

# Alternate pathways to reduced petroleum consumption and greenhouse gas emissions

**Use of Hydrogen for the Light Duty Transportation Fleet:  
Technology and Economic Analysis**

**NETL/ANL Scenario Analysis Results**

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# Disclaimer/acknowledgements

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# Dedication

**This presentation is dedicated to the memory of  
John Ruether (1941-2005)**

**NETL Senior Engineer, friend, colleague, and  
project inspiration**

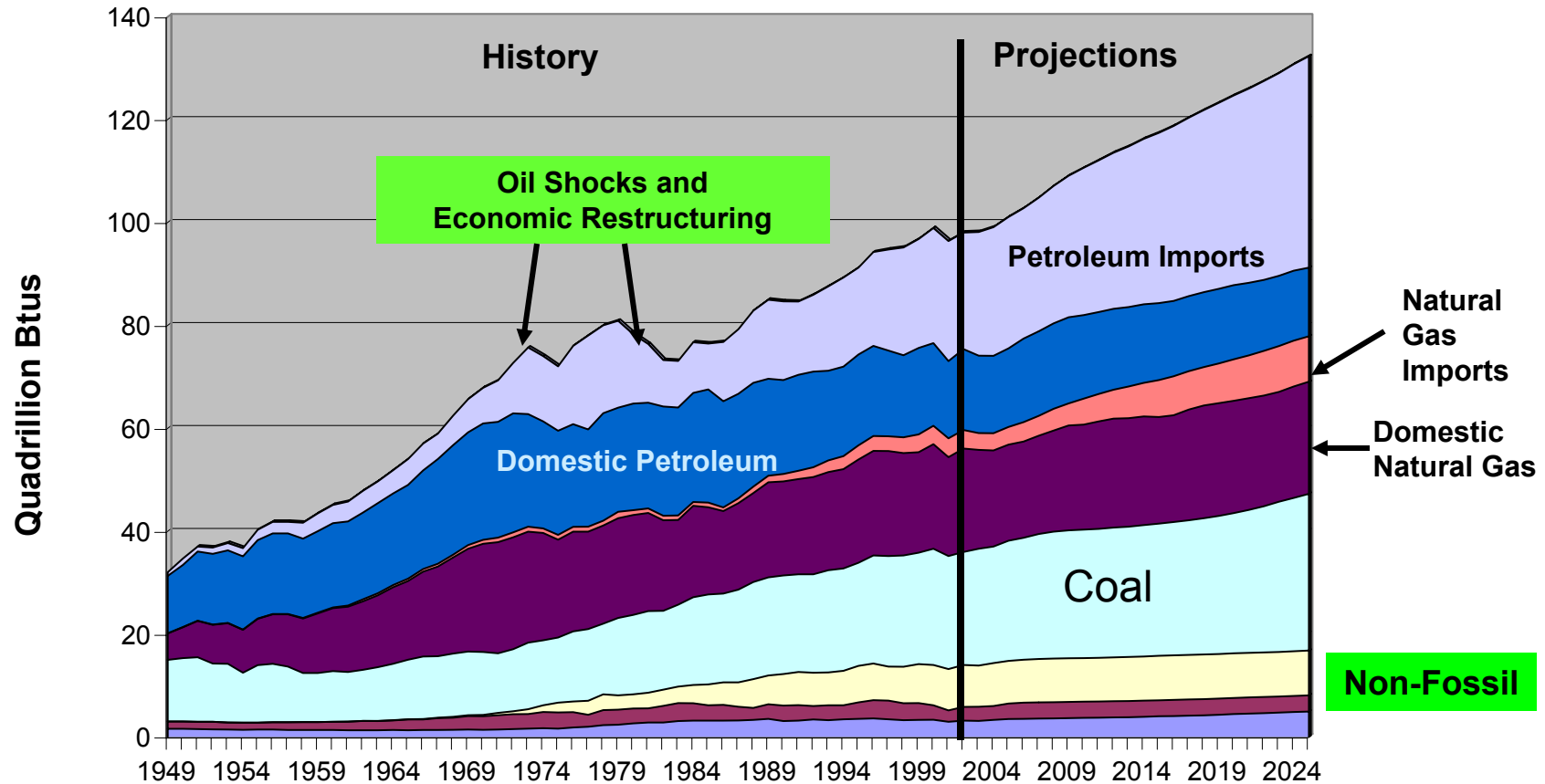


# Can Energy Security and Climate Concerns be Reconciled?

- **President Bush, February 2003:**
  - Reduction of Petroleum Consumption
    - 11 million barrels per day, by 2040
  - Reduction of Carbon Equivalent
    - 500 million metric tons per year, by 2040
- **NETL/ANL Study Assumption**
  - Reductions are from forecasted baseline



# US Energy Consumption by Fuel 1949-2025

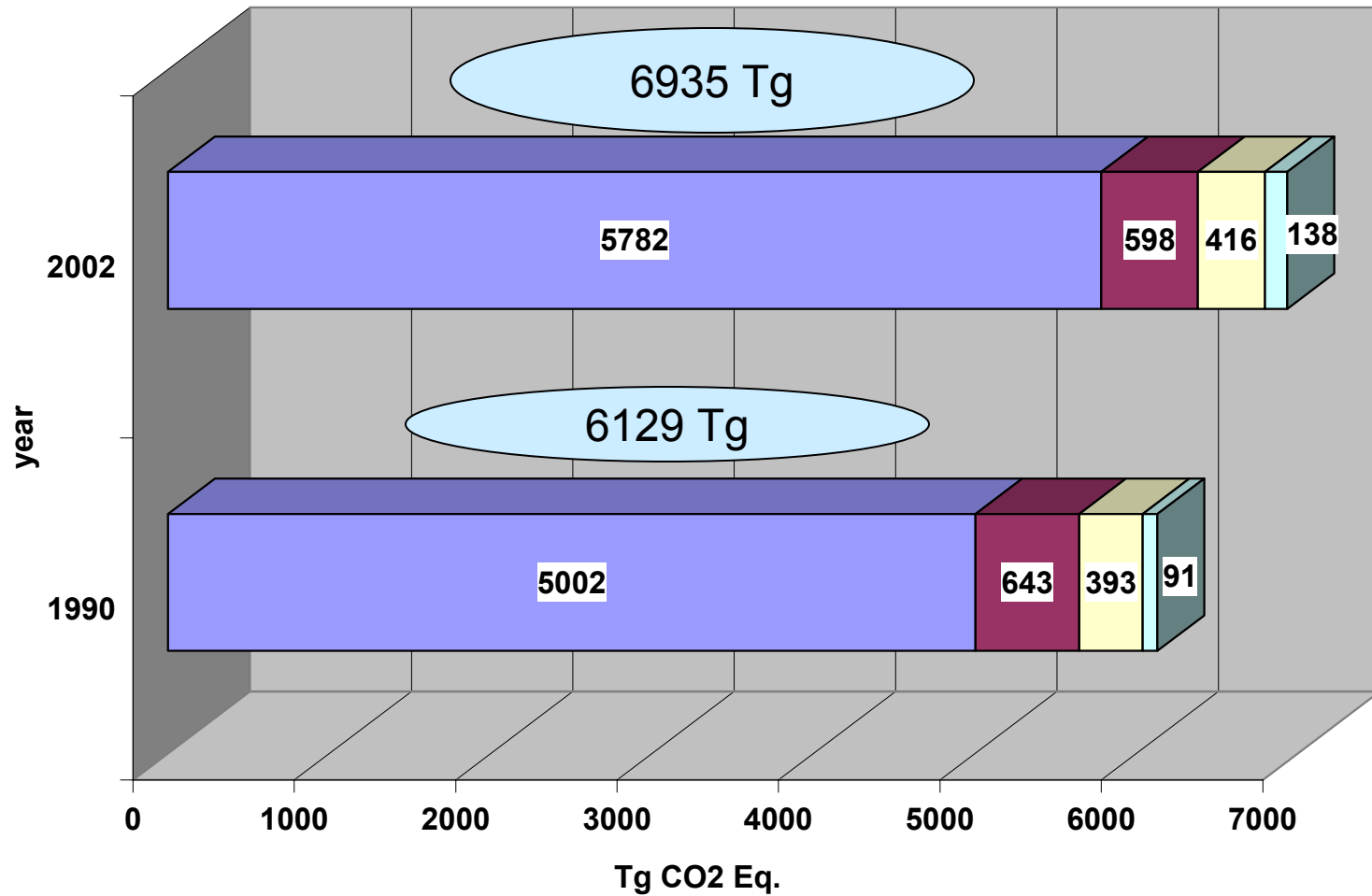


■ NH-Rew 
 ■ hydro 
 ■ nuclear 
 ■ coal 
 ■ NG dom 
 ■ NG imp. 
 ■ pet.dom 
 ■ pet imp.

Source: EIA; 1948-2003: *Annual Energy Review 2003*, Table 1.3; 2004-2025: *Annual Energy Outlook 2005*, Tables 1,2, and 17

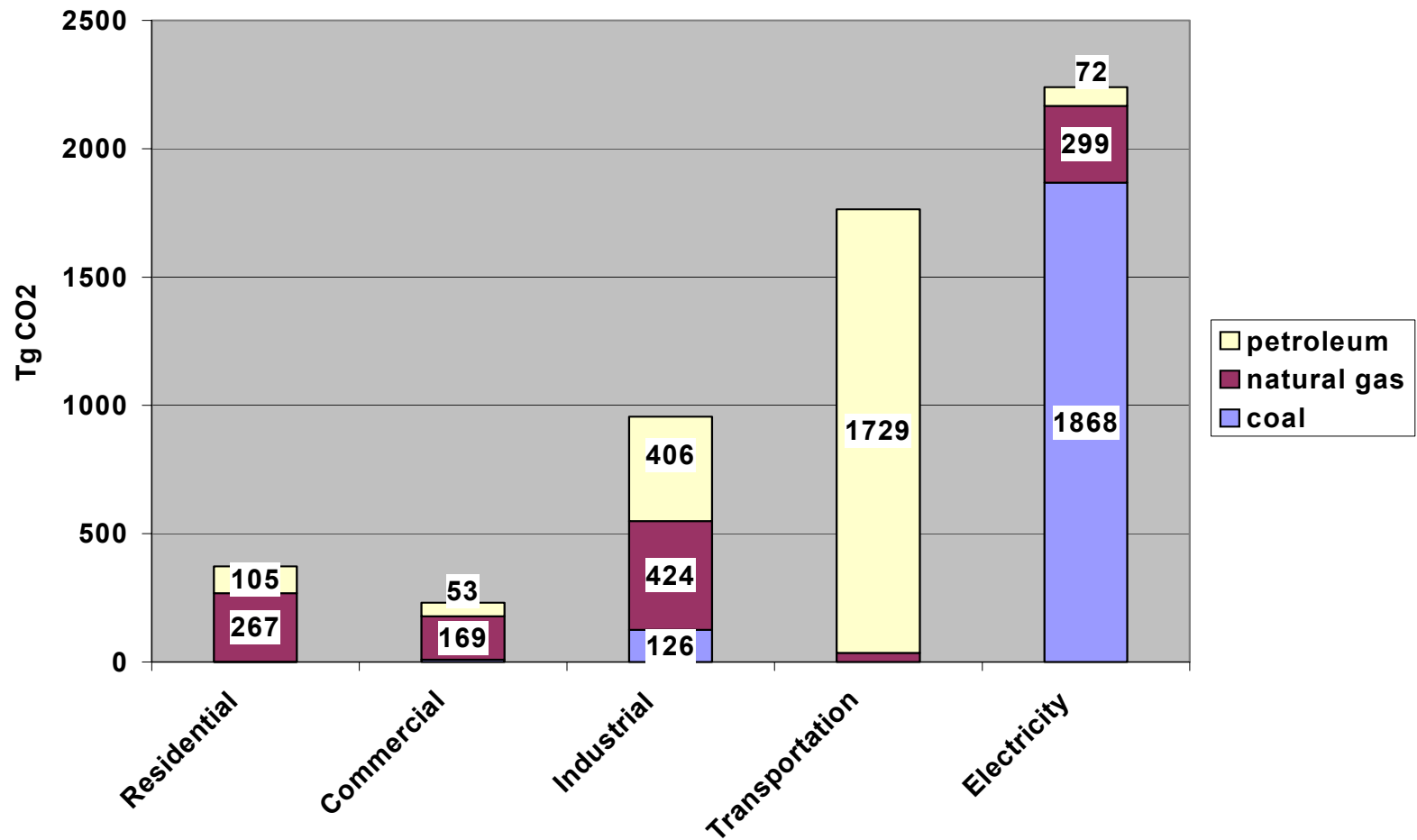


# US GHG Emissions, 1990-2002



Source: EPA, 2004 Greenhouse Gas Inventory, National Inventory Tables, Table ES-2

# 2002 US CO<sub>2</sub> Emissions from Fossil Fuel Combustion, by Sector



Source: EPA, 2004 Greenhouse Gas Inventory, National Inventory Tables, Table 3.3

# Scenario Project Purpose

- **Study plausible scenarios for “hydrogen economy”**
  - Recognition of role of petroleum complex and transportation fuels infrastructure
- **Investigate macro role of coal-based technologies**
  - For both petroleum substitution and carbon reductions





# Scenario Project Purpose, cont'd

- **Support wider DOE hydrogen economy modeling effort**
  - Initial implementation of DOE (H2A) cost estimates
  - Respond to National Academy call for Fossil Energy “Systems Analysis” to study H2 economy
- **Identify appropriate economic drivers**
  - Guide techno-economic system to optimal outcome within scenario period



# NETL/ANL Scenario Analysis

- **Target Transportation and Power Generation**
- **Enabling Technologies**
  - Hybrid-Electric Vehicles; Fuel Cells
  - Carbon Capture and Sequestration
  - Coal-to-Liquids (Fischer-Tropsch)
- **Externality Charges**
  - Energy Security Premium
  - Carbon Charge



# Technical Challenges

- **Integration of cost and performance specifications of refinery and coproduction plants with AMIGA economic model.**
  - Important for richer representation of investment choices
- **Implementation of H2A cost estimates for technologies not yet in existence**
  - Must assume technological breakthrough in FCV case
- **Identification of appropriate performance characteristics of advanced vehicles**

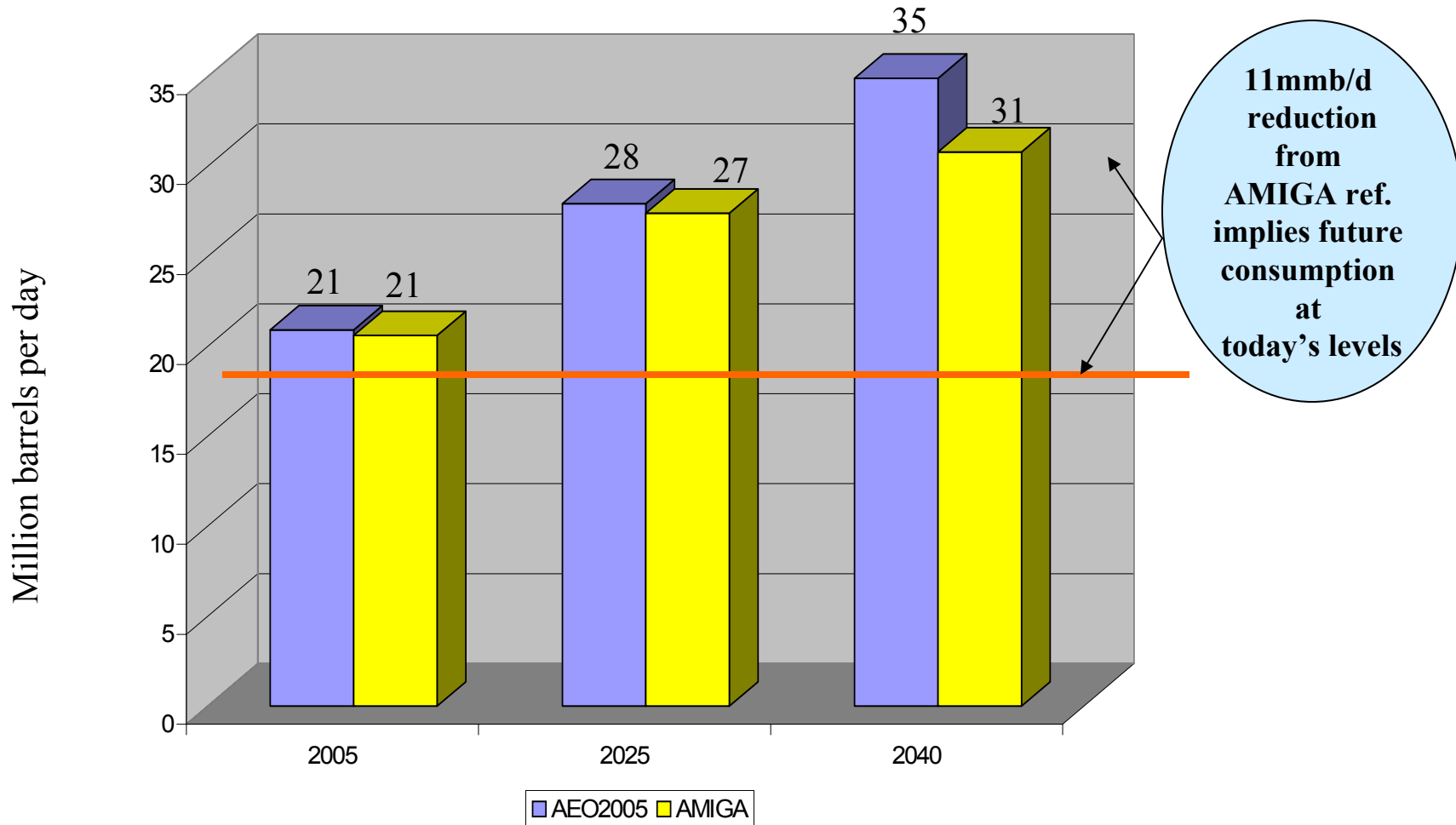


# Scenario Structure

- **Uses Presidential reduction goals as drivers**
  - Reductions from future, not current, levels
  - H2-economy based on FCV a possible means to achieving quantitative goals, not an end in itself
    - As distinct from Academy study (2004)
      - replacement of petroleum-based light-duty vehicle fleet, or
    - DOE H2 Posture plan (2005)
      - Focus on renewable hydrogen
- **Recognition of scientific debate**
  - E.g. Romm (2004), Shinnar (2003), Demirdöven and Deutch (2004)



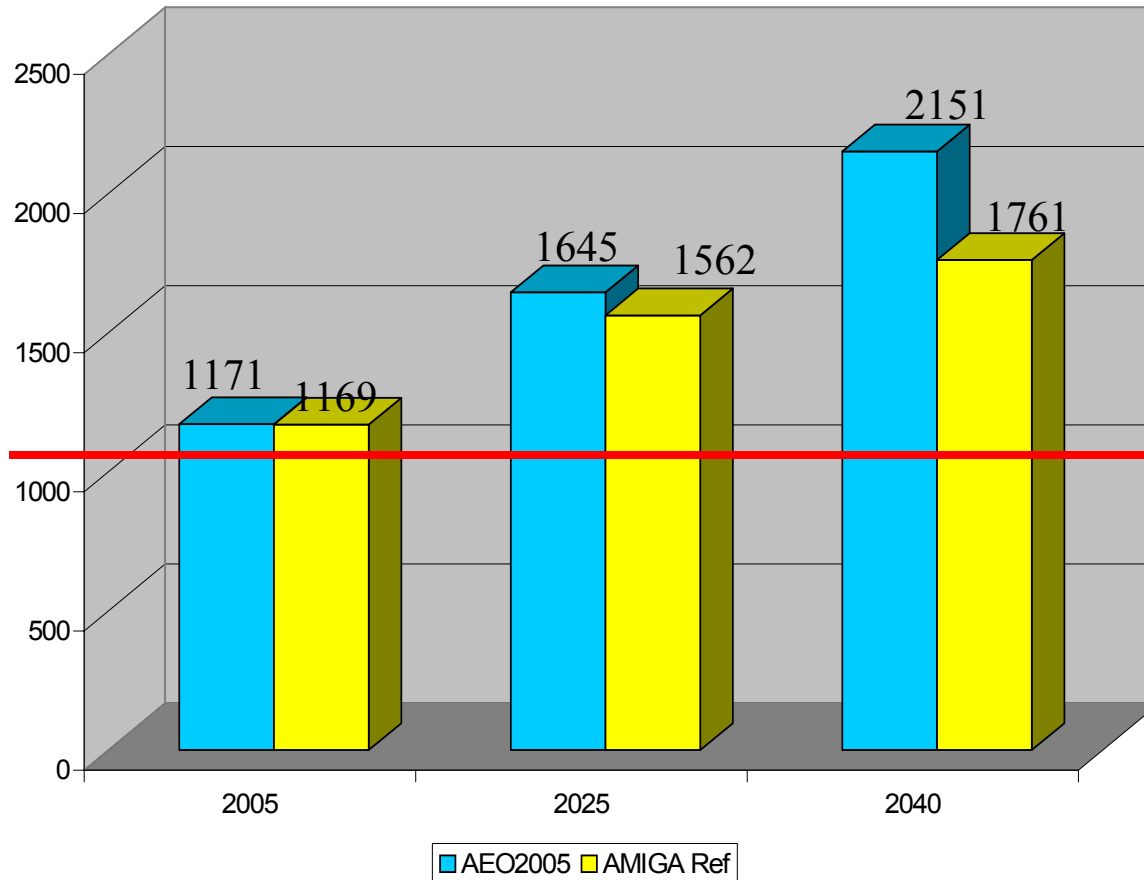
# Petroleum Target



Source: EIA AEO2005 Yearly Table 11; author extrapolation; AMIGA reference run

# Carbon Emissions Target

Million Metric tons C eq. per year

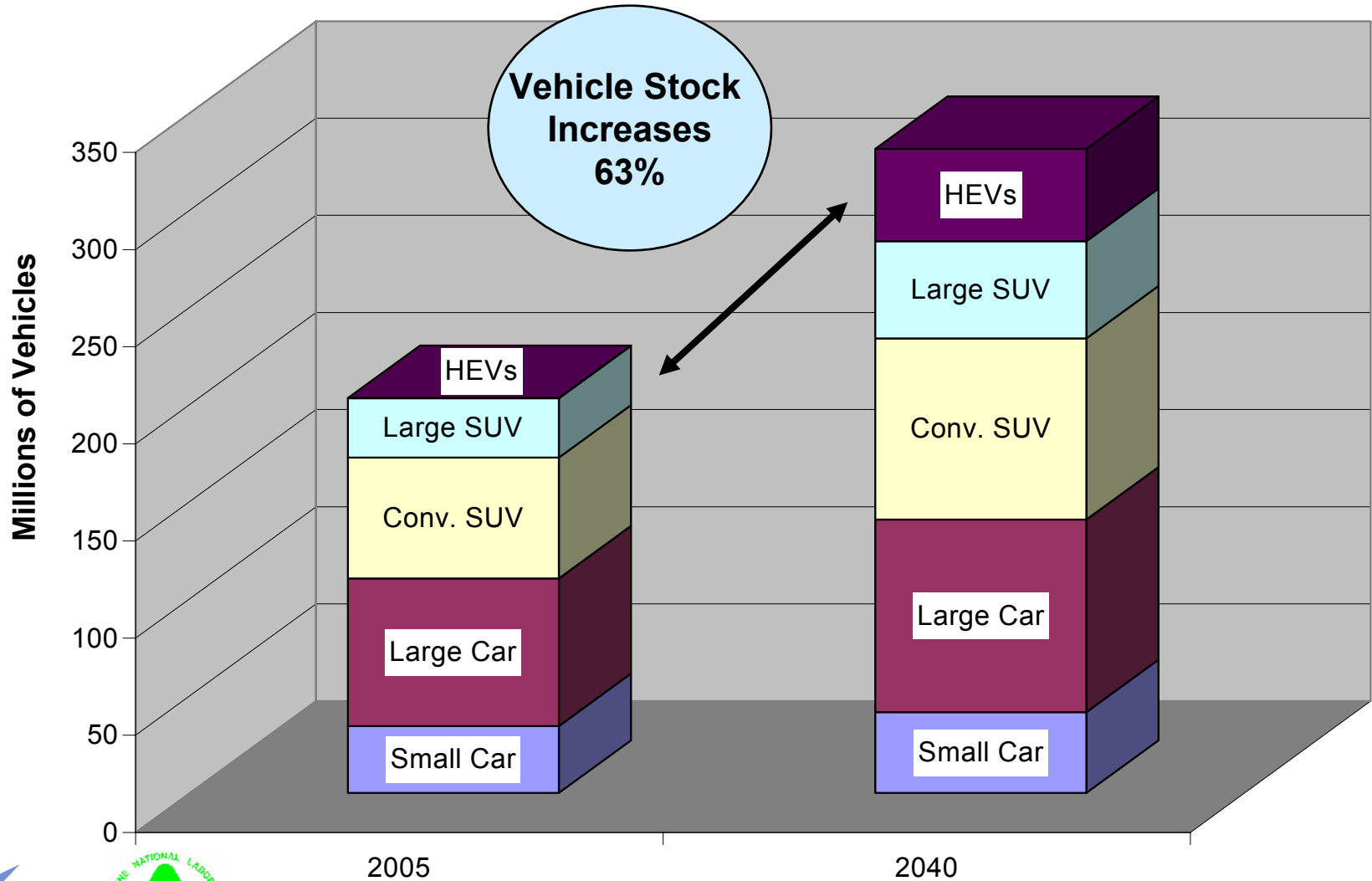


C target reduction from AMIGA ref. reduces C to level ~7% above today's



Source: EIA AEO2005 Yearly Table 18 (transport petroleum; electric power); author extrapolation; AMIGA reference run

# Scale of Challenge



# How to Achieve Cuts

<u>Reference Case:</u> “Business as usual”	<u>Extended Transition</u> Hybrid-electric vehicles and Clean Hydrocarbons “HEV case”	<u>Hydrogen Achievement</u> Hydrogen Production for Fuel Cell Vehicles “FCV case”
Oil Prices From \$37/b in 2010; Gas Prices from \$6/mmBtu	Coal Power/Fischer-Tropsch Co-Production Plants	DOE H <sub>2</sub> Posture Plan guidelines
“Clear Skies”-Like Emissions Targets	Energy Security Charges on premium fuels from 2010	H <sub>2</sub> A program (DOE EE) H <sub>2</sub> cost data
Gasification, Hydrotreating and Clean fuels Refinery Modeling	Carbon Charges on Electricity generation from 2015	More stringent clean air regulations begin in California
Nuclear Generating Capacity Constant	Four size categories of Hybrids; eventual Plug-Ins	Technological “breakthroughs” assumed

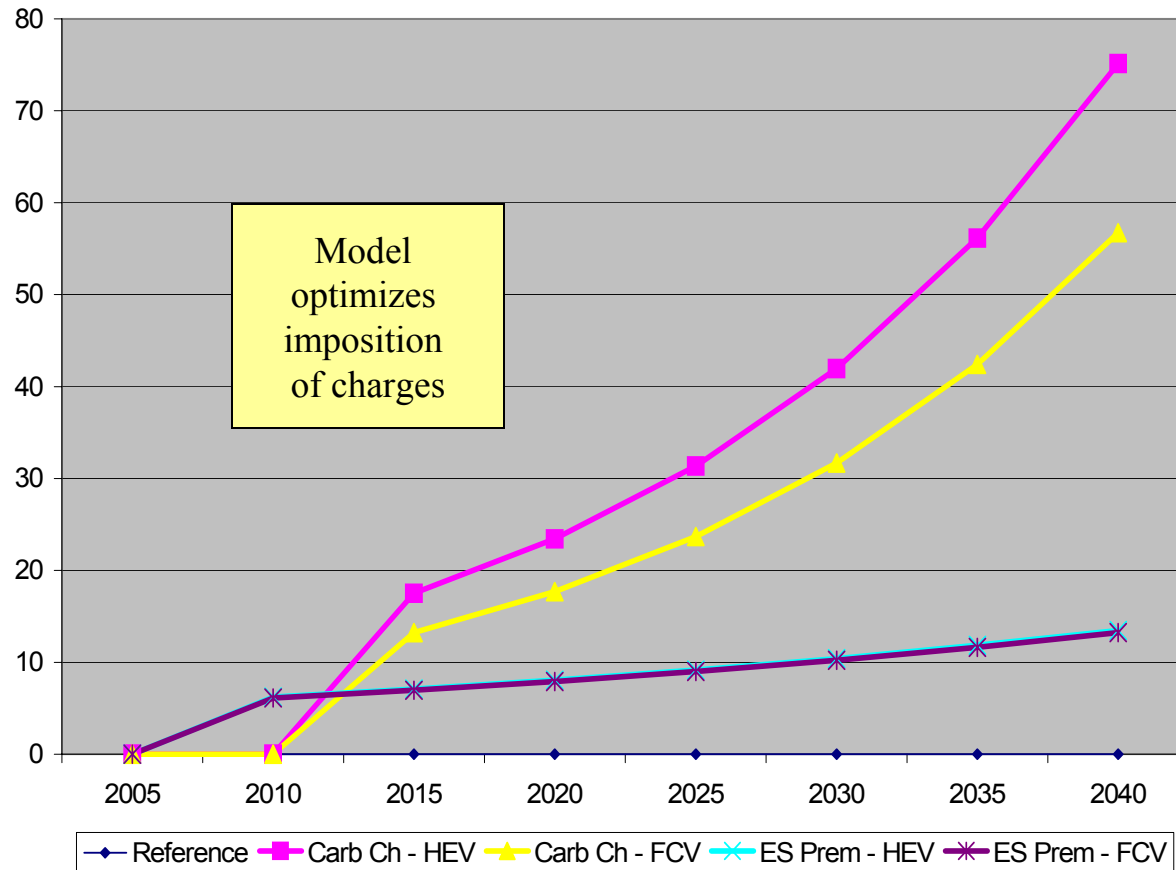
Assumptions are kept from left to right





# Externality Charges

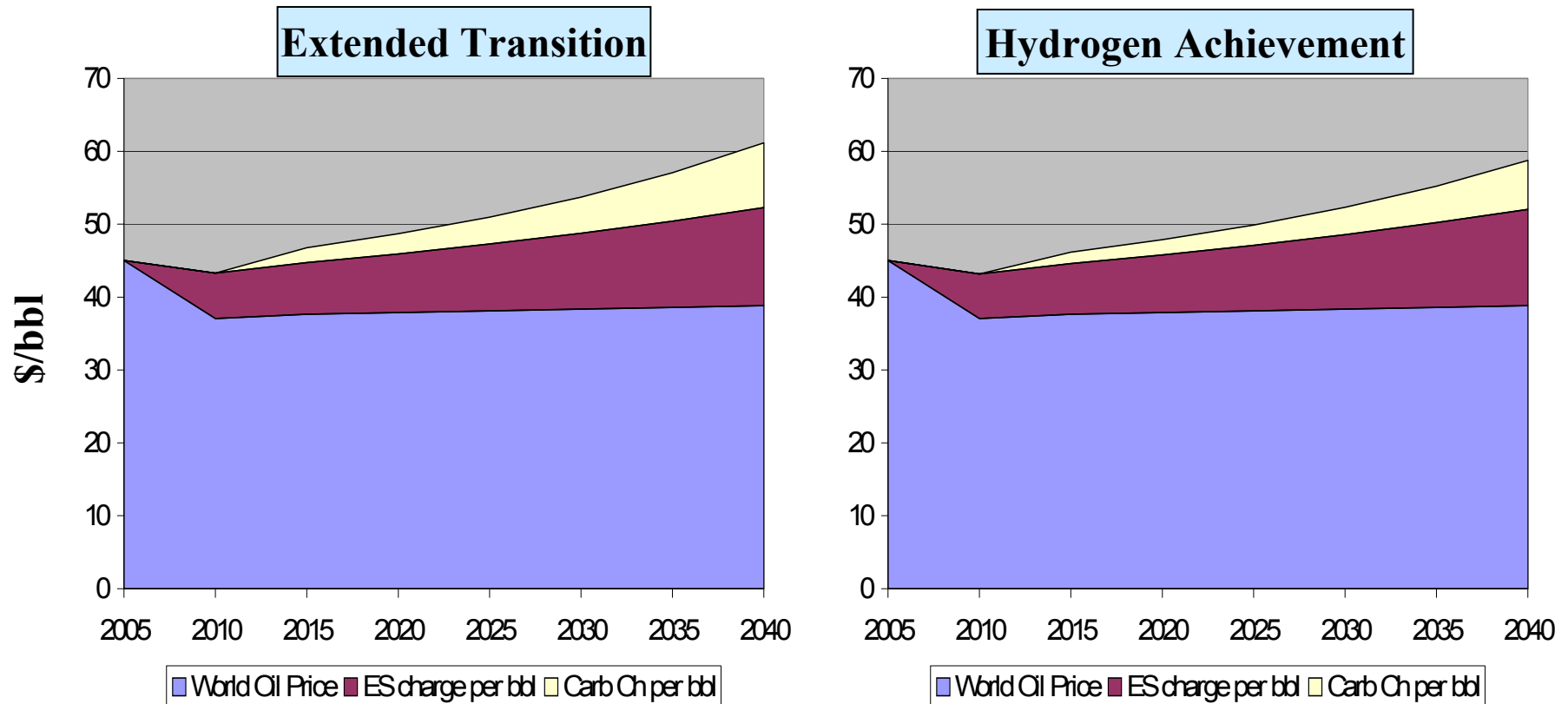
\$ per metric ton C;  
\$ per barrel oil



More stringent anti-smog measures + higher fuel economy implies lower C charge for FCV case



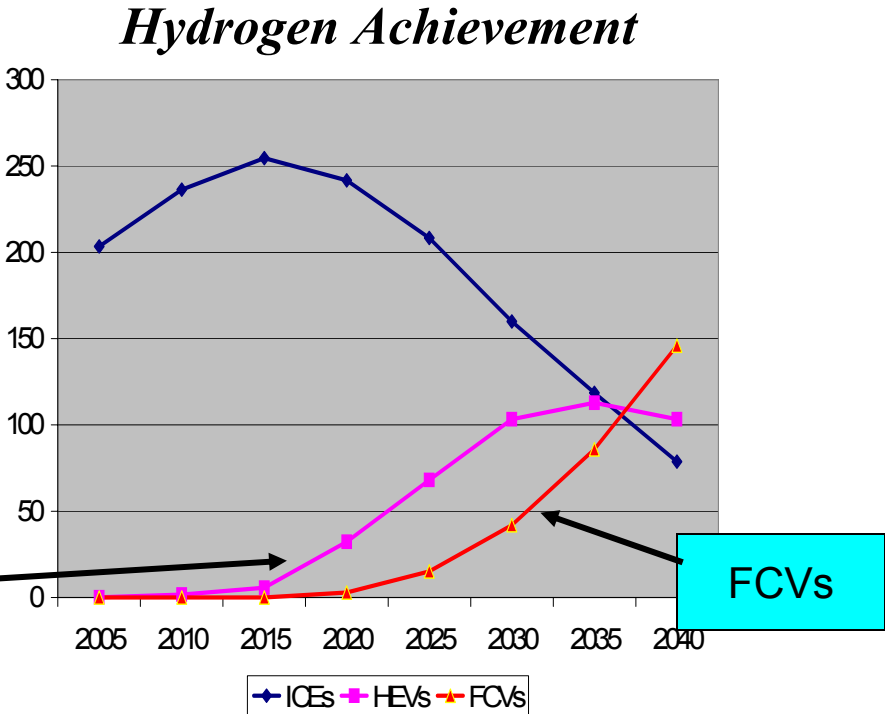
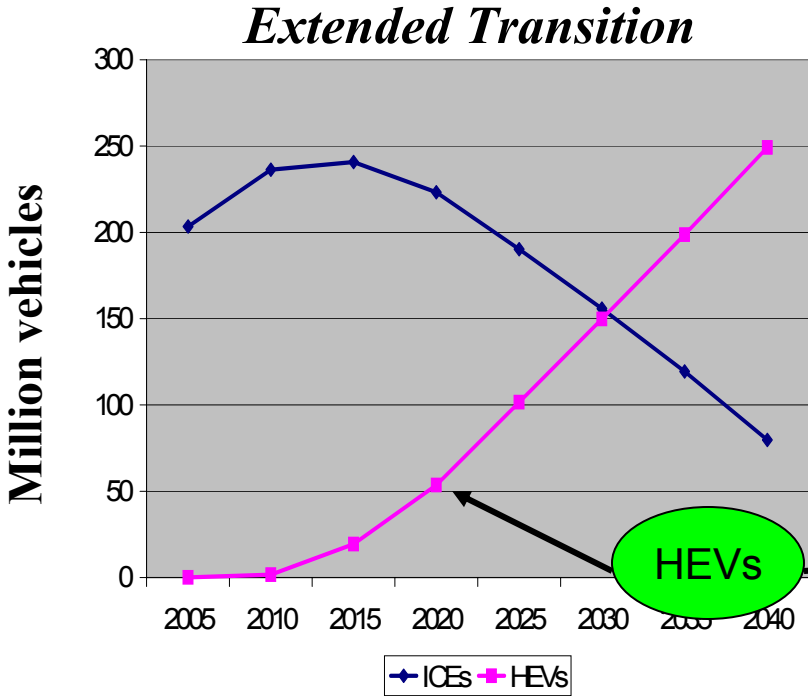
# Effective Oil Prices



Externality charges result in higher effective than nominal oil prices;  
Slightly higher imputed carbon and energy security charges in HEV-only case



# Vehicle Stocks



Source: AMIGA Presidential Goals Scenario Runs

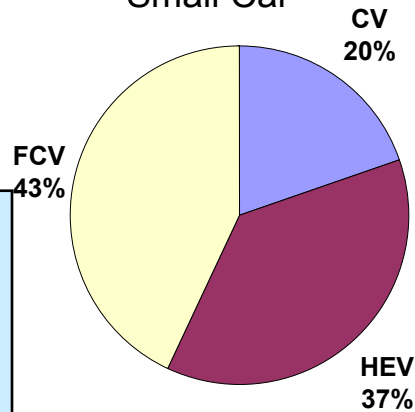


# Distribution of Vehicle Types in FCV Case

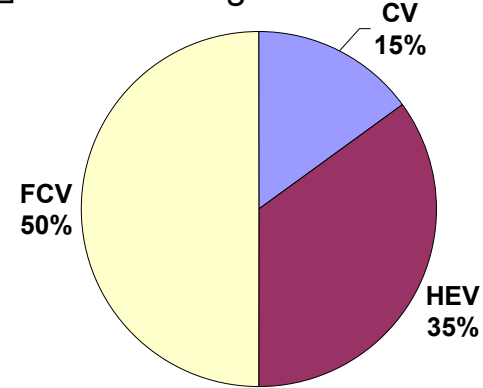
YEAR 2040

In end-period, FCVs dominate middle categories, but HEVs remain and large ICEs retain attraction

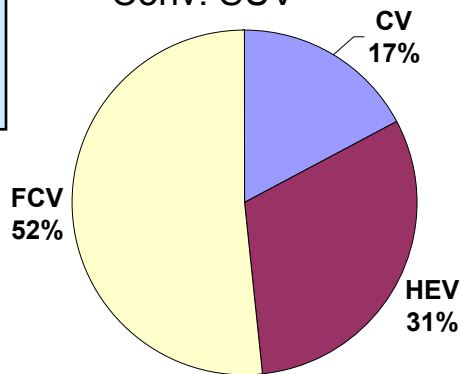
Small Car



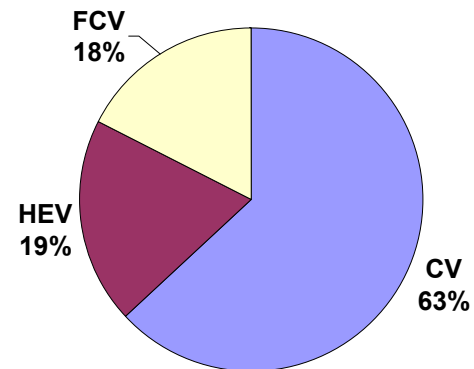
Large Car



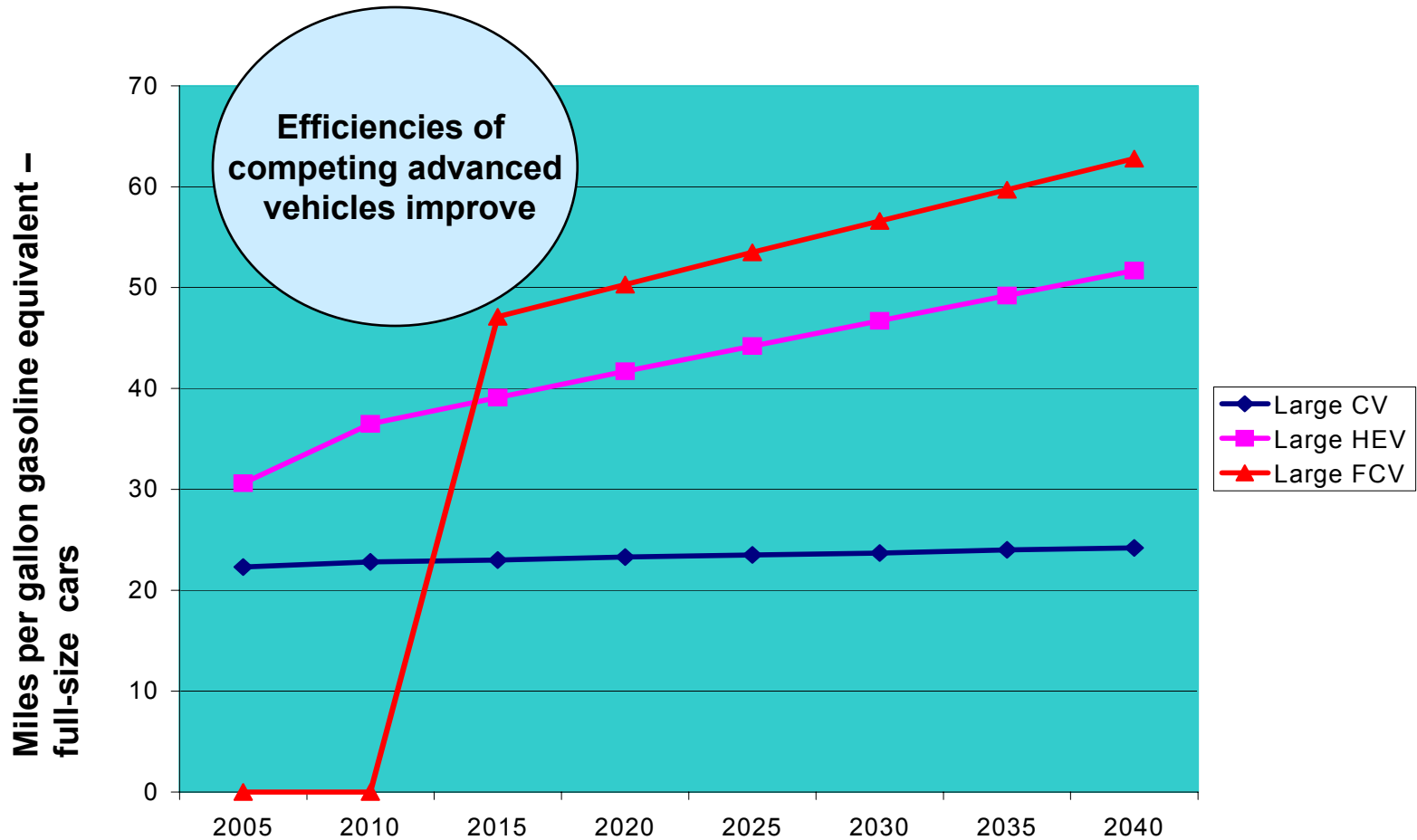
Conv. SUV



Large SUV

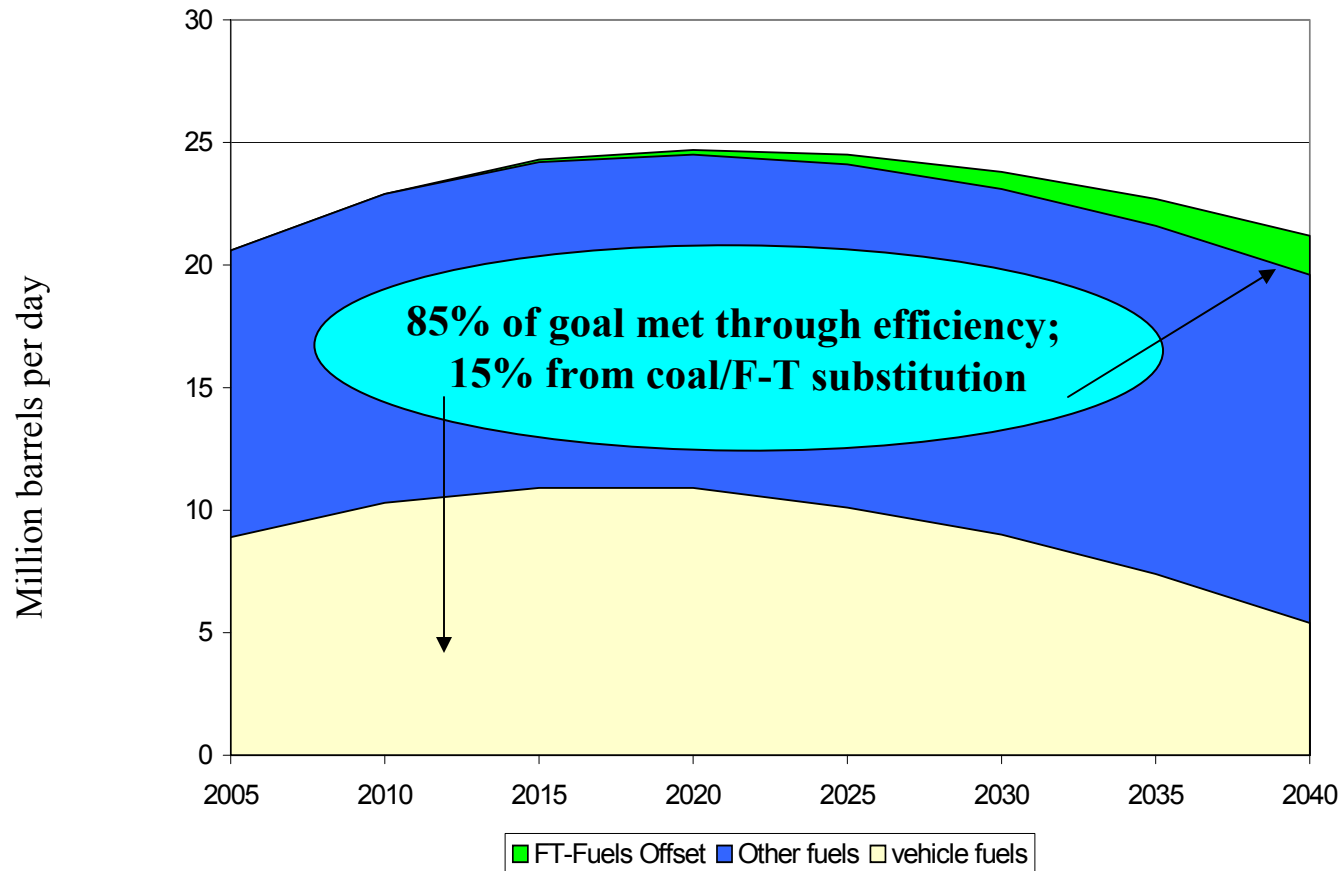


# Mileage, Full-size Cars, *Hydrogen Achievement*



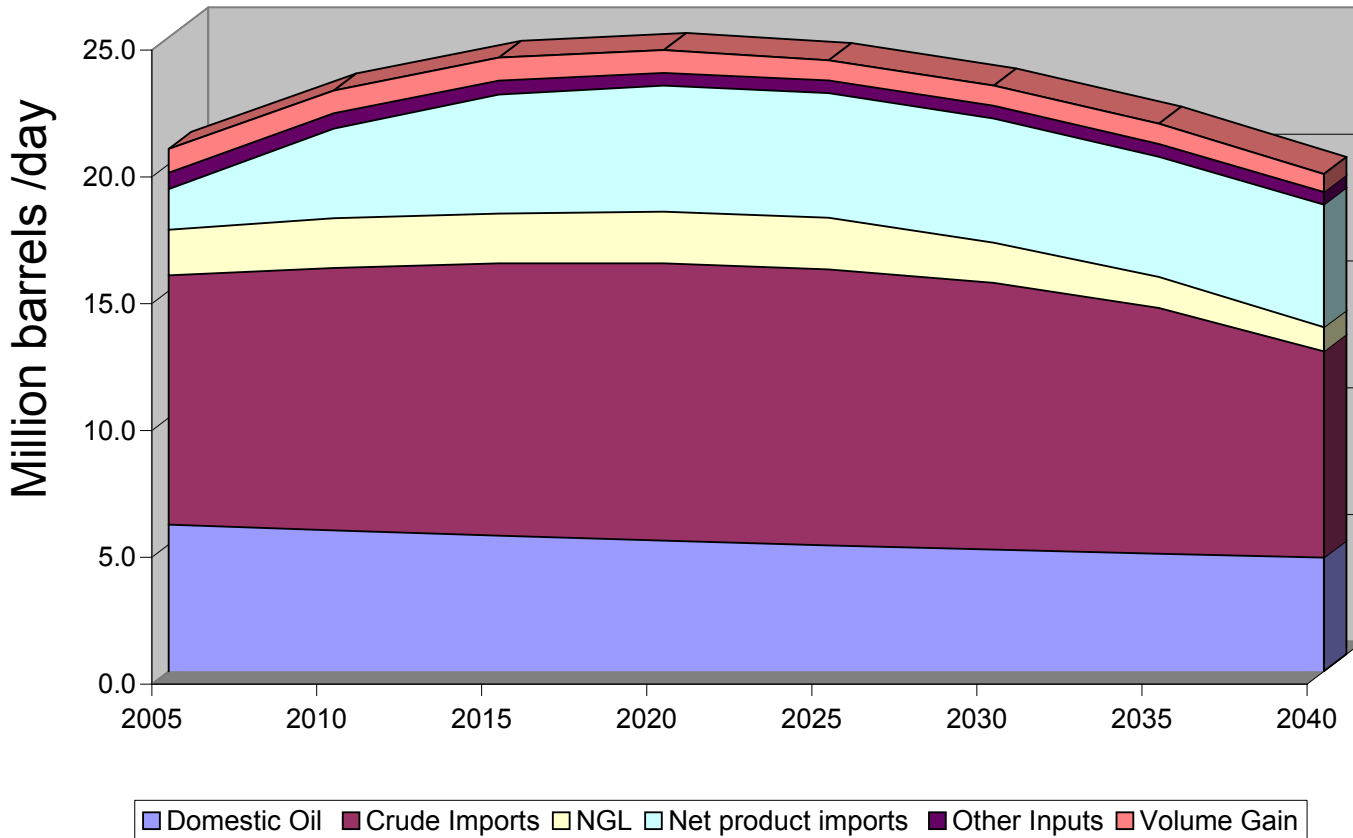
Source: AMIGA Presidential Goals Scenario Runs

# Reduced Petroleum Consumption

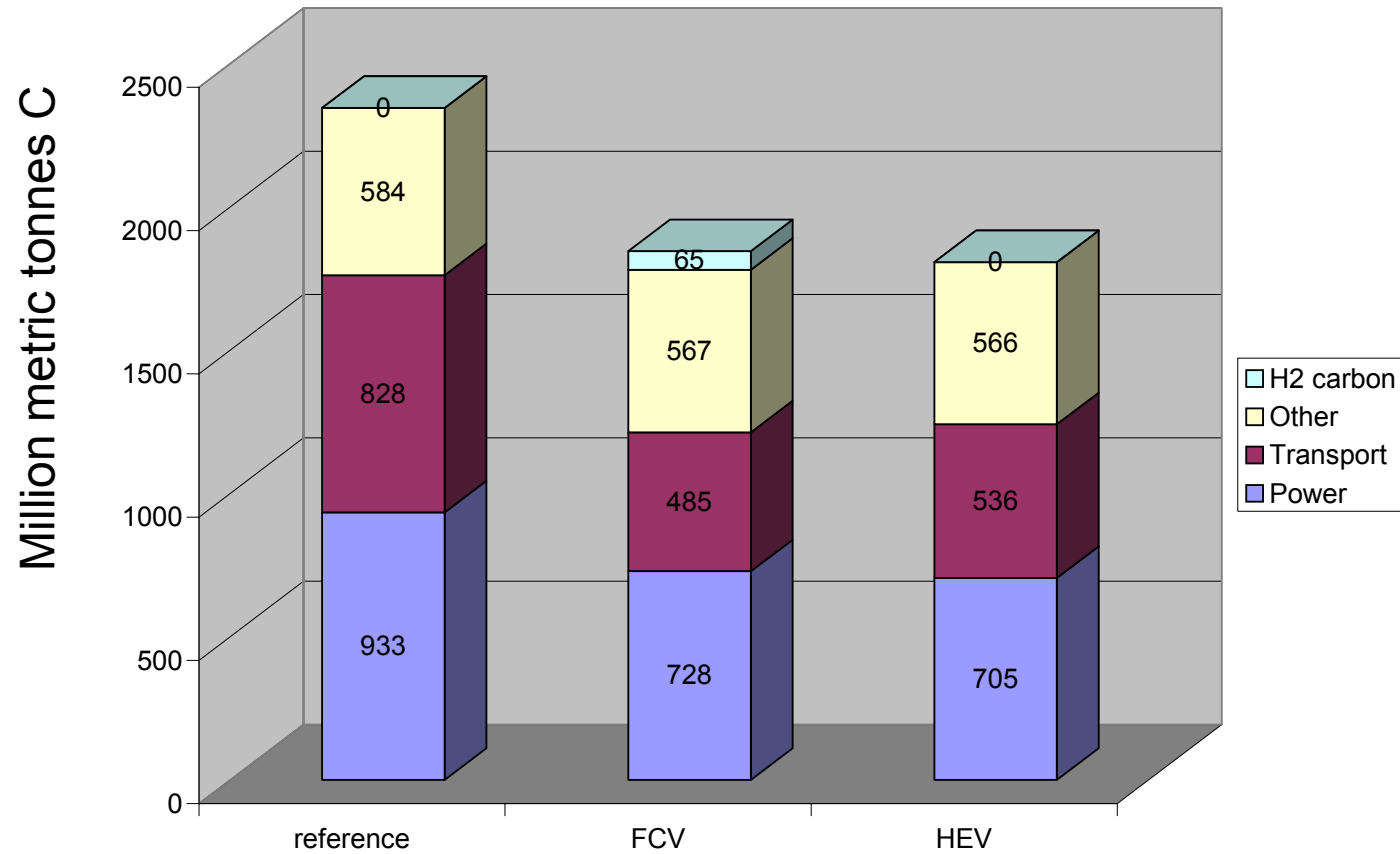


# Petroleum Supply Slate

## Extended Transition



# Carbon Emissions by Sector, year 2040

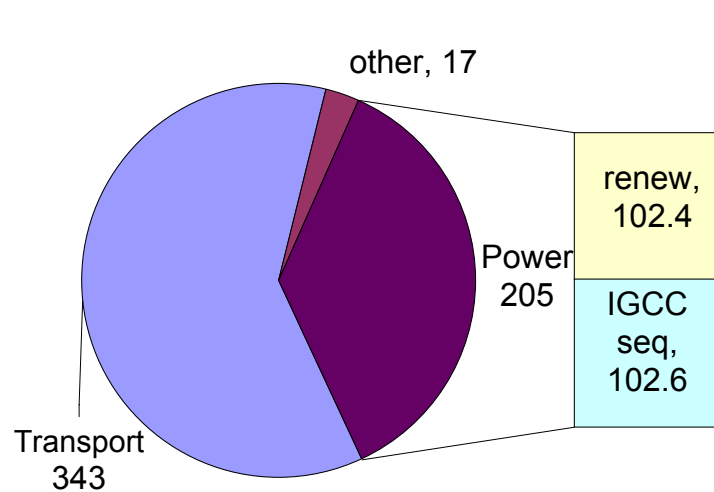


Source: AMIGA Presidential Goals Scenario Runs



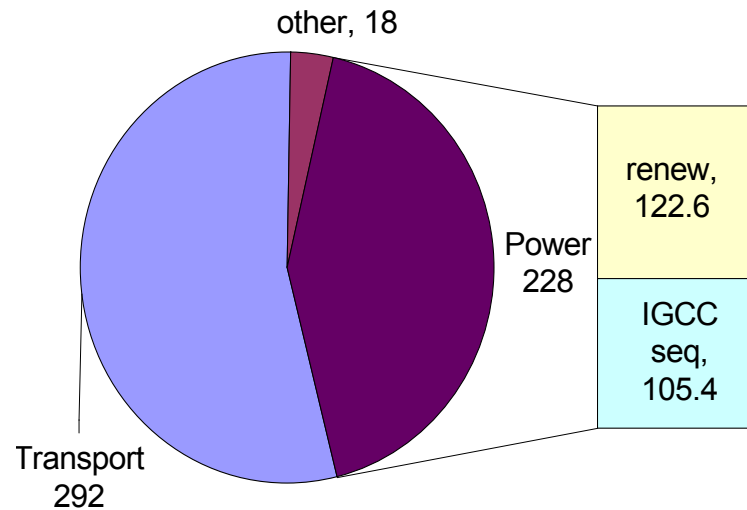
# Reductions in C, target year 2040

FCV Case total: 500 MmtC



Transportation bears larger burden of C reduction in FCV case

HEV Case total: 537 MmtC



Renewable power expansion plays bigger role in C reduction in HEV case

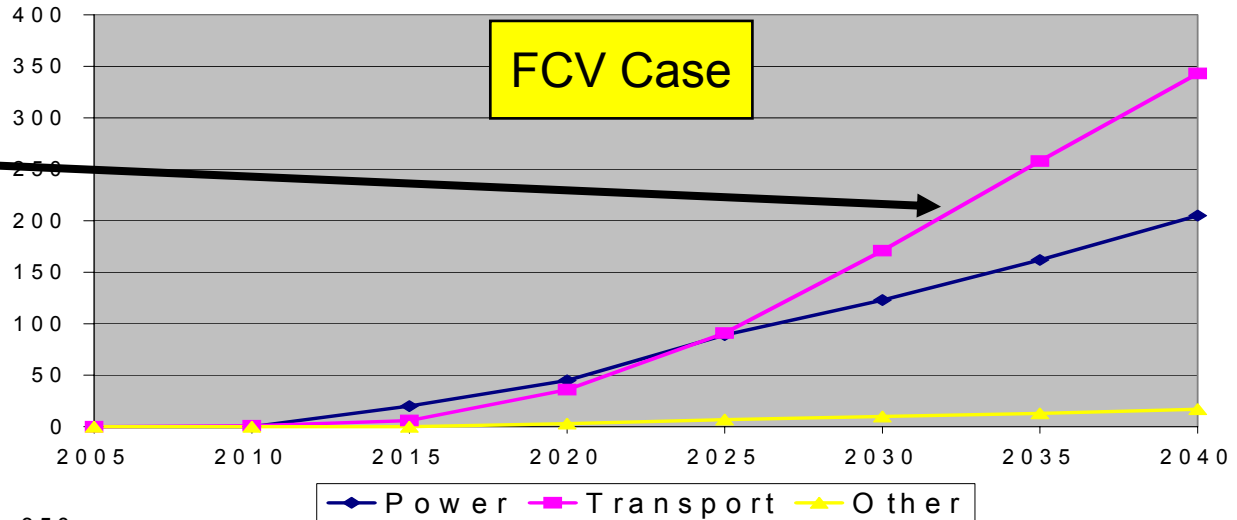


Source: AMIGA Presidential Goals Scenario Runs

# C Reductions over Time

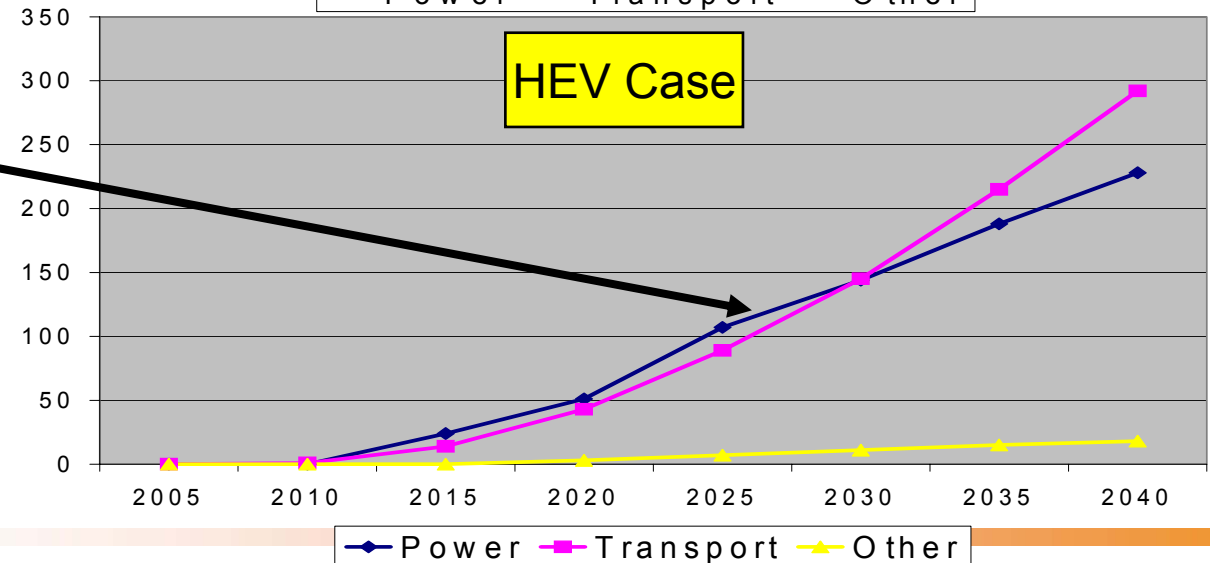
Anti-Smog measures push transport sector in FCV case

Million Metric Tons C

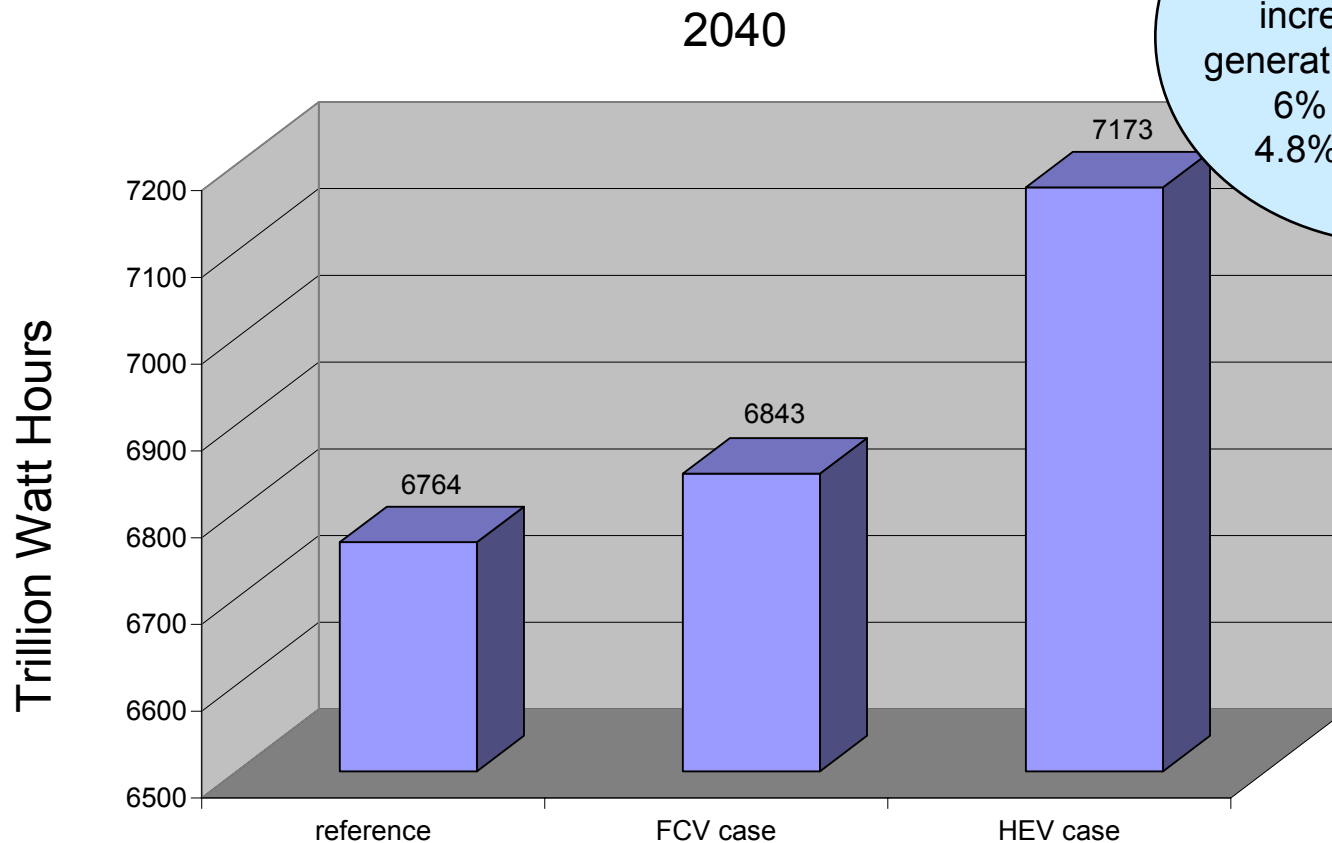


Higher C charge pushes power sector in HEV case

Million Metric Tons C



# Total Electrical Output, Year 2040

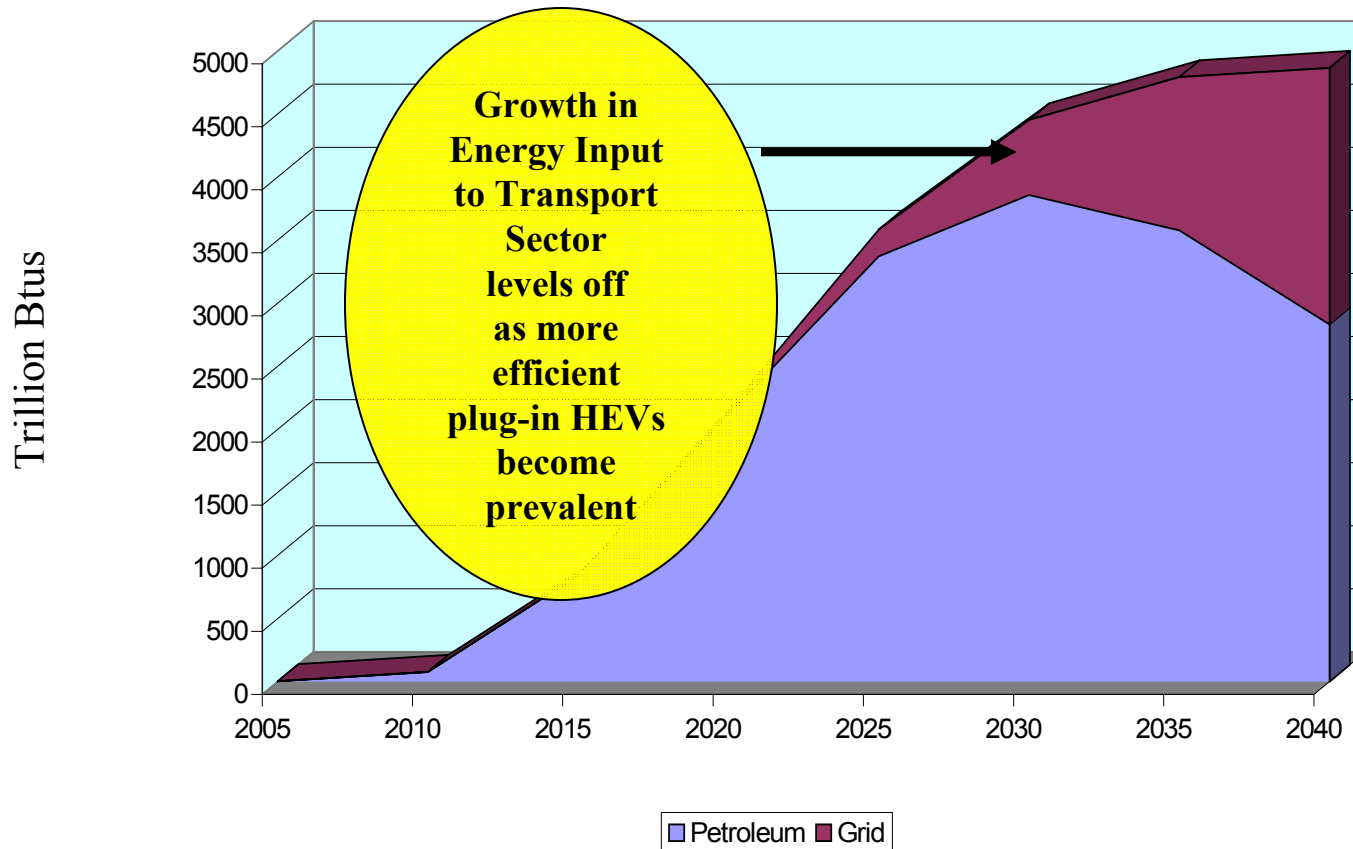


Growth in energy input to transport sector increases overall generation in HEV Case 6% v. reference 4.8% v. FCV case



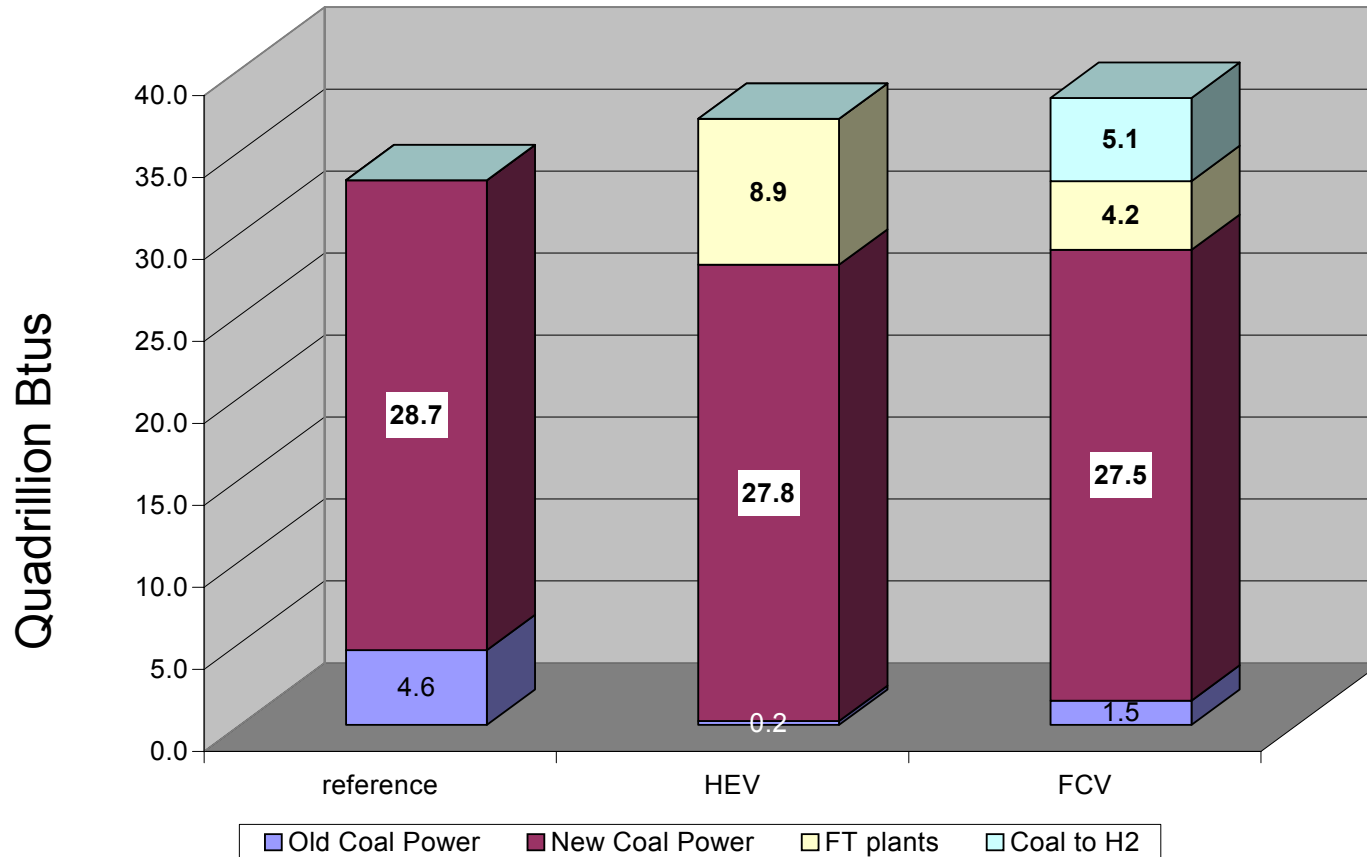
Source: AMIGA Presidential Goals Scenario Runs

# Energy Supply Growth to Vehicles HEV Case



Source: AMIGA Presidential Goals Scenario Runs - HEV case

# Coal Usage – Year 2040



Existing coal generation disappears except in reference case. Advanced coal generation highest in reference case, but coal use 11-15% higher in alternative scenarios due to increased usage in FT plants and coal-to-hydrogen plants



# Observations

- **HEVs are more efficient relative to both conventional ICEs and H<sub>2</sub> FCVs than in the National Academy Study**
- **Higher carbon reduction targets would require more coal plant sequestration**
- **More reduction in petroleum in sectors other than light-duty fleet**
- **Sensitivities could include**
  - constrained oil supplies
  - less efficient advanced vehicles
  - higher carbon reduction targets
  - faster development of coal technologies

