Institute of Transportation Studies
University of California, Davis

Marketable Emission Permits and Hydrogen Fuel Cell Vehicles

GWIC 2005
April 19-21, 2005

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Hydrogen Pathways Program

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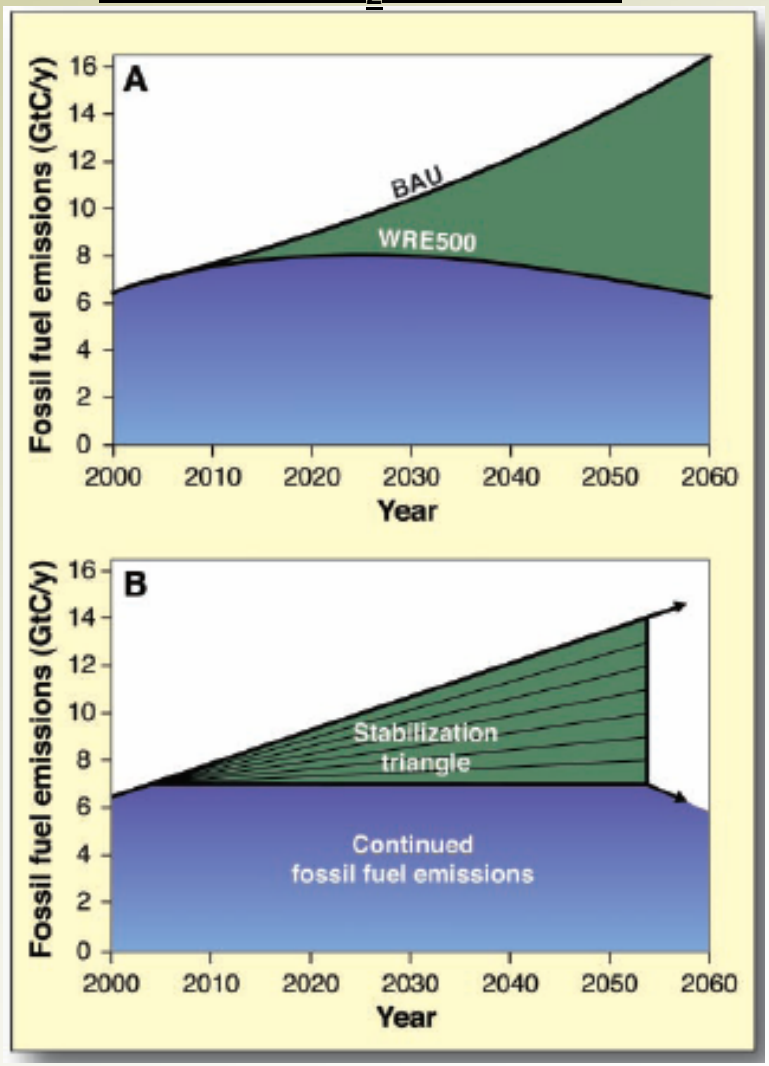
Climate Stabilization: Many Sectors

Global C (CO_2) Emissions



Pacala and Socolow:

- Target: Less than twice pre-industrial level or 500-600ppm
- Wedges represent 1GtC/year emission reductions
  - 2 billion cars 30 MPG→60 MPG
  - Add 700 GW nuclear fission (2X current capacity)
  - 2 million peak 1 MW windmills
  - Cut CO_2 emission by 25% in building and appliances (proj. 2054)

Source: Pacala, S. and R. Socolow, *Stabilization Wedges: Solving the Climate Problem for the Next 50 Years with Current Technologies.* Science, 2004. **305**: p. 968-972.

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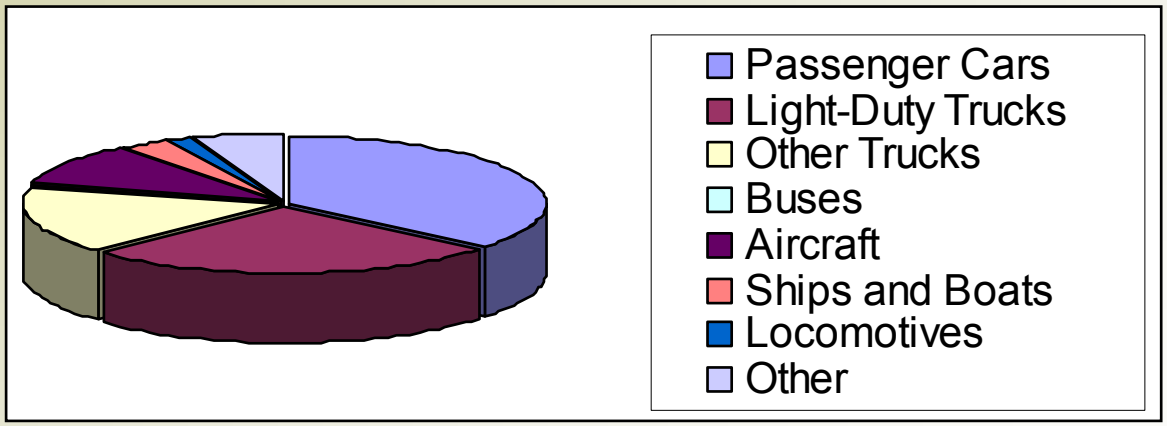
Role of Transport

Transportation-Related GHG Emissions

- IPCC Annex I Parties, 2002 transportation CO_2 emissions were 28% of total emissions up from 19.4% in 1990 (UNFCCC, 2005)
- In 2002, U.S. CO_2 emissions from transport represented ~31% of total CO_2 emissions (U.S. EPA, 2004)
- Passenger Cars and Light-Duty Trucks represented over half (36% and 26%) of 2002 U.S. transport CO_2 emissions (U.S. EPA, 2004)

U.S. Transport Sector 2002 CO_2 Emissions



Source: U.S. Environmental Protection Agency, Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990-2002, U.S. Environmental Protection Agency, Washington, DC, (2004).

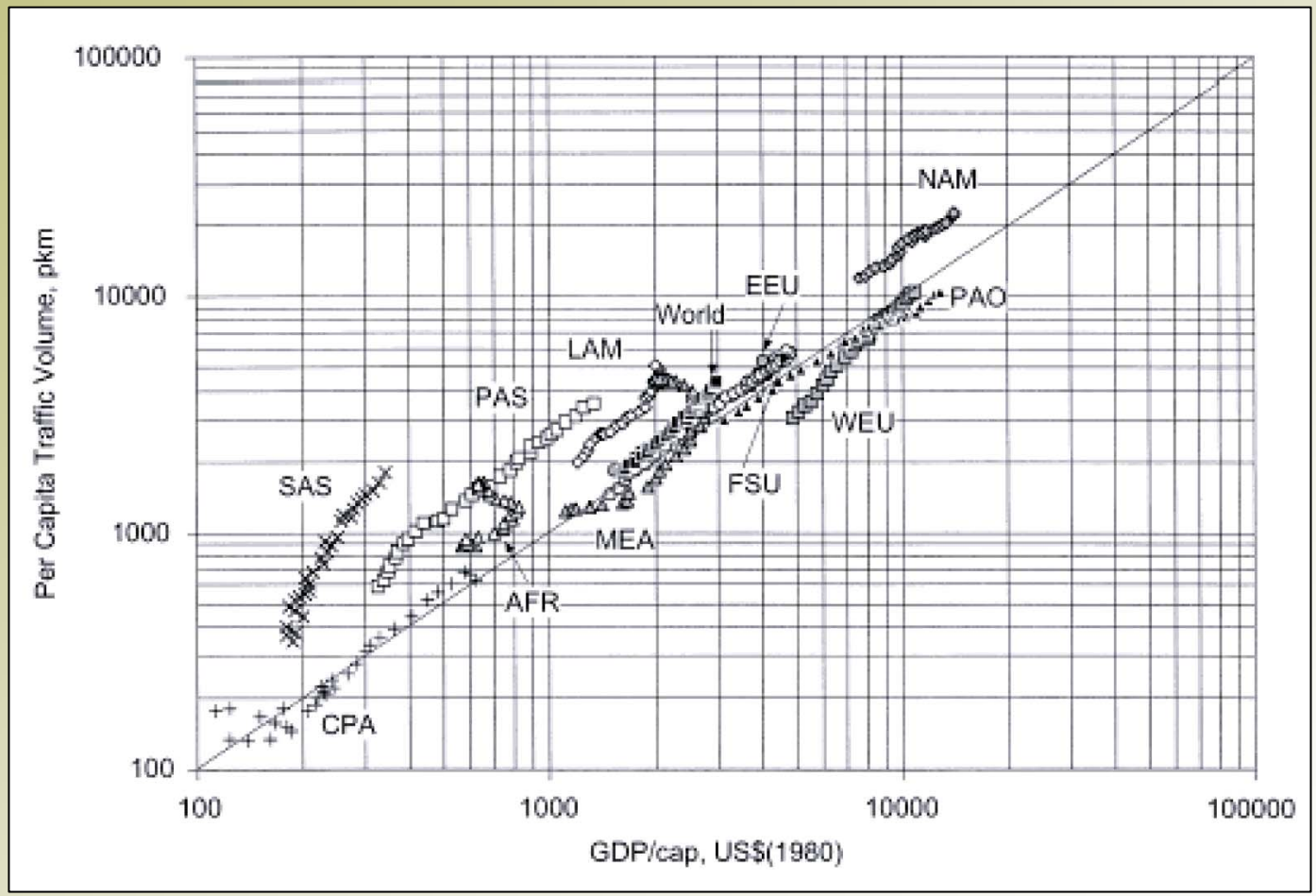
Strategies for Reducing GHG's in Transport

Many Will Likely Play a Role

- Transportation mode shifts
  - Mass transit, multimode transport, ride sharing
- Urban planning and design
  - Reducing travel distance, anti-sprawl
- Information technology
  - Telecommuting, online shopping
- **Advanced vehicle and fuel technologies**
  - **Historical trends in ↑ vehicle ownership and ↑ VMT**

The Importance of Vehicle Technology

Worldwide Motorized Mobility as a Function of GDP from 1960-1990



Automobile mode share also increased proportionally to GDP in all areas but NAM, where air travel is replacing automobile mode

Source: Schafer, A., The global demand for motorized mobility, Transportation Research Part A-Policy And Practice, 32(6), 455-477 (1998).

Advanced Vehicle Technologies

Advanced Vehicle Technologies

Near and Mid-Term Options

- Advanced internal combustion engine technologies
  - Turbo charging with engine downsizing
  - Advanced transmissions
  - Advanced valve actuation
  - Cylinder deactivation
  - 20-30% GHG emission reductions
  - Cost: $500-$2000 per vehicle
- Gasoline or diesel hybrid electric vehicles
  - 40-50% reductions in GHG emissions (cars)

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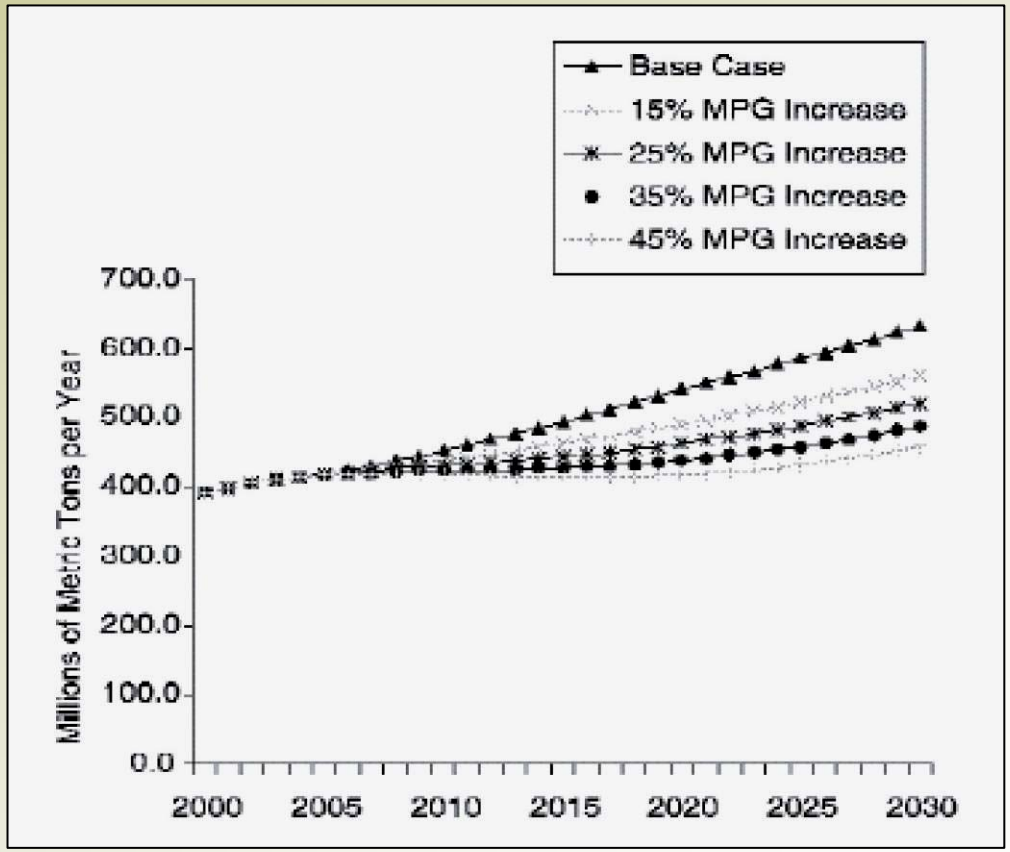
Vehicle Fuel Economy

- Significant increases in MPG are insufficient
- Long-term trend in increasing GHG emissions will increase

Passenger Car Greenhouse Gas Emissions

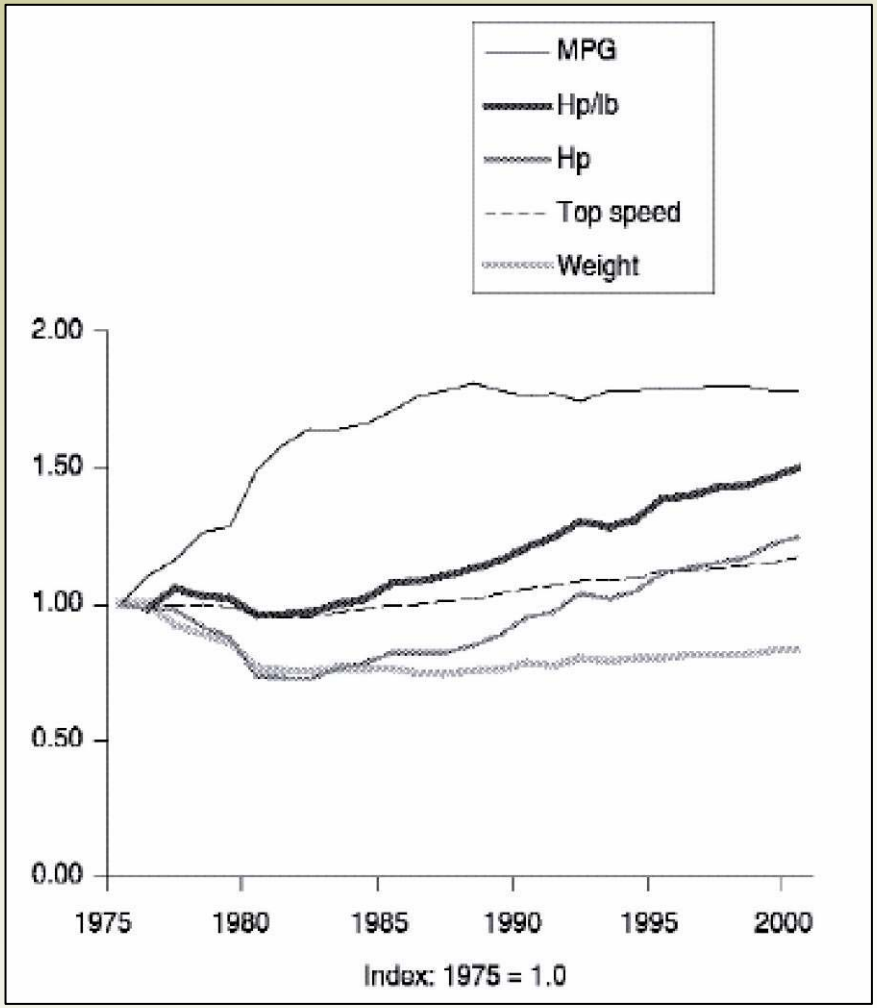


Source: National Research Council, *Effectiveness and Impact of Corporate Average Fuel Economy (CAFE) Standards*, National Academy Press, Washington, DC, (2002).

Efficiency Gains Largely Improve Performance

- CAFE highly successful in initial period of increasing standards
- Recent efficiency gains largely resulted in increased vehicle power and weight

Fuel Economy and Attributes of Passenger Cars



Source: National Research Council, *Effectiveness and Impact of Corporate Average Fuel Economy (CAFE) Standards*, National Academy Press, Washington, DC, (2002).

Advanced Vehicle and Fuel Technologies

Significant GHG Reductions Require Advanced Technology

- Worldwide motorized mobility, largely motor vehicle, expected to grow
- Large increases in MPG (45%) are unlikely to counteract VMT and vehicle ownership growth (U.S.)
- Efficiency gains (ICE's) may not translate into emissions reductions
- Need new technology

Advanced Vehicle and Fuel Technologies

Long-Term Options

- Biofuels
  - Closed carbon cycle
  - Large land and water requirements plus pesticide use and loss of habitat
- Battery electric vehicles (BEV's)
  - Good WTW emissions depending on electric grid mix
  - Vehicle range, weight and required battery charging time
- Hydrogen fuel cell vehicles
  - Many pathways which offer WTW emission reduction benefits
  - Variety of techno-economic challenges

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Hydrogen FCV's Potential

Public Benefits

- GHG emission reduction
- Criteria pollutant emission reduction
- Petroleum displacement

Private Benefits

- Vehicle design flexibility
  - Safety
  - Aesthetics/customization
- New products/features
  - Mobile electricity
  - Vehicle to grid power
- High levels of industry support

Source: General Motors Corporation

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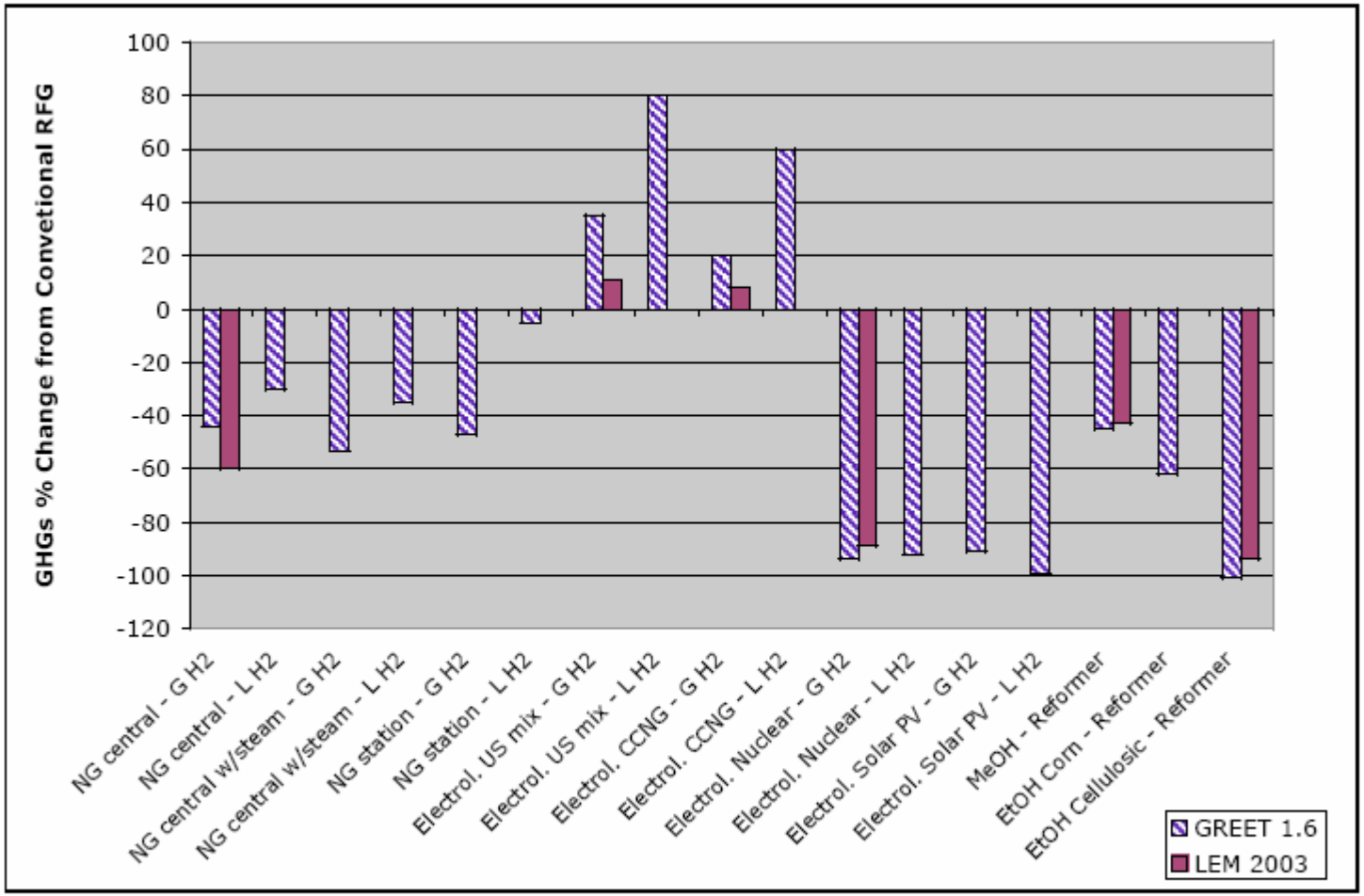
Hydrogen FCV's Potential

Figure ES-3: Relative Fuel-Cycle Greenhouse Gas Emissions of Hydrogen Fuel Pathways



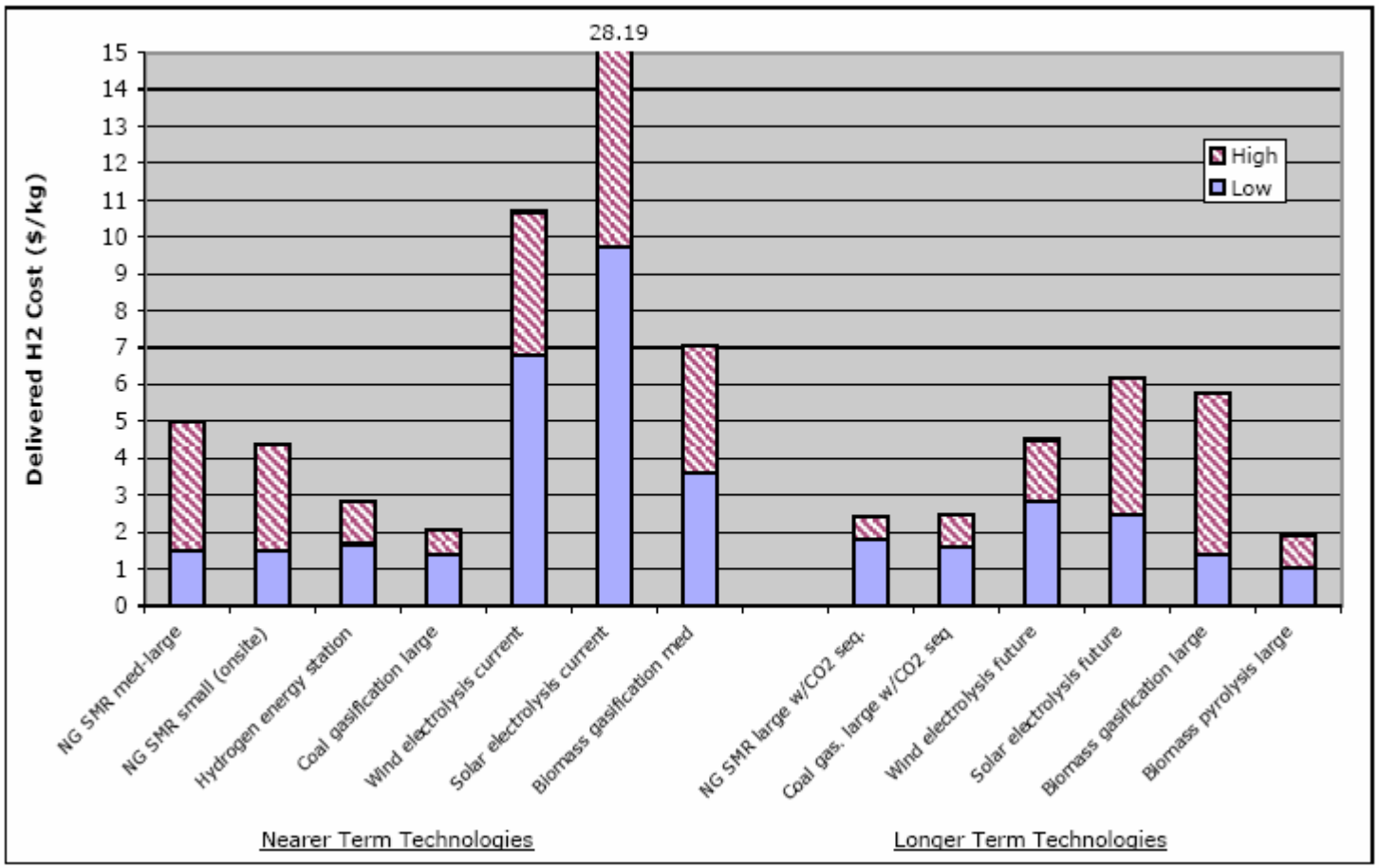
Notes: GREET 1.6 is the Greenhouse Gases, Regulated Emissions, and Energy Use in Transportation Model. LEM 2003 is the Lifecycle Emission Model. CCNG = combined cycle natural gas power plant; EtOH = ethanol; G = gaseous; L = liquid; NG = natural gas; MeOH = methanol; PV = photovoltaics; RFG = reformulated gasoline.

Source: Lipman, T. E., What Will Power the Hydrogen Economy? UCD-ITS-RR-04-10, University of California at Davis, Davis, CA, (2004).

Hydrogen FCV's Challenges

Hydrogen Pathway Costs Vary Significantly

Figure ES-2: Ranges in Delivered Hydrogen Cost Estimates



Source: Lipman, T. E., What Will Power the Hydrogen Economy? UCD-ITS-RR-04-10, University of California at Davis, Davis, CA, (2004).

Developing a Long-Term Strategy

Reducing GHG Emissions: Key Questions

1. Which technologies do we pursue and when?
   - Near, mid and long-term technologies?
   - Timing of each transition
2. If long-term option is FCV's, how do we choose the "right" pathways?
   - Transitional pathways/avoid "lock in"
   - Long-term hydrogen production options

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Role of Policy in Advanced Vehicle Technology

Policies Required to Internalize Externalities

- Cost-effective
- Foster development of new technologies
- Policy choices include: taxes, fee bates, fuel composition standards, fuel economy standards, etc.

Marketable Emission Permits

- Recognized as and efficient means of controlling pollution
- Market for abatement → encourages development of new technology
- Past examples:
  - CAAA: Leaded gasoline, SO_2
  - EU ETS (CO_2)
  - CA NO_x, NMOG (LEV II), CO_2 (AB 1493)

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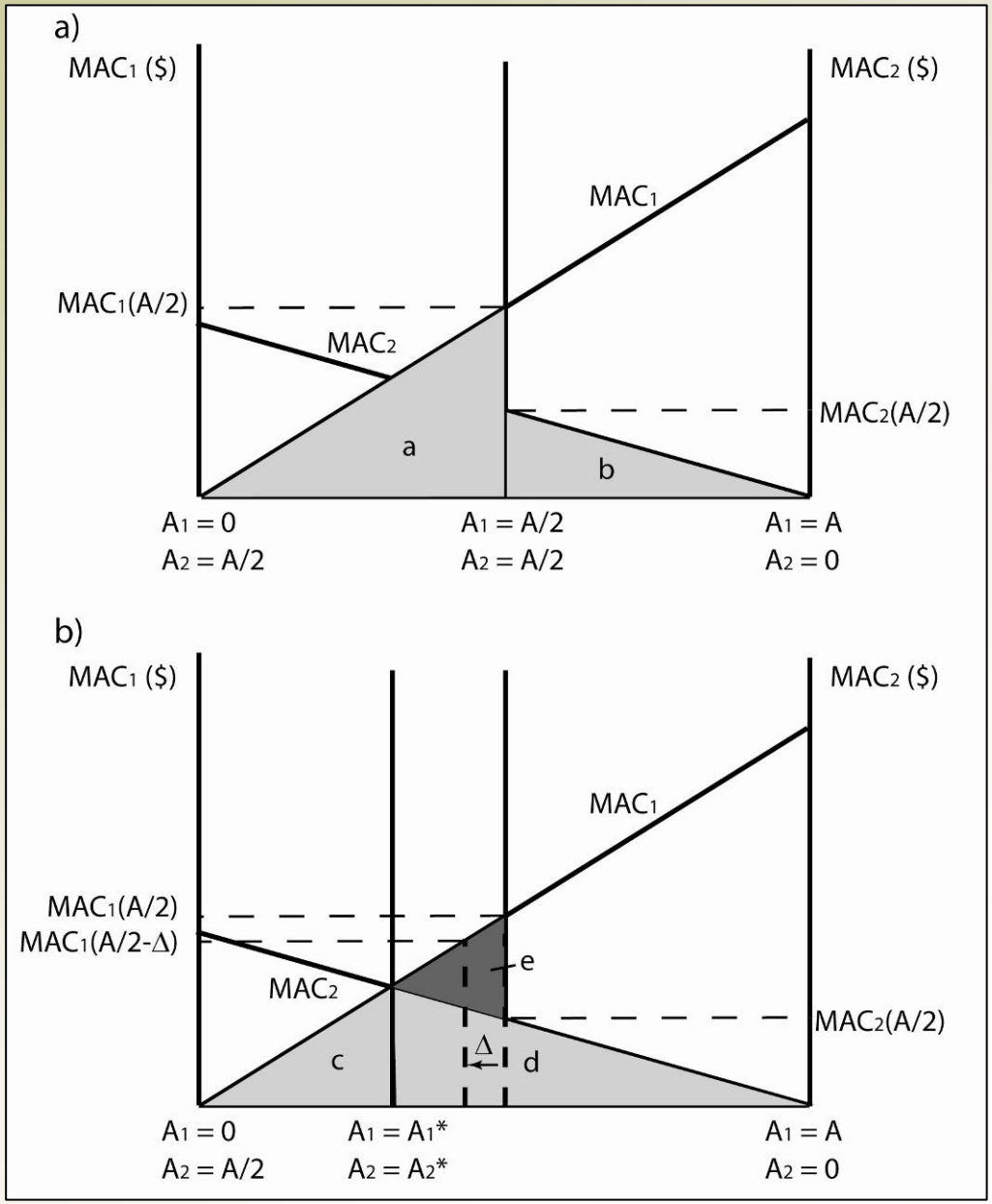
Review: Marketable Emission Permits

Marketable Emission Permits

Cost Effectiveness

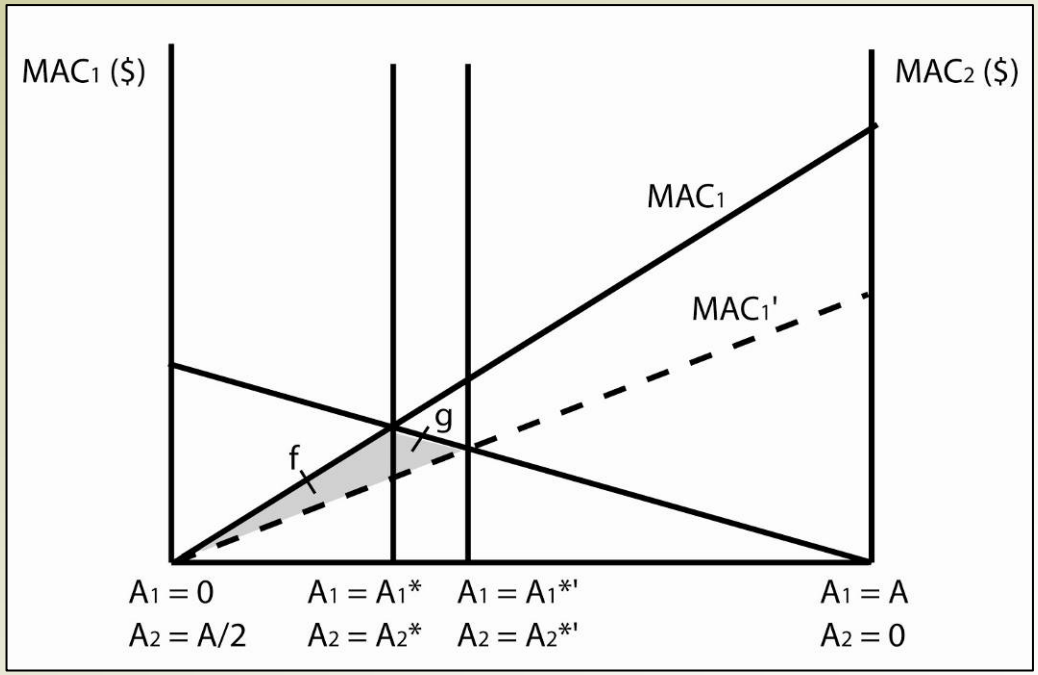
- Abatement of pollution (A) from 2 sources: A_1 and A_2
- Abatement cost characteristics: MAC_1 and MAC_2
  - a) Uniform standard (A/2)
  - b) Trading $A_1 \neq A_2$
- Cost savings (e)



Marketable Emission Permits

Technological Innovation

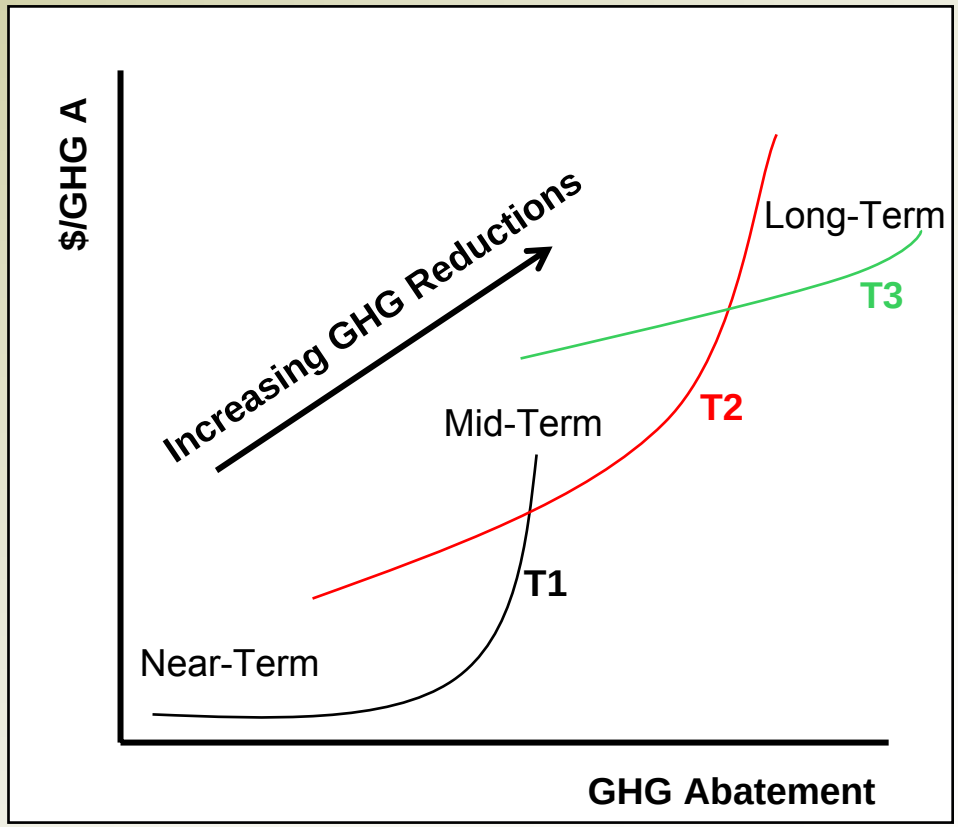
- Abatement Technologies for Source 1: MAC_1 and MAC_1'
- Incentives to adopt new technology
  - a) Cost Reduction (f)
  - b) Transfer (θg)



Which Technologies to Pursue/When

Permits Create Market Value for GHG Reductions

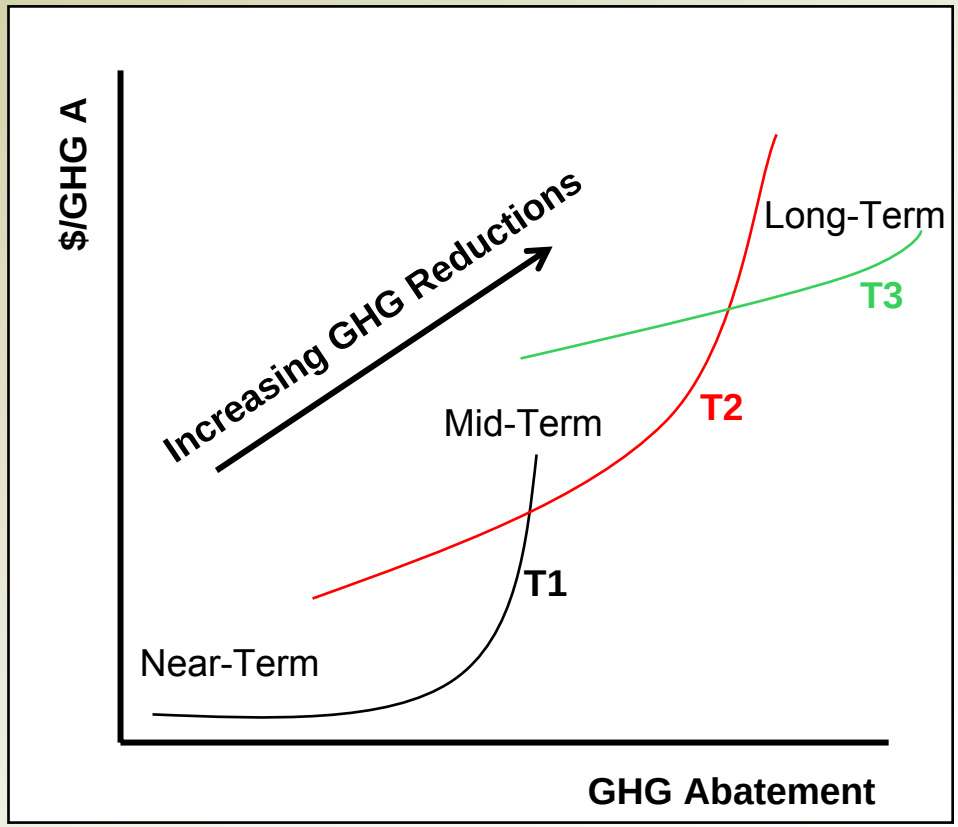
- As greater GHG reduction become necessary
  - Across sectors or within transport
  - ↑ Permit Prices ($/GHG A)
  - Firms/technologies with ($/GHG A) less than permit price become viable
- Marketable permits guide cost-effective transition from near-term to long-term technologies



The “Right” Hydrogen Pathways

Similar Story…

- Cost and GHG emissions characteristics of each hydrogen pathway = ($/GHG A)
- Increasing GHG reductions over time will reinforce cost-effective pathways



Marketable Emission Permits in Transportation

Lessons Learned from Modeling and Regulation

Motor Vehicle Marketable Permit Studies

- Cost effectiveness of CA LEV II with averaging, banking and trading (Wang, 1994)
- Potential benefits of permit banking
  - CA LEV II (Rubin and Kling, 1993)
  - Design considerations for flow pollutants (Rubin, 1996 and Kling and Rubin, 1997)
  - Optimal design for stock pollutants/GHG's (Leiby and Rubin, 2001)
- Accelerating the development of cleaner vehicles (GHG) (Albrecht, 2000)

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Lessons Learned from Modeling and Regulation

Existing Regulations

- Federal Clean Air Act – Mobile source averaging, banking and trading program (Ellerman, Joskow et al., 2003)
  - Control of criteria pollutants, began in heavy-duty and expanded to marine and off-road – allows averaging, banking and trading within engine families
- California Low Emission Vehicle Program
  - CO, NO_X and NMOG – allows averaging and banking, trading (NMOG only)
- California greenhouse gas law
  - CO_2 emissions from passenger vehicles - allows averaging, banking and trading
- Federal Corporate Average Fuel Economy Program
  - Fuel economy directly related to CO_2 emissions – allows averaging and banking (7 yr window)
  - NAS proposal to incorporate tradable fuel economy credits, show significant potential for cost saving (NRC, 2002; Sweeney, 2001; Leiby, 2004)

Lessons Learned from Modeling and Regulation

Lessons Learned - Effectiveness

- Marketable permit systems can offer significantly reduced costs relative to command and control regulations
  - 13-30% LEV II HC, NO_x, CO (Wang, 1994)
  - 8%-12% LEV II HC (Rubin and Kling, 1993)
- Can achieve environmental benefits and foster development of new technologies
  - CO_2 emissions reduced 25%-38% compared to BAU scenario for Belgian LDV's with permit prices of $40 - $100/ton CO_2 (Albrecht, 2000)

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Marketable GHG Permit System Design

Considerations

- Integrate upstream (fuel producers) and downstream (vehicle makers) firms
  - Provide direct fuel price signals and vehicle efficiency incentives
  - Facilitate coordination on long-term efforts to develop advanced technology/alternative fuel vehicles (esp. given long product dev.)
- Emissions averaging and trading
  - Cost saving benefits of permit trading not always realized due to : small number of trading partners; competition among firms; and administrative costs - **LEV II has only 1 reported NMOG trade**
  - Successful programs such as U.S. lead and SO_2 trading programs may provide lessons for creating active permit markets

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Marketable GHG Permit System Design

- Potential to leverage existing frameworks
  - California GHG law provides a foundation for full marketable GHG permit system
    - Court challenges regarding CARB's ability to regulate fuel economy
    - Future could incorporate upstream
  - CAFE provides Federal mandate, potential incorporation of tradable fuel economy credits
    - Fuel economy proportional to GHG emissions for ICE's
    - Could be adapted to better incorporate alt. fuels and upstream

Conclusions

- Long-term strategies for the control of GHG emissions will require advanced vehicle and fuel technologies
- Hydrogen fuel cell vehicles are perhaps the most promising long-term option
- Marketable emissions permits systems have the properties of fostering the development of new technologies and achieving cost-effective levels of emissions reduction
- A system of marketable GHG emission permits for transportation would:
  - Guide cost-effective development of new vehicle and fuel technologies for GHG abatement such as H2 FCV's
  - In the case of H2 FCV's, permits will reinforce H2 production pathways that offer the greatest GHG benefits at the least cost

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Future Work

- Beginning new research project to investigate market-based policies for fostering the development of advanced vehicle technologies
  - Economic implications of regulating, fuels vs. vehicles vs. both
  - Evaluation of policy alternatives in terms of economic and political considerations
  - Model system for GHG emission regulation in motor vehicles

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Thank You

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Extra Slides

Transport CO_2 Emissions Trading Schemes

Upstream

- Fuel producers hold permits for carbon content of the fuel they sell
- Covers entire transportation system
- Incentives for reducing output and alternative fuels
- Fuel price signal for increase efficiency and VMT reductions

Downstream

- Vehicle makers hold permits for the emissions of the vehicles they sell
- Incentives for increased efficiency and alternative fuels
- Calculation of imputed emissions difficult

Combined

- Regulation of both fuel producers and vehicle manufacturers
- Maximum benefits of fuel price signals, direct incentives for alternative fuels and efficiency
- Hybrid approach or upstream with carbon efficiency standard
- Coordination between fuel and vehicle technologies
- Allocation of responsibility for abatement difficult

Adapted from: Winkelman, S., T. Hargrave, et al., Transportation and Domestic Greenhouse Gas Emissions Trading, Center for Clean Air Policy, 1-30 (2000).

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Potential Vehicle and Fuel Technologies

Near and Mid-Term

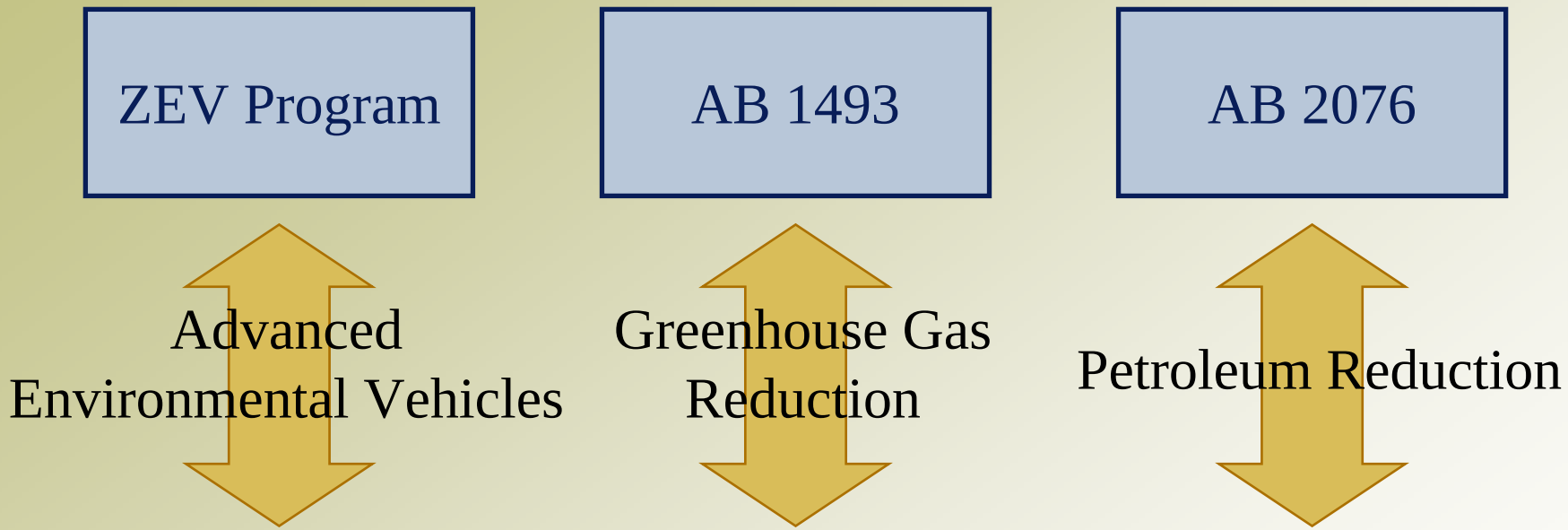
- Advanced ICE's (Gasoline)
- Hybrids
- Alternative fuels/blends (Ethanol, biodiesel, CNG)

Long-Term

- Biofuels
- Battery electric vehicles (BEV's)
- Hydrogen fuel cell vehicles

California Transportation Initiatives

Current Activity



California Assembly Bill 1493 (AB 1493)

Greenhouse Gas Reduction

- First vehicle GHG bill passed in the U.S. (2002)

Overview

- Adopt regulations to achieve maximum feasible and cost-effective reduction in GHG's from motor vehicles (cars and light trucks) by Jan 1, 2005
- 2009 model years and later

California Assembly Bill 1493 (AB 1493)

- 2009 model years and later
- Regulations shall not:
  - Impose new fees or taxes
  - Ban sale of any vehicle category
  - Limit vehicle speed or VMT

Average CO_2 Emissions Change by Model Year

Year			All major 6
2009	Near-term phase-in	PC/LDT1	-1.3%
		LDT2	-2.1%
2010		PC/LDT1	-4.4%
		LDT2	-5.5%
2011		PC/LDT1	-14.0%
		LDT2	-11.8%
2012		PC/LDT1	-24.9%
		LDT2	-18.3%
2013	Mid-term phase-in	PC/LDT1	-26.7%
		LDT2	-19.6%
2014		PC/LDT1	-28.5%
		LDT2	-20.9%
2015		PC/LDT1	-31.2%
		LDT2	-22.9%
2016		PC/LDT1	-33.9%
		LDT2	-24.8%

CA EPA & ARB staff report – August 6, 2004

California Assembly Bill 1493 (AB 1493)

	Near-term (2009)	Mid-term (2013-2015)	Long-term (2015+)
CO_2 Reduction (2009 baseline)	14-24%	< 30%	30-50%
Potential Technologies	•Turbochargers with engine downsize •Variable valve timing •Improved transmission •Improved electric accessories •Cylinder deactivation	•Gasoline direct injection •Camless valve actuation •42 volt ISG •Improved transmissions	•Moderate HEV's •Advanced gasoline and diesel HEV's •FCV's?

*Adapted from ARB presentation, Lisa Kasper, May 6, 2004

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California Assembly Bill 1493 (AB 1493)

AB 1493 Summary

- Find cost effective means of reducing GHG emissions from motor vehicles
- Utilize improvements in “conventional” technologies
- Regulation pending

California Assembly Bill 2076 (AB 2076)

California Assembly Bill 2076 (AB 2076)

Petroleum Reduction

- Directs the California Energy Commission (CEC) and the California Air Resources Board (CARB) to develop and adopt recommendations for reducing California's petroleum dependence (2002)
  - Opportunity for California to provide state leadership in reducing GHG's from transportation
  - Hedge against risk from future oil supply disruptions
  - Dampen fuel demand and moderate price impacts on the CA economy
- Final Joint Report Issued August 2003

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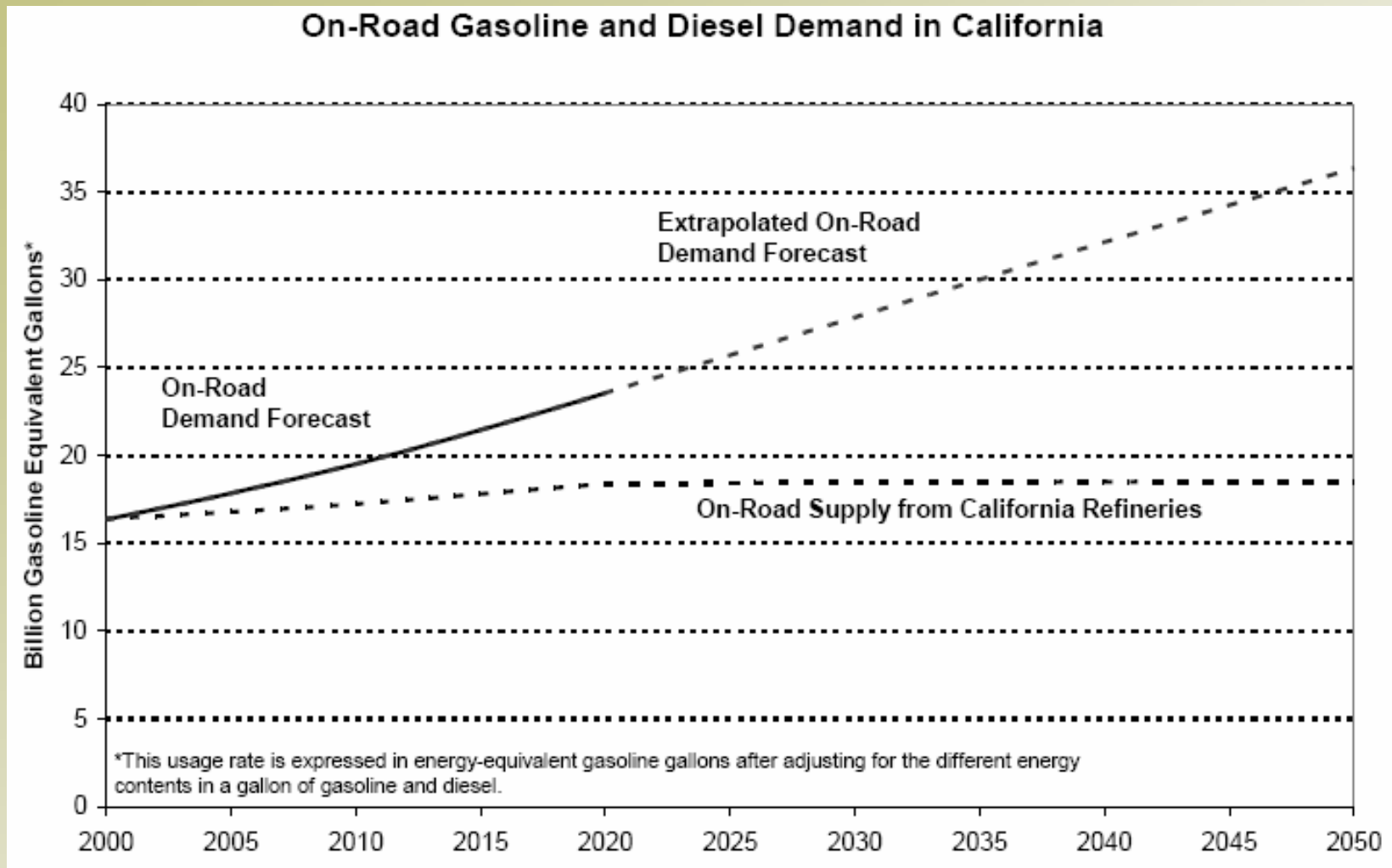
California Assembly Bill 2076 (AB 2076)



California Energy Commission, California Air Resources Board joint report – August 2003

California Assembly Bill 2076 (AB 2076)

Petroleum Reduction

- Report recommendations:
  - Reduce gasoline and diesel
    - 15% below 2003 demand by 2020
  - Double the efficiency of vehicles
    - (40 mpg) CAFE requirements
  - Increase non-petroleum fuels
    - 20% of fuel consumption by 2020
    - 30% by 2030 (eg Fischer-Tropsch, ethanol in blends, H2 etc)

California Assembly Bill 2076 (AB 2076)

Potential Technologies

Near-term (2010)	Mid-term (2010-2020)	Long-term (2020-2030)
•Efficient replacement tires •Efficient government fleets •Improved vehicle maintenance	•Double fuel efficiency (CAFE) – best gasoline •Fischer-Tropsch Diesel – best diesel •Other options: Ethanol, LNG, CNG, grid connected hybrids	•Hydrogen fuel cell vehicles •Introduce in 2012, increase to 20% of NV sales by 2030

California Assembly Bill 2076 (AB 2076)

AB 2076 Summary

- Find cost effective means of reducing petroleum dependence in transportation
- Utilize improvements in “conventional” technologies in near-term→ advanced technology in long-term
- No further regulatory action

California Hydrogen Highway Network

- California Governor Schwarzenegger signs Executive Order S-07-04 on April 20, 2004 at UC Davis
- Promoting the creation of a “Hydrogen Highway Network” across the state’s interstate highways
  - “To support and catalyze a rapid transition to a clean, hydrogen transportation economy in California, thereby reducing our dependence on foreign oil, and protecting our citizens from health harms related to vehicle emissions”

California Hydrogen Highway Network

- Final Blueprint report due to Governor and Legislature on January 1, 2005
- Implementation Plan
  - Development of H_2 stations in CA, vehicle demonstration and public education programs
- Governor's Executive Order Team
  - Terry Tamminen (Secretary Cal EPA), Anne Baker (Deputy), Shannon Baxter (Director), Daniel Emmett (Advisor)
- Advisory Panel
  - 20 leaders from: government; academia; NGO's; the automotive, utility and energy industries
- Topic Teams
  - Approximately 250 volunteers

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Summary

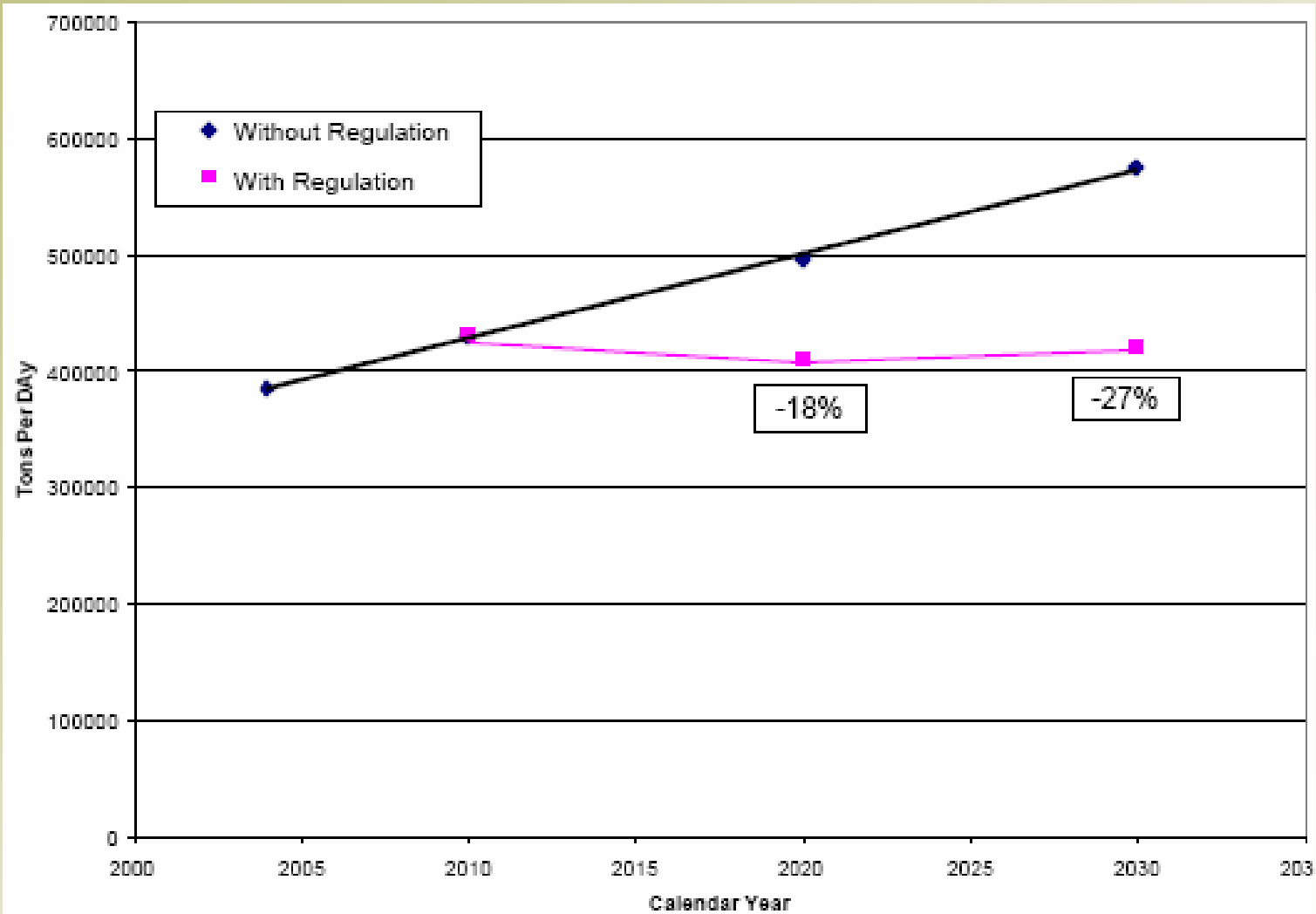
- California is the U.S. leader in developing policies for sustainable transportation
- Currently developing long-term, transitional plans for addressing:
  - Air Quality (ZEV);
  - GHG emissions (AB 1493 and ZEV);
  - Petroleum dependence (AB 2076).
- Current long-term strategy: Hydrogen Highway

Key ITS-Davis Research Areas

- Fuel Cells and Hydrogen Production (EVC Test Bed)
- Electric Drive Systems (EVC Test Bed)
- Hybrid and ICE (EVC Test Bed)
- Heavy-Duty Vehicles (EVC Test Bed)
- Fuel Pathways and System Modeling
- Policy and Systems Analysis
- Market Research and Social Marketing
- Education and Outreach

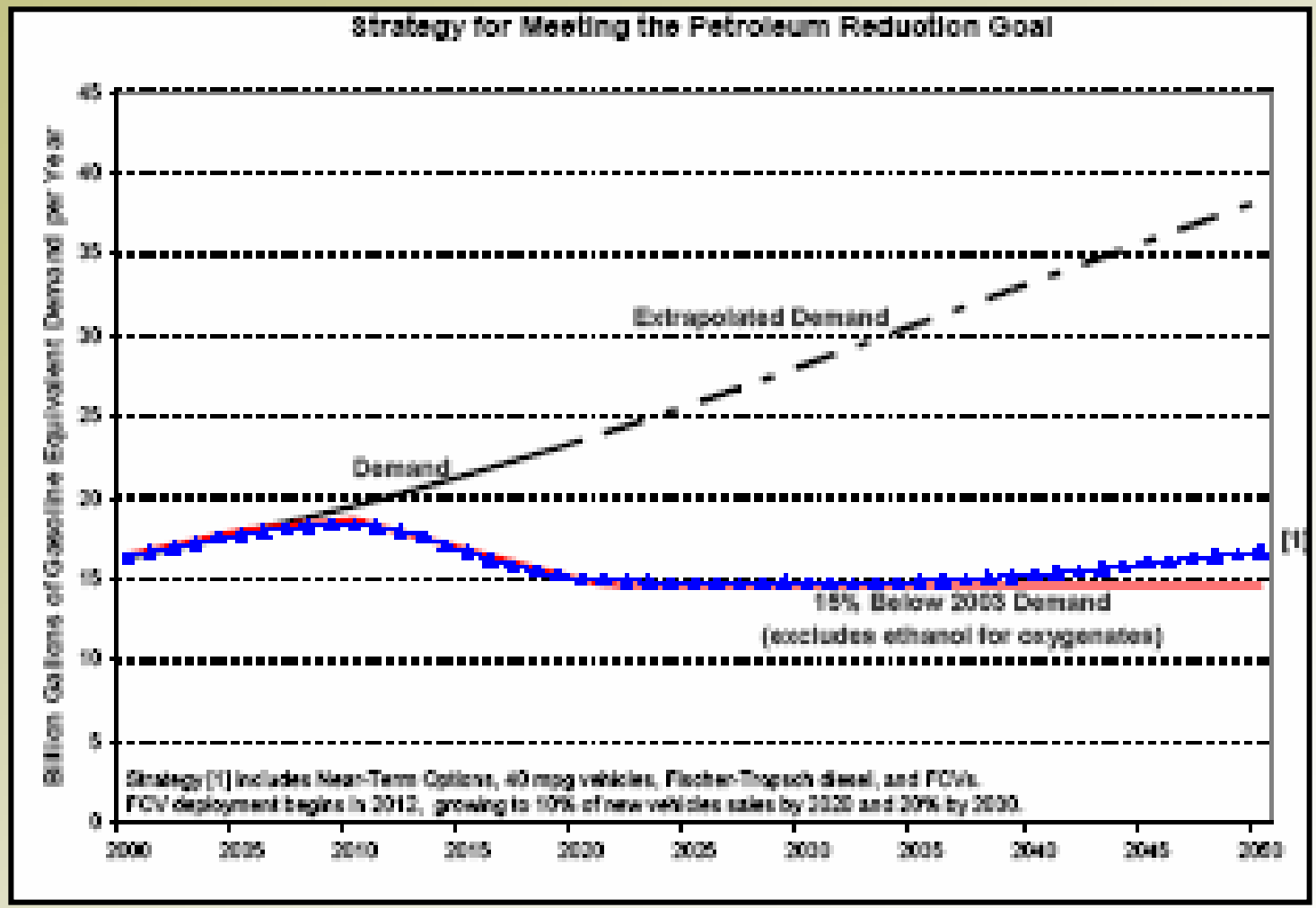
California Assembly Bill 1493 (AB 1493)

Motor Vehicle Greenhouse Gas Emissions (Excluding Upstream Emissions)



CA EPA & ARB staff report – August 6, 2004

California Assembly Bill 2076 (AB 2076)



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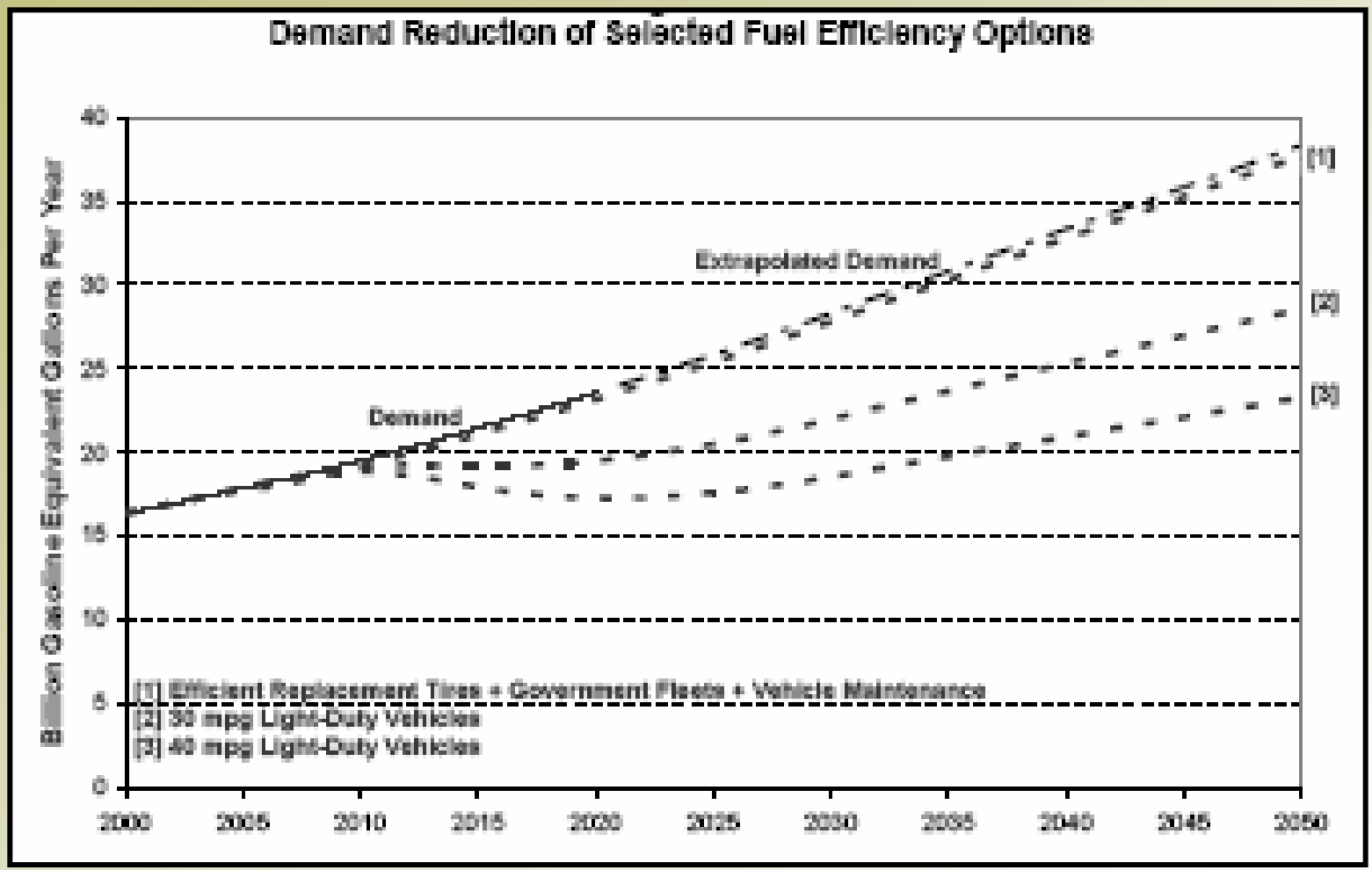
California Assembly Bill 2076 (AB 2076)



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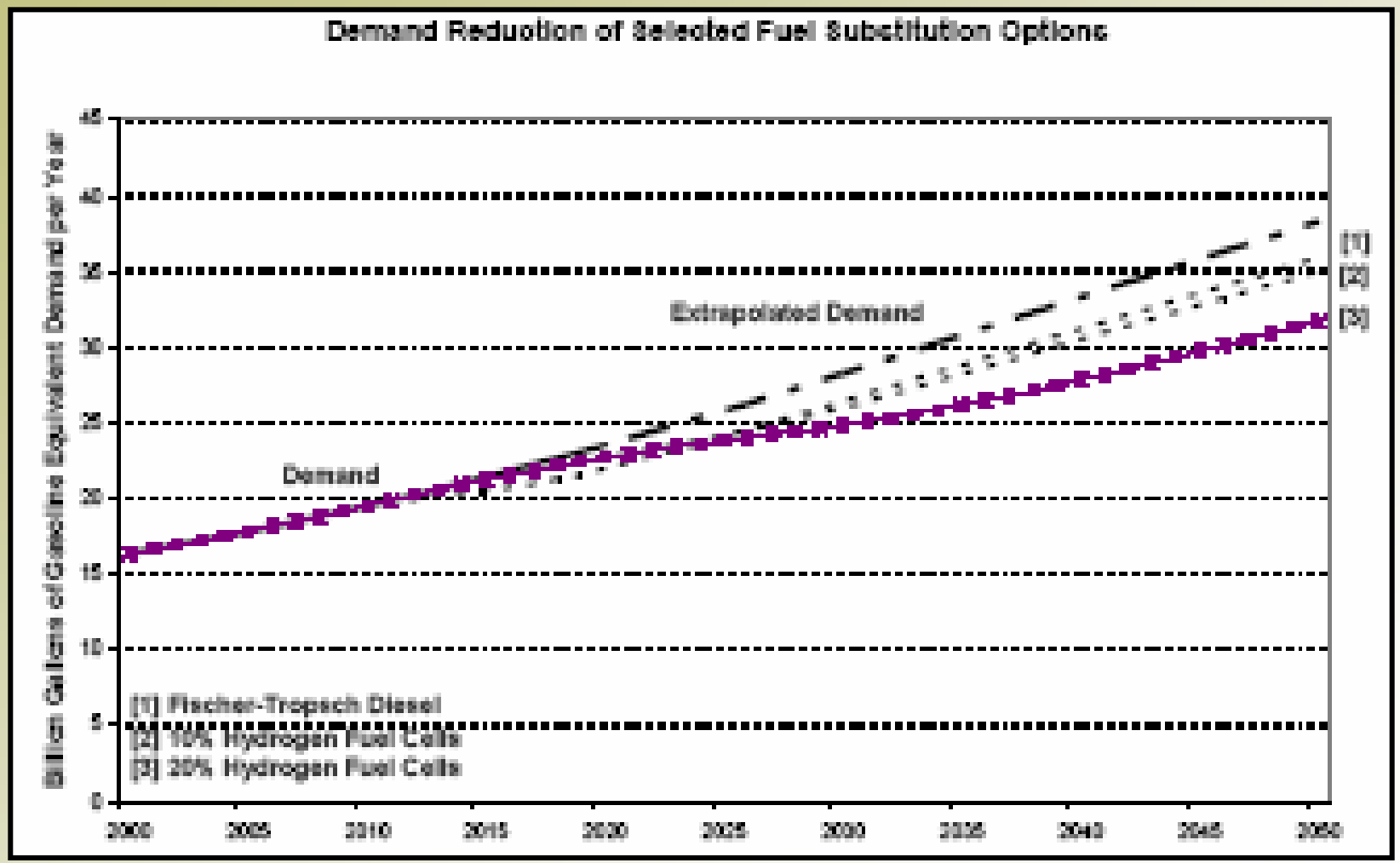

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