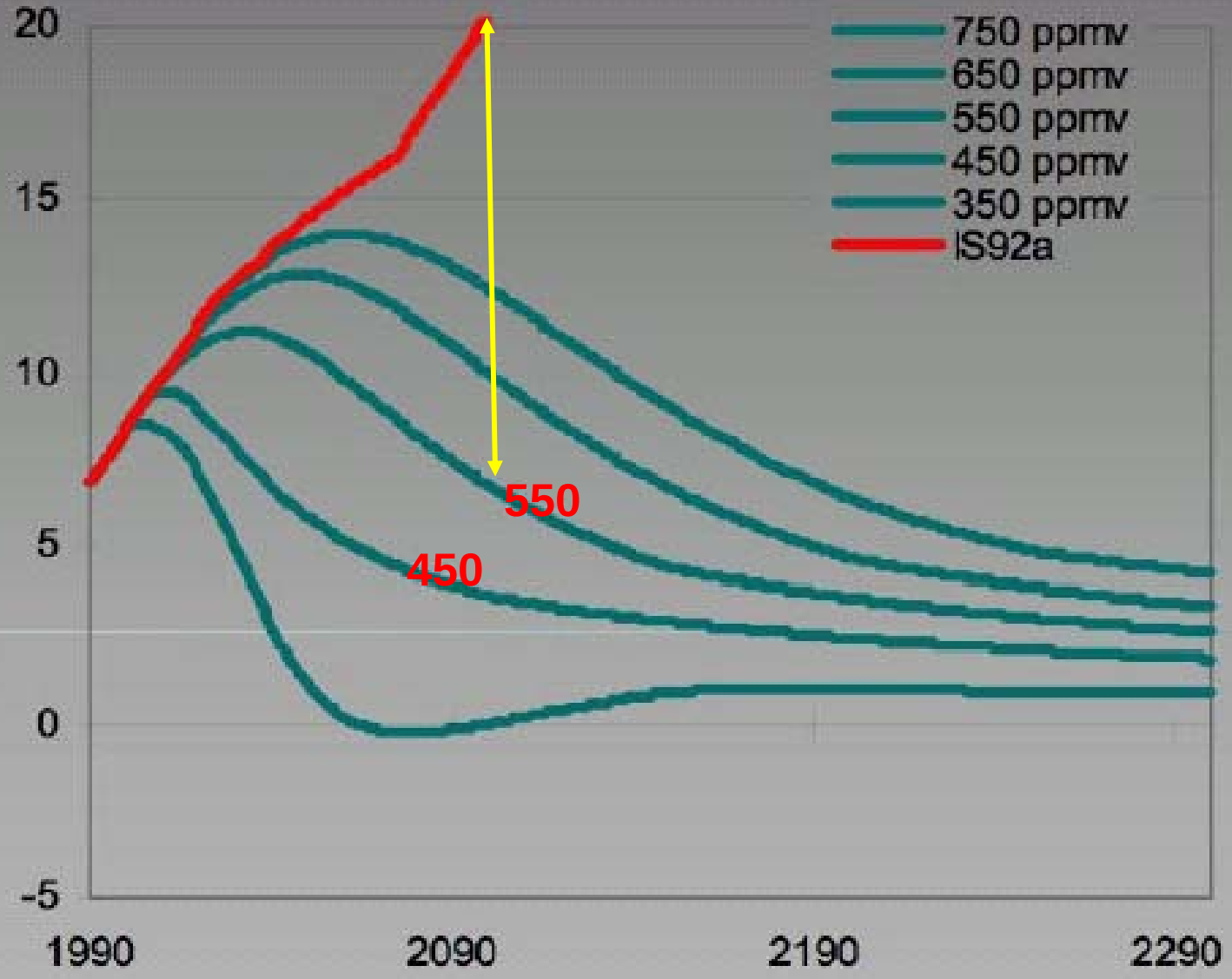
***With contributions from Dan Sperling and Anthony Eggert, UC Davis**

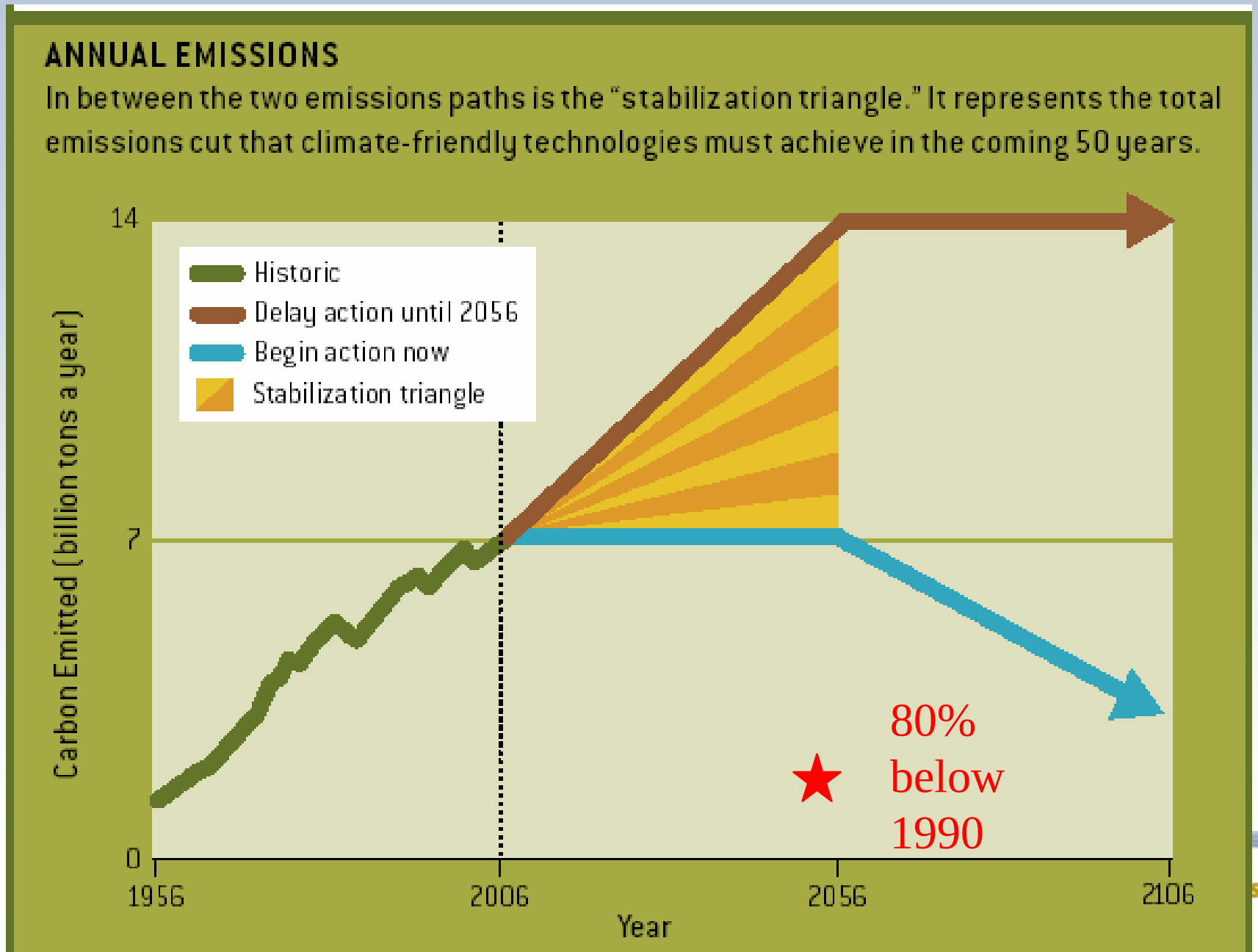
# FUEL SECTOR IS IMPORTANT

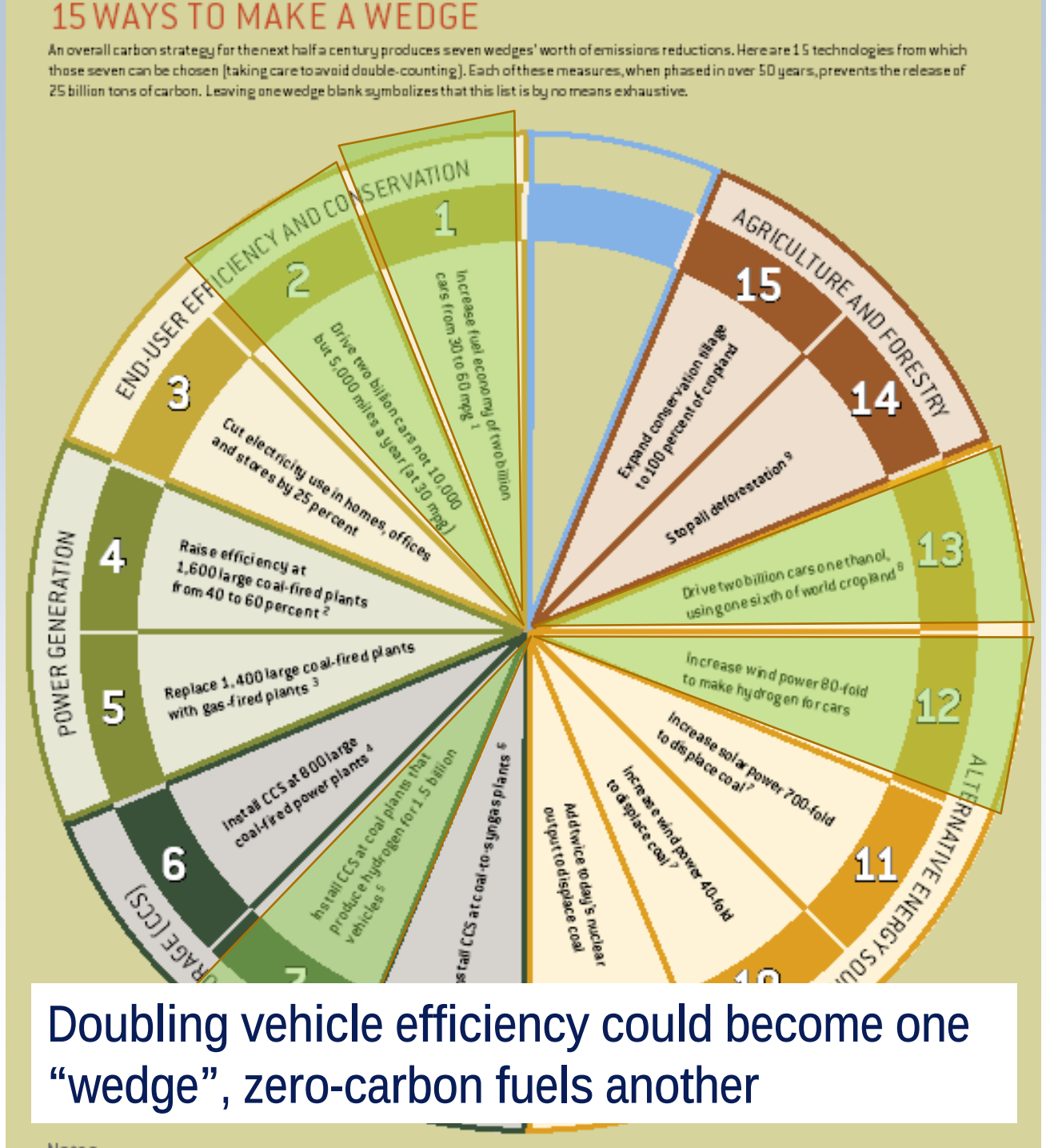
- Direct combustion of fuels for transportation and heating accounts for about 2/3 of primary energy use and GHG emissions, and a large fraction of air pollutant emissions.
- The world transportation sector is 97% dependent on oil.
- # vehicles projected to triple worldwide by 2050
- In CA, ~40% of GHG emissions are from transportation

# Emissions Trajectories Consistent With Various Atmospheric CO2 Concentration Ceilings



# STABILIZATION WEDGES

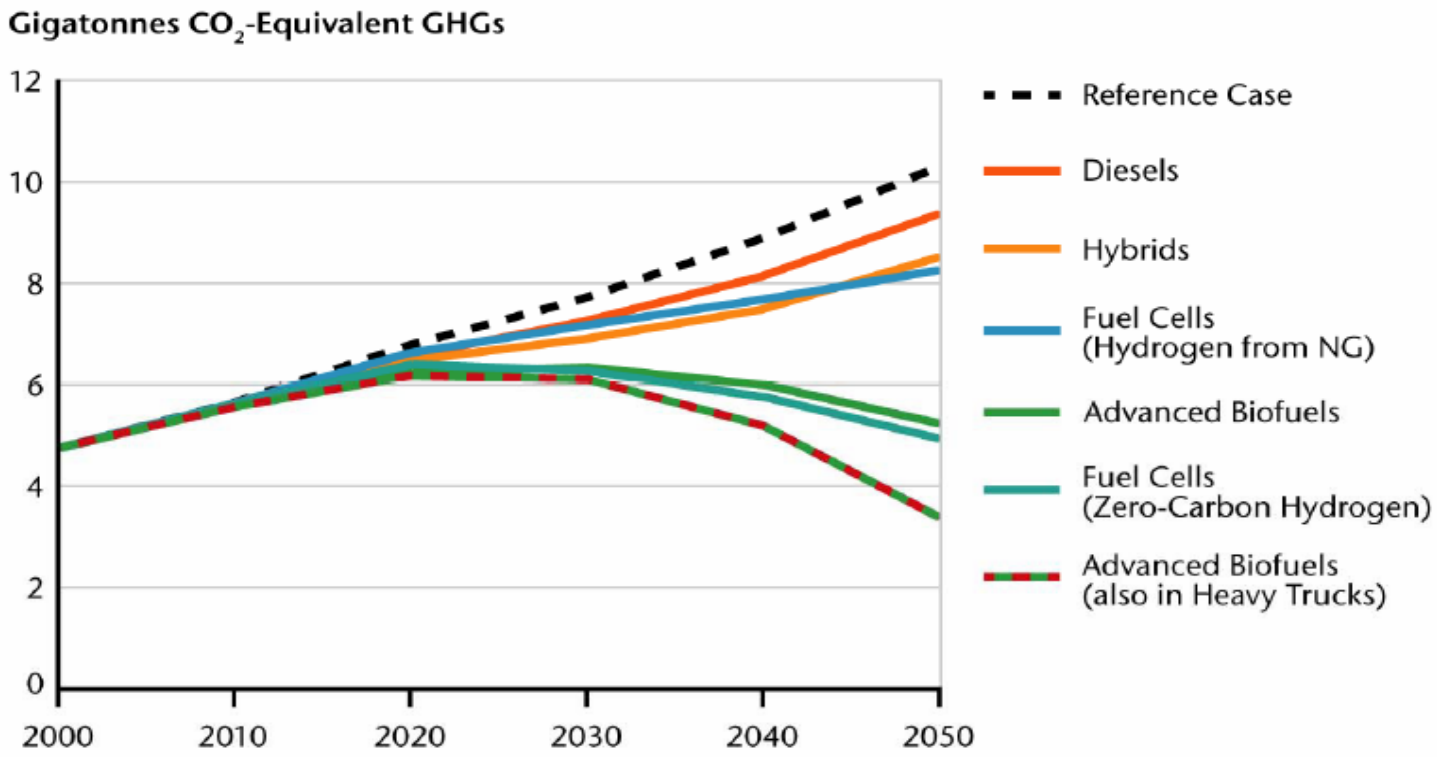





Doubling vehicle efficiency could become one "wedge", zero-carbon fuels another

# WHAT IS THE POTENTIAL?

## Hypothetical potential of individual technologies to lower road transport Well-To-Wheels CO2 emissions




Note:
The cases represent very high hypothetical levels of technology penetrations, thus they cannot be added together.

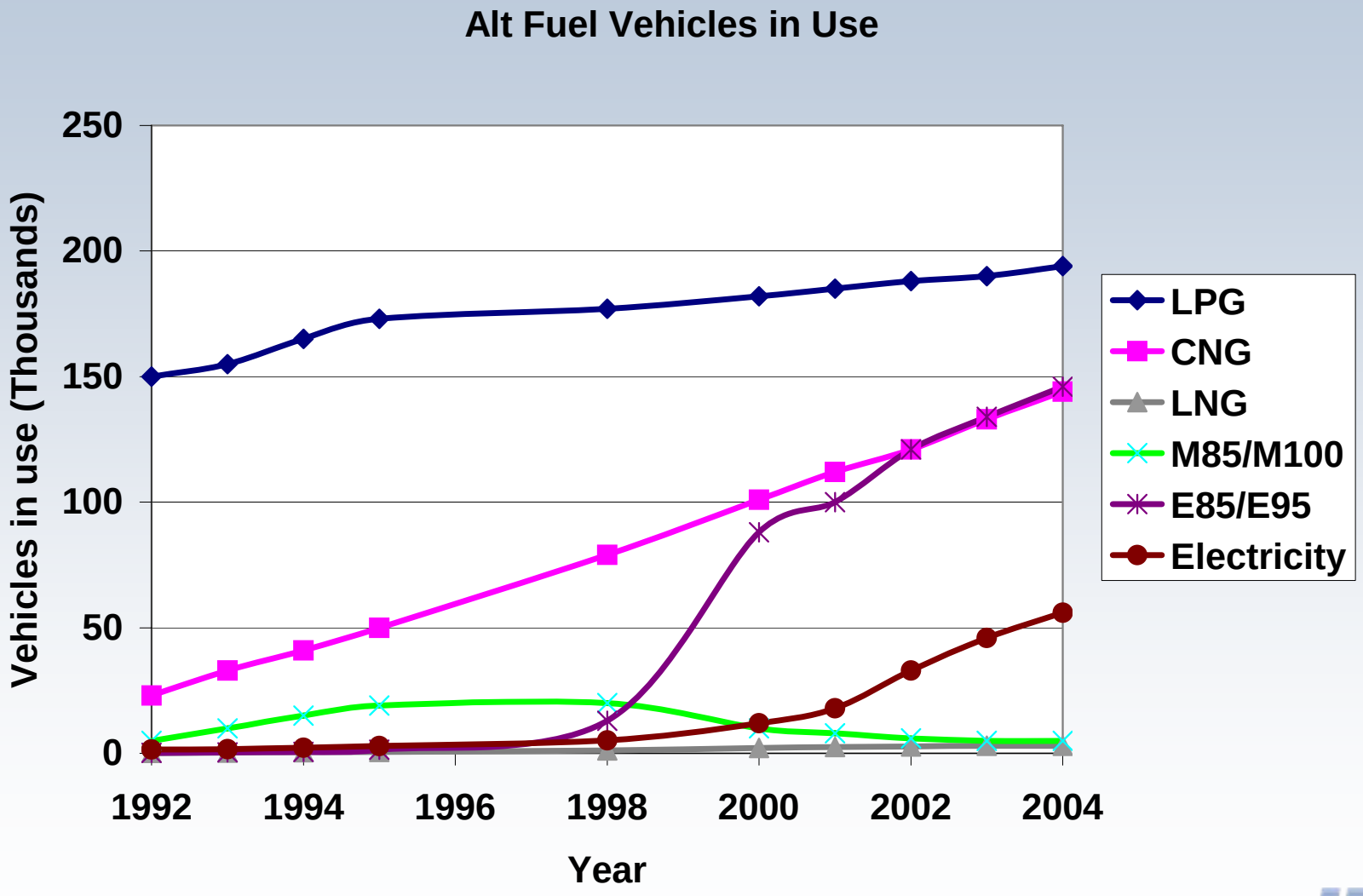
*Source: WBCSD, Mobility 2030: Meeting the challenges to sustainability. 2004*

# THE CHALLENGE OF LOW-C

- **"*Even if implemented worldwide*, diesels and hybrid ICE's fueled with conventional gasoline and diesel fuel, or fuel cells fueled by natural gas-derived hydrogen, can no more than <u>SLOW THE GROWTH</u> in road transport CO2 emissions [AND HYDROCARBON CONSUMPTION] during the period 2000-2050. Only the use of carbon-neutral hydrogen in fuel cells and/or advanced biofuels in ICE-powered vehicles can largely or totally offset the growth in CO2 emissions produced by the growth in road travel during the period 2000-2050." *Mobility 2030*, p. 114**

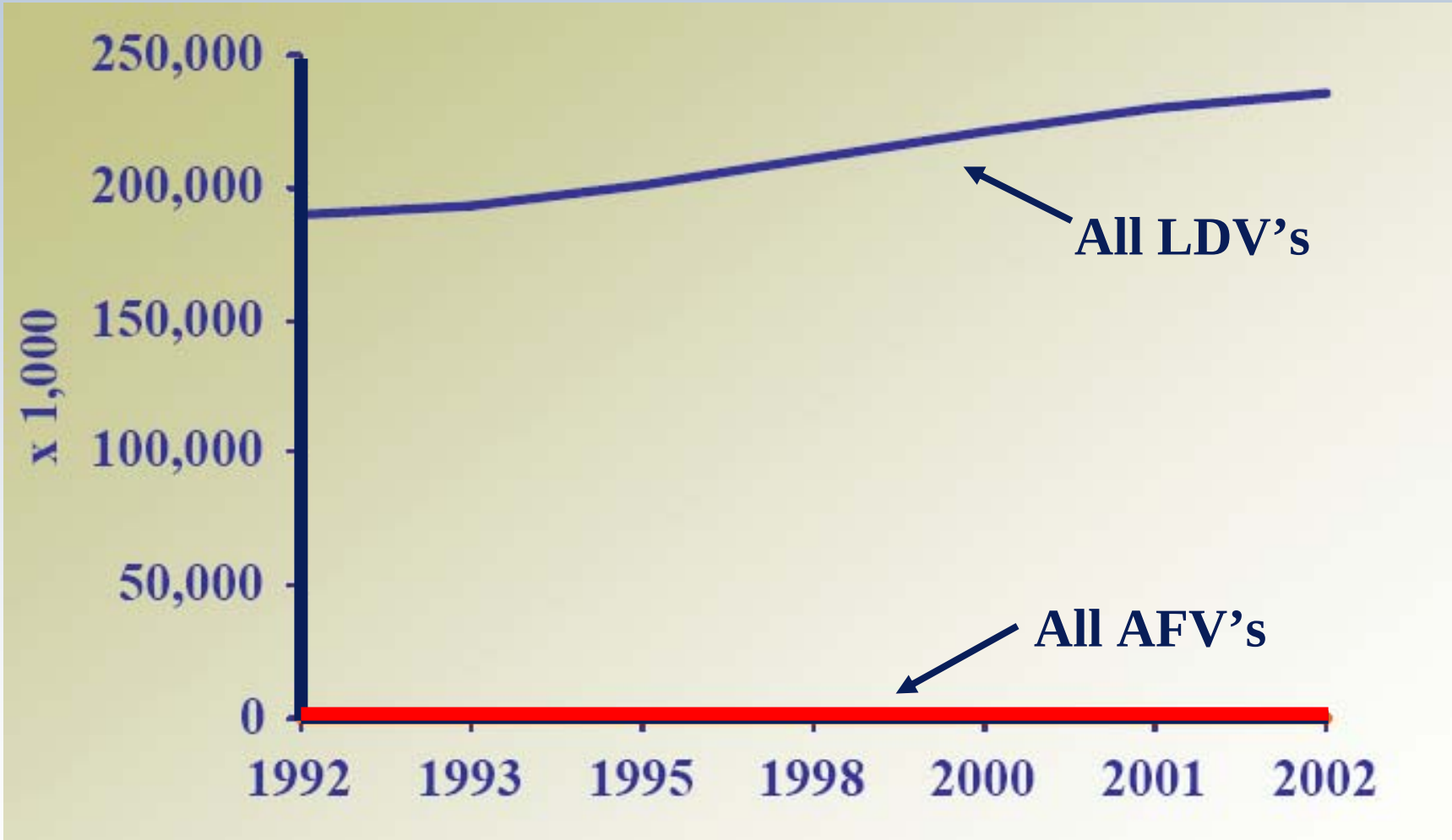
**[Note: Capitalization added for emphasis. Items in [brackets] added by A. Eggert.]**

# History of alternative fuel vehicles (US)




References: Davis, Transportation Energy Data Book (2004)

# History of alternative fuel vehicles (US)




**Will the future be different?**

# Dynamic New Context for Alternative Fuels

- Continuing tech progress in variety of alt fuel and vehicle technologies
- Growing imperative for alternative fuels
  - Oil supply security
  - Climate Change
- Search for "silver bullet" by politicians
- In 2003 $H_2$ was widely seen as the "end-game"
  - Now, recognition it will take time. (FCV commercialization c. 2012-2020; decades for full transition)
- Now several options are widely discussed as "nearer term" and/or more compatible w/ existing energy system.
  - Biofuels
  - Plug-in Hybrid vehicles
- Innovative Policy Landscape

Perspectives from National Academies *Hydrogen Economy* Study

# $H_2$ vehicles could radically reduce oil use

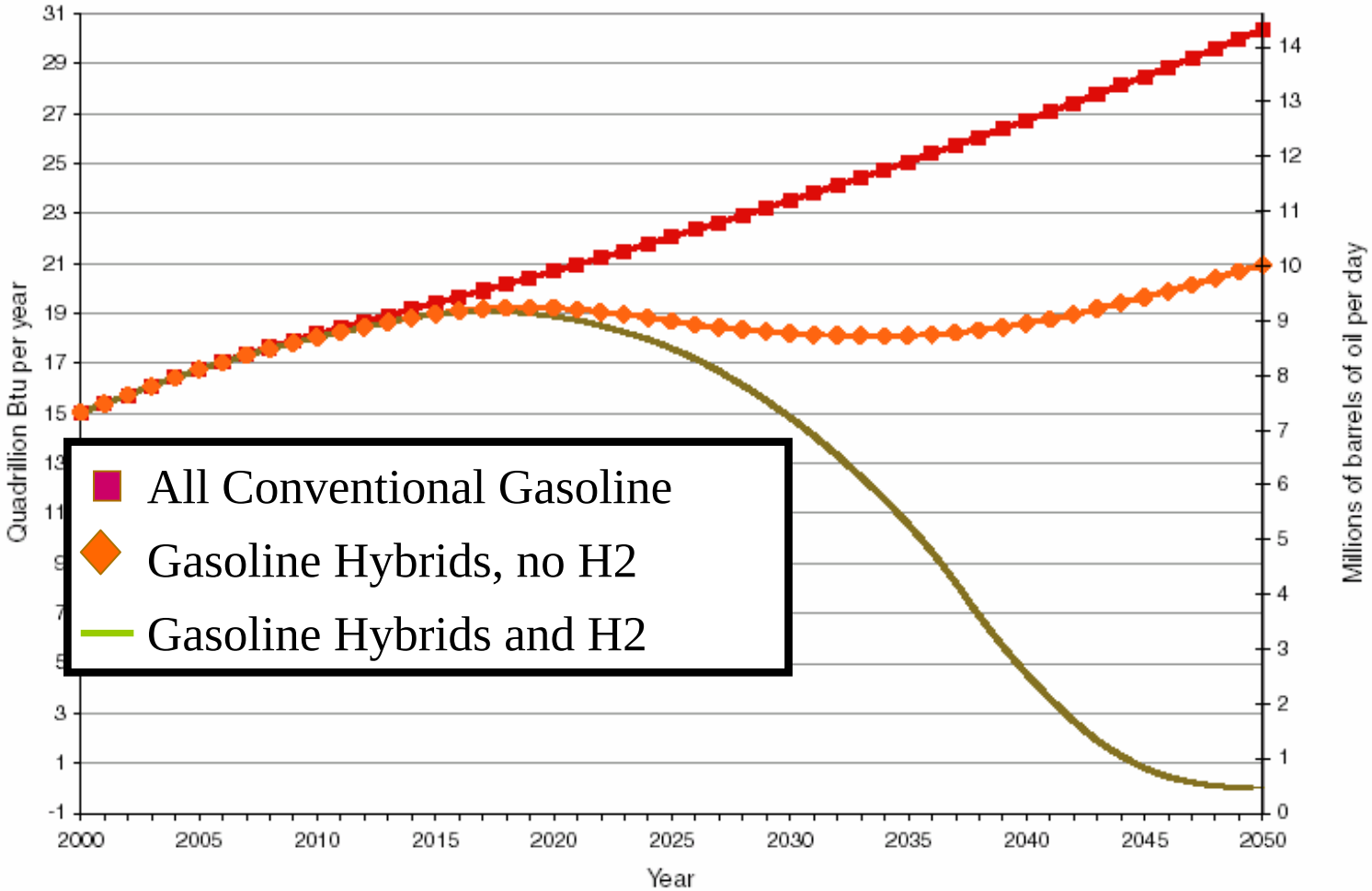



FIGURE 6-4 Gasoline use by light-duty vehicles with or without hybrid and hydrogen vehicles, 2000–2050, based on the optimistic vision of the committee.

# and well-to-wheel GHG emissions from vehicles

## depending on the $H_2$ supply pathway

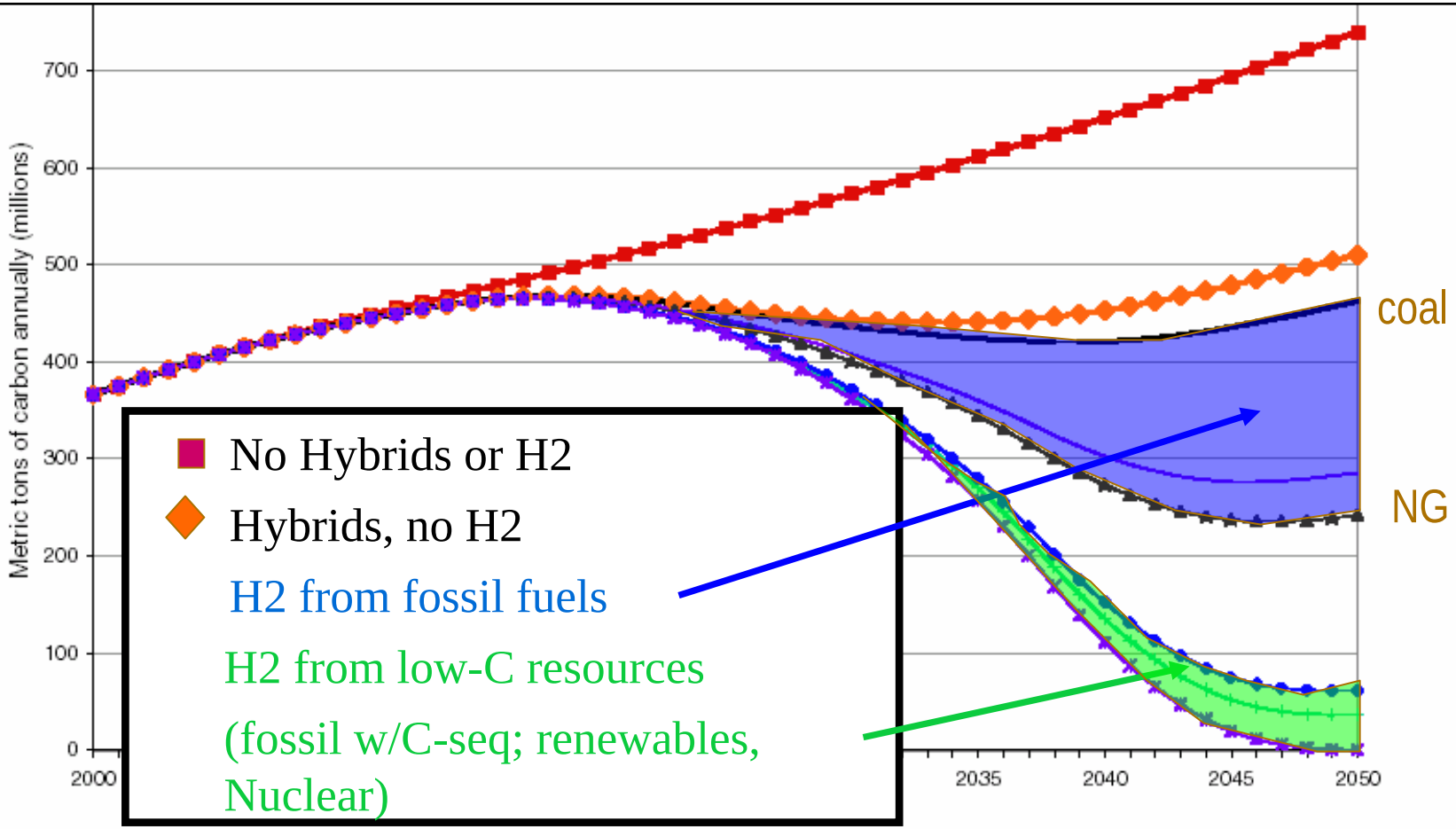
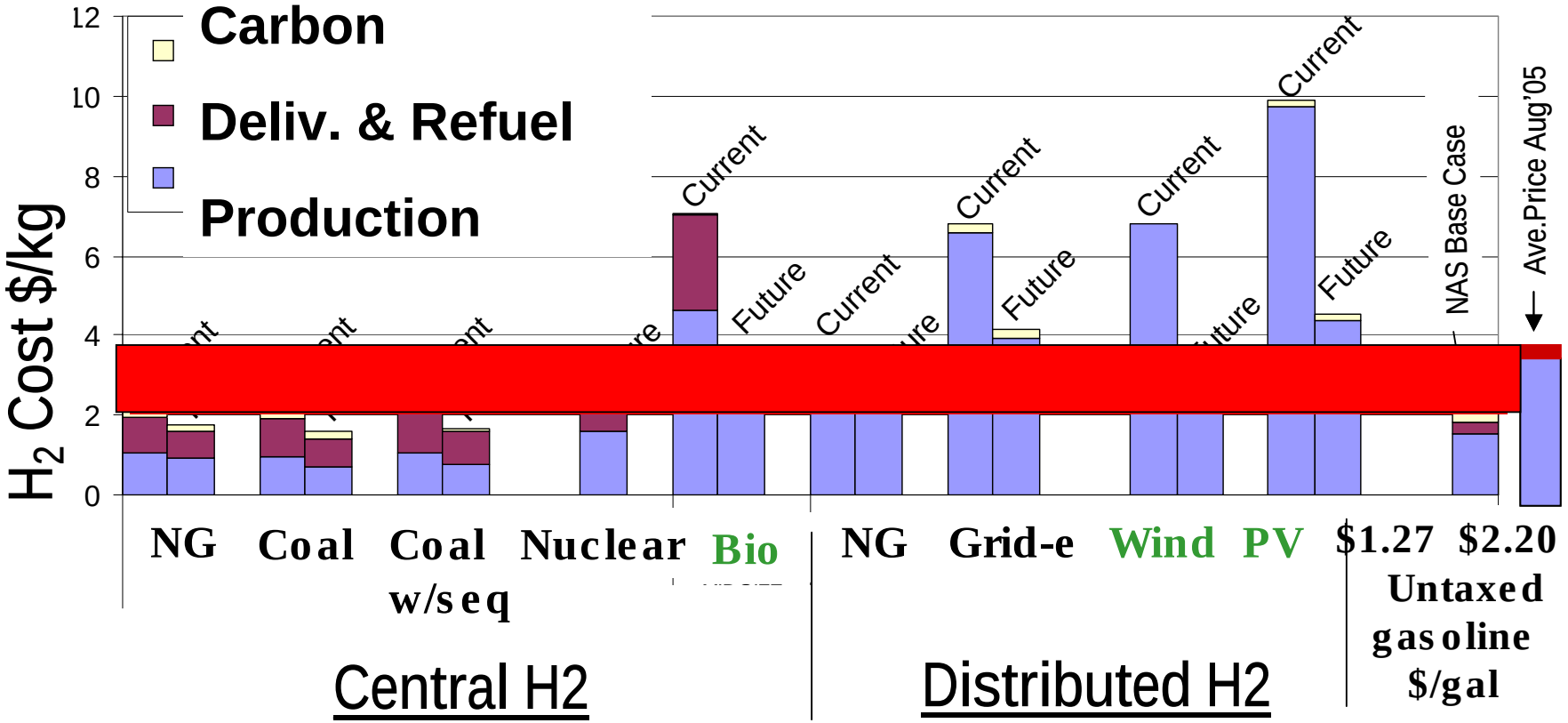



FIGURE 6-8 Estimated volume of carbon releases from passenger cars and light-duty trucks: possible future hydrogen production technologies (fossil fuels and nuclear energy), 2000–2050. See Table 5-2 in Chapter 5 and discussion in text.

# At fuel cost/km competitive w/gasoline (long term, large scale)

## DELIVERED $H_2$ COSTS
### W/CURRENT AND FUTURE TECH




Gasoline
scaled by hybrid fuel economy

Source: http://books.nap.edu/books/0309091632/html/53.html

# Barriers to $H_2$ in Transportation

TECHNOLOGY

- $H_2$ storage on vehicles
- Fuel Cells (cost, lifetime)
- Zero-Carbon $H_2$ production

LOGISTICS

- Current lack of a $H_2$ infrastructure to fuel vehicles
- “Chicken & Egg Problem

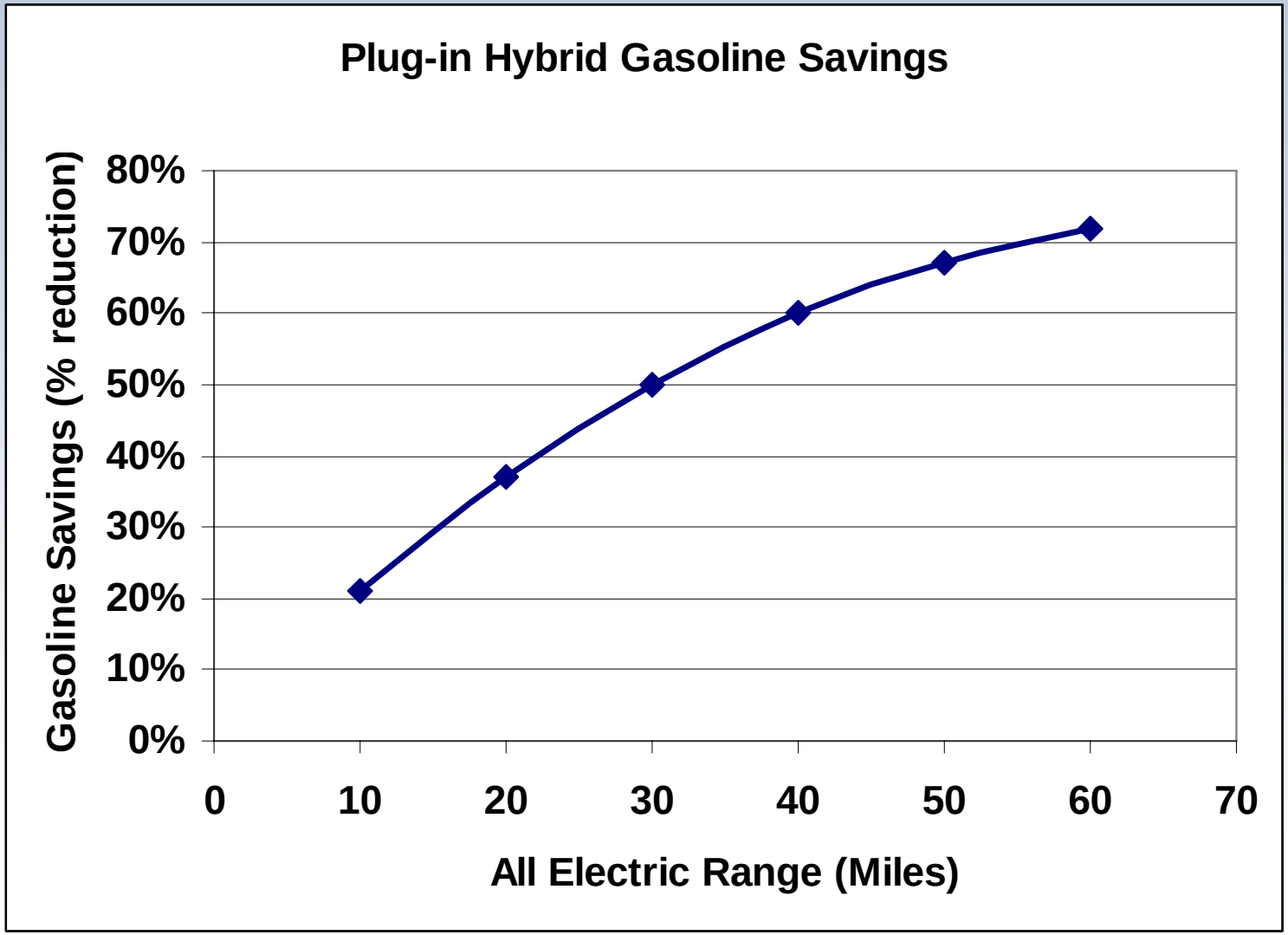
# H2 transition => Multiple transitions

- Vehicle technology
- Supply infrastructure
- New, low carbon primary supply

Some first steps of these transitions are underway (though not exclusively tied to H2)

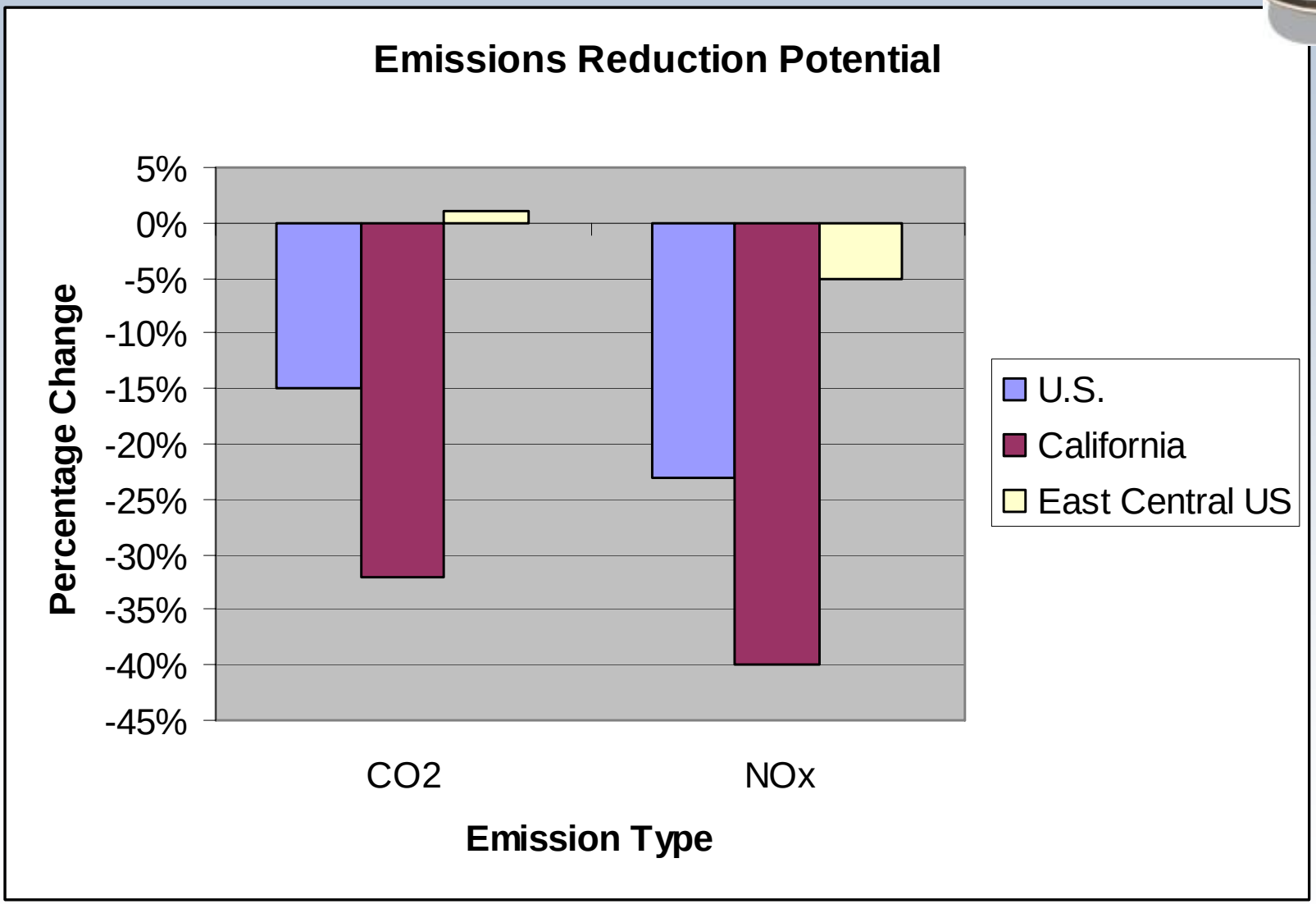
- Need for durable commitments (> 15-20 years)
  - Policy makers: Address Climate change and oil security
  - Consumers: To buy based on green, high-tech values now captured by gasoline hybrids (and in future by H2 and/or FCVs?)
  - Automakers: To mass produce H2 vehicles
  - Energy suppliers: To build H2 infrastructure
- This will time  and some real $ (to cross “valley of death”)
- Several actors will probably have to commit together.

# Plug-in hybrids can save petroleum.



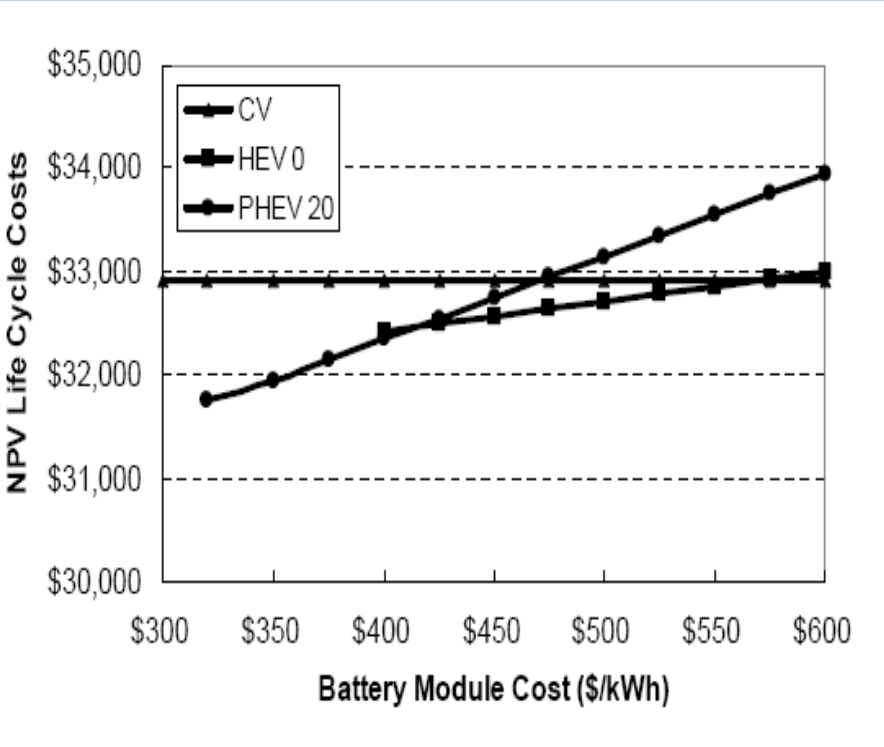

**Source: ACEE "Plug-in Hybrids: An Environmental and Economic Performance Outlook", 2006**

# …and could reduce emissions…




**Source: ACEE "Plug-in Hybrids: An Environmental and Economic Performance Outlook", 2006**

# …but battery prices still too high…



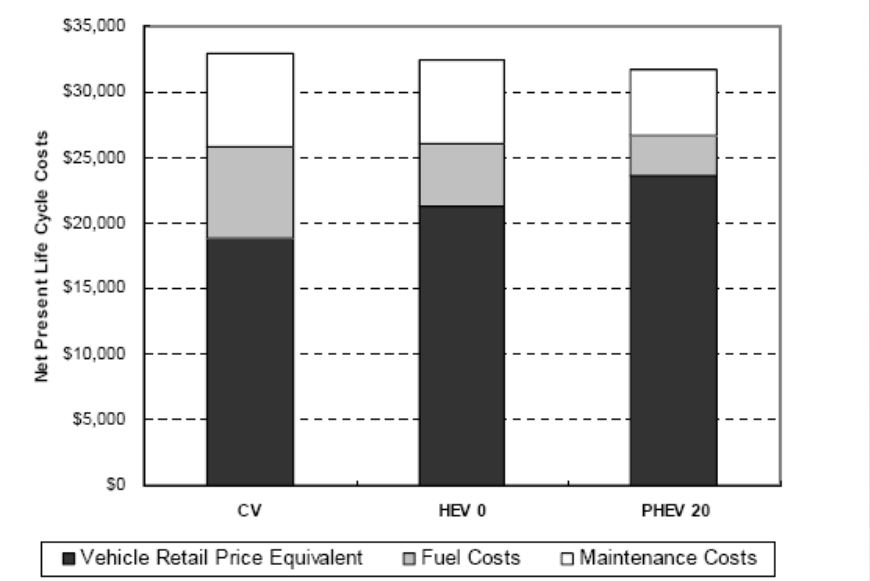




**Figure 1-1**
**Net Present Value of Full Life Cycle costs for Mid-size Sedans**

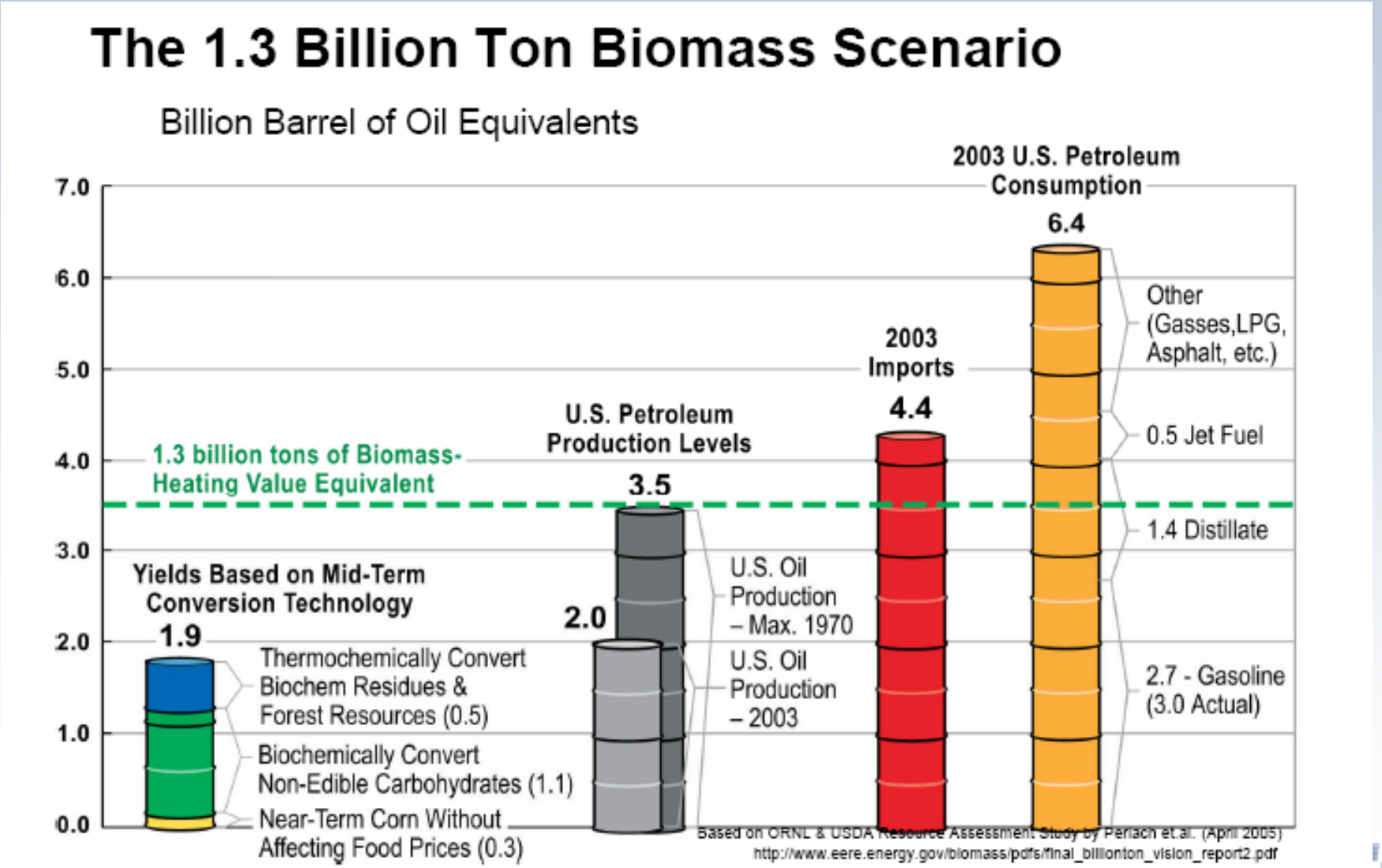
***Key Assumptions: 10 year/150K mileage, 8% discount***
***Battery cost = $400/kwh for HEV, $320/kwh for PHEV20***

**Source: EPRI, Advanced Batteries for Electric Drive Vehicles (2004) [mid-size car NiHM, $1.75 gasoline, $0.05 off-peak electricity rates, 10 year/150K]**

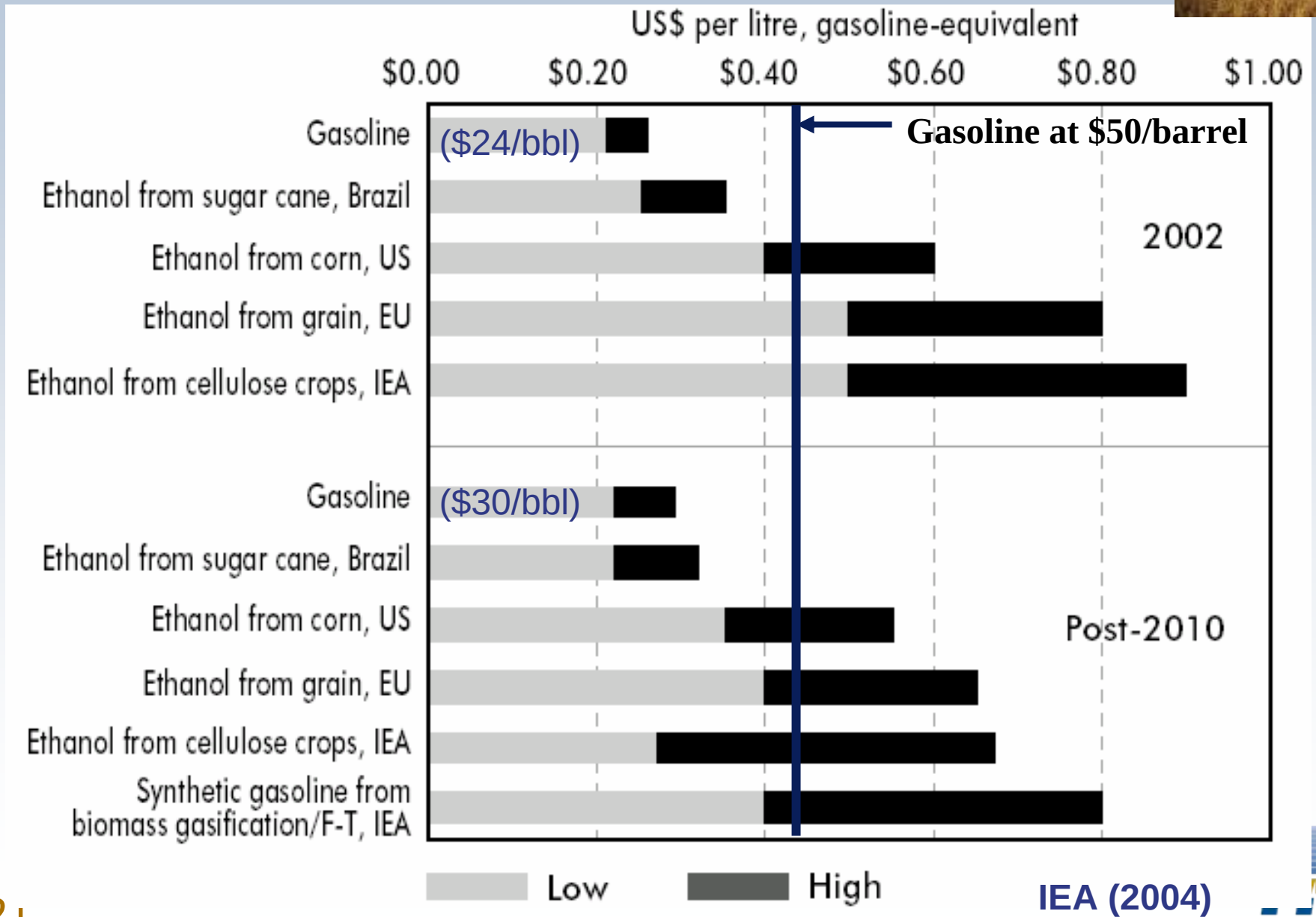
# Plug-in hybrids: Conclusions

- **Gaining popular attention as easy option to get large, quick energy/enviro improvements.**
- **Good News for Plug-in's**
  - **Plug-in hybrids could substantially reduce petroleum consumption and shift transportation energy to the stationary power sector.**
  - **Potentially low GHG emissions, replace oil imports,**
  - **Positive consumer attributes, utilities favorable**
- **Uncertain and Limiting Factors**
  - **Requires widespread installation of chargers**
  - **Battery costs will have to be reduced and durability improved**
    Requires larger, heavier, more durable (to handle deep-discharge) batteries than gasoline HEVs, with much higher vehicle/battery cost
  - **Initial cost of PHEV (purchase cost) will be significant**
  - **Automakers only recently getting involved**
  - **Business model for oil industry (?)**

# “Maximum” US Biofuels Supply is Large

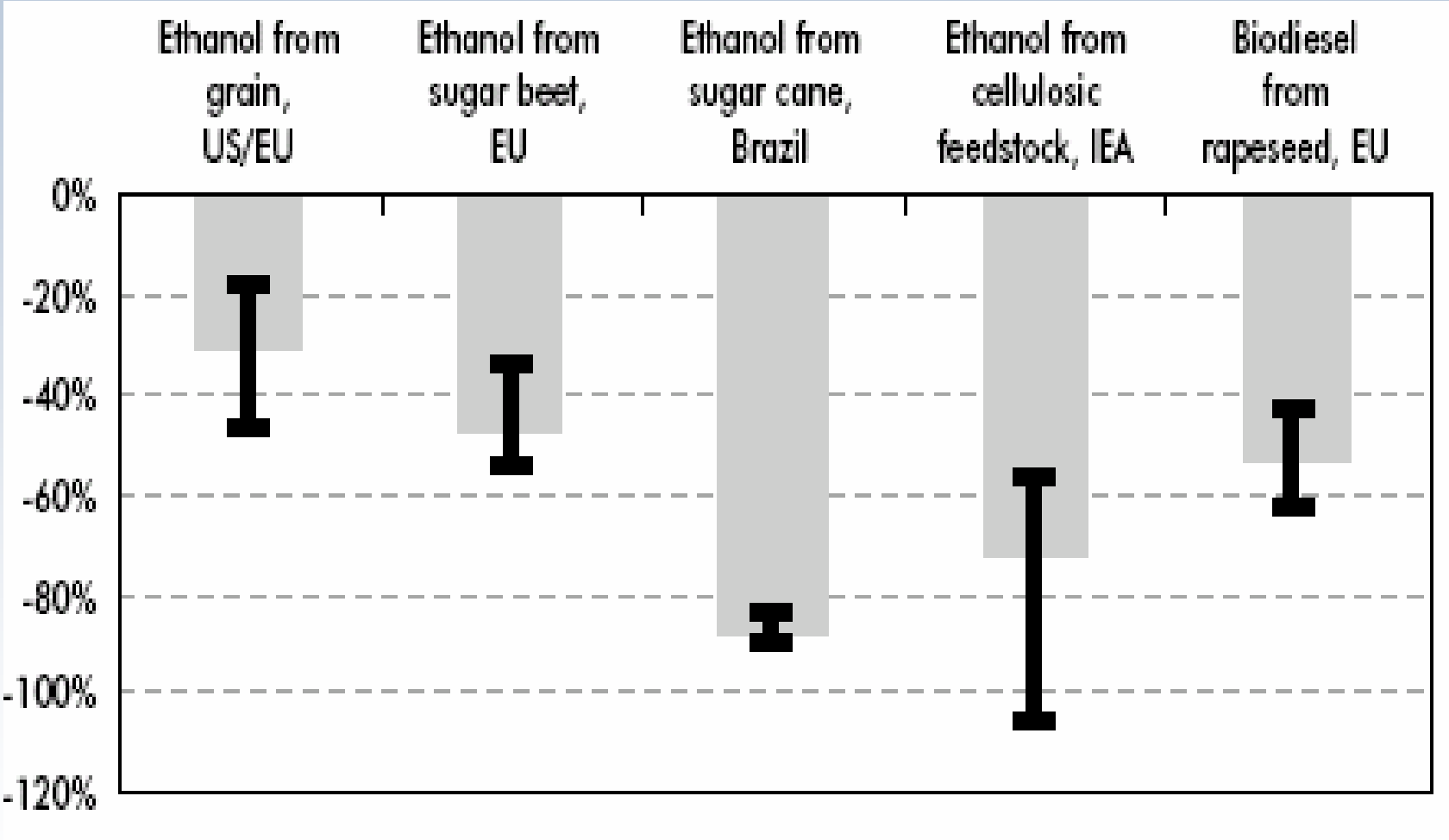


# … at (reasonably) competitive prices…




IEA (2004)

# … with significant GHG benefits…




**Lifecycle GHG emissions, compared to gasoline from petroleum. Black bars indicate range of estimates. From IEA (2004).**

# Liquid Bio-fuels: Conclusions

- Biofuels could potentially replace substantial amounts (10-30%) of petroleum consumption in US and UK (and Brazil and a few other regions)
- Good News for Biofuels
  - Low GHG emissions, replace oil imports, stimulate agricultural and silvicultural industries
  - Minimal changes in vehicles required
  - Corn-etoh competitive with oil at ~$40/bbl
  - Cellulosic ethanol has large energy/enviro benefits, and large production potential (~30% of gasoline),
  - Strong support from politically potent alliance between enviros, farm interests, and those concerned with national security
- Uncertain and Limiting Factors
  - Biodiesel is very expensive, except from recycled oils
  - Corn Ethanol has limited supply potential (<5% of gasoline) and minimal energy/enviro benefits
  - Cellulosic fuel costs still uncertain
  - Requires entirely new businesses for farming, harvesting, processing, and delivering fuel, and large investments
  - Production is limited by scale issues (feedstock collection, co-products, distribution)
  - Potentially significant environmental impacts (and food vs energy)

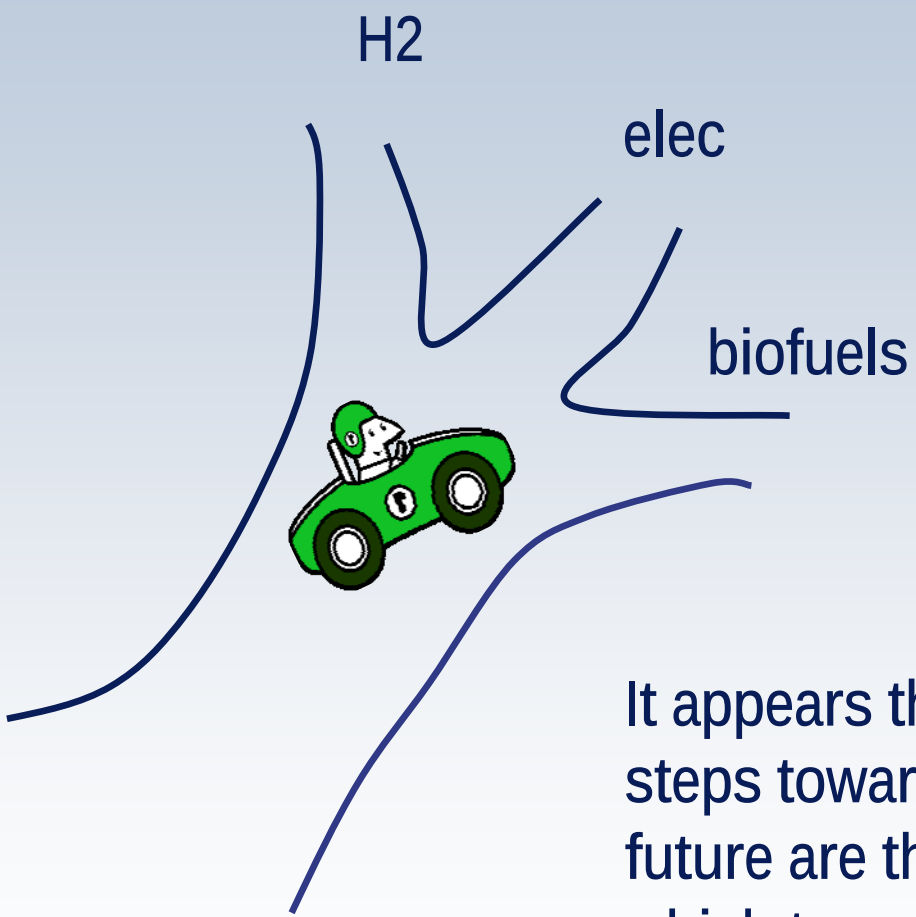
# There will be “Time constants” and “Rate Limiting Steps” in transition to any new fuel

- Tech and cost issues for key technologies
  - Fuel cells
  - Advanced batteries
  - Low-C fuel conversion pathways (biofuels, CCS)
- Market adoption of vehicle innovations
  - Historically, 25-60 years from R&D to >35% of fleet
- Building new transportation infrastructure
  - Historically, 30-70 years
- Policy driving major change ($\geq$15 years?)
- Resource, land and water use

# Conclusions

- All strategies to reduce transportation oil use and GHGs face major challenges.
- Improved efficiency (and fuel economy) are crucial, but not enough to meet long term goals for deep reductions in GHG and oil use.
- No silver bullet. Several promising non-petroleum, low-carbon alternatives:
  - Biofuels
  - Electricity (PHEVs and BEVs)
  - Hydrogen
- Transitions take a LONG time
- Unclear whether one transportation fuel eventually dominates… Mix of fuels? Regional differences?
- Policy and business leadership is key; ultimately, the customer will determine winners

# Choices on the road forward




From the Op-Ed pages it sometimes seems that society has to make a choice right now

But, technology paths and interactions are uncertain. It's still too early in the process of innovation to pick winners.

It appears that some of the first steps toward a low carbon energy future are the same no matter which transportation fuels we ultimately use. Synergy may be as likely as competition.