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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Peter C. Balash
Economist
National Energy Technology Laboratory

Disclaimer/acknowledgements

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Dedication

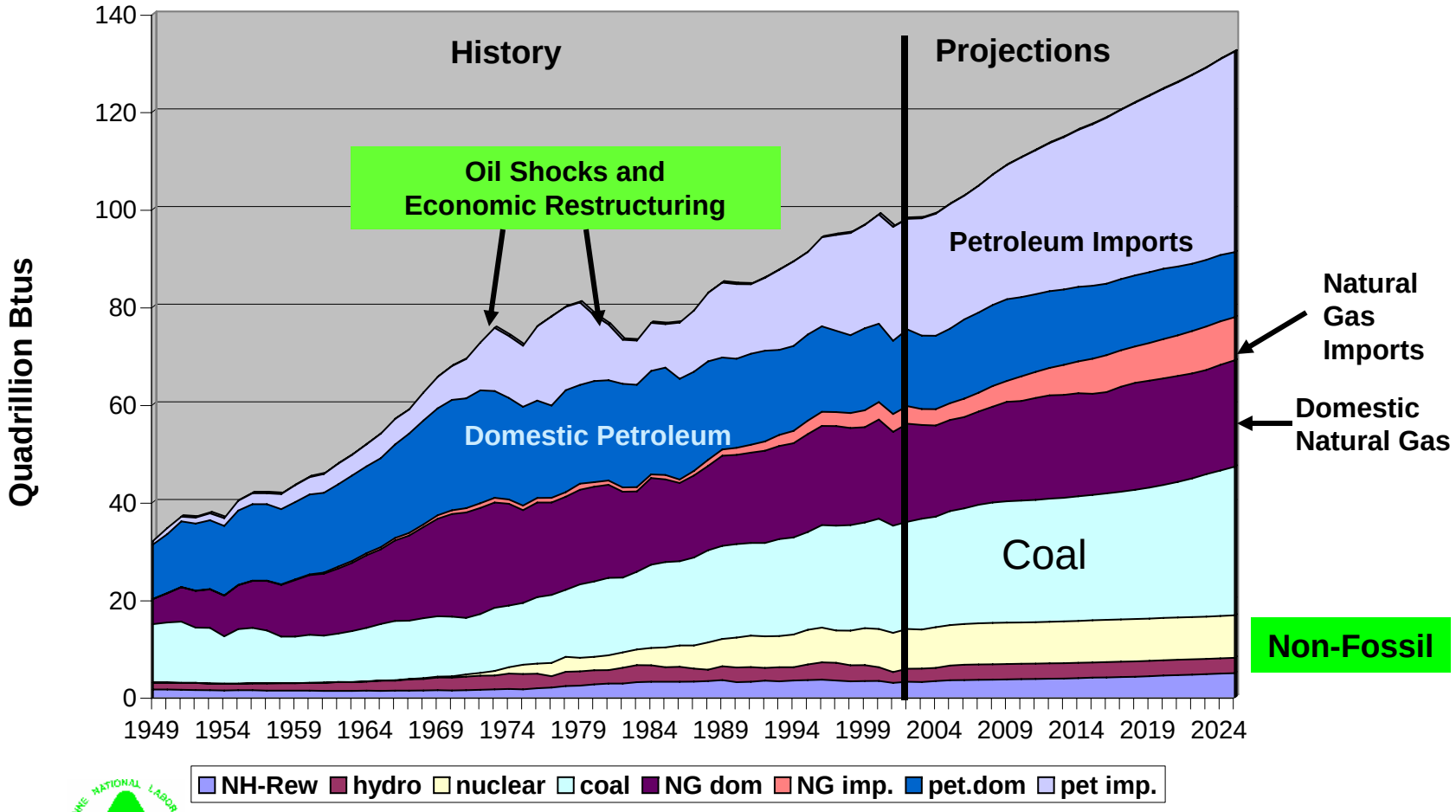
This presentation is dedicated to the memory of John Ruether (1941-2005)

NETL Senior Engineer, friend, colleague, and project inspiration

Can Energy Security and Climate Concerns be Reconciled?

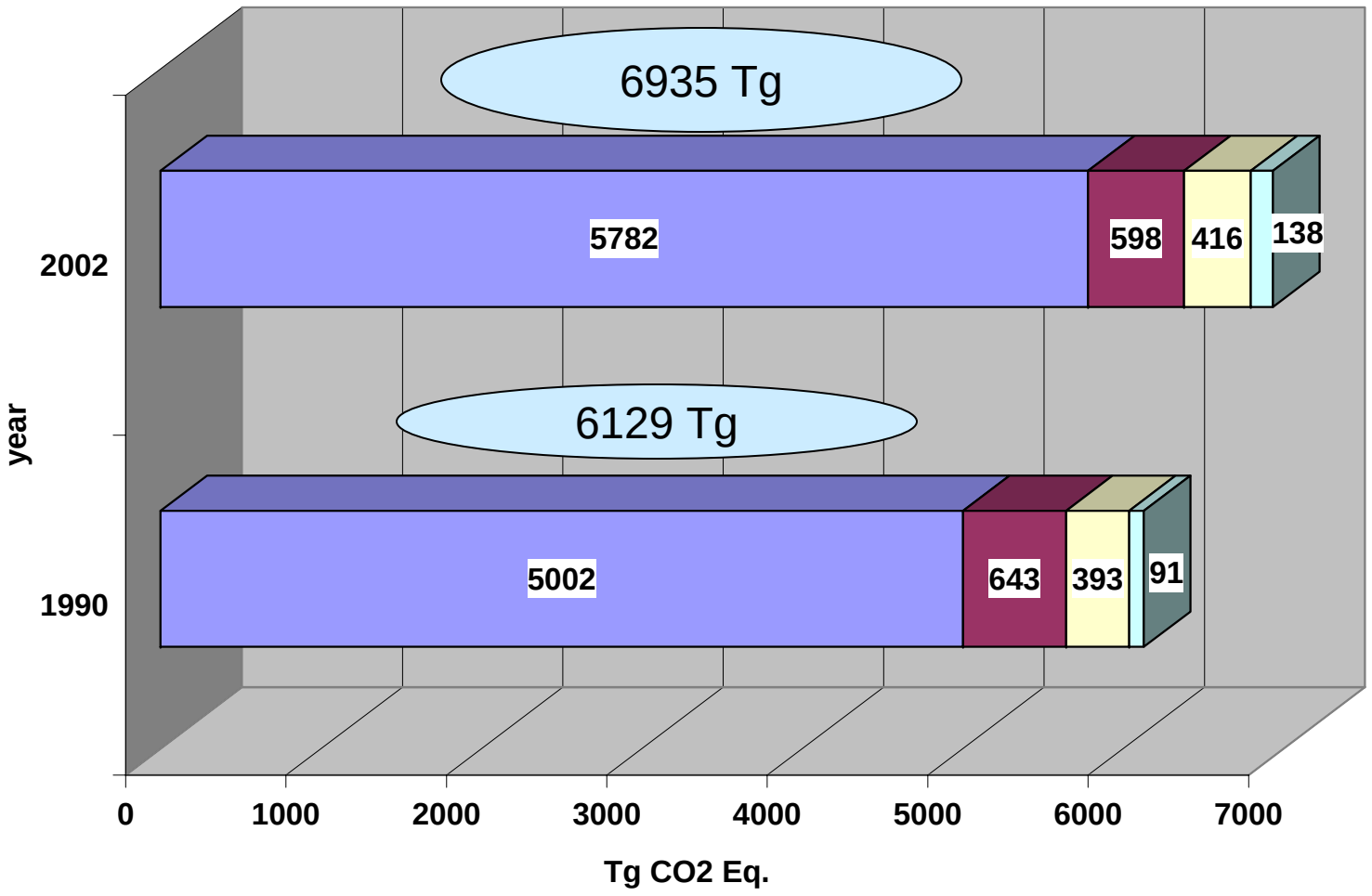
- **President Bush, February 2003:**
  - Reduction of Petroleum Consumption
    - 11 million barrels per day, by 2040
  - Reduction of Carbon Equivalent
    - 500 million metric tons per year, by 2040
- **NETL/ANL Study Assumption**
  - Reductions are from forecasted baseline

US Energy Consumption by Fuel 1949-2025



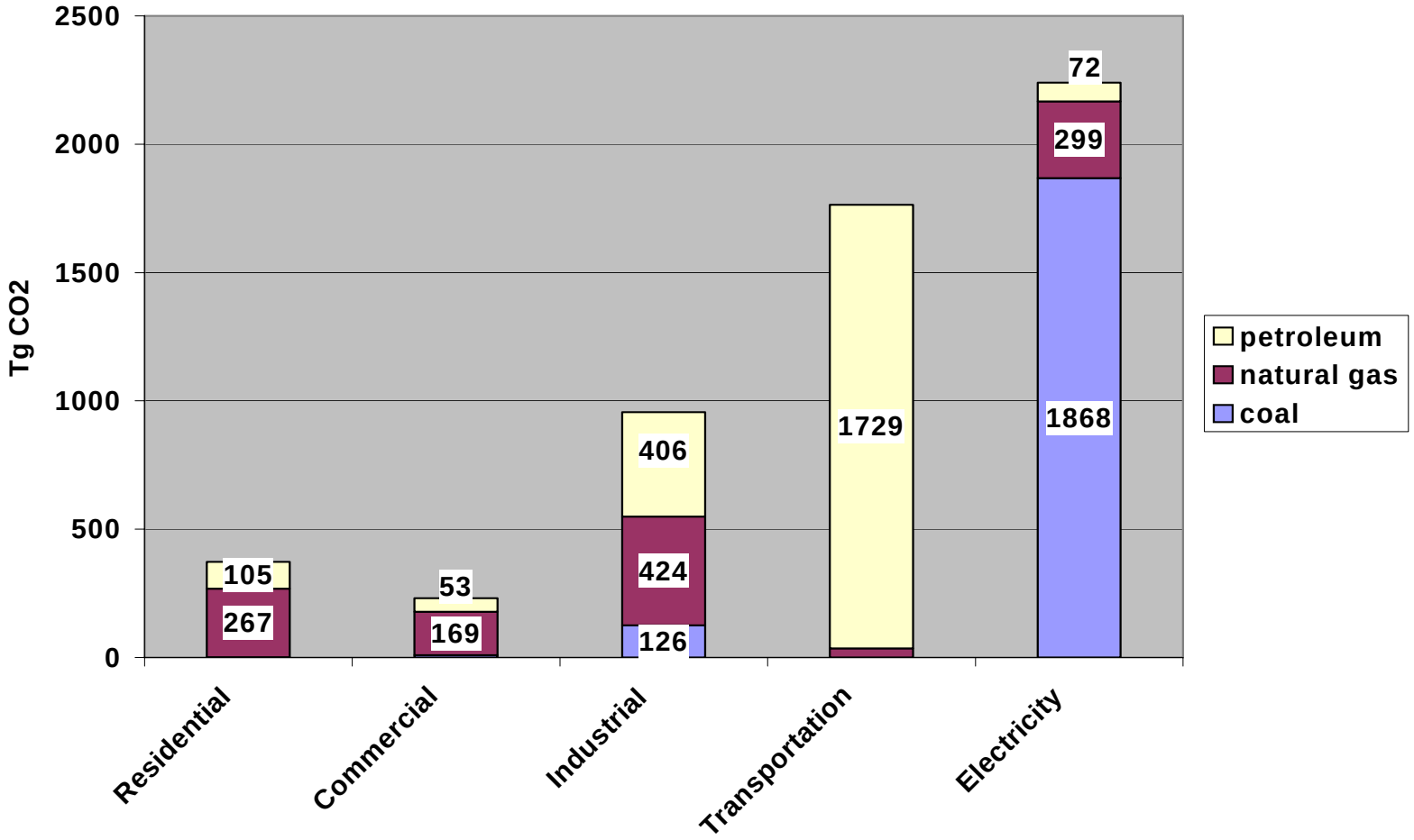
Source: **EIA**; 1948-2003: ***Annual Energy Review 2003***, Table 1.3; 2004-2025: ***Annual Energy Outlook 2005***, Tables 1,2, and 17

US GHG Emissions, 1990-2002



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

2002 US CO_2 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

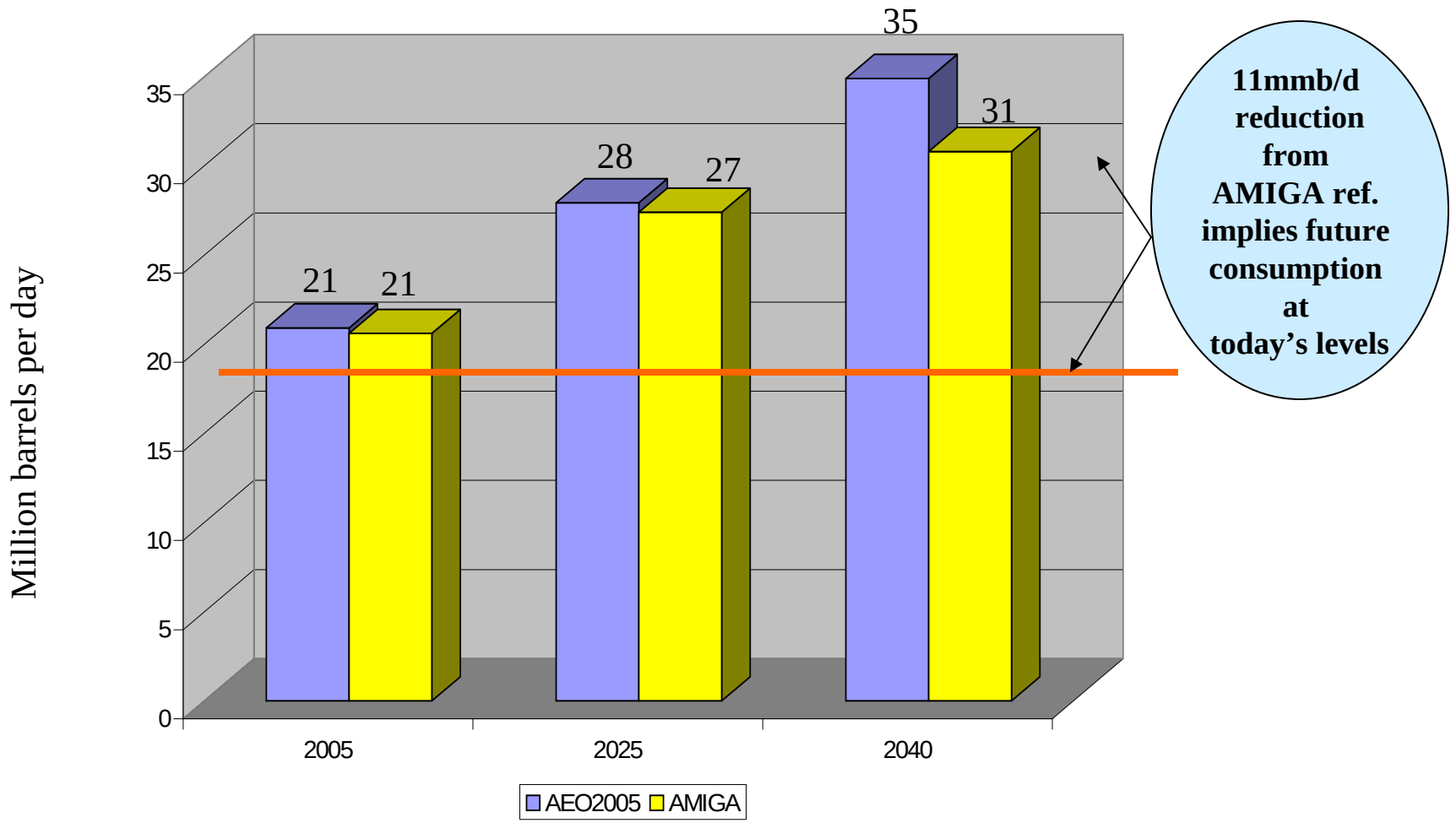
Technical Challenges

- **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

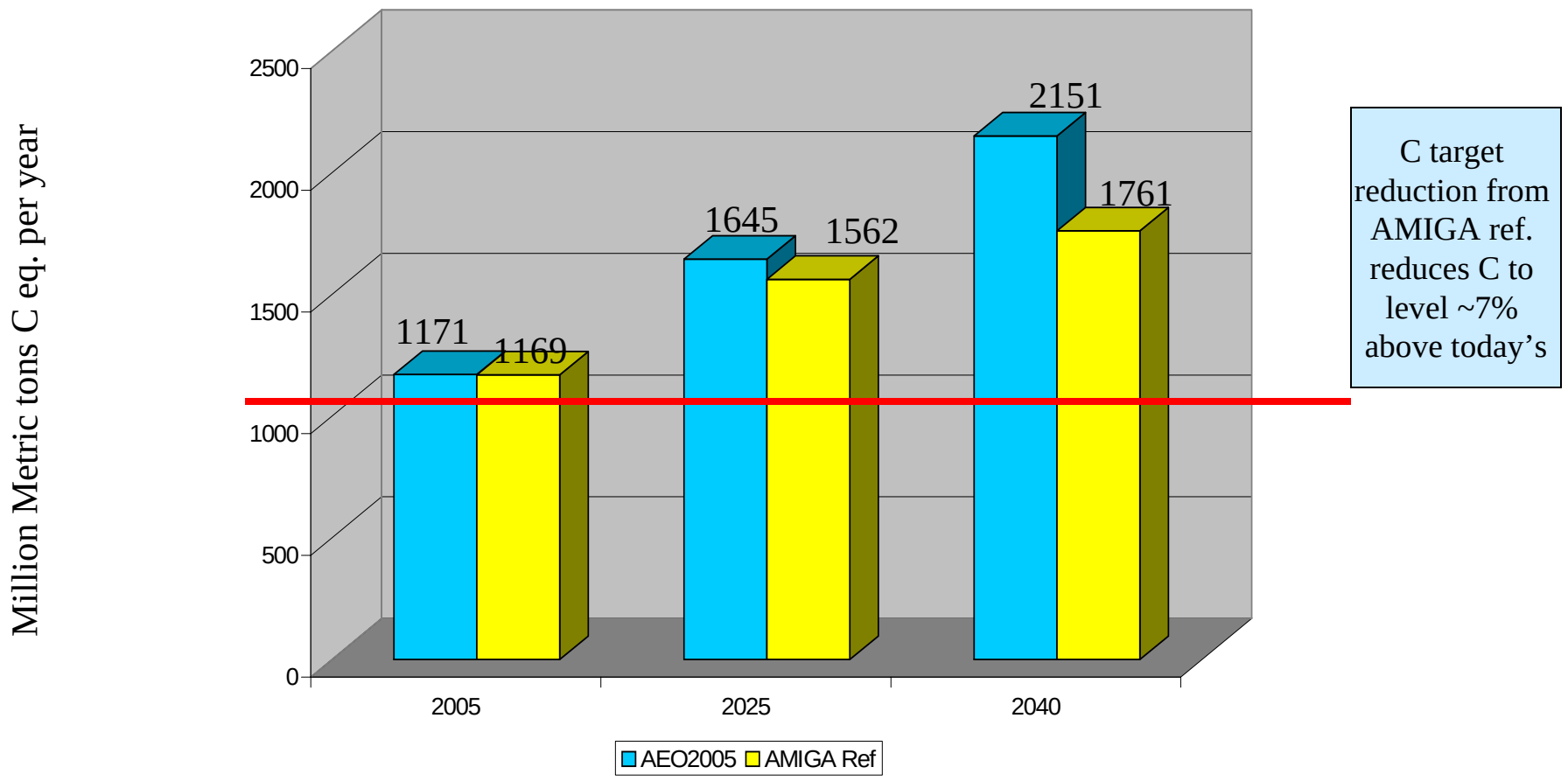
- **Uses Presidential reduction goals as drivers**
  - Reductions from future, not current, levels
  - H2-economy based on FCV a possible means to achieving quantitative goals, not an end in itself
    - As distinct from Academy study (2004)
      - replacement of petroleum-based light-duty vehicle fleet, 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



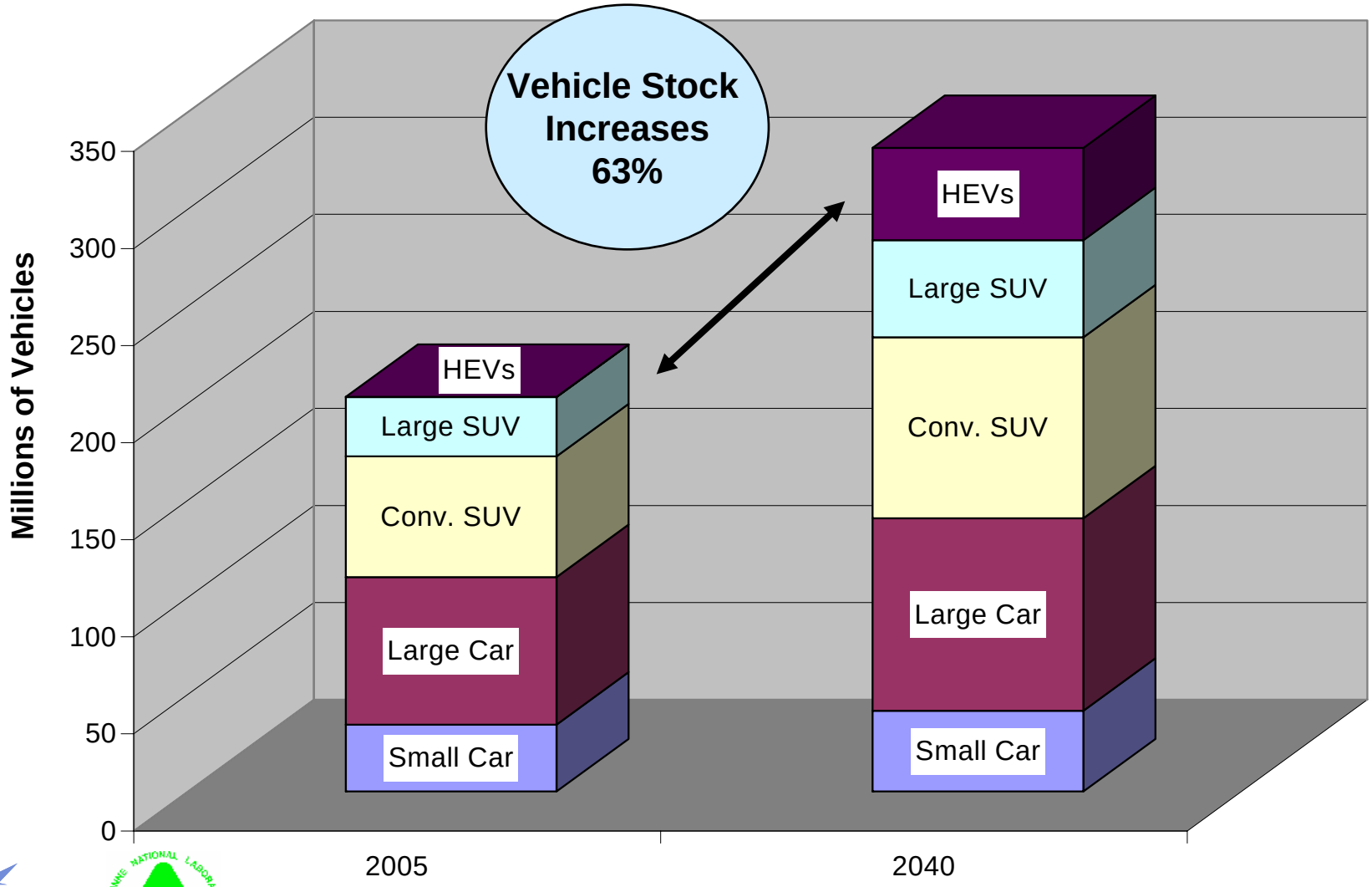
Source: EIA *AEO2005* Yearly Table 11; author extrapolation; AMIGA reference run

Carbon Emissions Target



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

Scale of Challenge



Source: AMIGA Reference Run

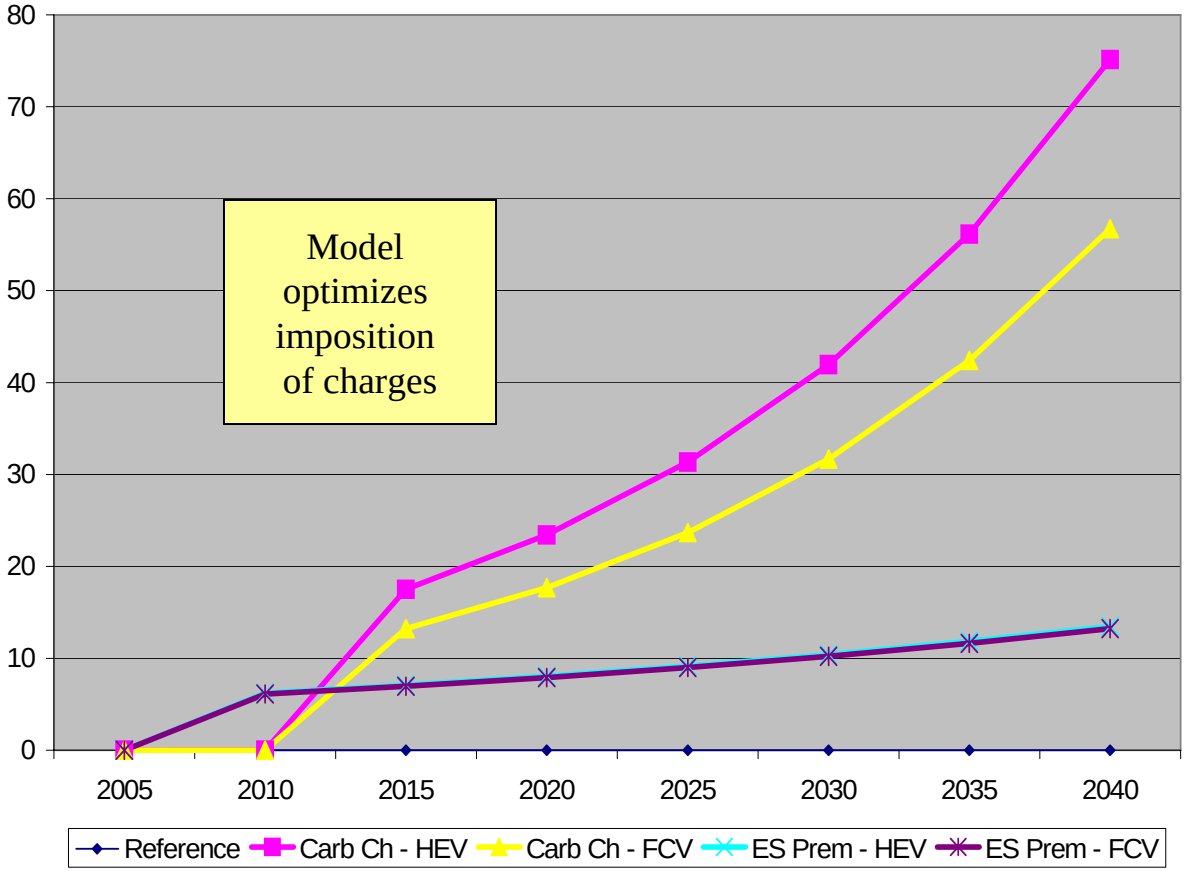
How to Achieve Cuts

Reference Case:	*Extended Transition*	*Hydrogen Achievement*
"Business as usual"	**Hybrid-electric vehicles and Clean Hydrocarbons "HEV case"**	**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_2 Posture Plan guidelines**
"Clear Skies"-Like Emissions Targets	**Energy Security Charges on premium fuels from 2010**	**H_2A program (DOE EE) H_2 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

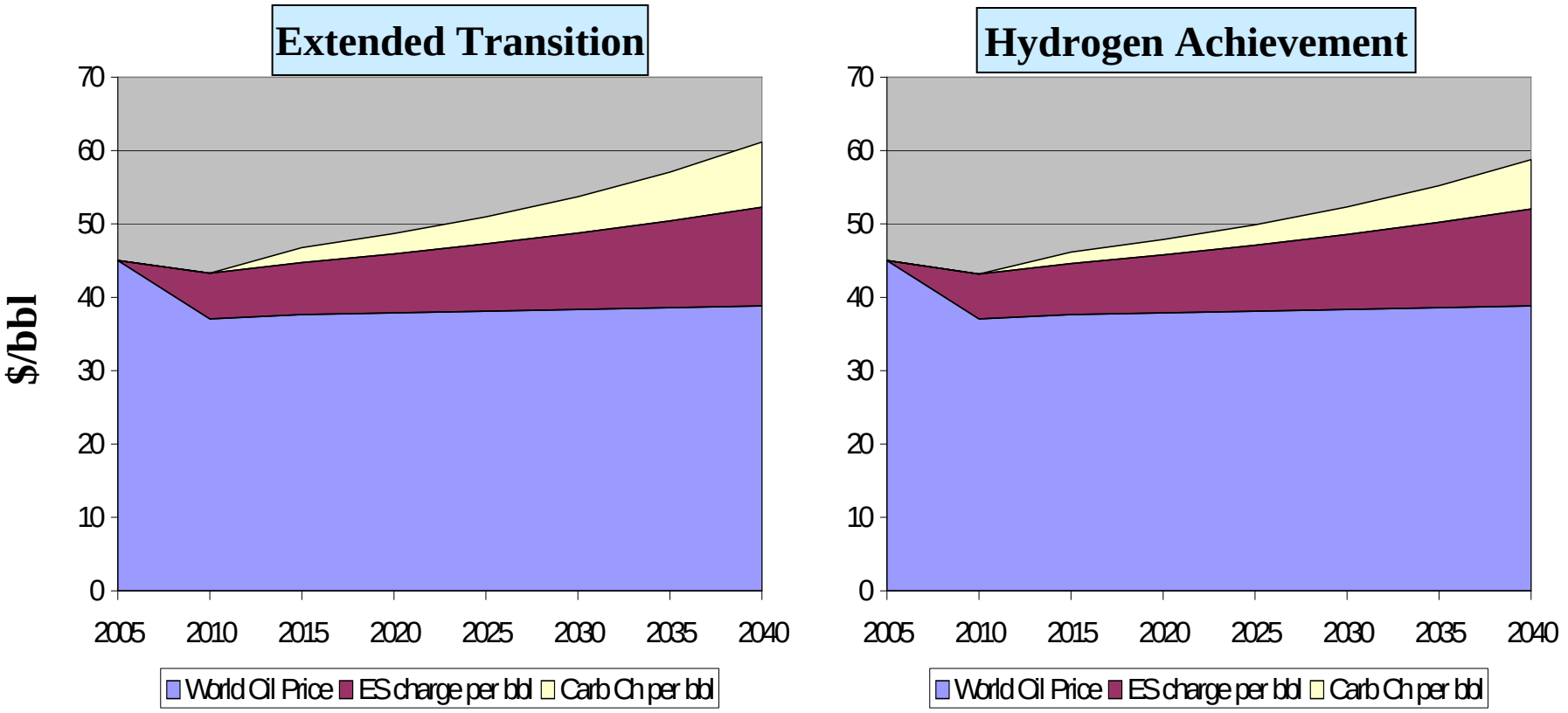
$ per metric ton C;
$ per barrel oil



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

Source: AMIGA Presidential Goals Scenario Runs

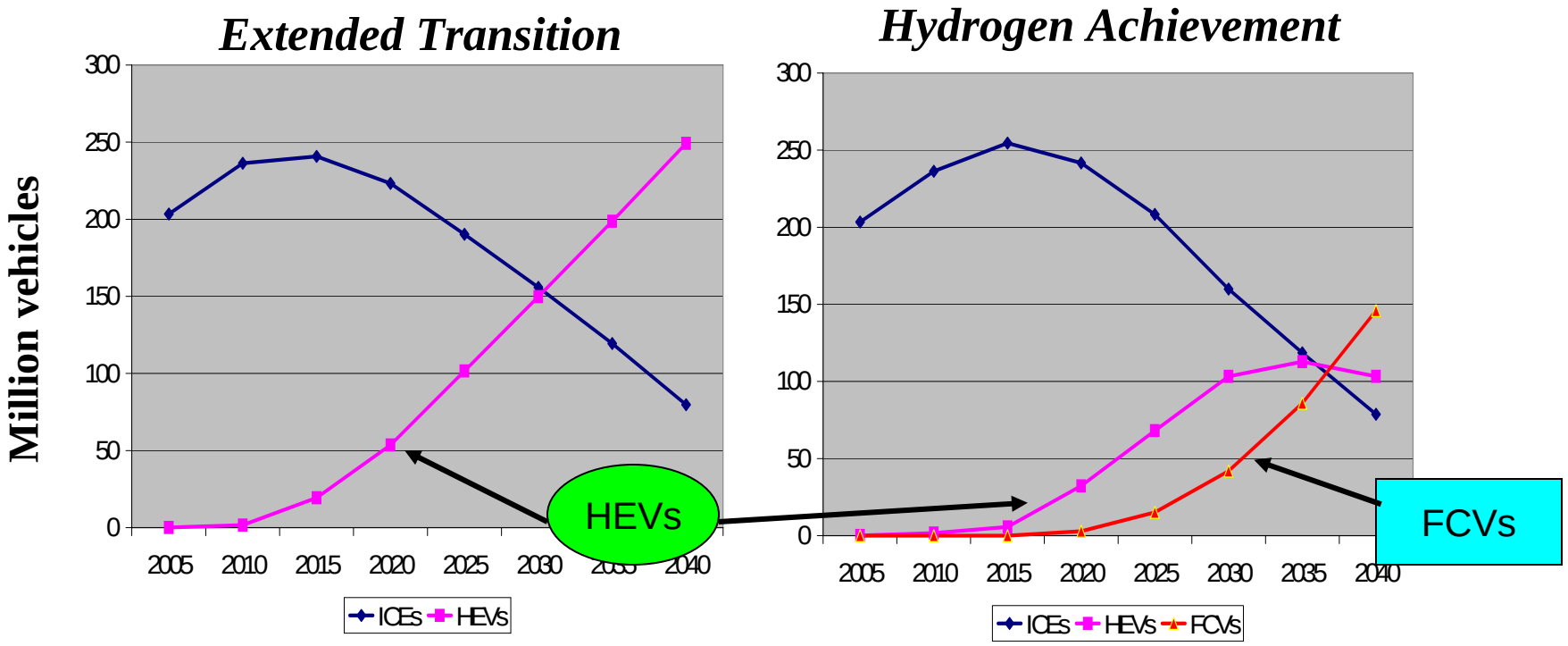
Effective Oil Prices



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

Source: AMIGA Presidential Goals Scenario Runs

Vehicle Stocks

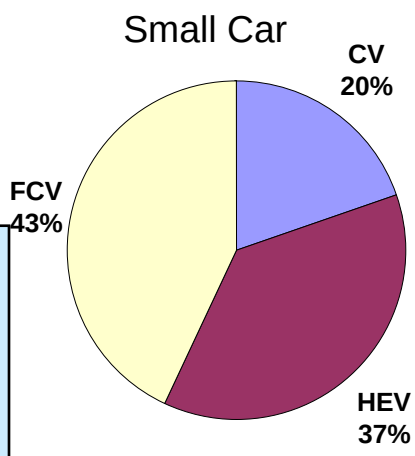


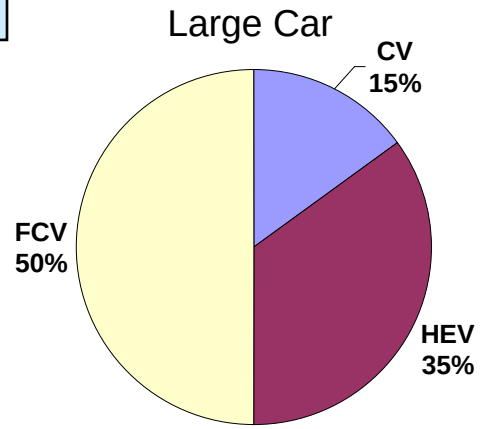
Source: AMIGA Presidential Goals Scenario Runs

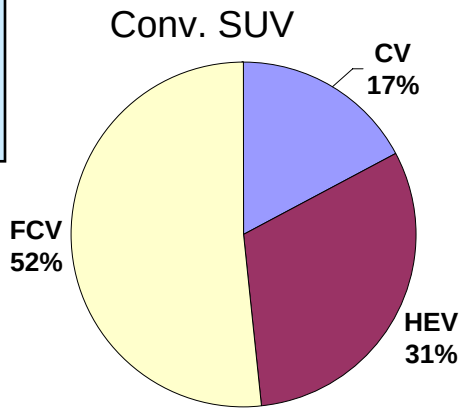
Distribution of Vehicle Types in FCV Case

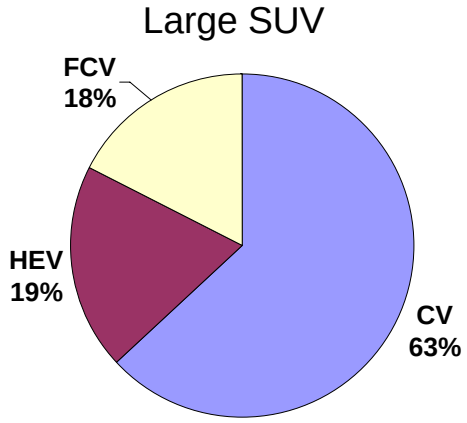
YEAR 2040

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



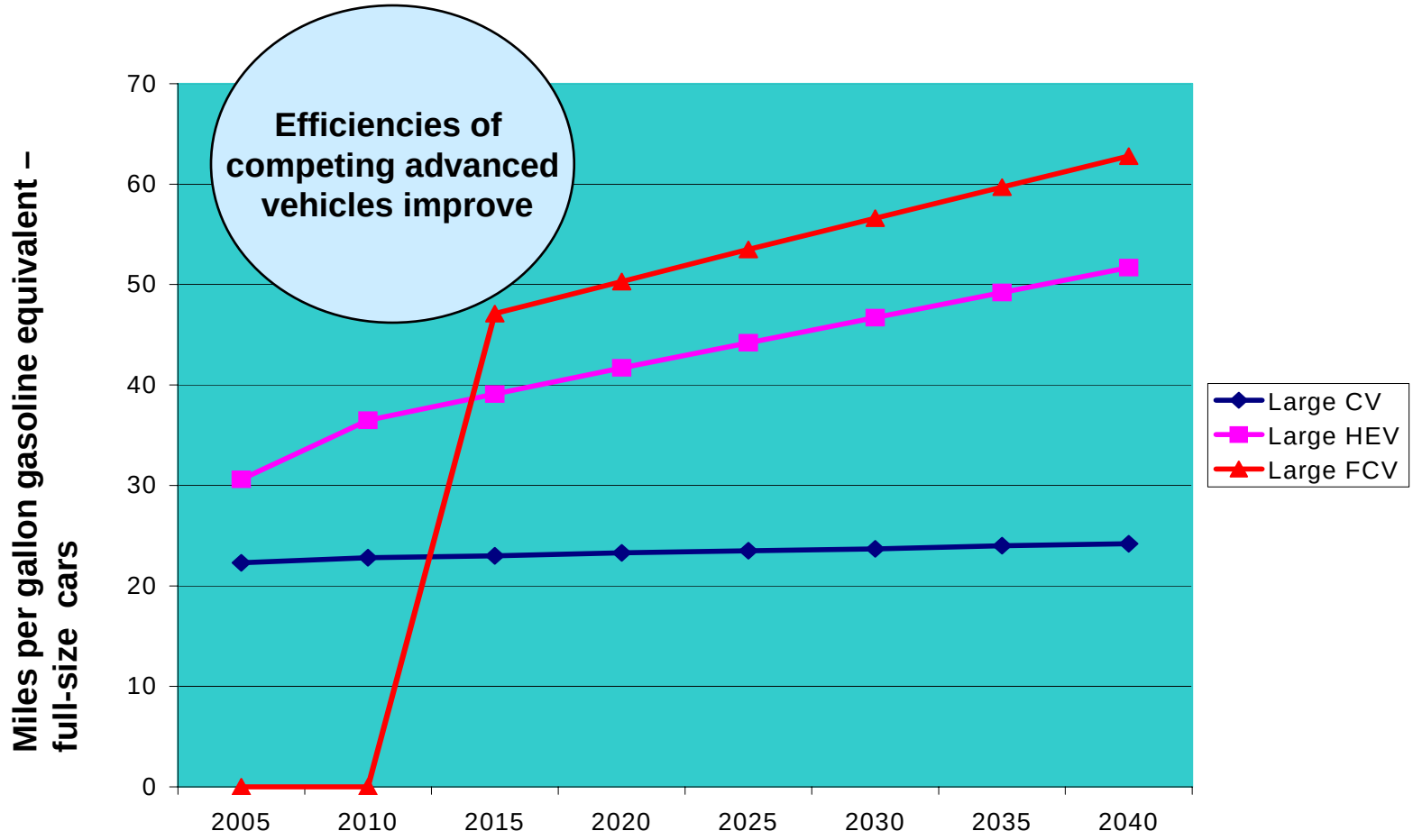






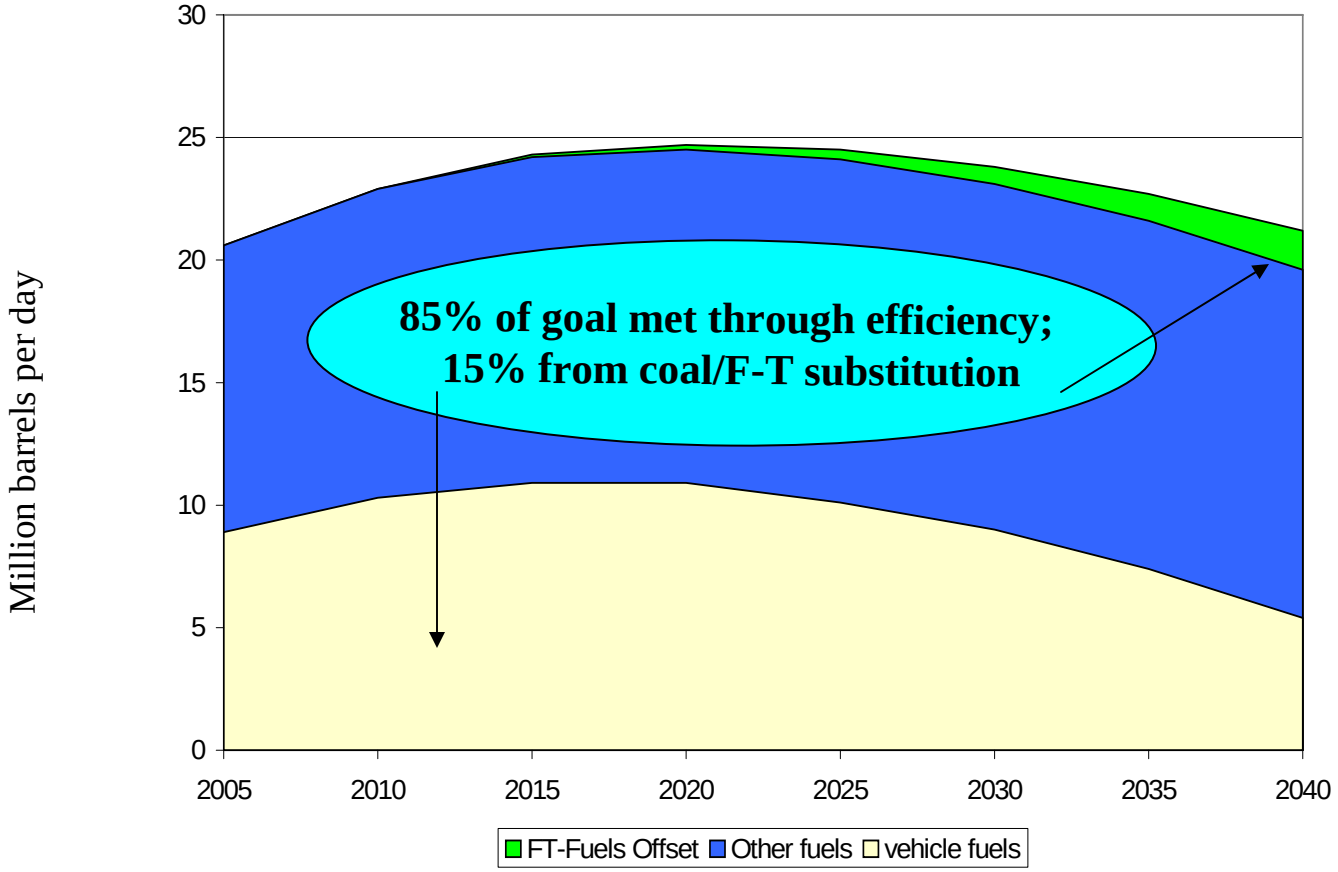
Source: AMIGA Presidential Goals Scenario Runs, FCV Case

Mileage, Full-size Cars, *Hydrogen Achievement*



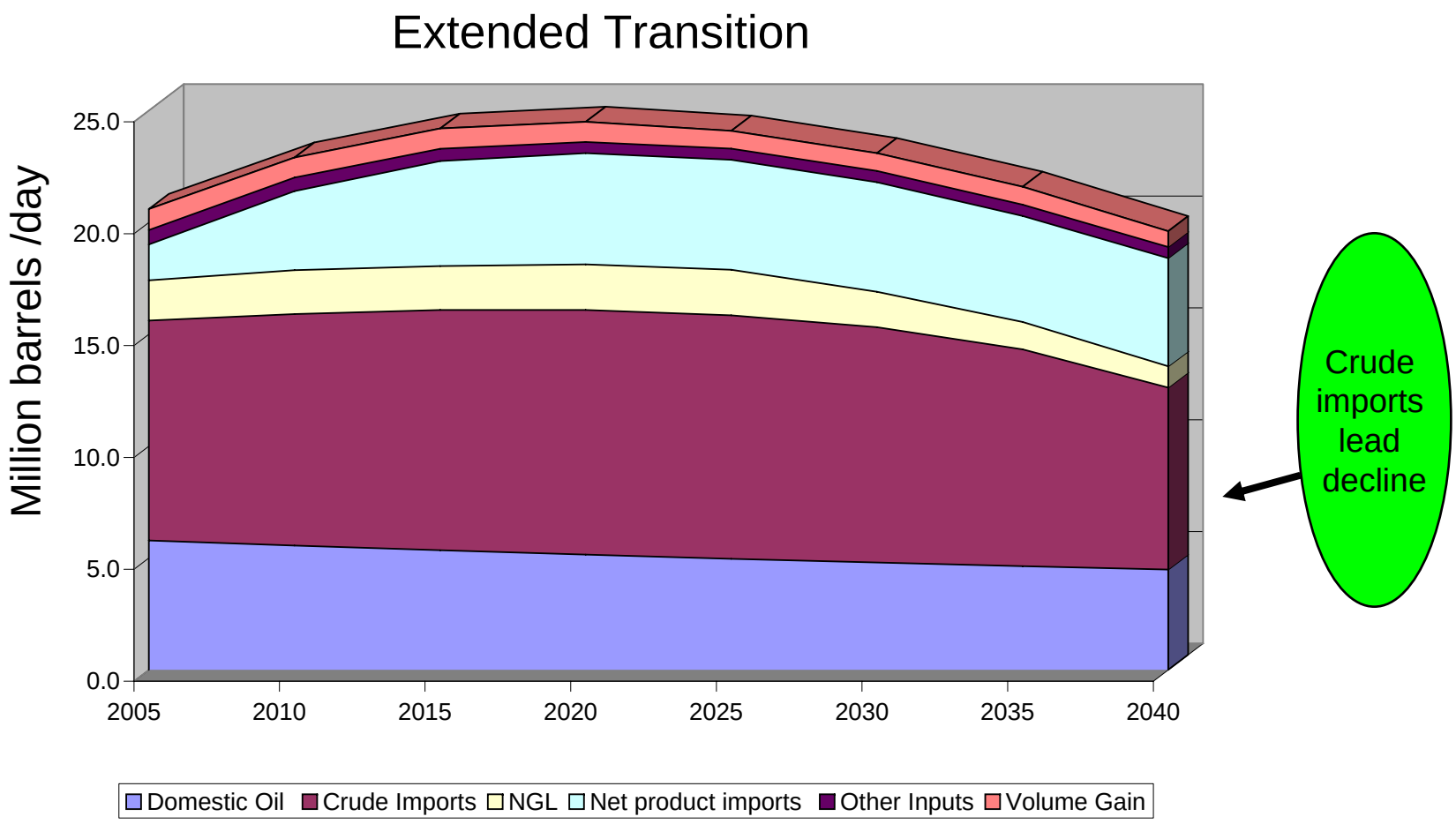
Source: AMIGA Presidential Goals Scenario Runs

Reduced Petroleum Consumption

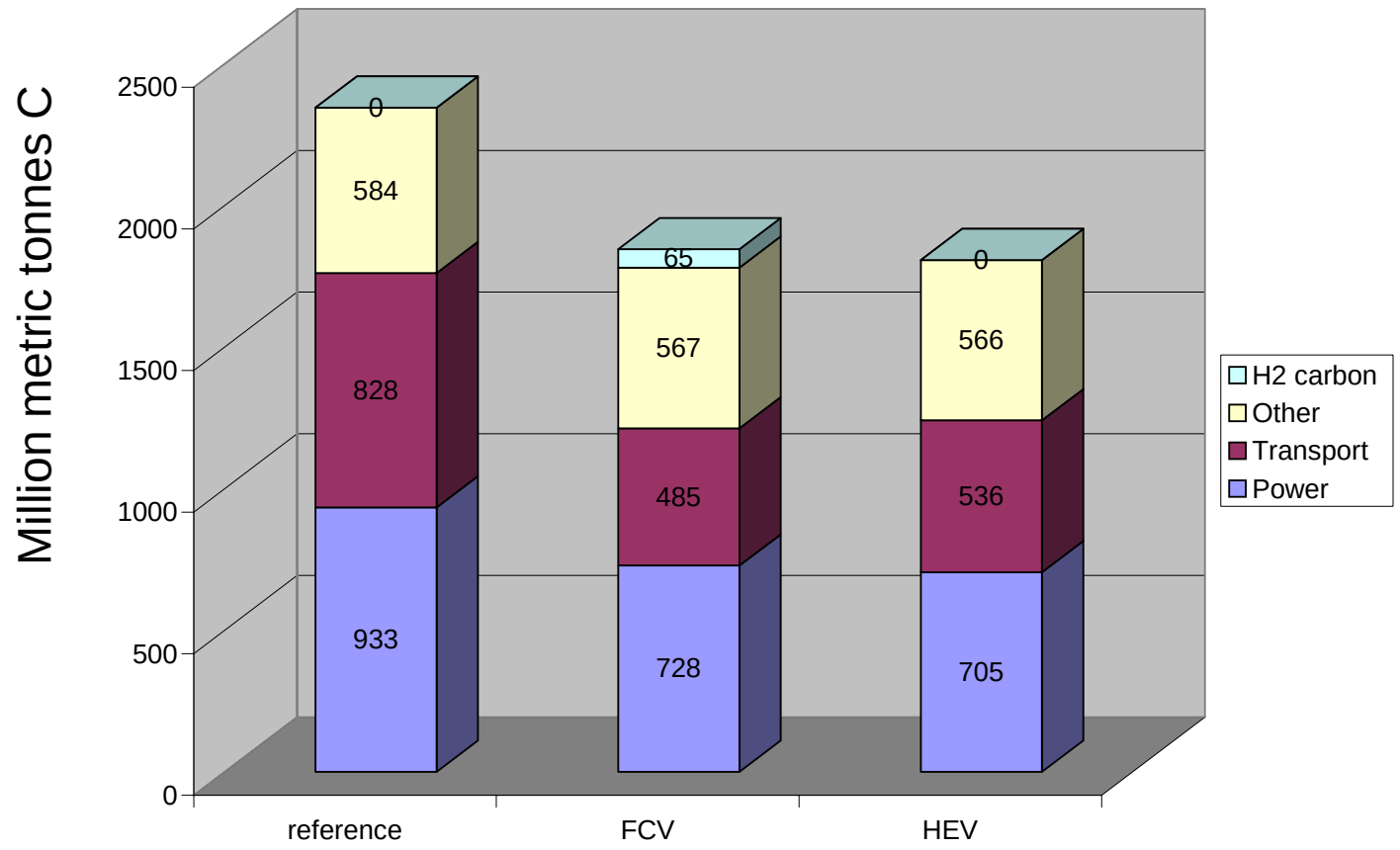


Source: AMIGA Presidential Goals Scenario Runs - HEV case

Petroleum Supply Slate



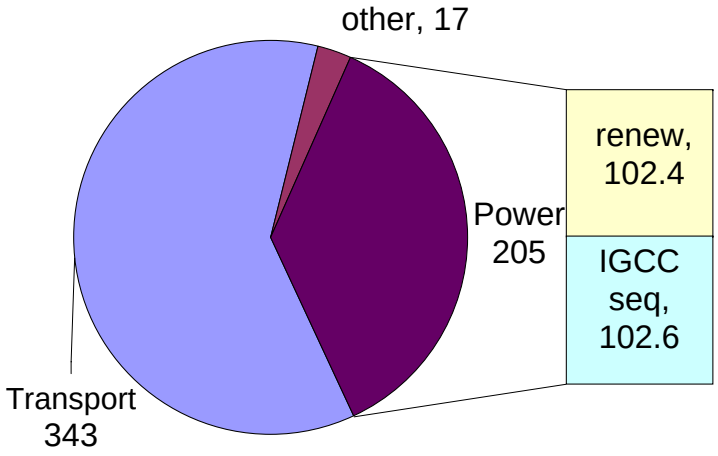
Carbon Emissions by Sector, year 2040



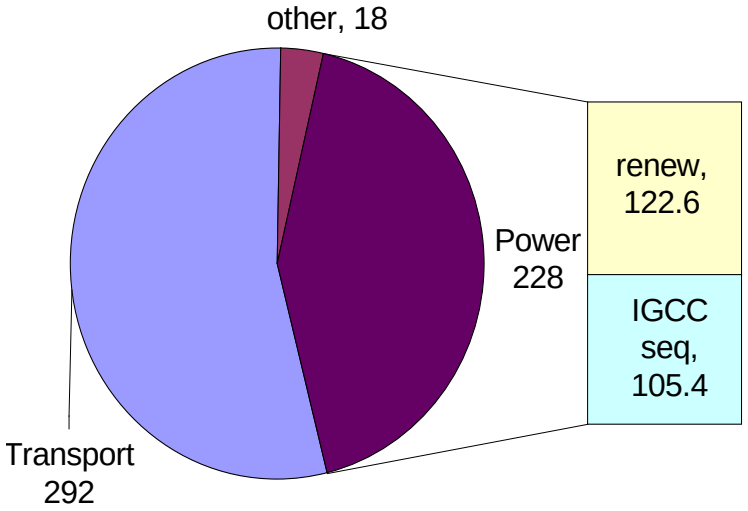
Source: AMIGA Presidential Goals Scenario Runs

Reductions in C, target year 2040

FCV Case total: 500 MmtC



HEV Case total: 537 MmtC



Transportation bears larger burden of C reduction in FCV case

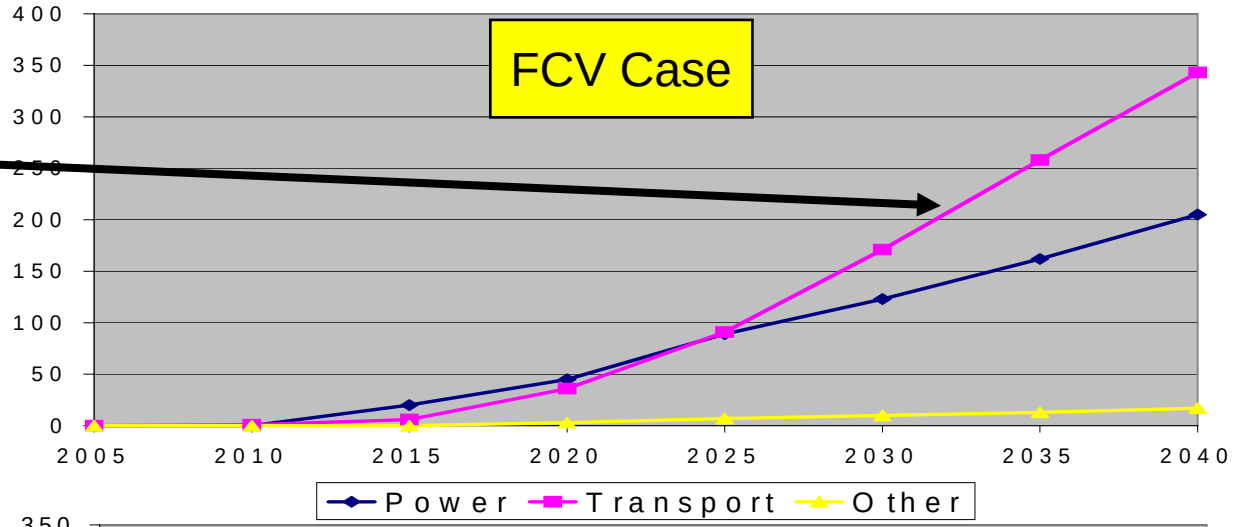
Renewable power expansion plays bigger role in C reduction in HEV case

Source: AMIGA Presidential Goals Scenario Runs

C Reductions over Time

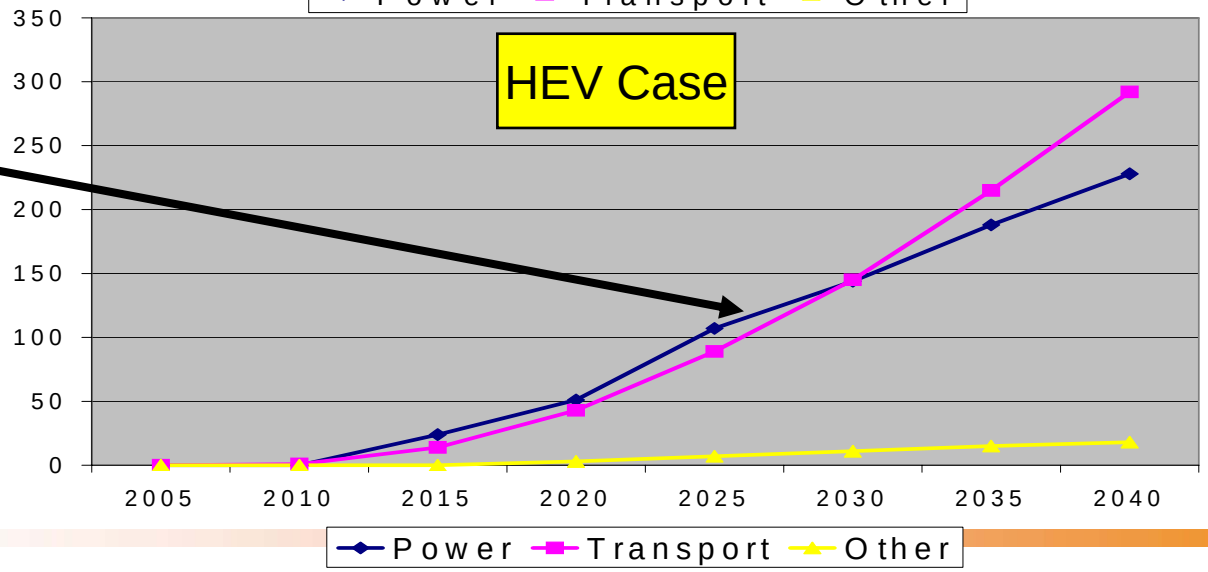
Anti-Smog measures push transport sector in FCV case

Million Metric Tons C



Higher C charge pushes power sector in HEV case

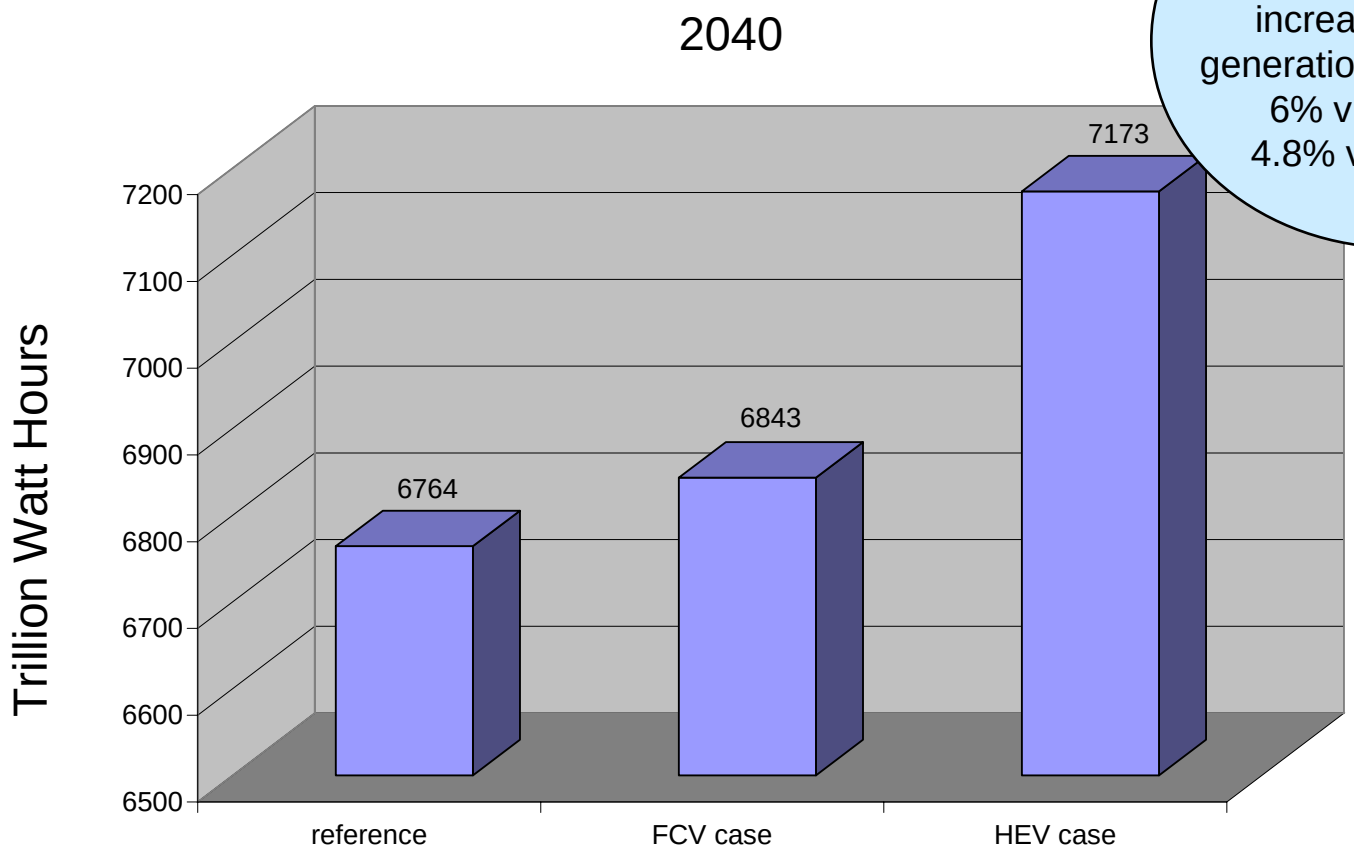
Million Metric Tons C



Source: AMIGA Presidential Goals Scenario Runs

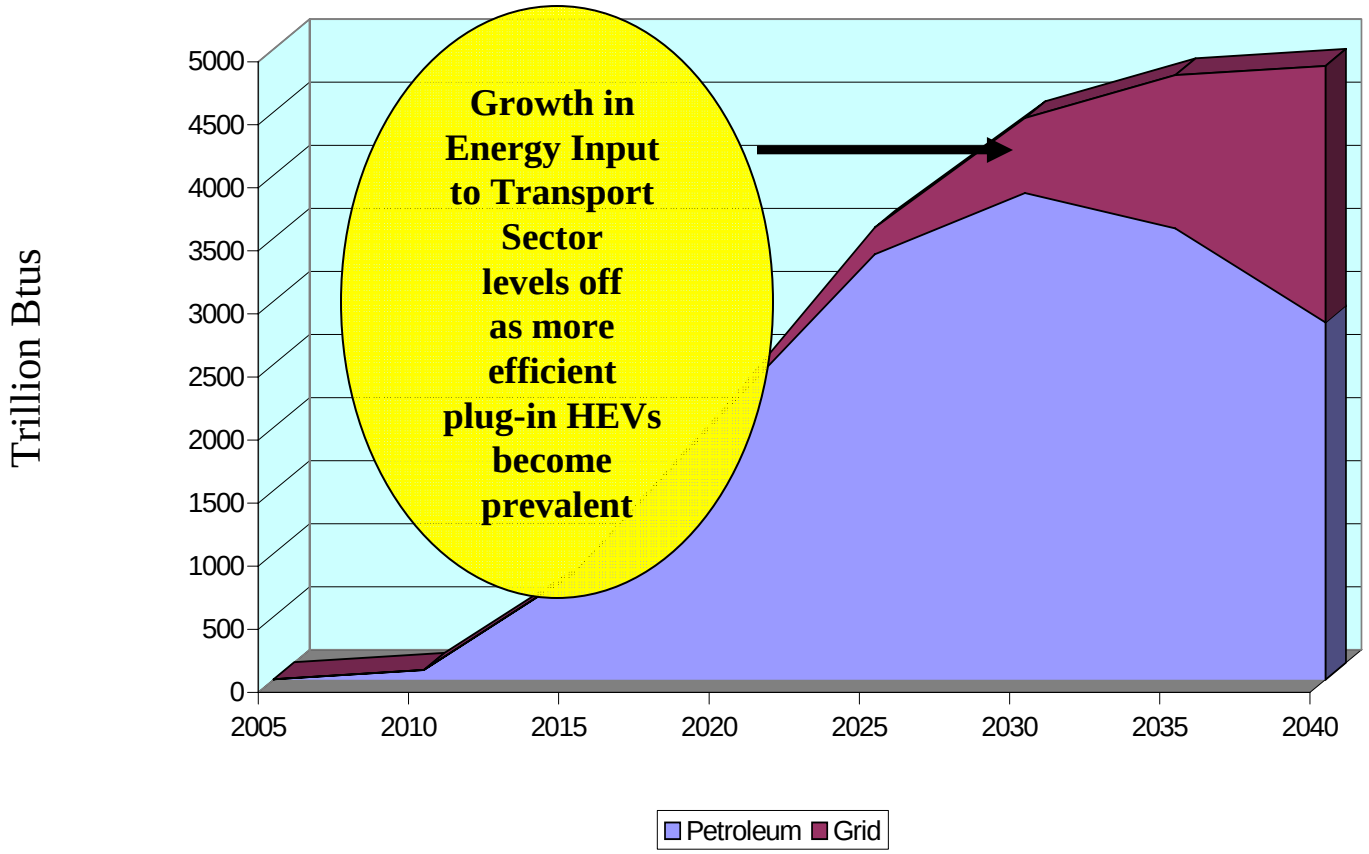
Total Electrical Output, Year 2040

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



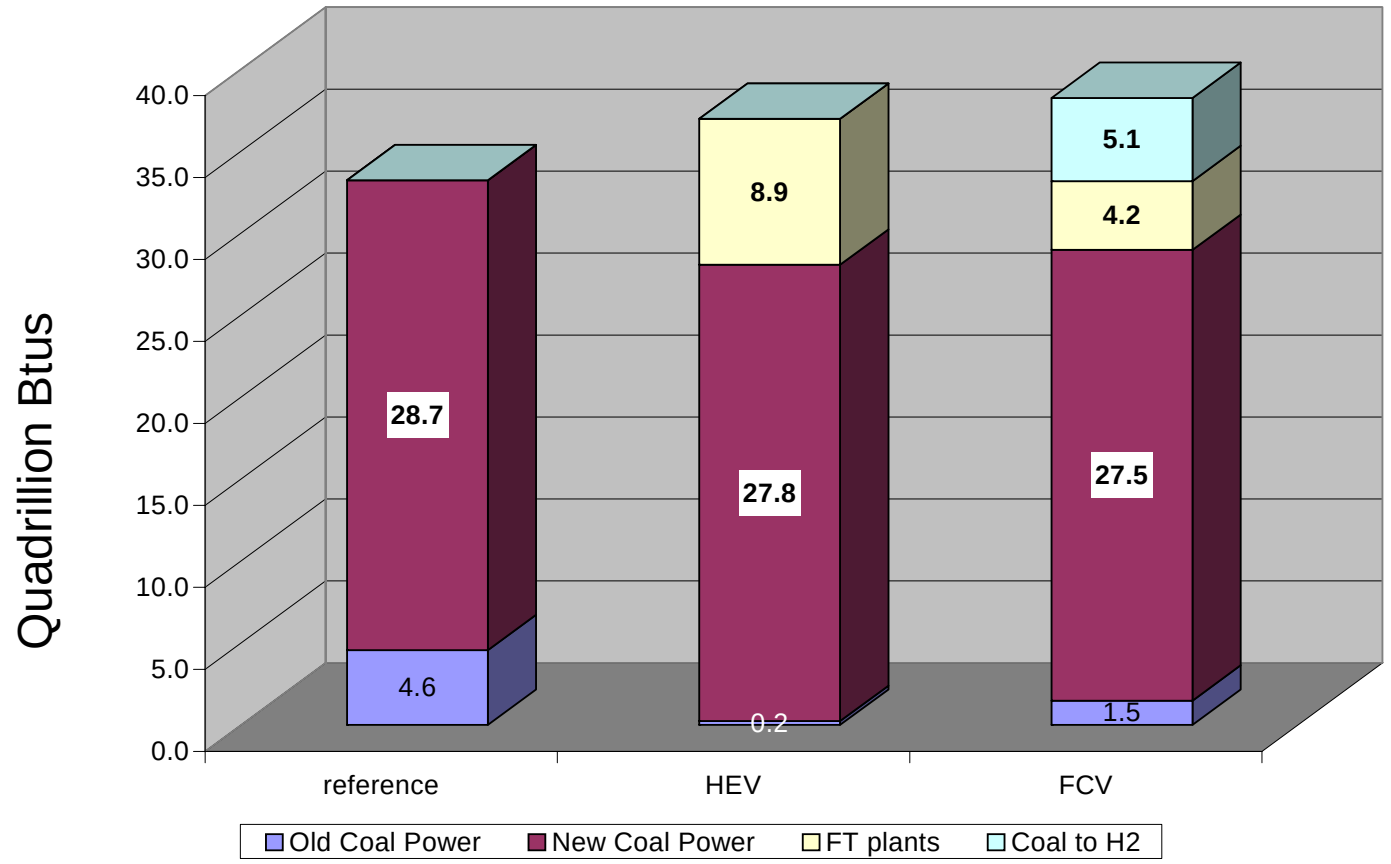
Source: AMIGA Presidential Goals Scenario Runs

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

Source: AMIGA Presidential Goals Scenario Runs

Observations

- **HEVs are more efficient relative to both conventional ICEs and H_2 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