Transportation Technologies:
Which Goal?
Which Transition?

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Economics of Technologies
to Combat Global Warming
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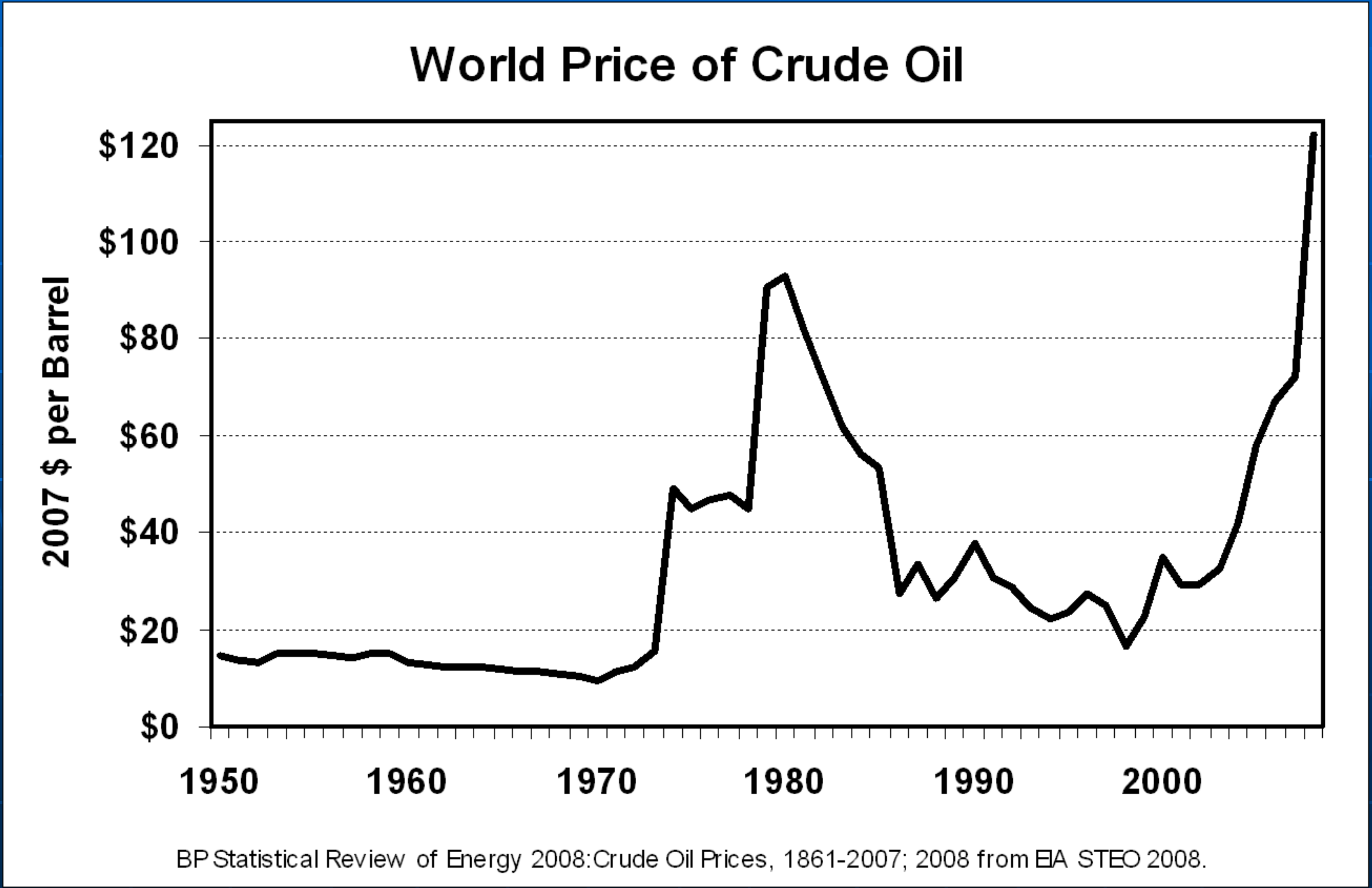
For countries like the US and China, oil security seems to be as important an objective as climate protection.

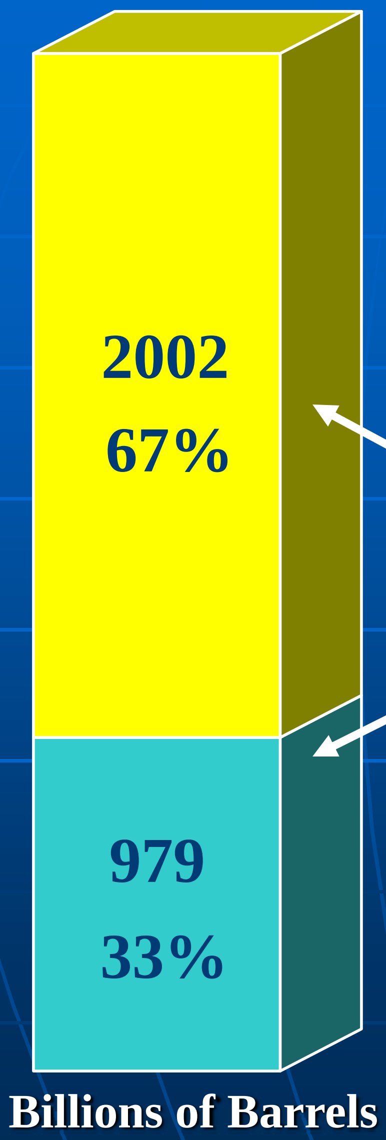
"The real problem we face over oil dates from after 1970: a strong but clumsy monopoly of mostly Middle Eastern exporters operating as OPEC." Prof. M. Adelman, MIT, 2004.



Today, there are no proven technological solutions.

- Energy efficiency:
  - 2X or 3X for passenger vehicles requires weight reduction, improved batteries, advanced engines.
  - Other half of transportation energy use has perhaps half the energy efficiency potential.
  - More efficient transport systems seem necessary
- Biofuels:
  - What is the efficient system: cellulosic ethanol or jet fuel, what produced where?
- Reductions of 50-80% over 2005 will require:
  - Electricity from a low-C grid
  - Hydrogen from low-C sources
  - Almost certainly requires CCS

The RATE of world oil use is alarming.



The 2007 Nat'l Petroleum Council Report, "Hard Truths", expects 1.1 trillion barrels of oil production over the next 25 years. More than consumed in in all of human history.

Remaining recoverable crude oil*

Cumulative Production to end of 2005

Cumulative Production to the end of 1995 was 710. Over ¼ of all oil ever consumed was consumed in the last 10 years.

USGS

* From USGS 2000, USGS 1995, and MMS 1996

Which transition?

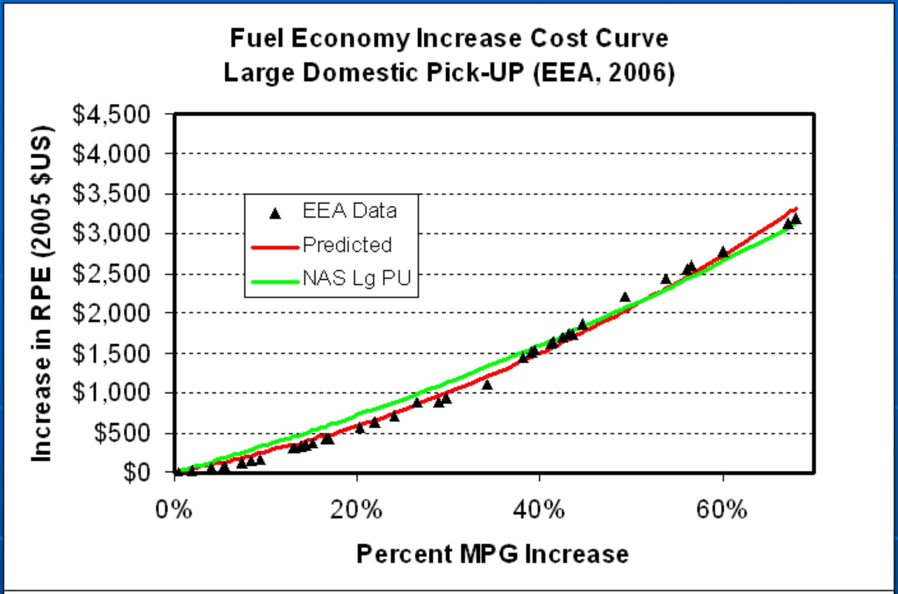
- To Unconventional Fossil Energy
  - Modest to dramatic efficiency gains
  - 10-20% biofuels
- To electricity, hydrogen or both
  - Dramatic efficiency improvements
  - Advanced electric drive technologies
  - New transportation energy infrastructure
  - Renewable primary energy or CCS or both

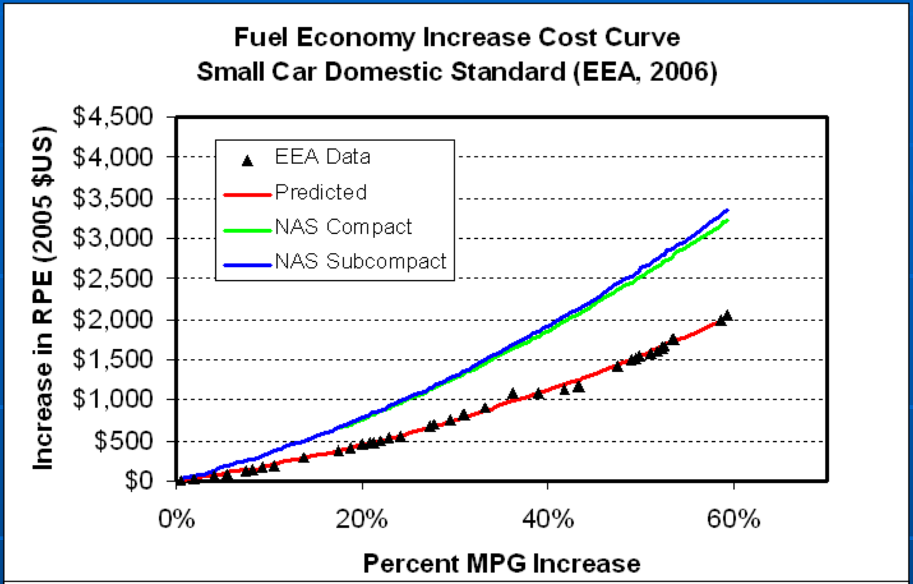
The 40% light-duty vehicle fuel economy improvement required by the EISA of 2007 essentially exhausts the store of proven conventional gasoline ICE technologies.

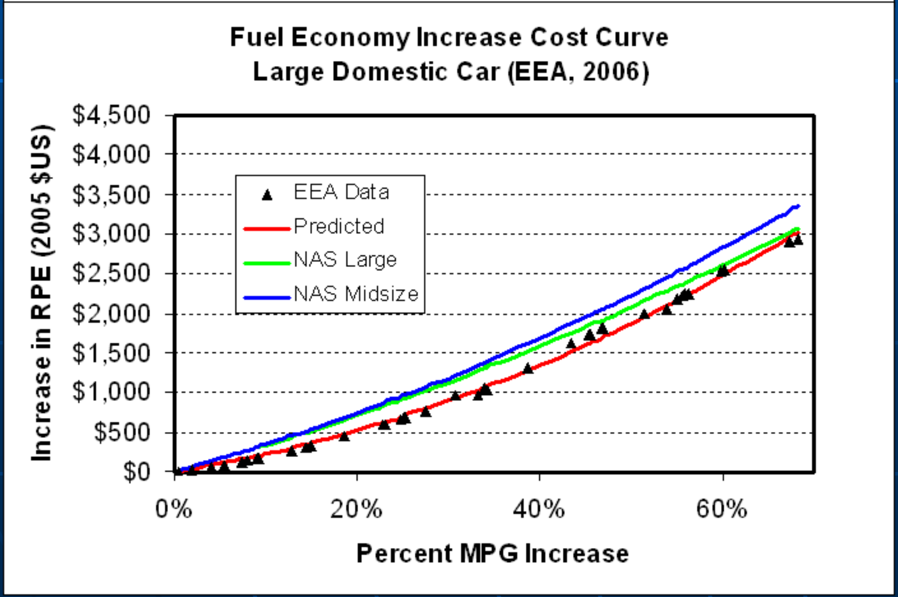
TECHNOLOGY TYPE	Short Term (2006-2012) Cumulative GHG Benefit [%]	Short Term (2006-2012) Cumulative RPE [US$]	Medium Term (2013-2018) Cumulative GHG Benefit [%]	Medium Term (2013-2018) Cumulative RPE [US$]	Long Term (2019-2025) Cumulative GHG Benefit [%]	Long Term (2019-2025) Cumulative RPE [US$]
Early Torque Converter Lockup	0.50	5	0.50	5	0.50	5
Rolling Resistance Reduction by 10%	1.99	25	1.99	25	1.99	25
Drag Reduction by 10%	3.95	53	3.95	53	3.95	53
Rolling Resistance Reduction by 20%	3.95	53	5.30	85	5.30	85
Drag Reduction by 20%	3.95	53	7.00	127	7.00	127
Aggressive Shift Logic	4.17	58	7.21	132	7.21	132
Improved Lube Oil						
Engine Friction Reduction by 8% I4						
Stoichiometric GDI I4						
Weight Reduction by 5%						
Engine Friction Reduction by 15% I4						
DOHC VVT (Intake) I4						
VVT (Intake plus Exhaust) DOHC I4						
Engine Friction Reduction by 8% V6						
Alternator Improvements						
VVL Discrete OHV-2v V6						
Stoichiometric GDI V6						
VVL Discrete OHC-4v I4						
Engine Friction Reduction by 8% V8						
Engine Friction Reduction by 15% V6						
VVLT Intake Continuous DOHC I4						
Engine Off at Idle (Manual Transmission)						
VVL Discrete OHV-2v V8						
Engine Friction Reduction by 15% V8						
Electric Power Steering						
Five Speed Automatic Transmission						
Six Speed Automatic Transmission						
Seven Speed Automatic Transmission						
Continuously Variable Transmission (Engines <						
4.5 Valves I4						
Camless Valve Actuation I4						
Stoichiometric GDI V8						
Weight Reduction by 10%						
Turbocharging & GDI with Engine Downsize V6						
DOHC VVT (Intake) V6						
DOHC VVT (Intake) V8						
VVT (Intake plus Exhaust) DOHC V6						
VVT (Intake plus Exhaust) DOHC V8						
VVL Discrete OHC-4v V6						
VVLT Intake Continuous DOHC V6						
Continuously Variable Transmission (Engines >						
Turbocharging & GDI with Engine Downsize V8						
4.5 Valves V6						
VVL Discrete OHC-4v V8						
VVLT Intake Continuous DOHC V8						
Cylinder Deactivation V6 with Noise Cancellation						
Cylinder Deactivation V8 & Cont. VVLT						
Camless Valve Actuation V6 Incl. Cyl Deact.						
Camless Valve Actuation V8 Incl. Cyl Deact.	20.10	1104	[illegible]	[illegible]	[illegible]	[illegible]
Engine Off at Idle (Auto. Transmission & AC)	20.10	1104	40.11	2901	40.31	2939
Weight Reduction by 15%	20.10	1104	40.11	2901	41.92	3596
Electric Water Pump	20.10	1104	40.41	2951	42.21	3646
Homogeneous Combustion Compression Ignition (HCCI) I4	20.10	1104	40.41	2951	42.21	3646
Homogeneous Combustion Compression Ignition (HCCI) V6	20.10	1104	40.41	2951	42.30	3772

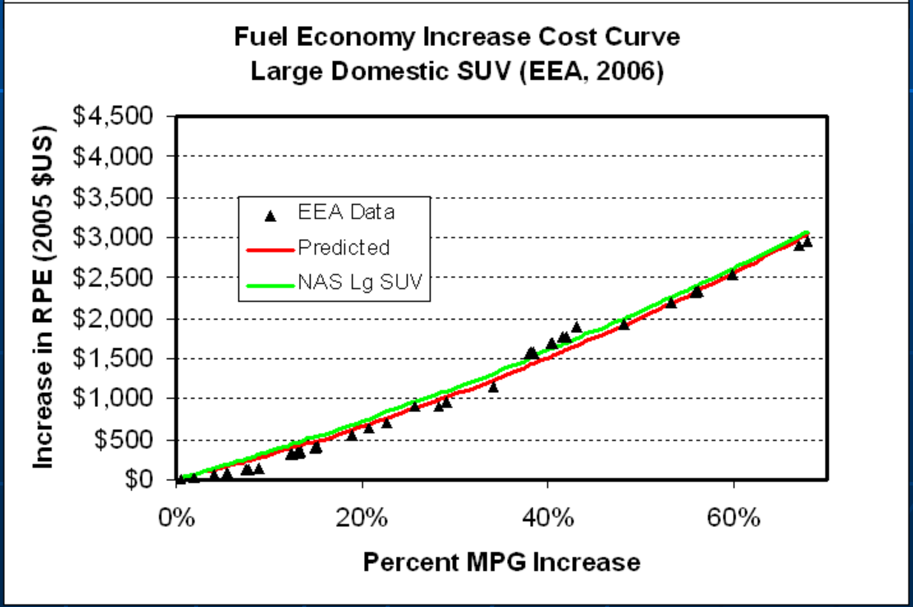
Technology	Medium Term % FC Red.	Potential Cost	Cumulative % FE Incr.
Early Torque Converter Lock-up	0.50%	$5	0.503%
Rolling Resistance Reduction by 10%	1.99%	$25	2.030%
Drag Reduction by 10%	3.95%	$53	4.112%
Rolling Resistance Reduction by 20%	5.30%	$85	5.597%
Drag Reduction by 20%	7.00%	$127	7.527%
Aggressive Shift Logic	7.58%	$139	8.202%
Improved Lube Oil	8.50%	$159	9.290%
Engine Friction Reduction by 8% I4	9.52%	$189	10.522%
Stoichiometric GDI I4	12.13%	$278	13.804%
Weight Reduction by 5%	14.85%	$369	17.440%
Engine Friction Reduction by 15% I4	15.79%	$409	18.751%
DOHC VVT (Intake) I4	16.70%	$447	20.048%
VVT (Intake plus Exhaust) DOHC I4	17.25%	$467	20.846%
Engine Friction Reduction by 8% V6	17.55%	$479	21.286%
Alternator Improvements	17.96%	$496	21.892%
VVL Discrete OHV-2v V6	18.63%	$528	22.895%
Stoichiometric GDI V6	19.39%	$565	24.054%
VVL Discrete OHV-4v I4	21.42%	$676	27.259%

With mild hybrid and certain other technologies not included in the NAS 2002 study, perhaps a 60% improvement is possible for ICEs by 2020 (EEA, Inc., 2006).

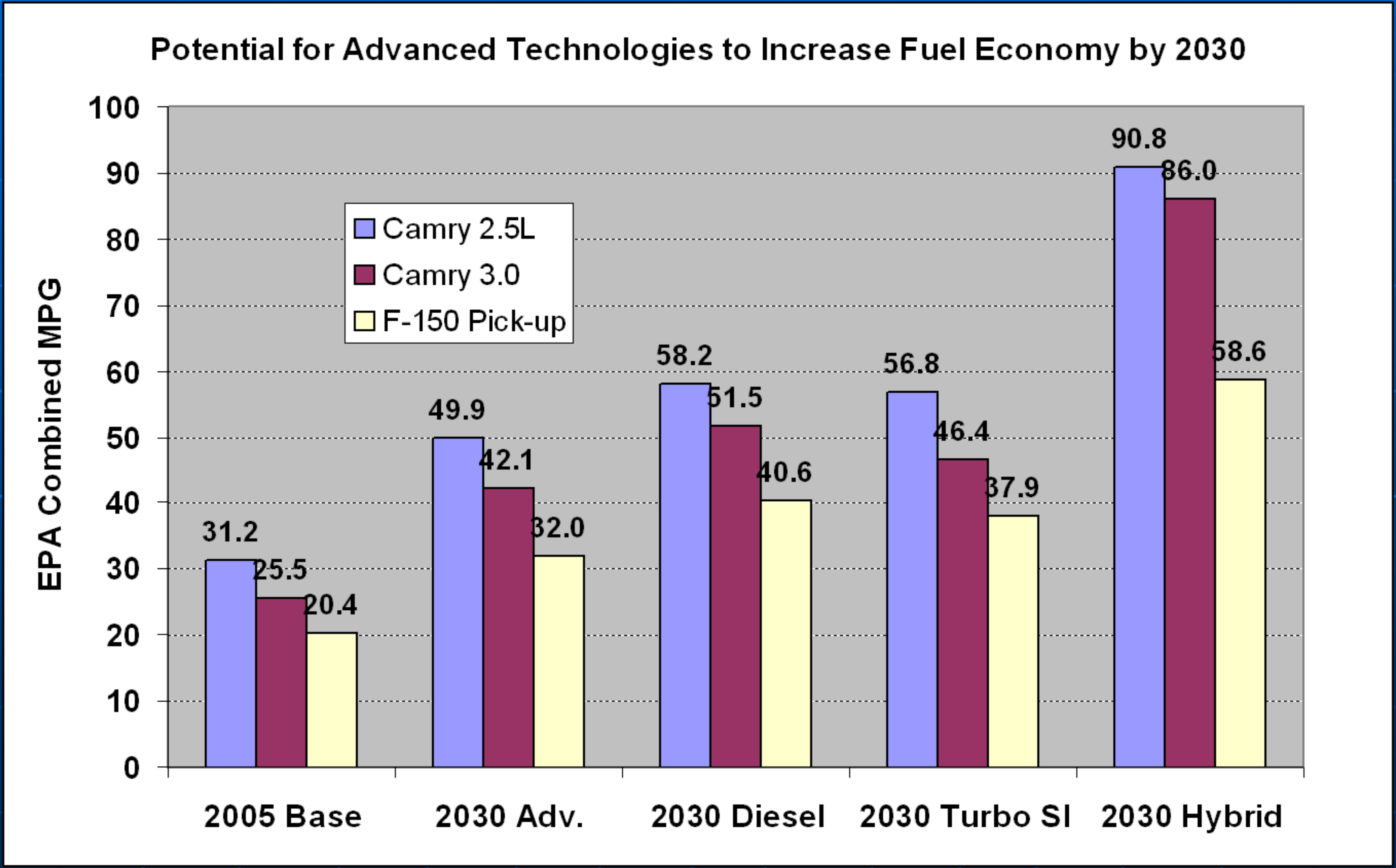






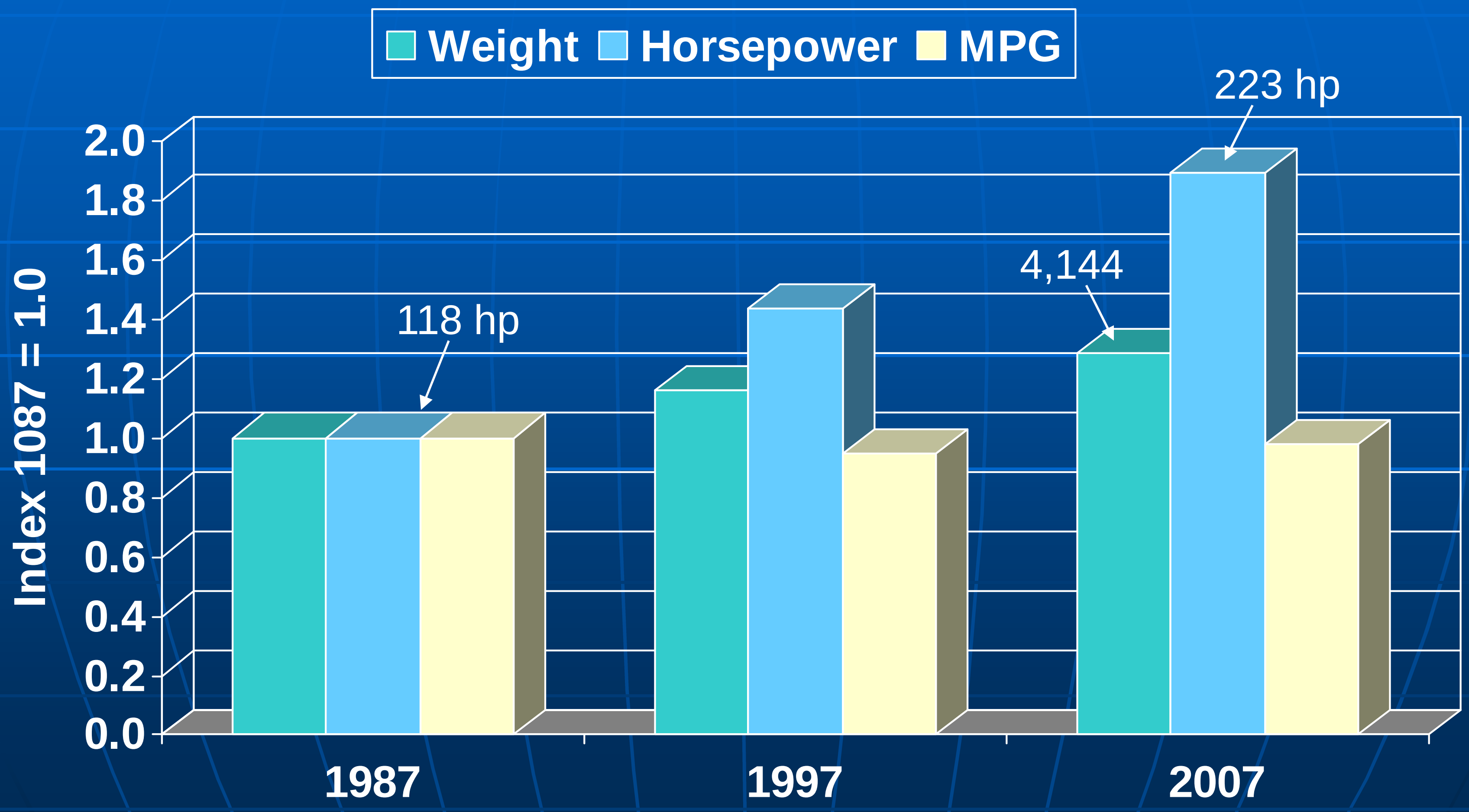


A 2007 MIT study predicts MPG gains of 80-85% for model year 2030 vehicles via continuous improvement of conventional technology at a rate of 2-2.5%/year.



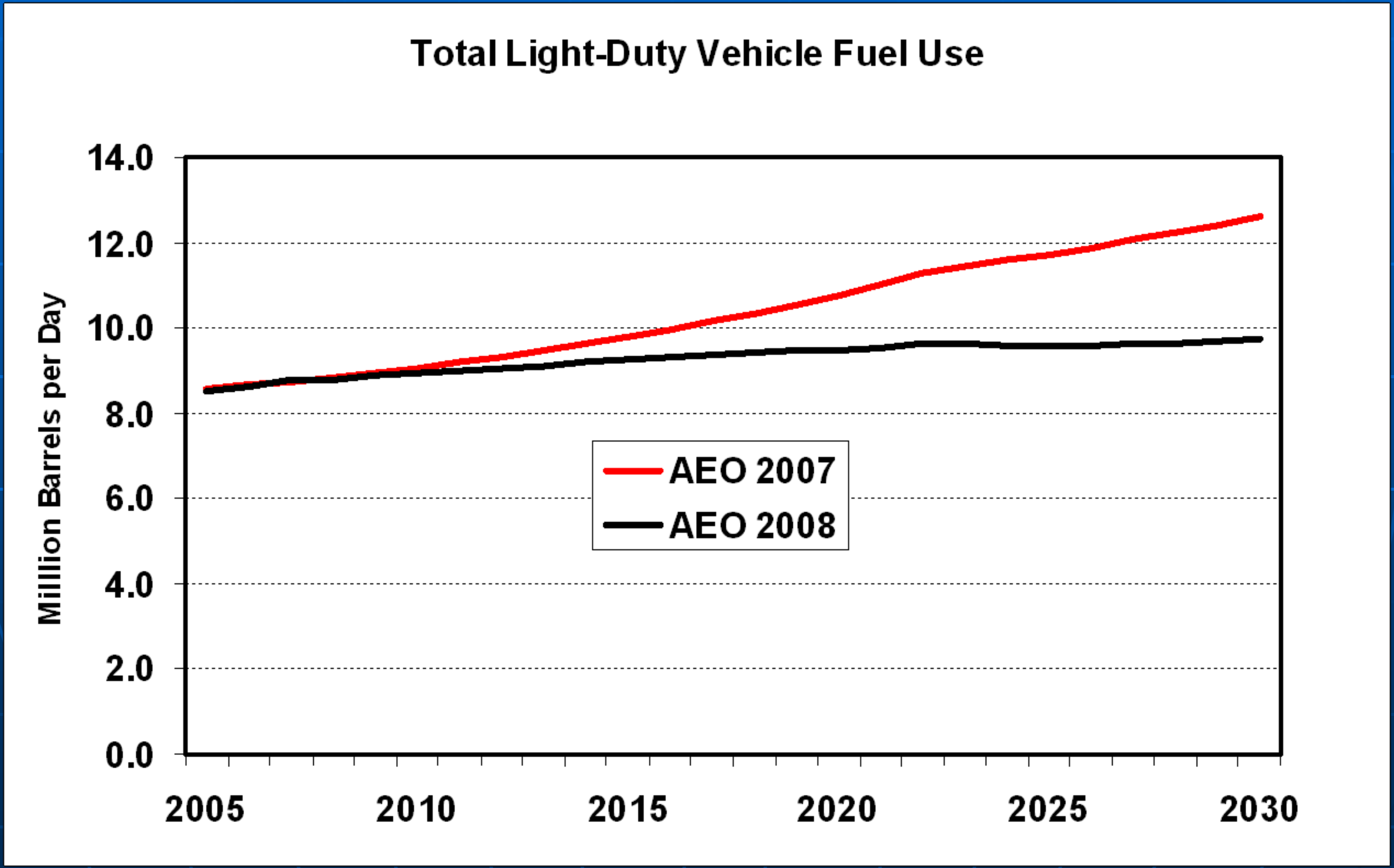
Source: Kasseris & Heywood, SAE Technical Paper 2007-01-1605, April, 2007.

What must we give up?
The horsepower & weight race.
Weight reduction on the order of 20% is necessary.

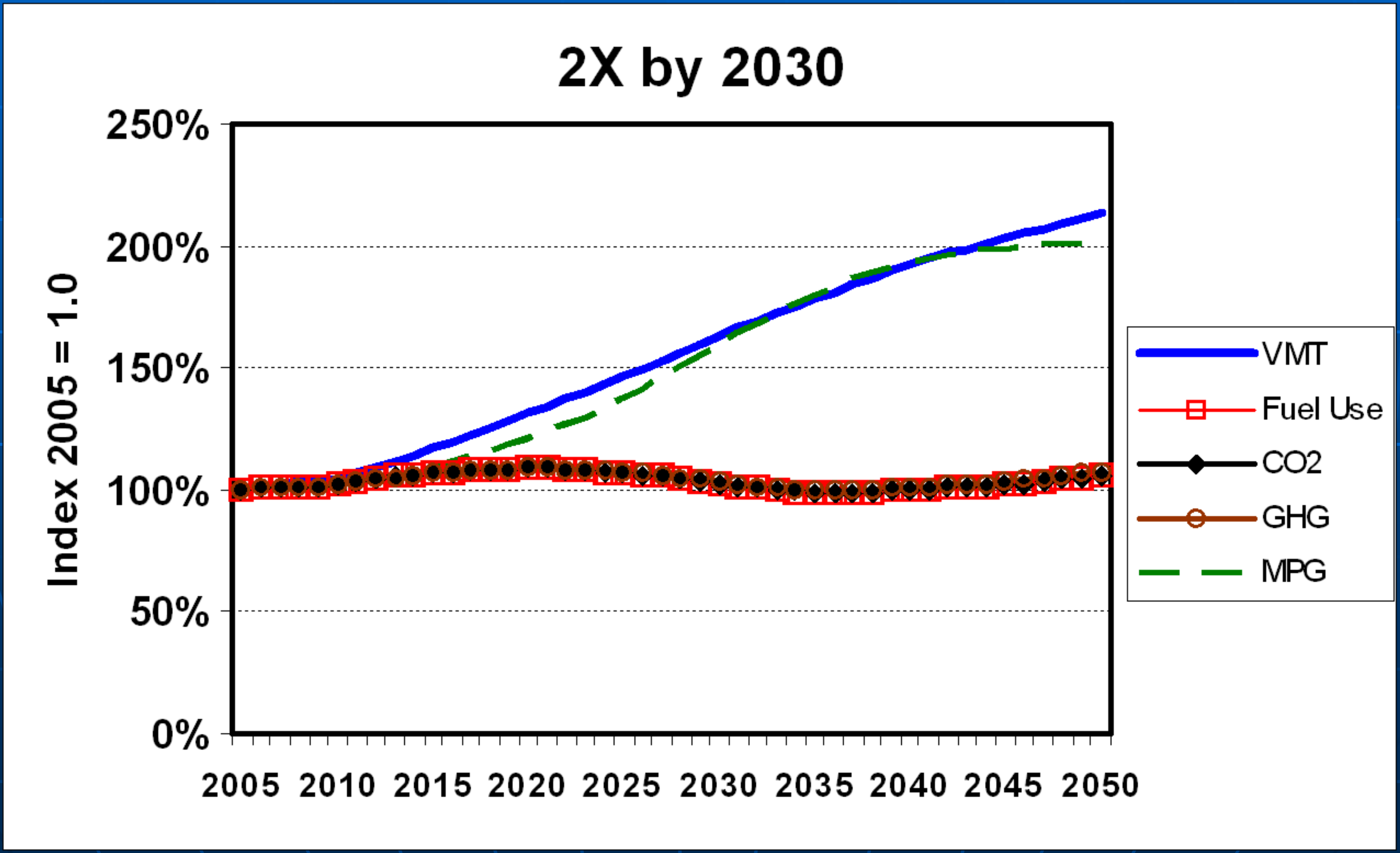


Source: U.S. EPA, Light-Duty Automotive Technology and Fuel Economy Trends: 1975-2007, p. ii.

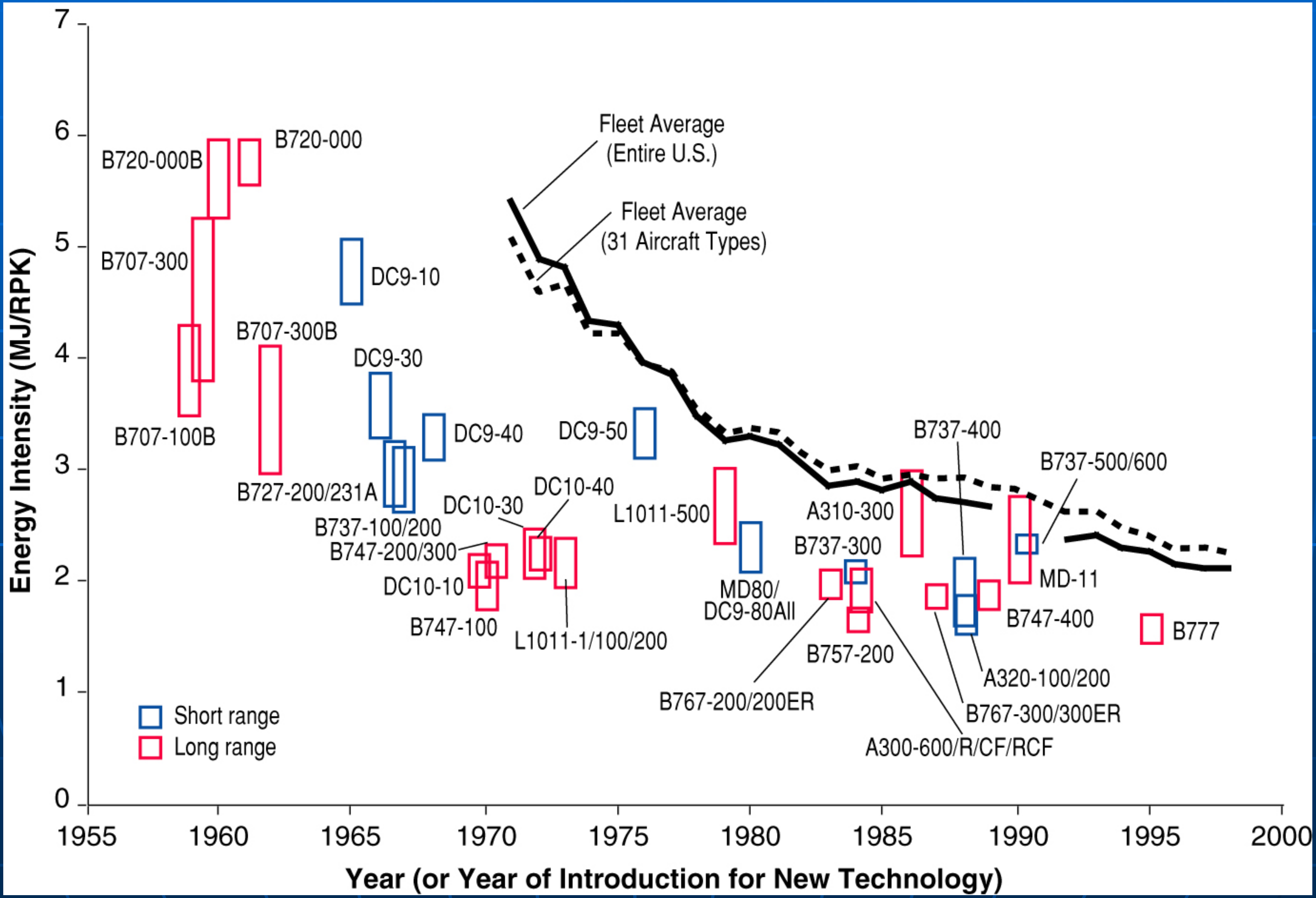
What will the 2007 EISA accomplish?
Reduce LDV fuel use by almost 3 mmbd.



And, if we could double new LDV fuel economy by 2030, that would hold LDV oil use and CO2 emissions approximately constant through 2050.

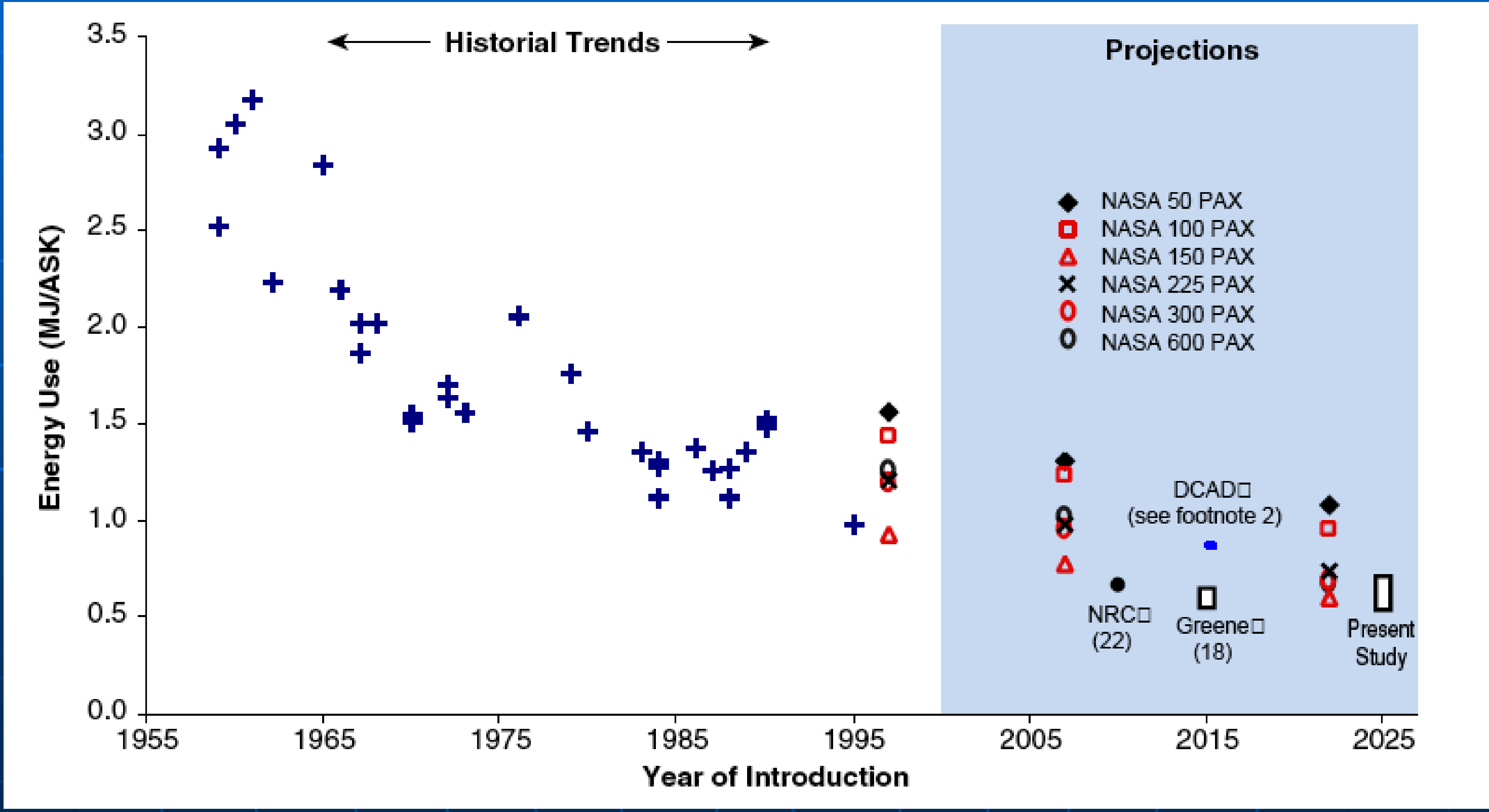


For heavy trucks and aircraft, fuel economy gains of 50-75% may be possible by 2050. Commercial aircraft energy intensity is less than half what it was in 1970 but progress is has been slowing.



"Historical and Future Trends in Aircraft Performance, Cost and Emissions," Lee, J. J., Lukachko, S. P., Waitz, I. A., and Schafer, A., *Annual Review of Energy and the Environment,* Volume 26, 2001

Projections for the future: energy intensity reductions of 1%-2% per year for next 20 yrs



“Historical and Future Trends in Aircraft Performance, Cost and Emissions,” Lee, J. J., Lukachko, S. P., Waitz, I. A., and Schafer, A., *Annual Review of Energy and the Environment,* Volume 26, 2001

2007 ICAO Environmental Report projected a 40% reduction in fuel consumption by 2025.

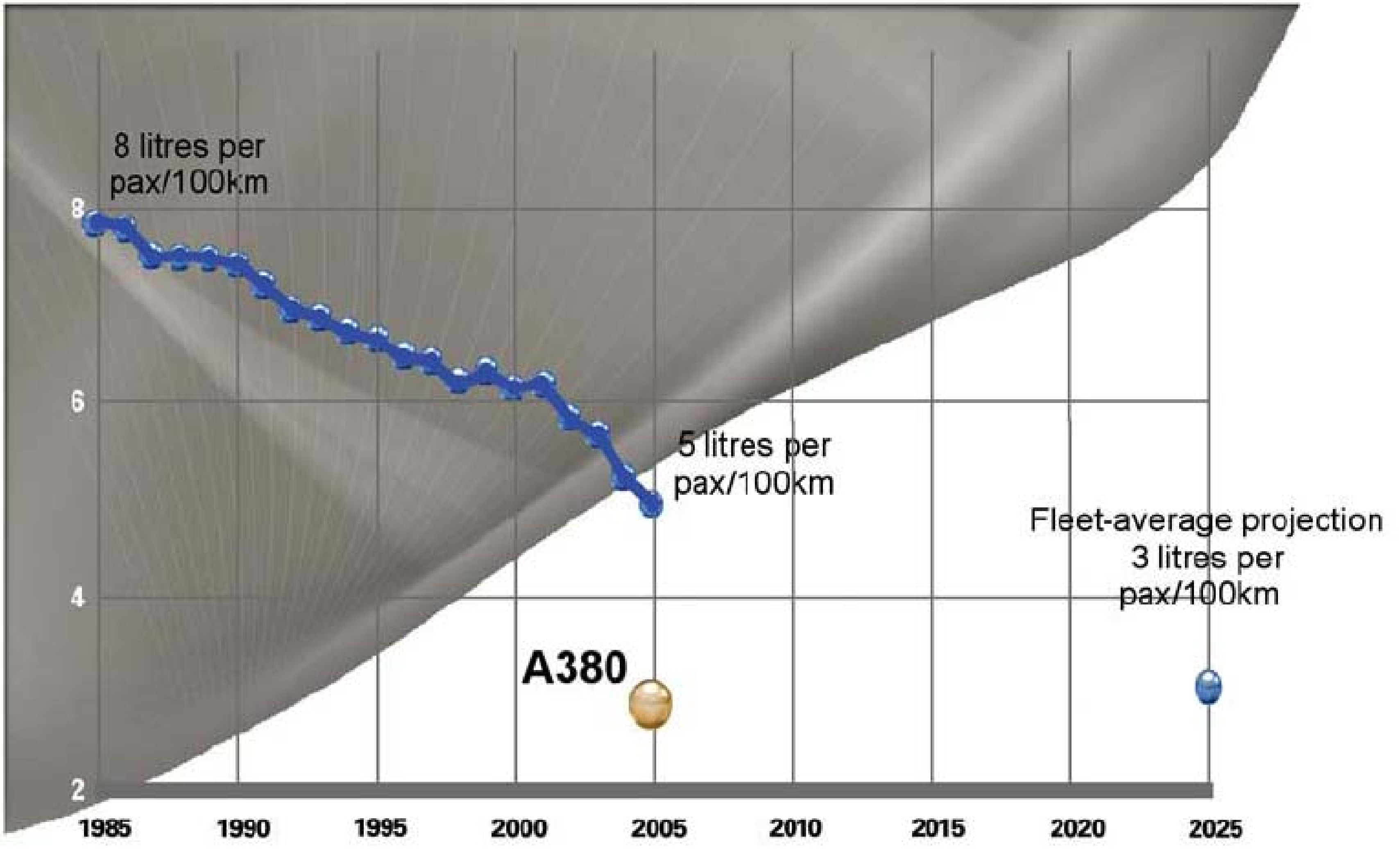
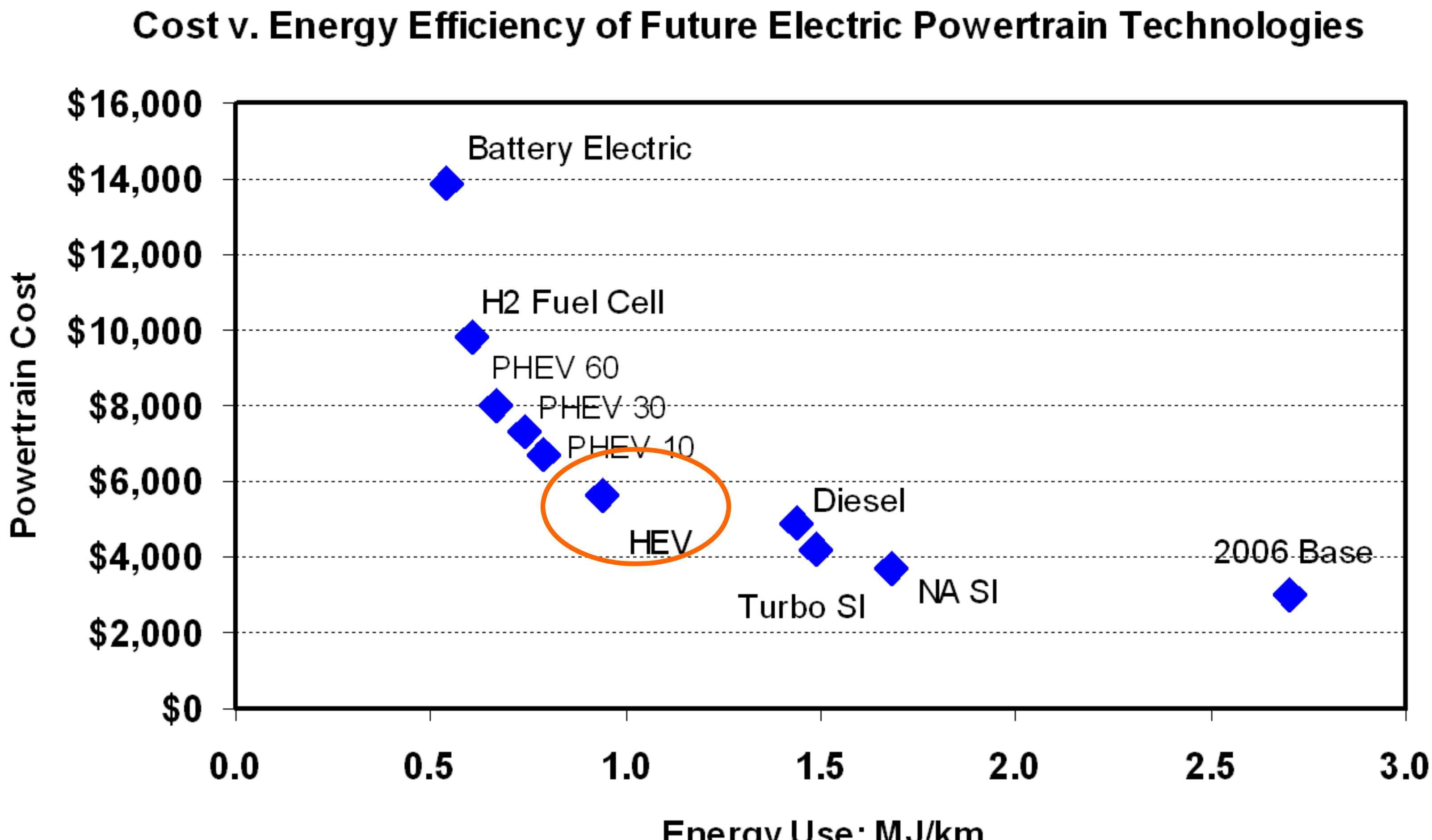


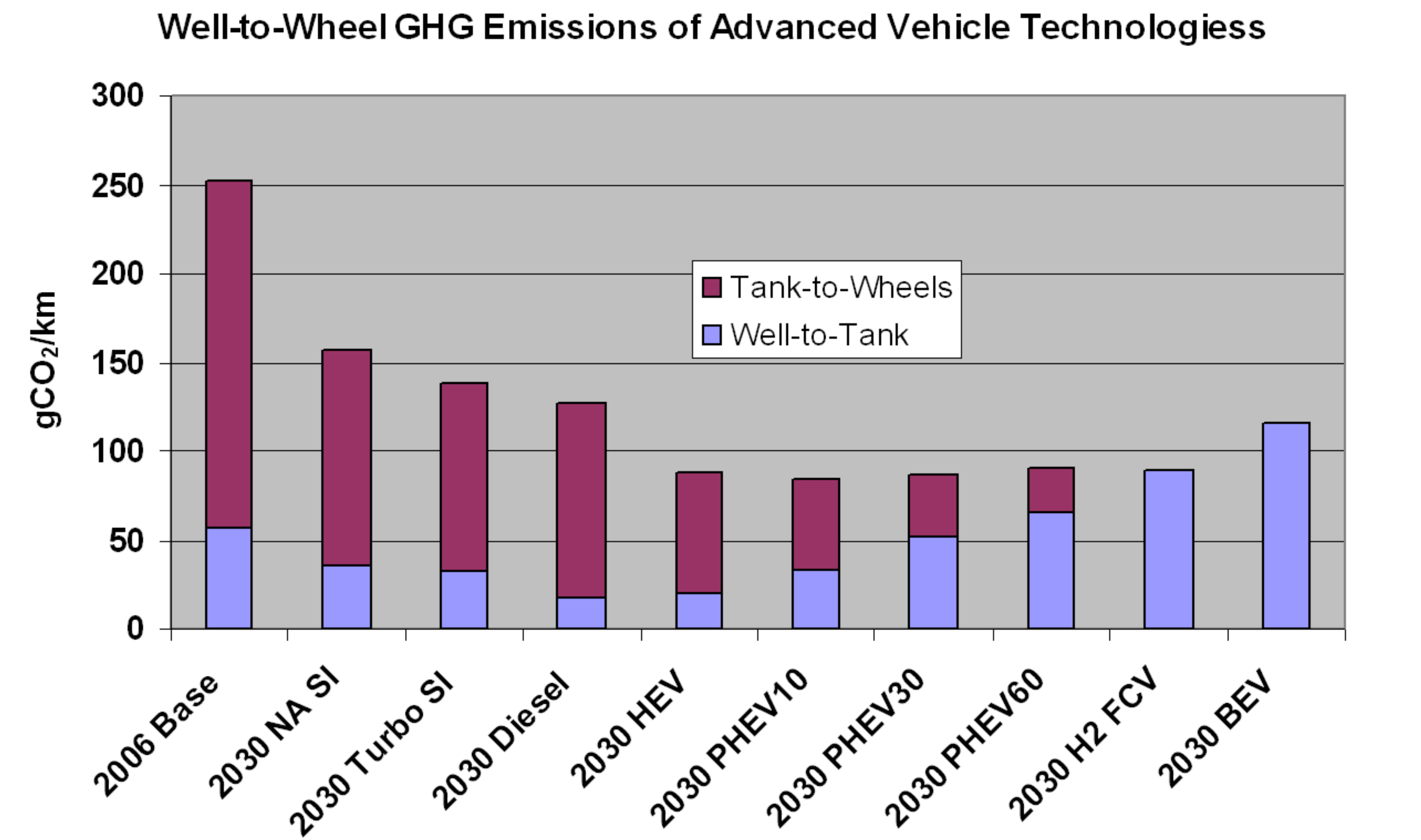
Figure 3 – Worldwide passenger air traffic fuel consumption (litres per passengers (pax) per 100 km). The new Airbus A380 has the lowest fuel consumption per passenger of any large commercial airliner yet built.
Source : Airbus

Kromer & Heywood analyzed the technical potential & cost for electric drive to raise passenger car and light truck energy efficiency by 2030.



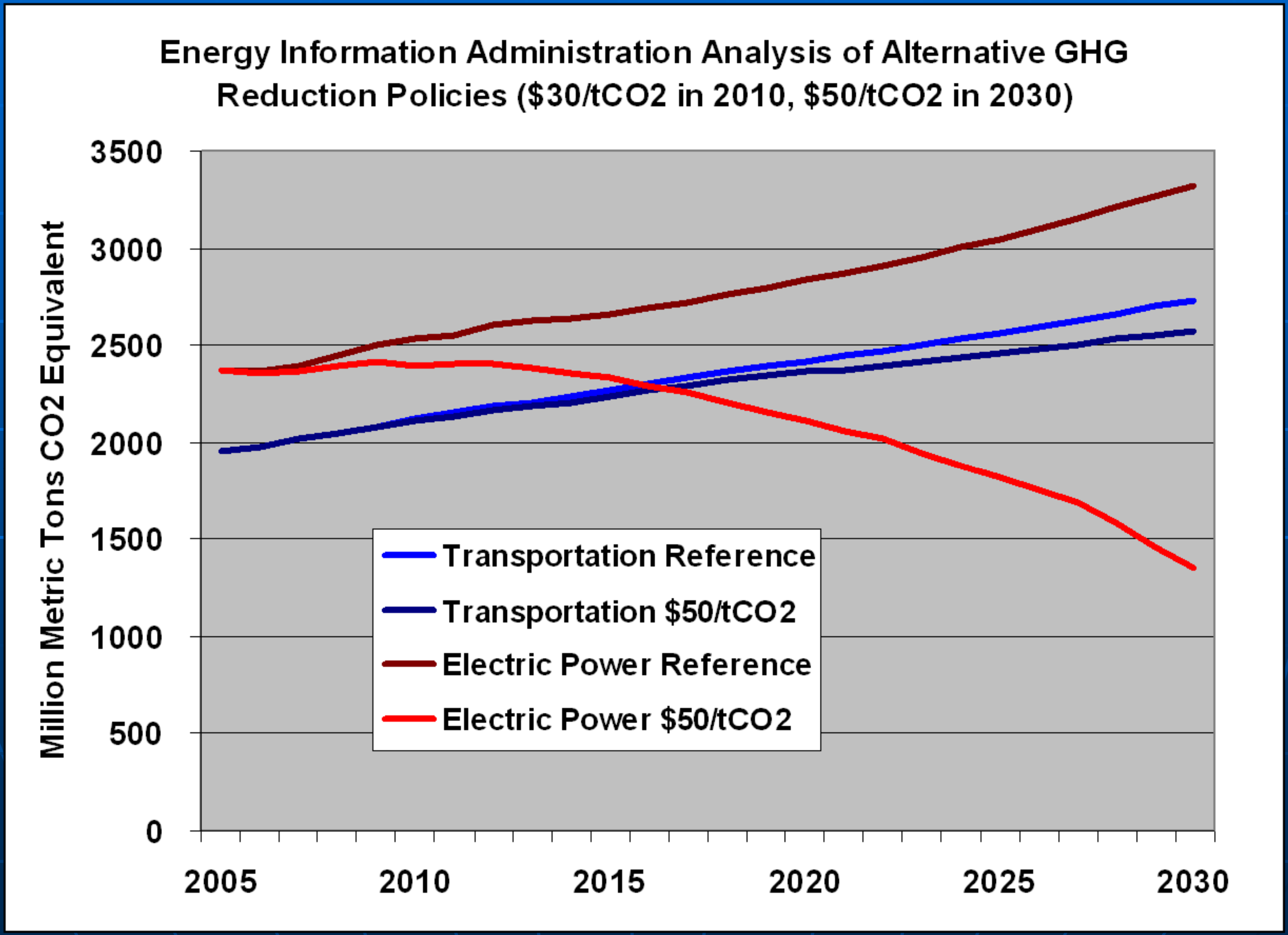
Source: Kromer & Heywood, LFEE 2007-02 RP, May, 2007.

The greater energy efficiency of electric drive technologies can cut well-to-wheel GHG emissions in half **and much more if…**

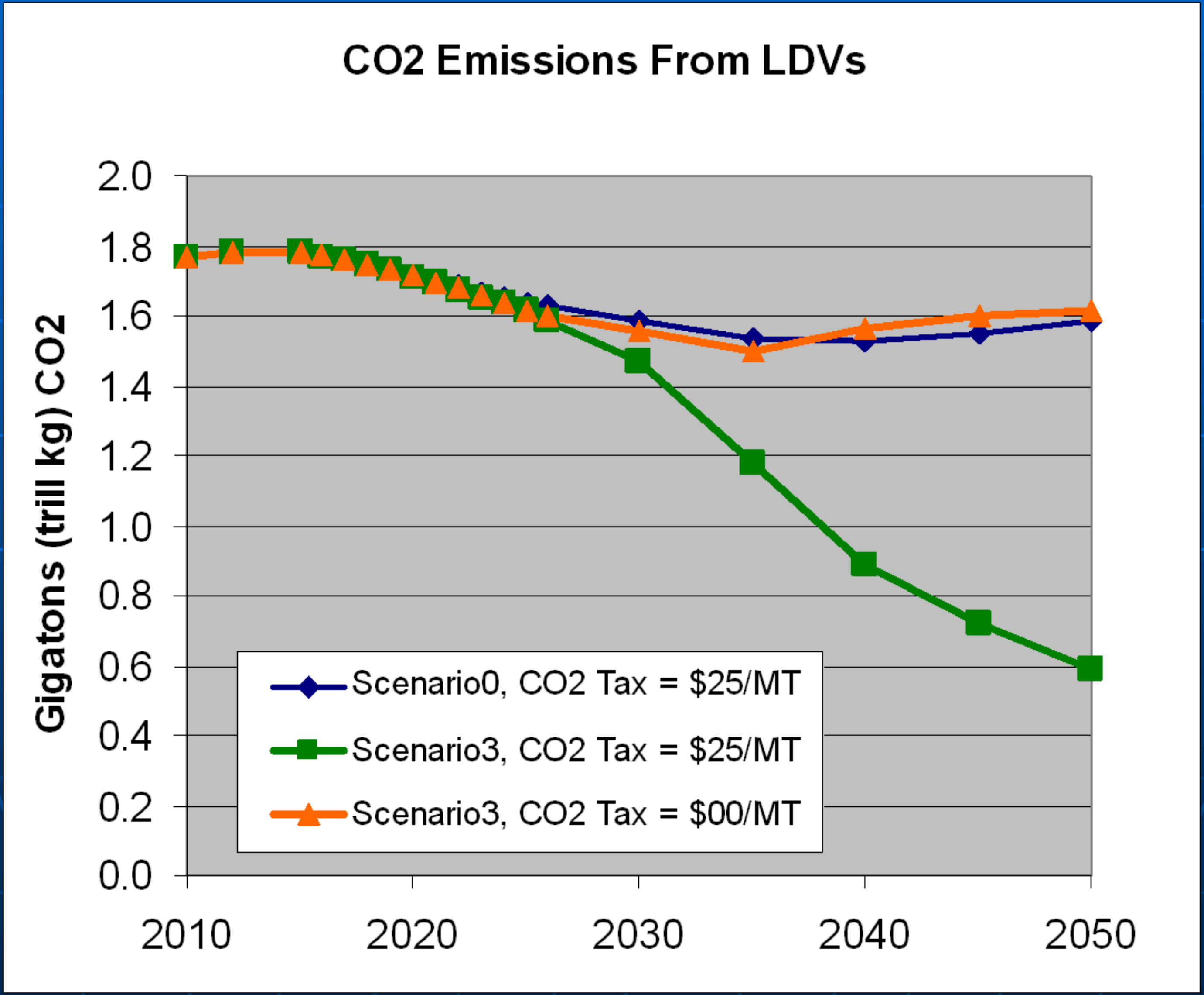


Source: Kromer & Heywood, 2007. Assumes H2 from natural gas, electricity is EIA 2030 mix.

Pricing carbon is not be a panacea for transportation, on the other hand grid electricity is almost certain to be low-C energy given any serious GHG policy (EIA, 2006).



IF hydrogen fuel cell technology could be made economically competitive, a reasonable GHG policy would also likely result in low-C hydrogen (assuming CCS).



DOE's market simulation of the transition to FCVs explored three scenarios intended to span a range that would encompass an efficient transition.

Scenario 1:

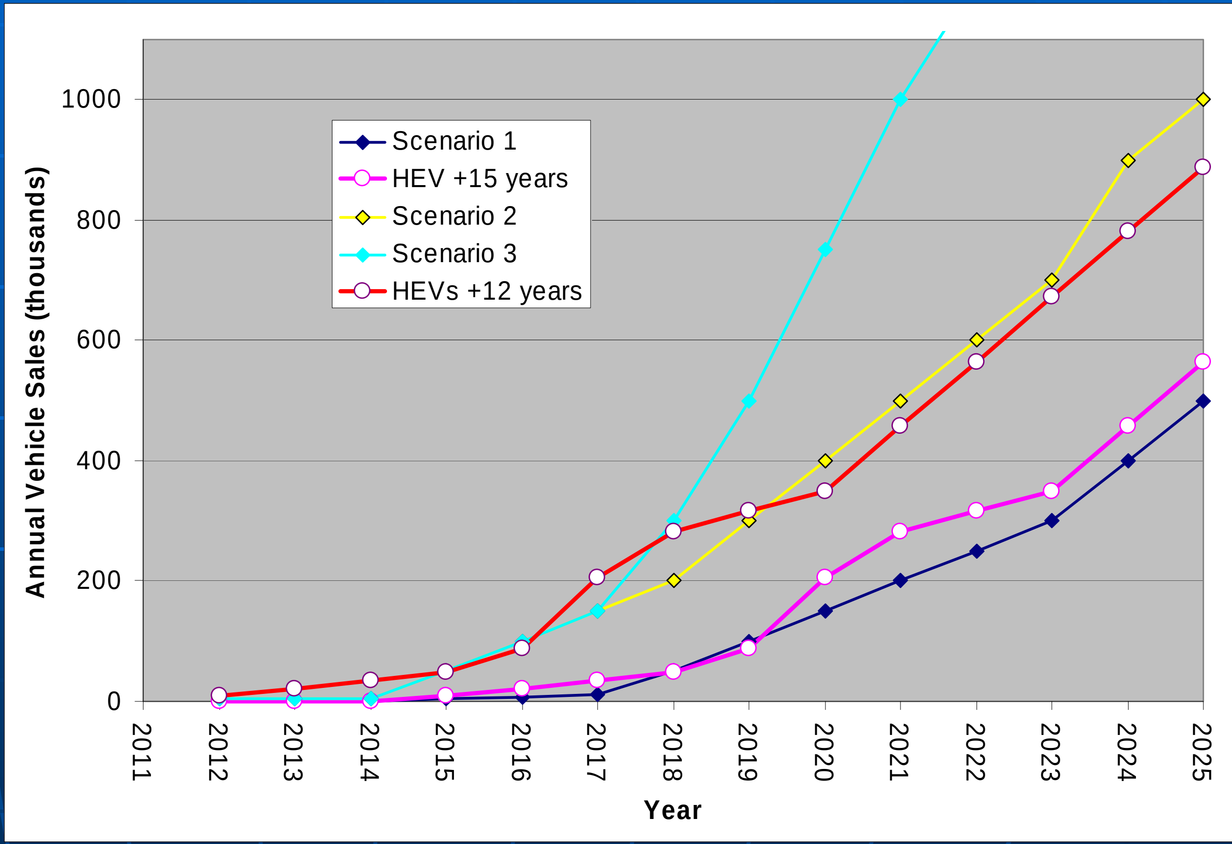
100s per year by 2012, *tens of thousands* of vehicles per year by 2018. On-road fleet of 2.0 million FCVs by 2025.

Scenario 2:

1,000s of FCVs by 2012, *tens of thousands* by 2015 and *hundreds of thousands* by 2018. On-road fleet of 5.0 million FCVs by 2025.

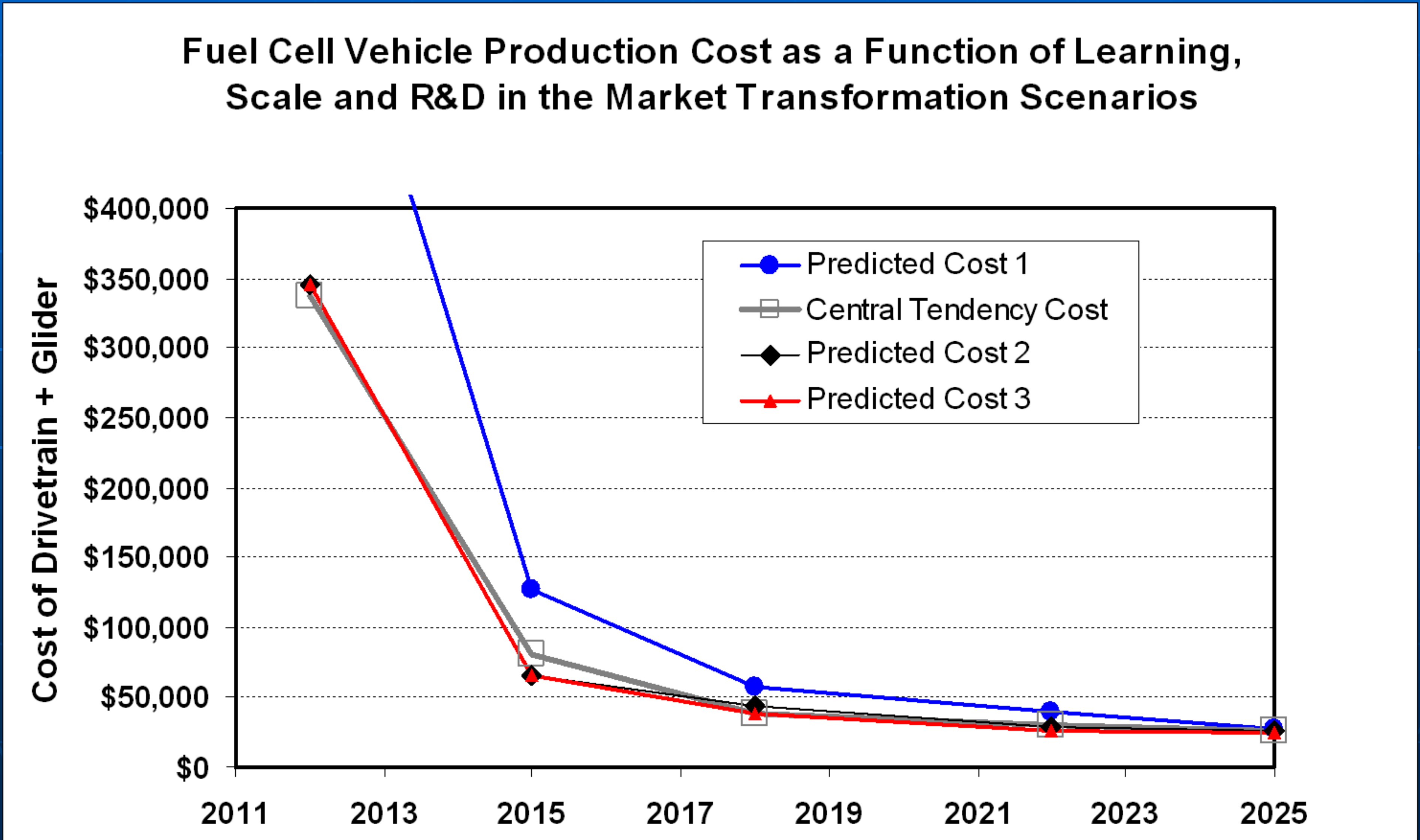
Scenario 3 (NRC scenario):

1,000s of FCVs by 2012, and *millions* by 2021, 10 million on the road by 2025.

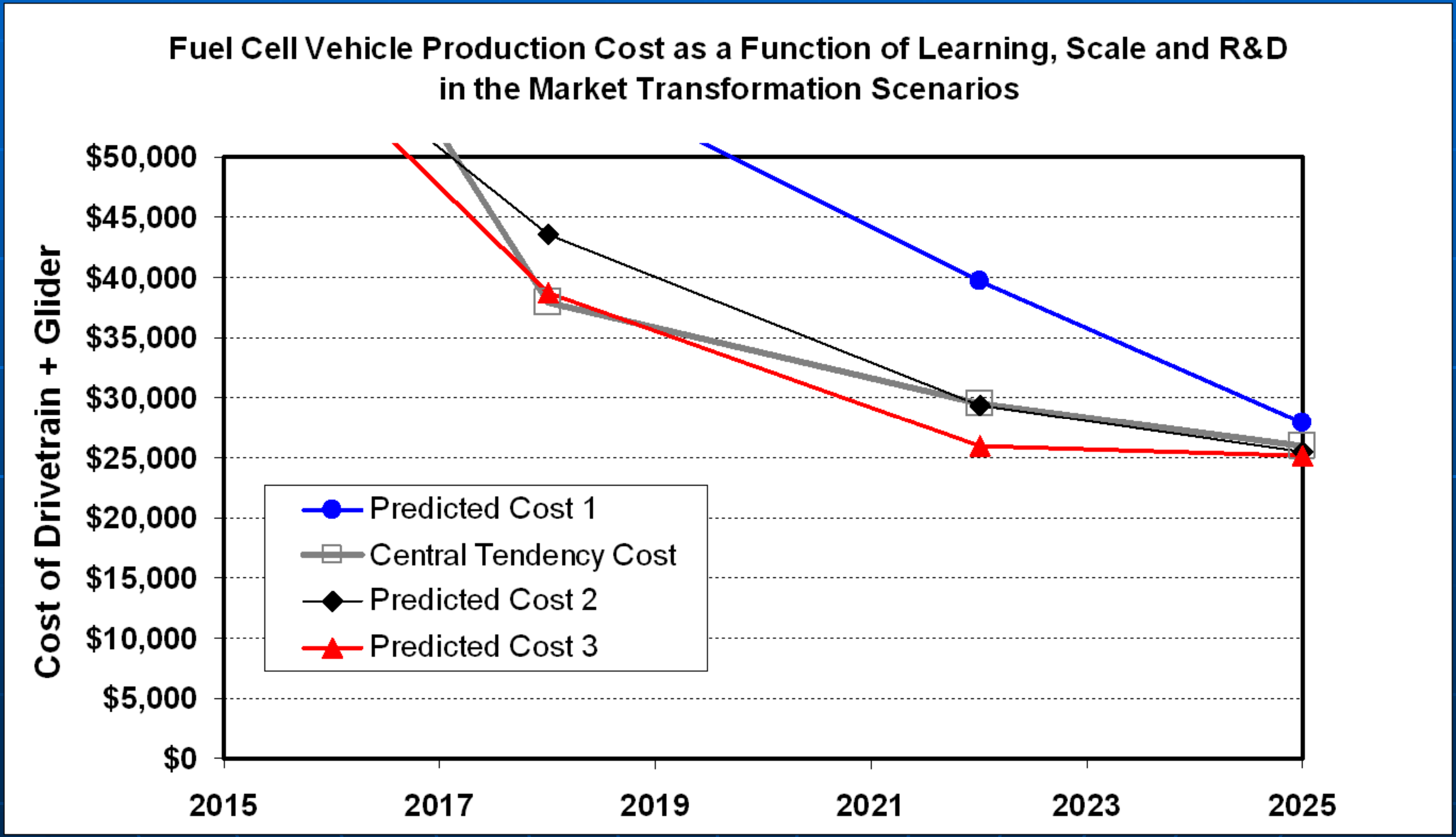


Scenarios 1 and 2 are consistent with current and projected HEV penetration rates

Assuming DOE's program goals for FCVs were met, we calibrated scale economies (elasticity of -0.28) and learning-by-doing (progress ratio ~0.9) using proprietary cost estimates supplied by 3 OEMs.

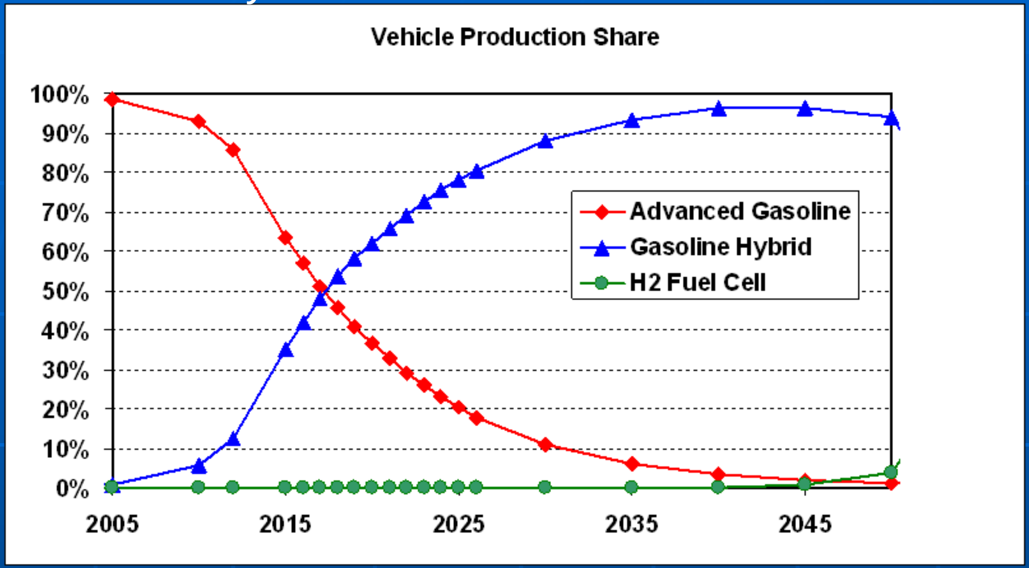


Magnification of the scale and learning effects shows important differences, 2015 to 2025.



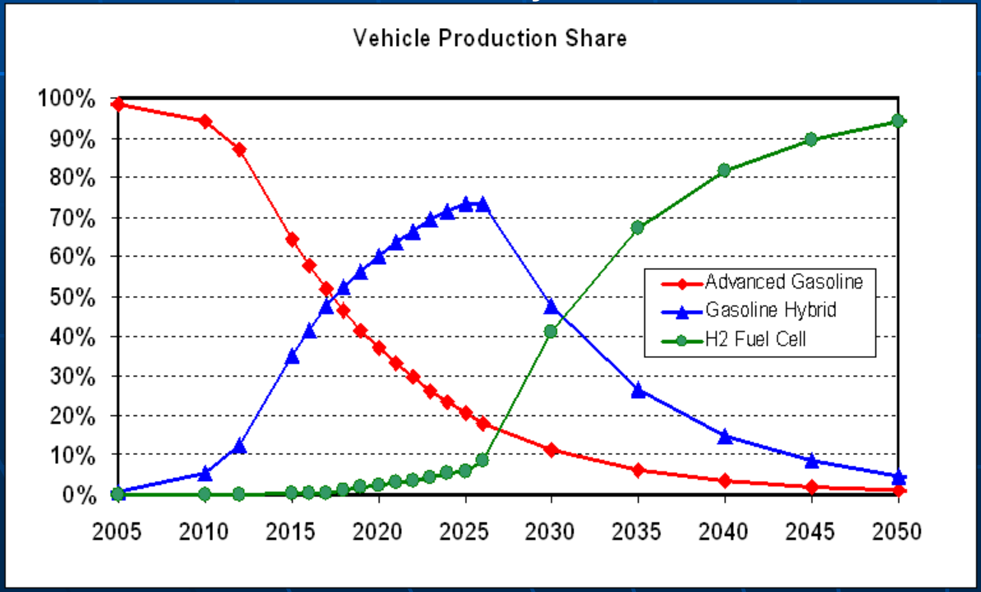
With no early transition scenario, FCVs do not begin to penetrate the market until after 2045.

No Policy Scenario



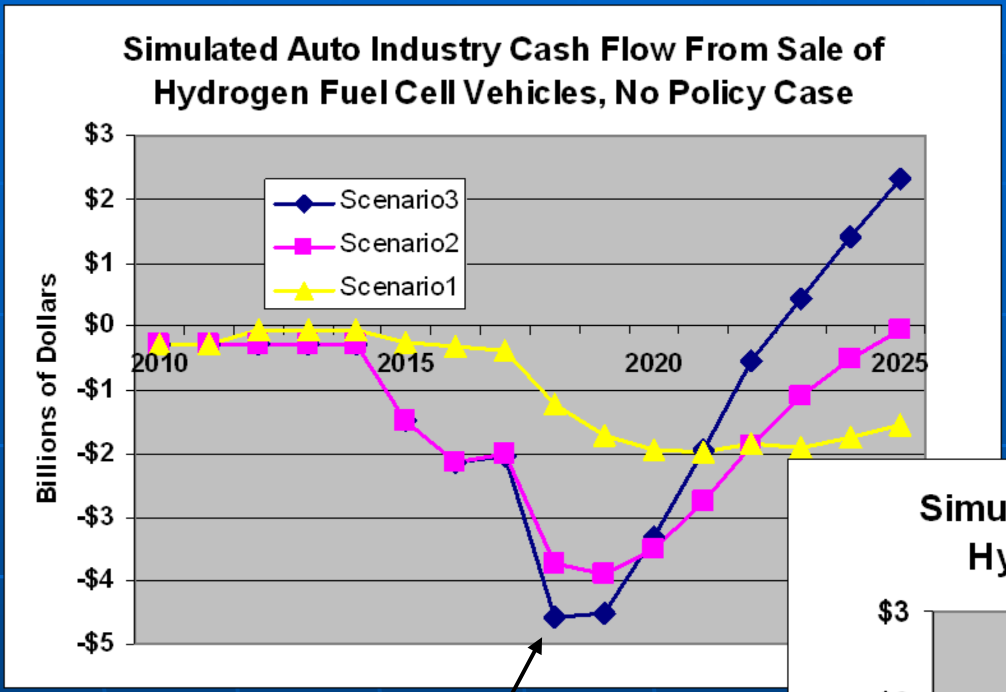
In the absence of an early transition strategy, advanced hybrid electric vehicles come to dominate light-duty vehicle propulsion.

AEO HWOP, $90/bbl by 2030



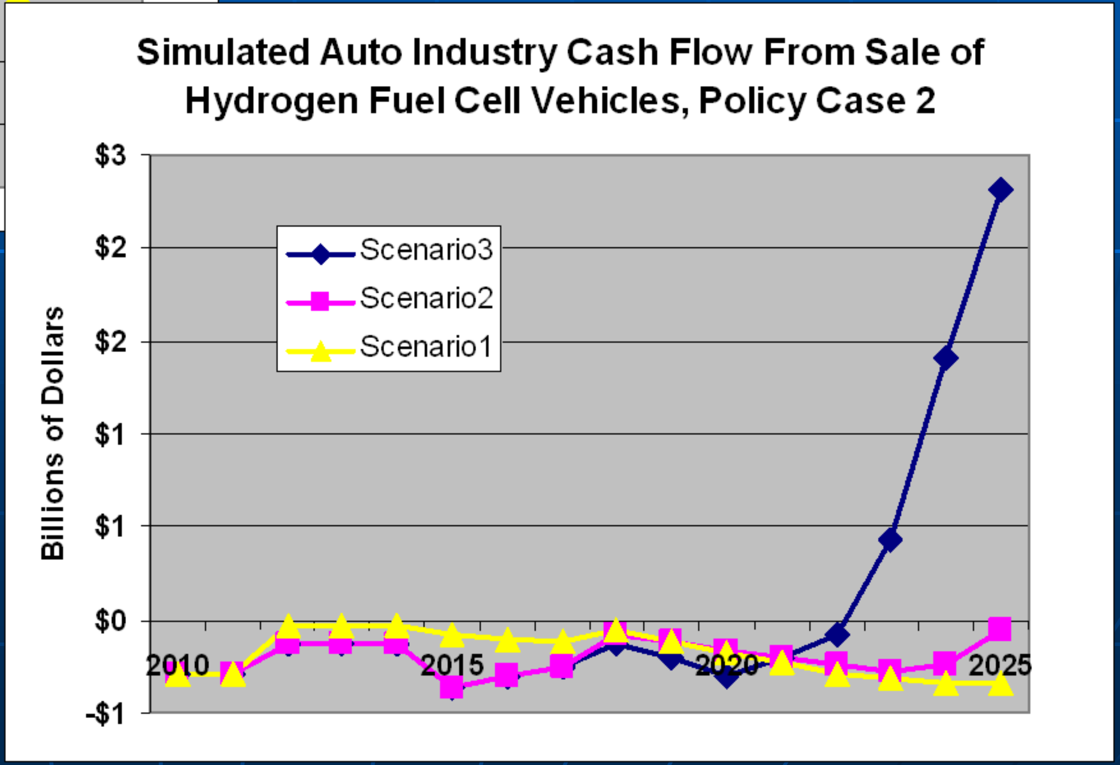
Any of the three transition scenarios led to a sustainable transition to FCVs assuming technology success, foresight and the 2006 High Oil Price Scenario.

Without government cost sharing a transition to hydrogen vehicles would be costly to the auto industry and prolonged.

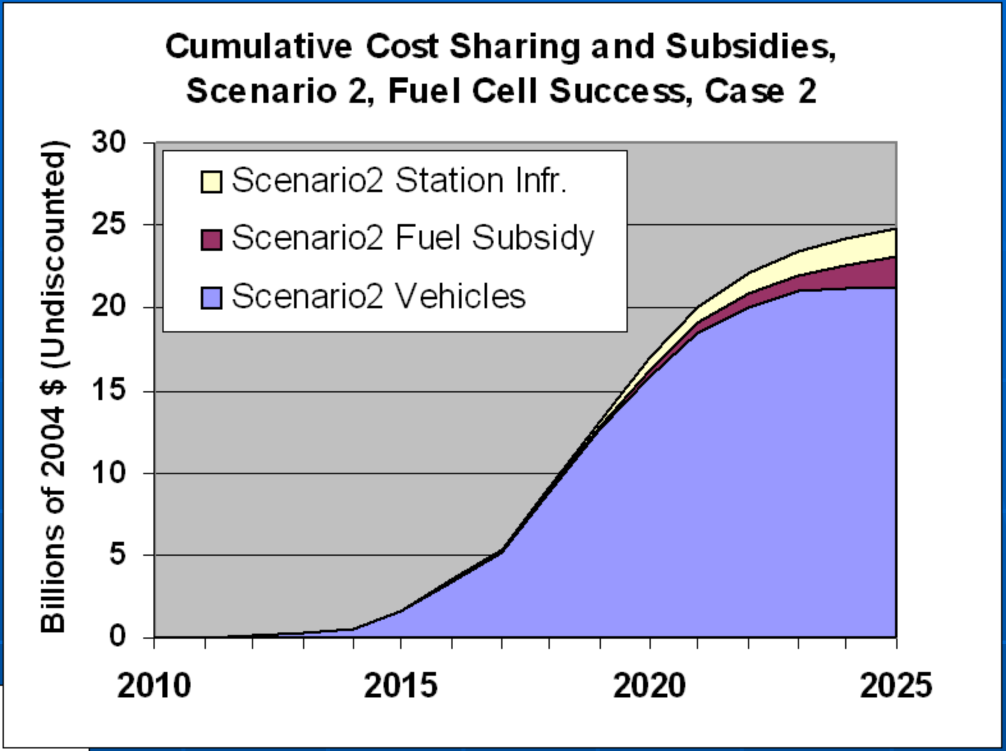


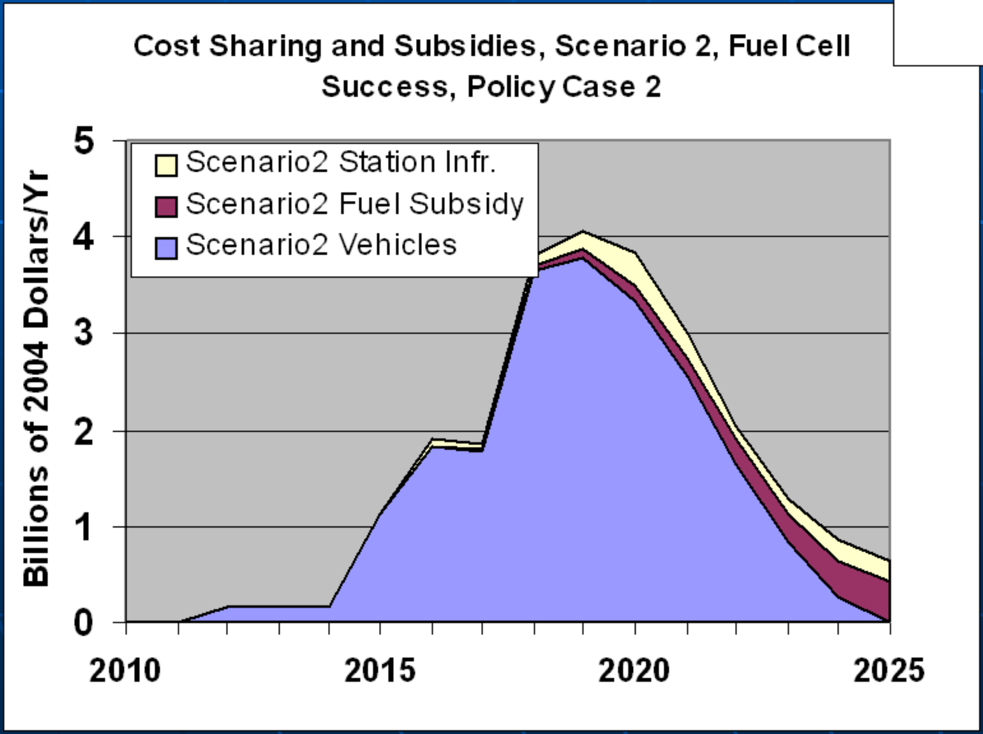
- Fuel availability
- Make/model diversity
- Cost hurdles
  - Scale
  - Learning-by-doing

“Valley of Death” (without government cost-sharing policy)



From a national perspective, the costs of transition appear to be practicable. In scenario 2, annual national costs peak at $4B, cumulative costs reach $25B.





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- Biofuels:
  - What is the efficient system: cellulosic ethanol or jet fuel, what produced where?
- Reductions of 50-80% over 2005 will require:
  - Electricity from a low-C grid
  - Hydrogen from low-C sources
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THANK YOU.

Backup slides.

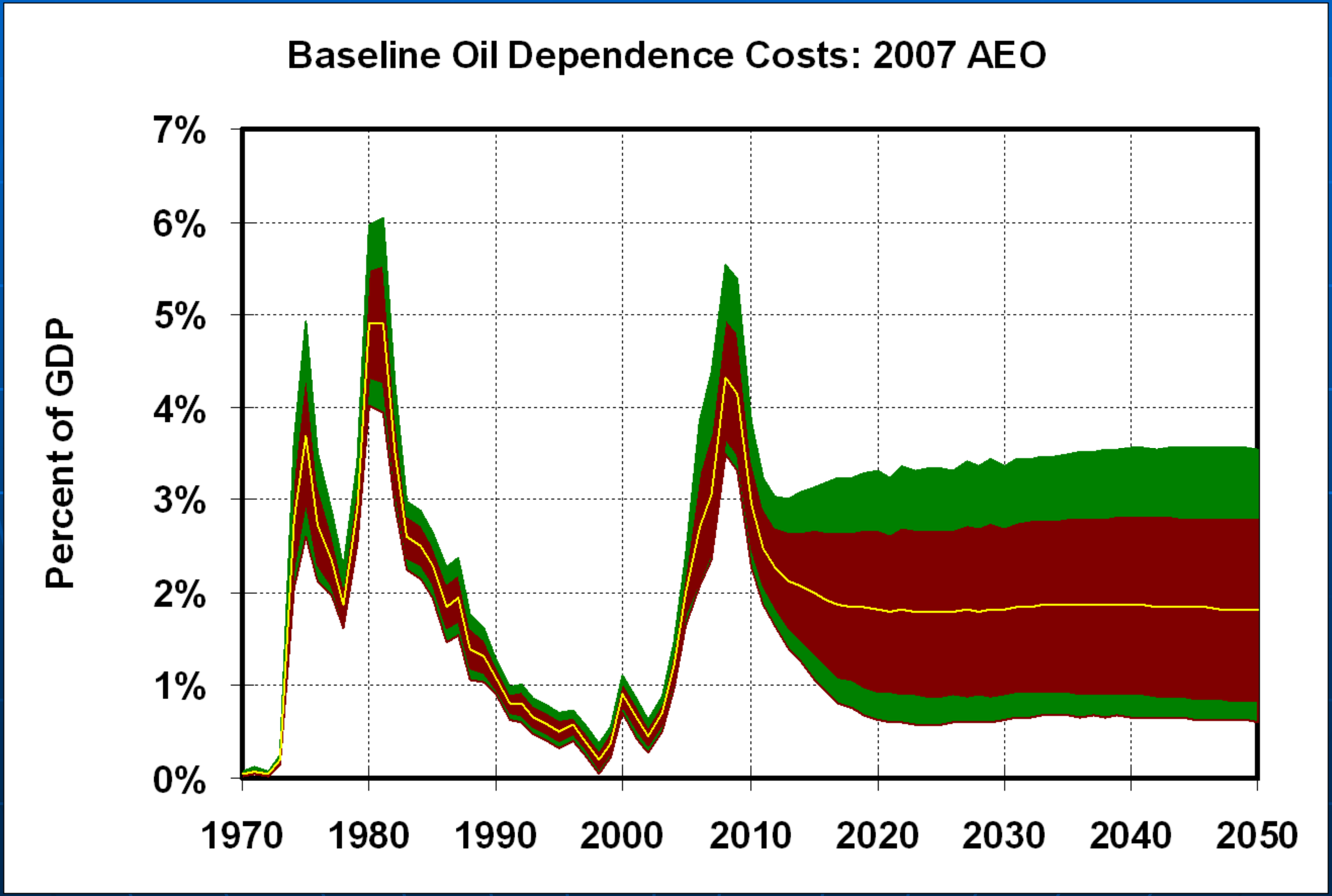
Like the US, most nations are striving for multiple energy goals.

- Avoiding dangerous climate change
  - 450-550 ppm
  - U.S.: 50%-70% reduction by 2050
- Energy Security
  - ?
  - U.S.: Freedom from “oil dependence”
  - 11 mmbd by 2030
- Economic prosperity
- Other

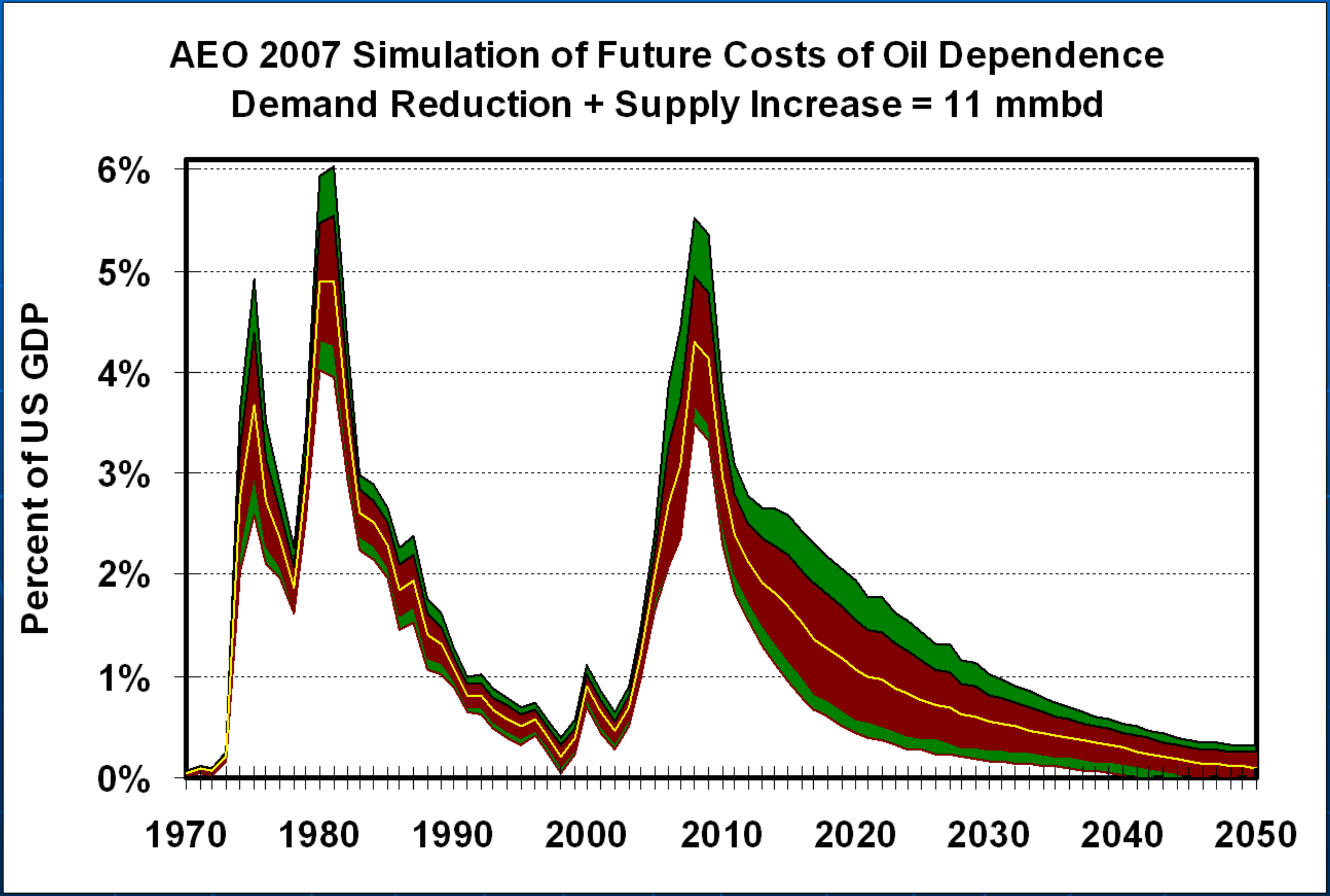
A measurable goal is needed.

- QUALITATIVE:
  - For all conceivable world oil market conditions, the costs of oil dependence to the economy will be so small that they have no effect on economic, military or foreign policy.
- QUANTITATIVE:
  - The estimated total economic costs of oil dependence in any year will be less than 1% of GDP with 95% probability by 2030.

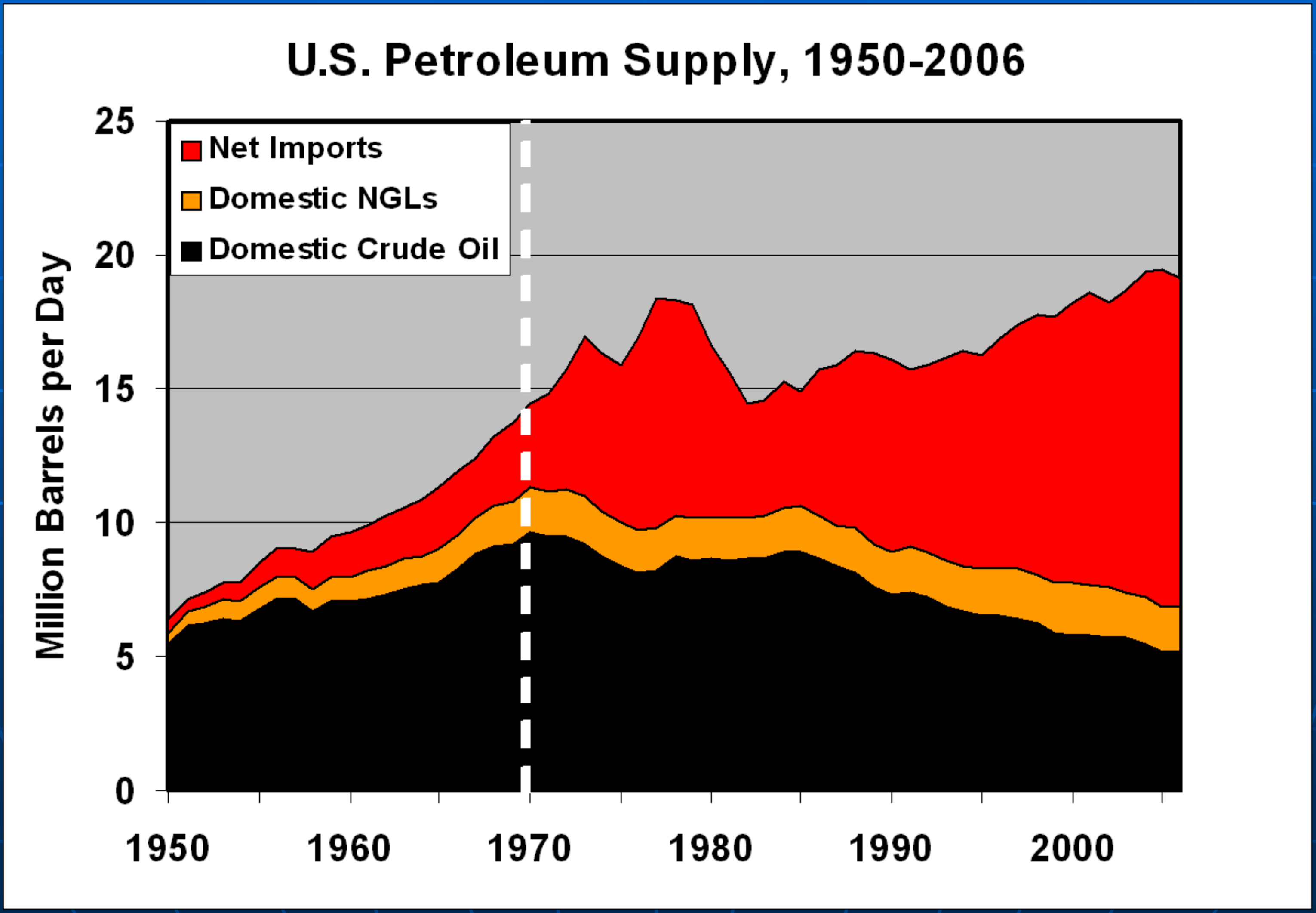
Based on EIA Reference, High and Low Oil Price projections, expected costs are 2% of GDP, or $400B/yr., 95th percentile is 3.5% or about $700B/yr. in 2030.



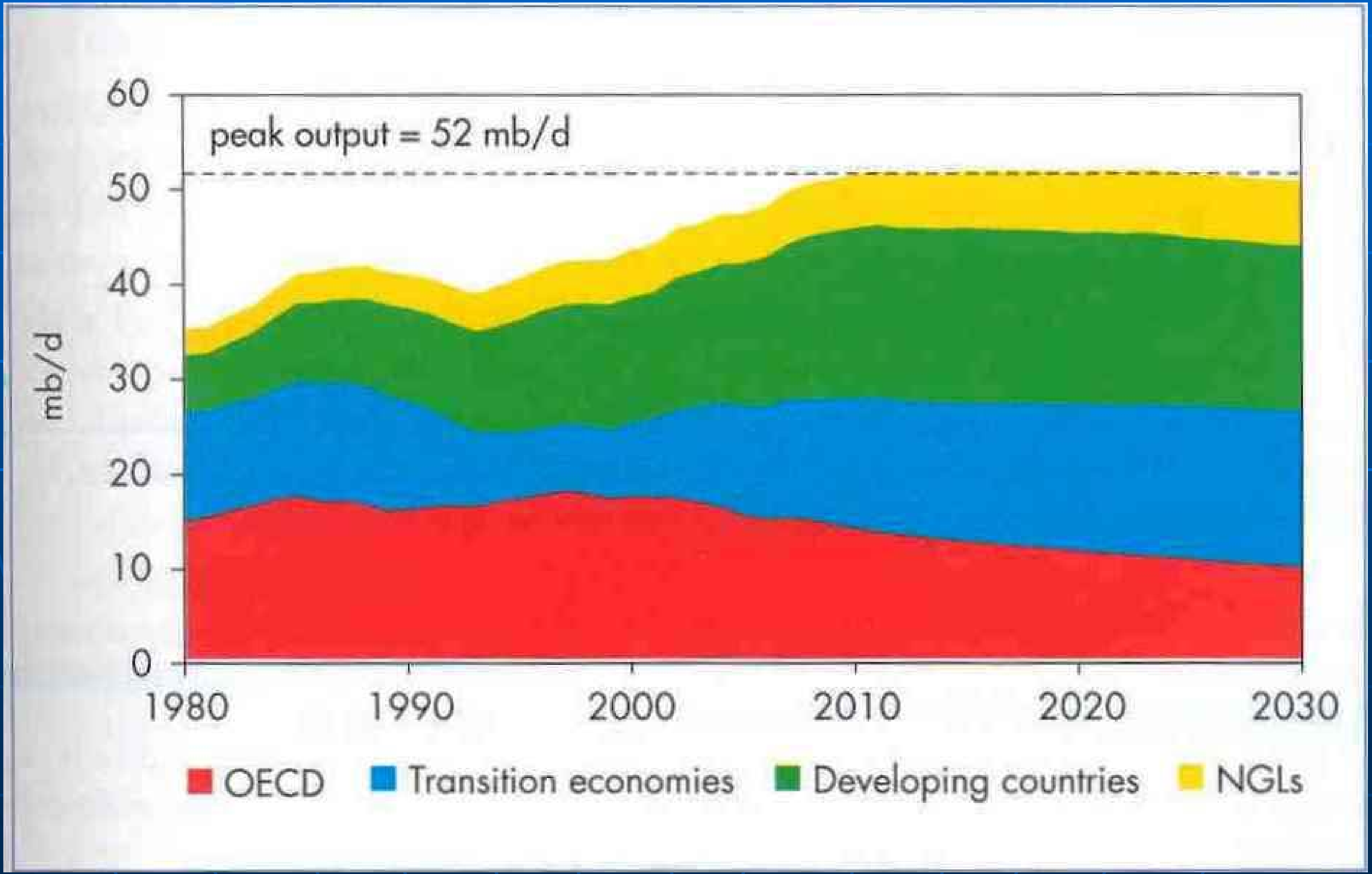
"Oil independence" requires an 11 mmbd change in the U.S. petroleum balance by 2030. Reference 27 mmbd of consumption and 10 mmbd of production in 2030.



The peaking of US crude oil production in 1970 and rapid growth of world oil demand (7%/yr.) strengthened the newly formed OPEC cartel's market power.

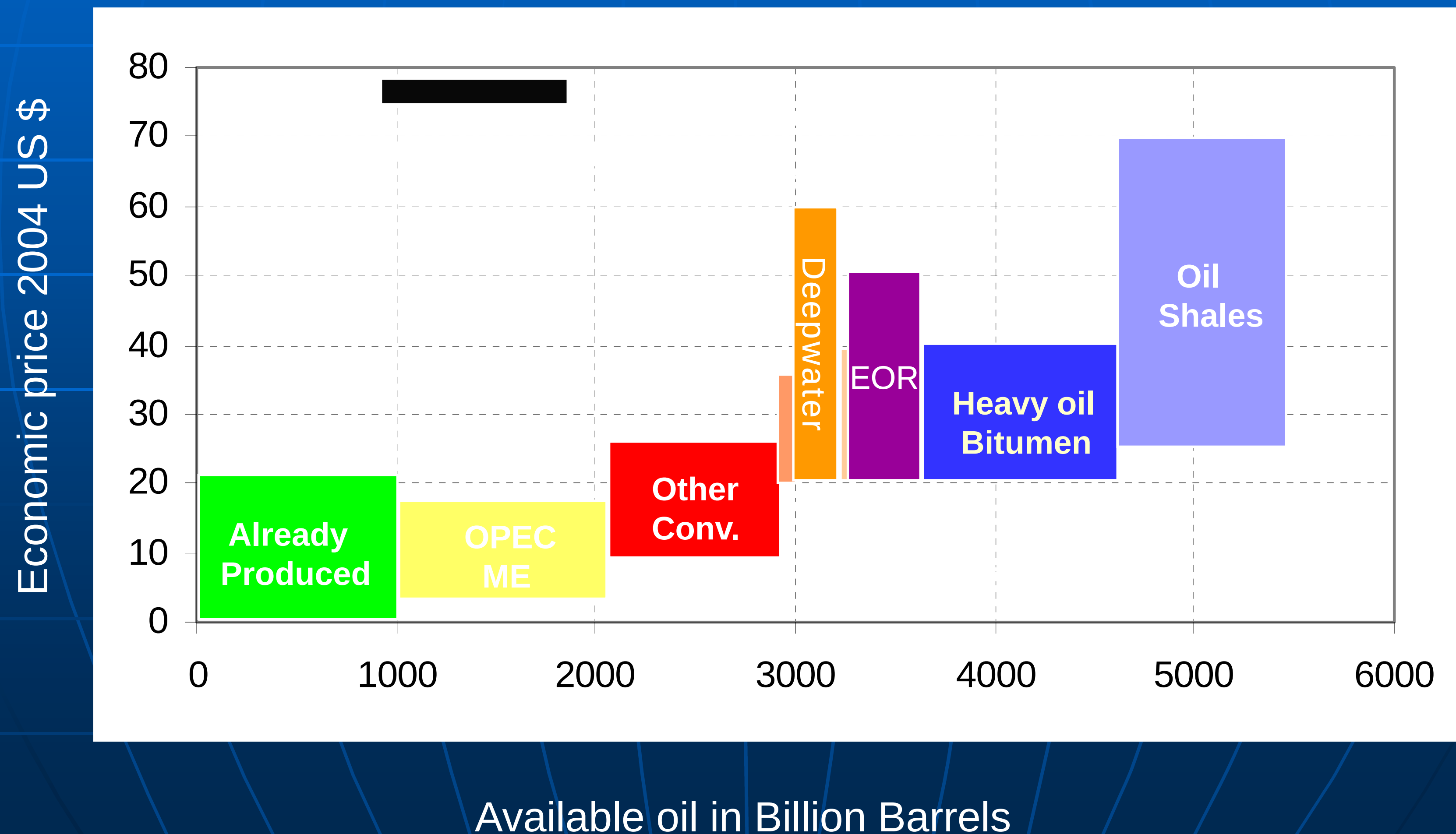


The International Energy Agency foresees a non-OPEC plateau with less OPEC supply and more unconventional resources filling the gap. But energy companies face enormous uncertainty.

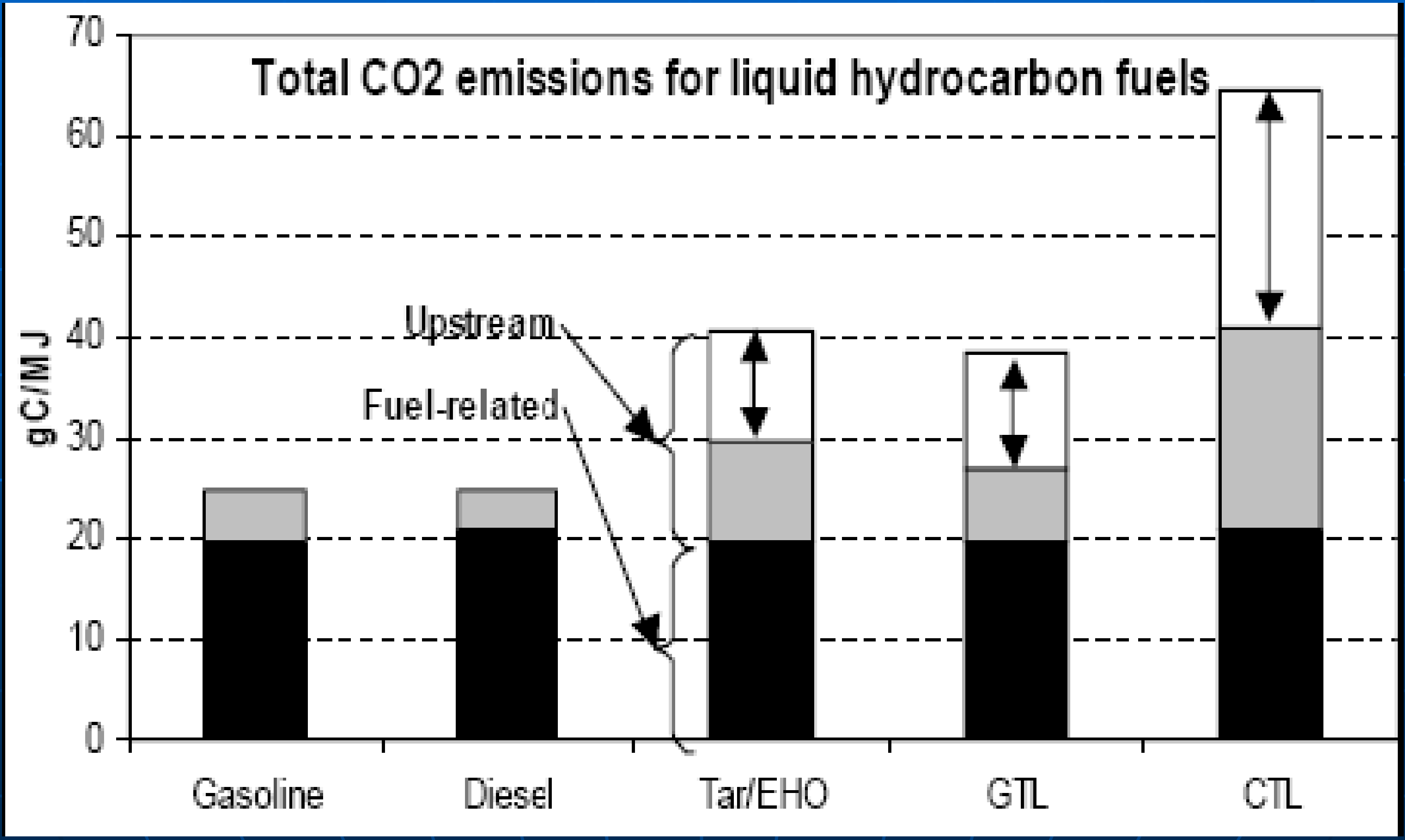


The **transition of least resistance**? Vast quantities of unconventional sources of liquid hydrocarbons are available, compatible with the existing infrastructure, at prices we are willing to pay.

IEA “Resources to Reserves” 2005



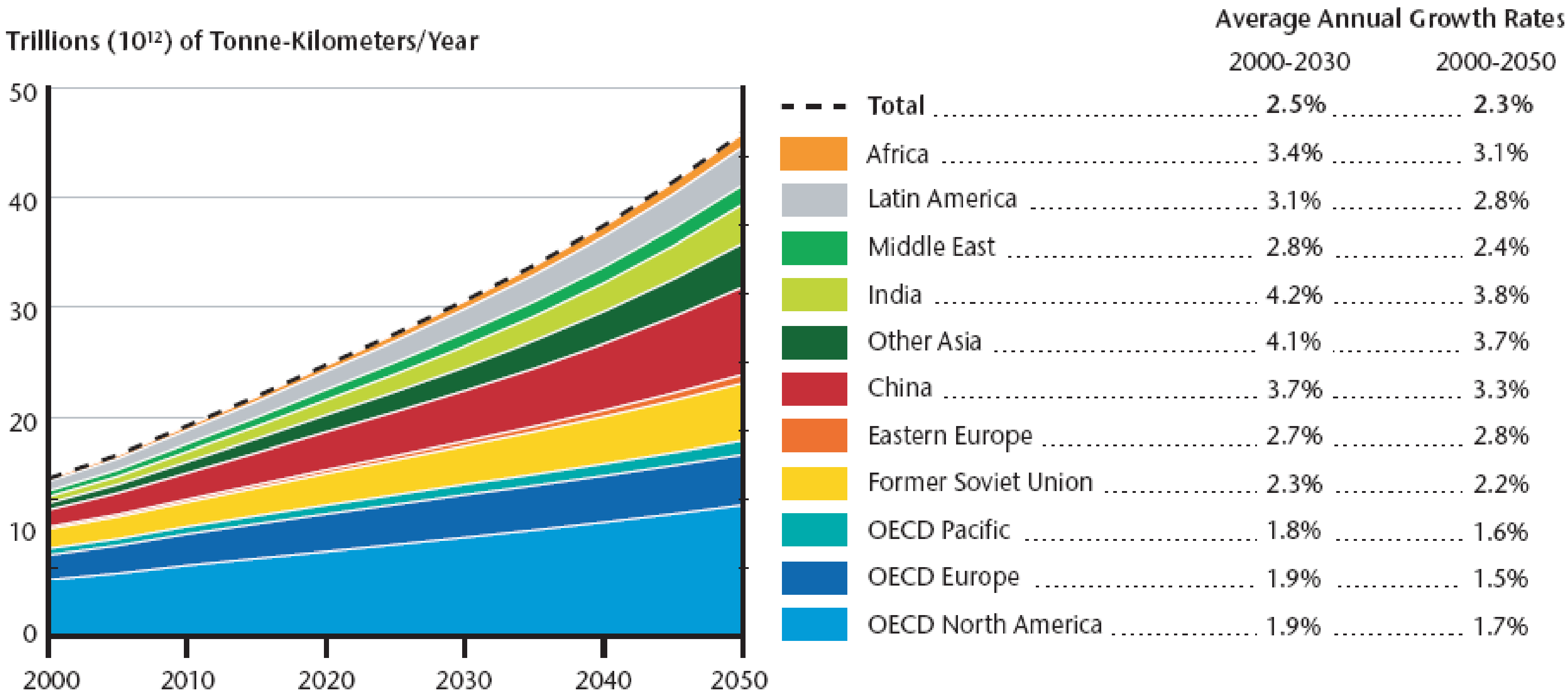
GHG emissions from oil sands could be 20% to 80% higher than gasoline from conventional oil, CTL emissions more than double (without CCS).



Source: Farrell, 2006.

Both passenger and freight transport are growing most rapidly in the developing economies.

WBCSD: Projected goods transport activity by region

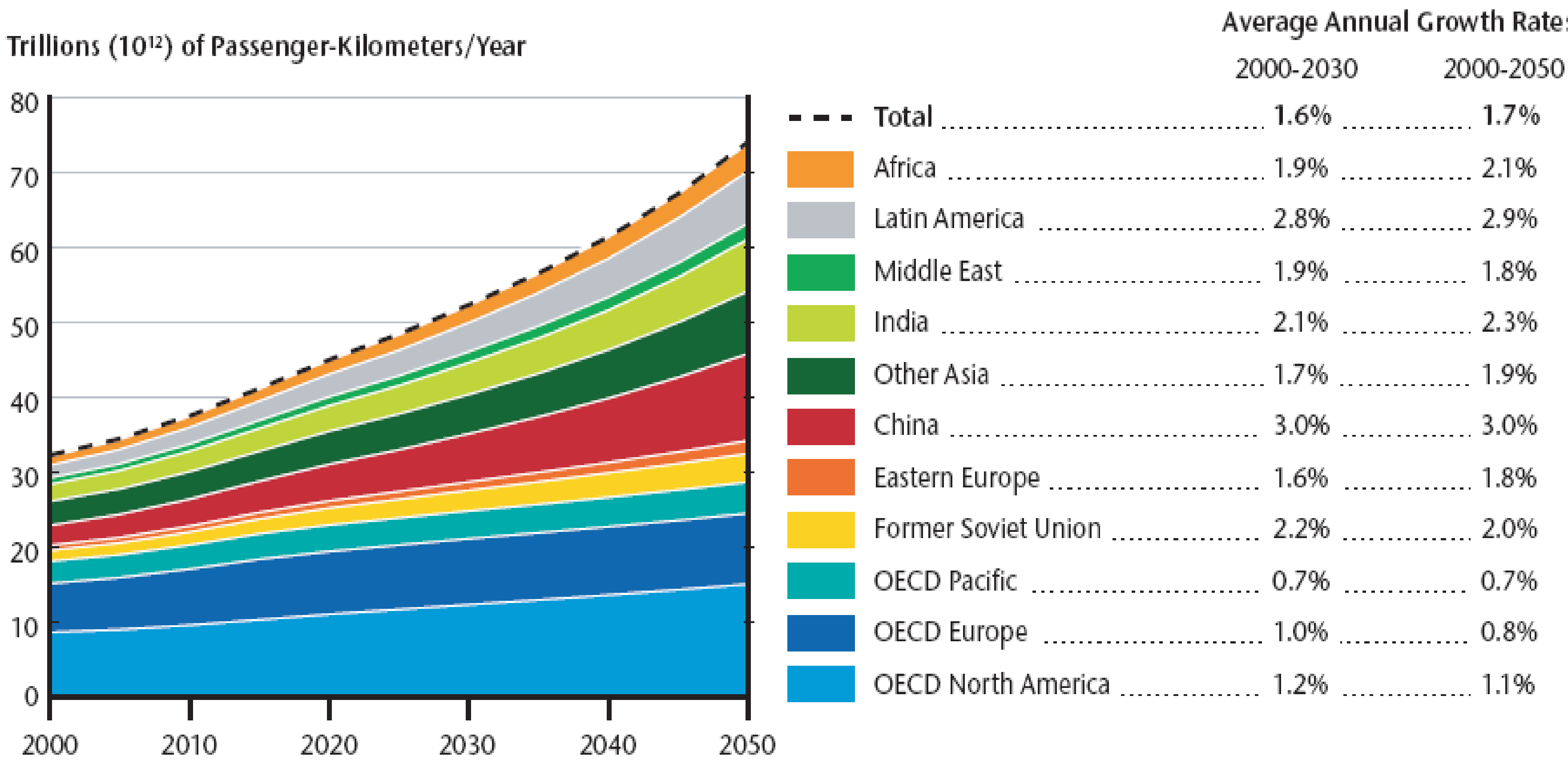


Note:
Excludes air waterborne and pipeline.

Source:
Sustainable Mobility Project calculations.

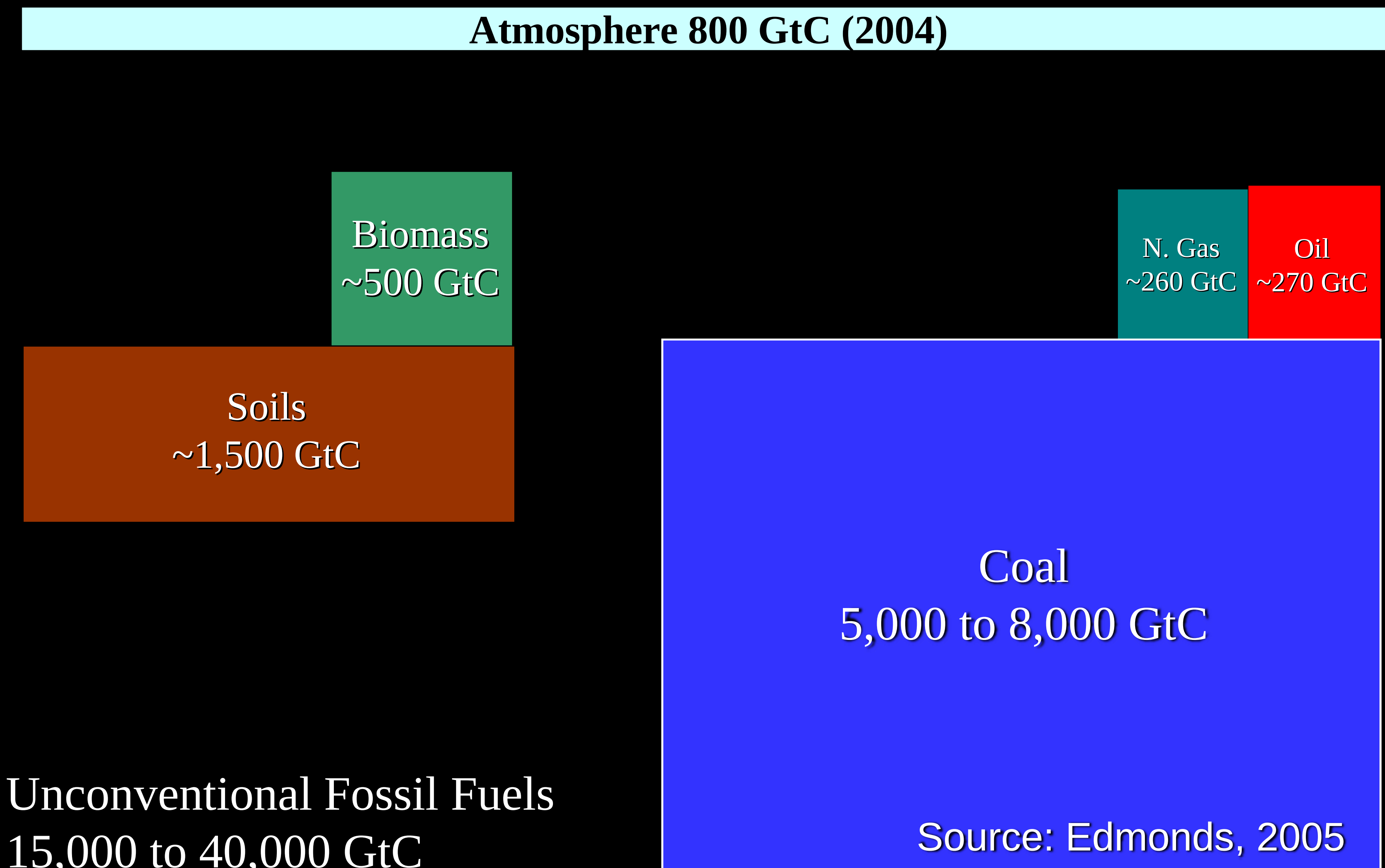
World oil consumption is accelerating because of growing demand for motorized mobility.

WBCSD: Projected personal transport activity by region

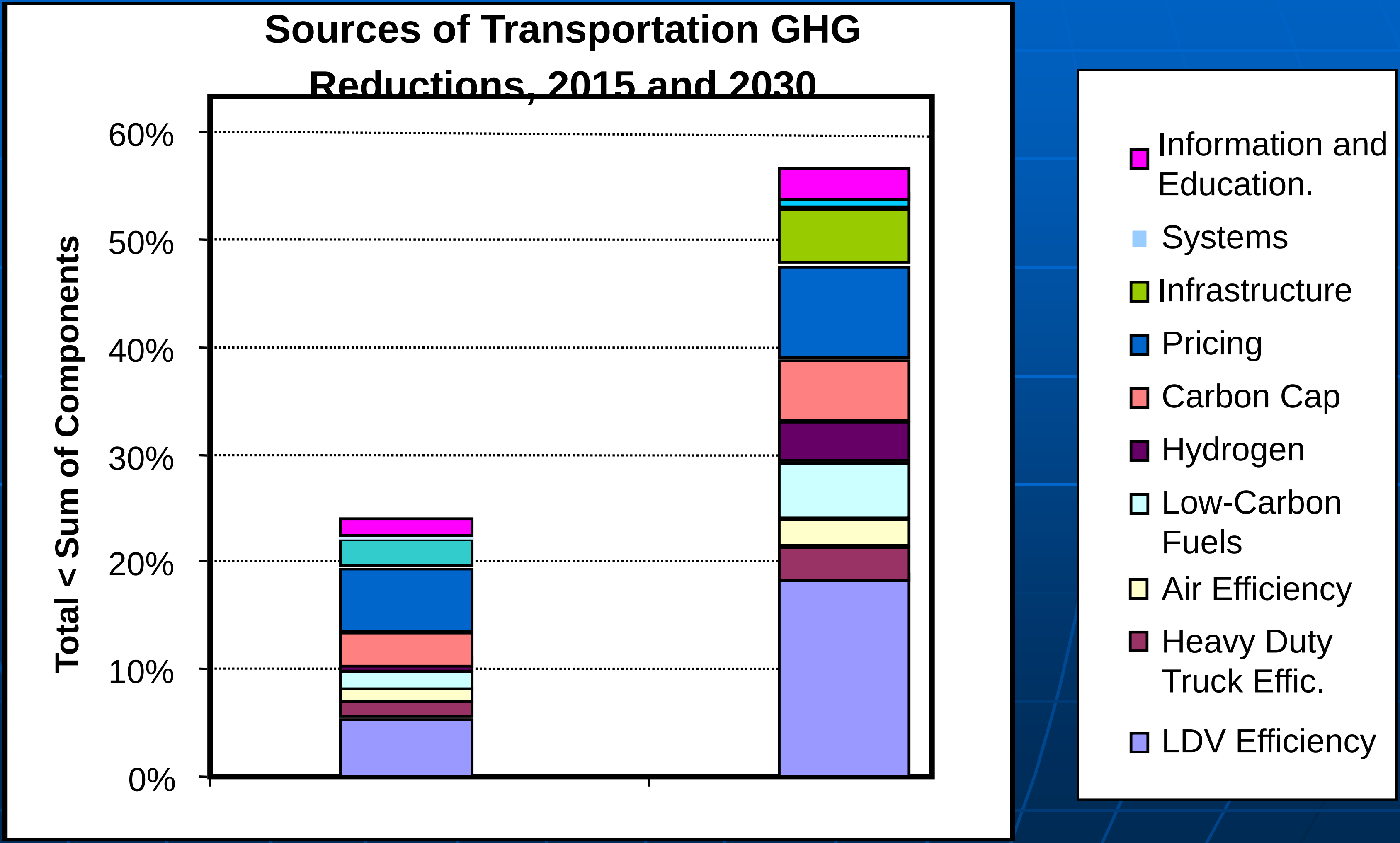


Source:
Sustainable Mobility Project calculations.

Carbon Reservoirs

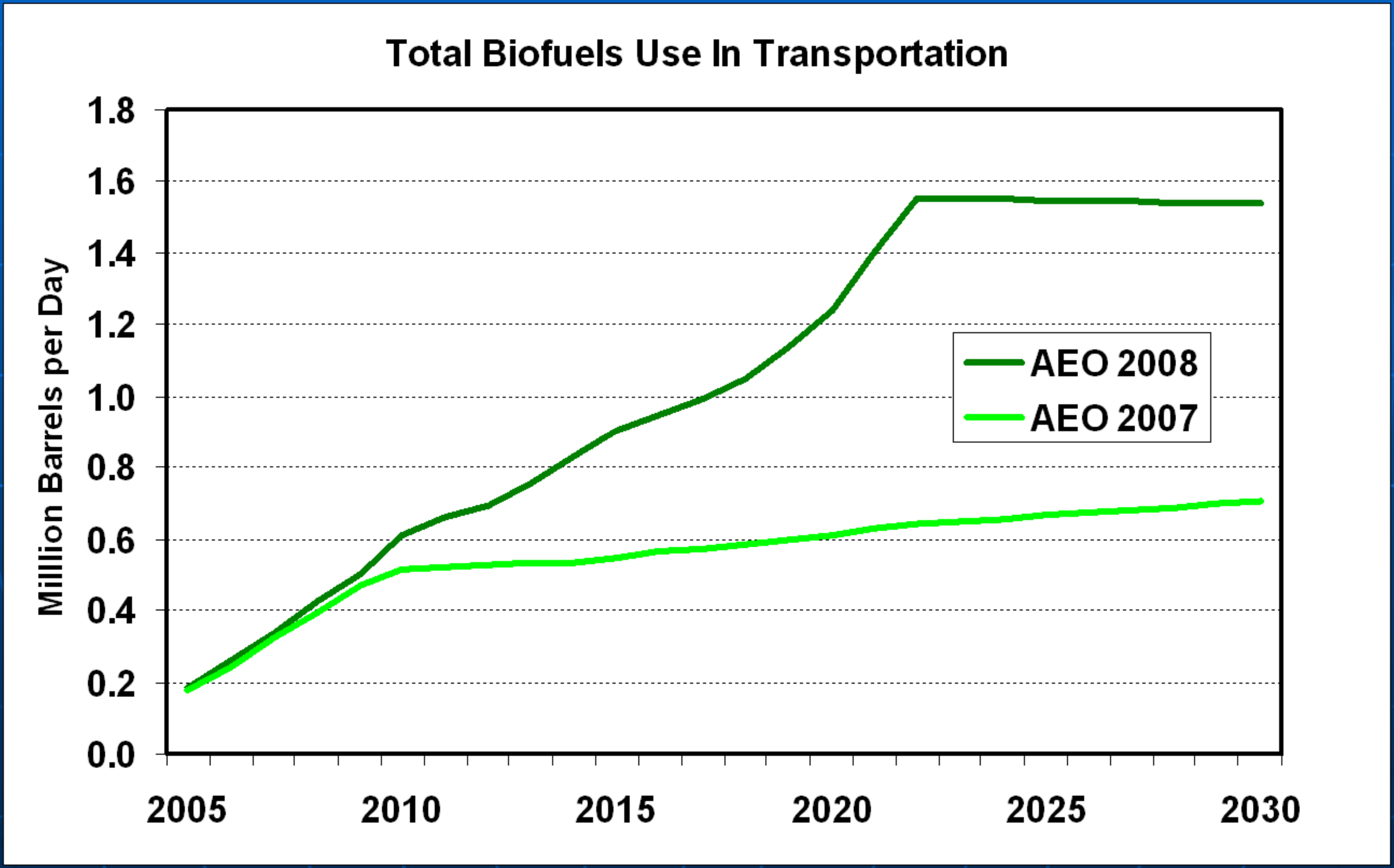


Transportation requires a comprehensive strategy with a long-term perspective (50-100 years), involving all levels of government, industry and individuals.

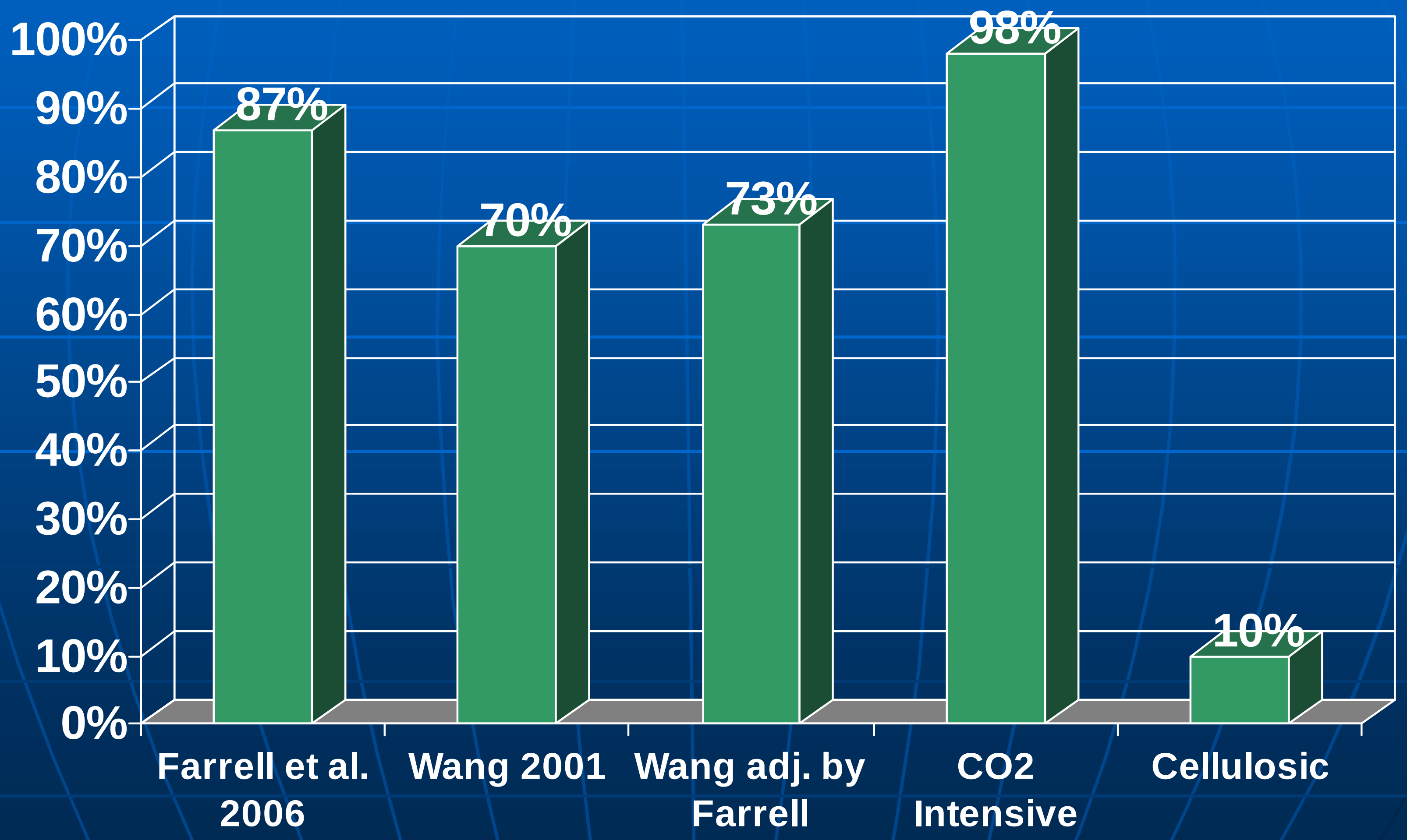


Source: Greene and Schafer, Pew Center on Global Climate Change, May 2003.

What will EISA accomplish?
Increase biofuel use by 1.5 mmbd oil eq.



The Depts. of Energy and Agriculture estimate that biofuels could replace up to 30% of U.S. transportation energy (less worldwide). But to realize significant GHG reductions this must not be ethanol made from corn (Farrell et al., 2006). Better ideas?



The non-partisan National Commission on Energy Policy proposed a comprehensive plan to address oil dependence and reduce GHG emissions (here augmented).

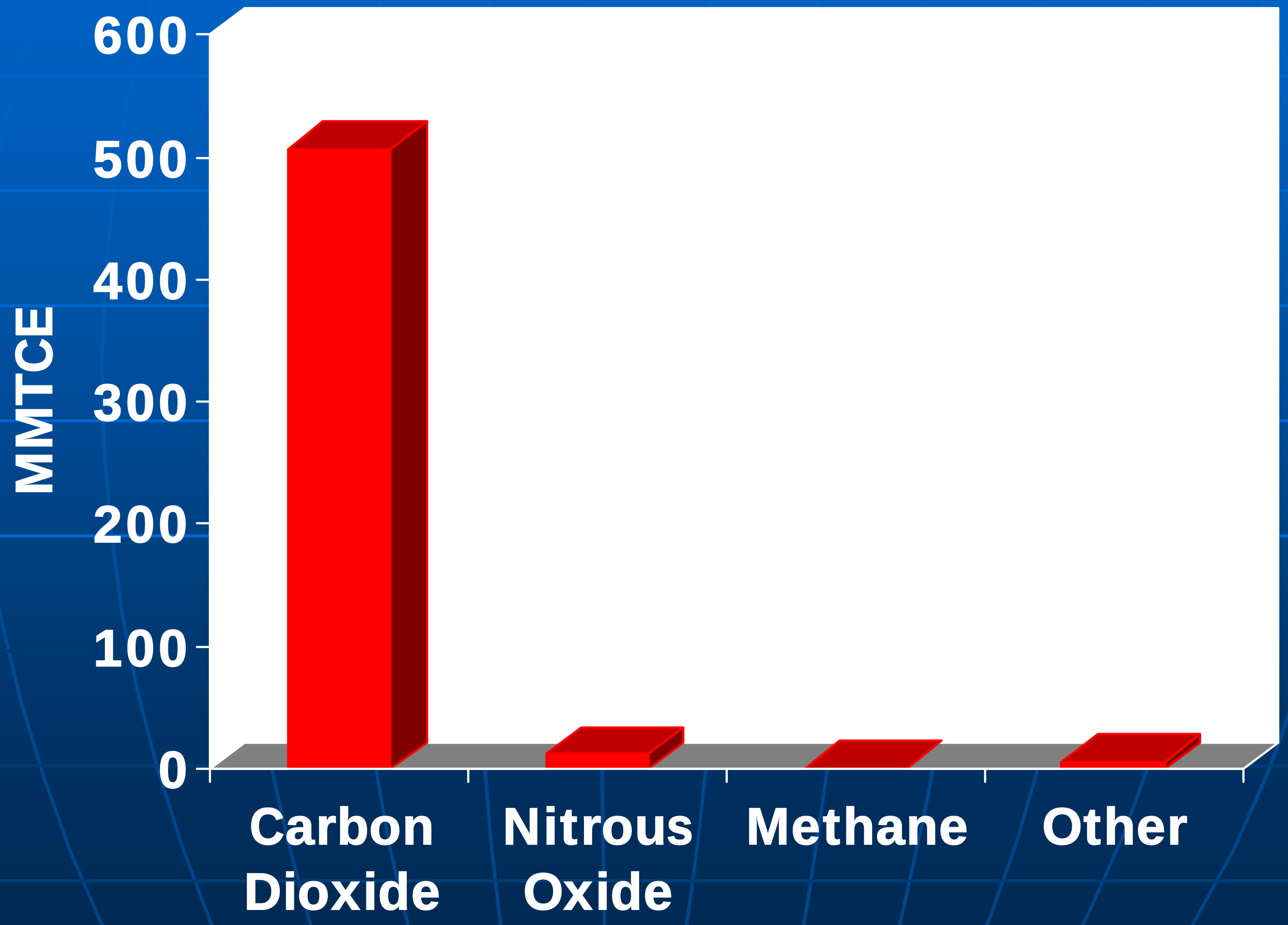
Demand

- From 35 MPG in 2017 increase light-duty vehicle MPG to 43 MPG by 2030 (+75%).
- Displace 2 mmbd of gasoline with biofuel by 2020.
- Reduce heavy truck energy use by 0.5 mmbd by increasing fuel economy by 15%.
- Reduce rail and water oil use by 0.2 mmbd.
- Eliminate the use of #2 distillate fuel to heat residential and commercial buildings.
- Cut industrial petroleum use by 0.6 mmbd.

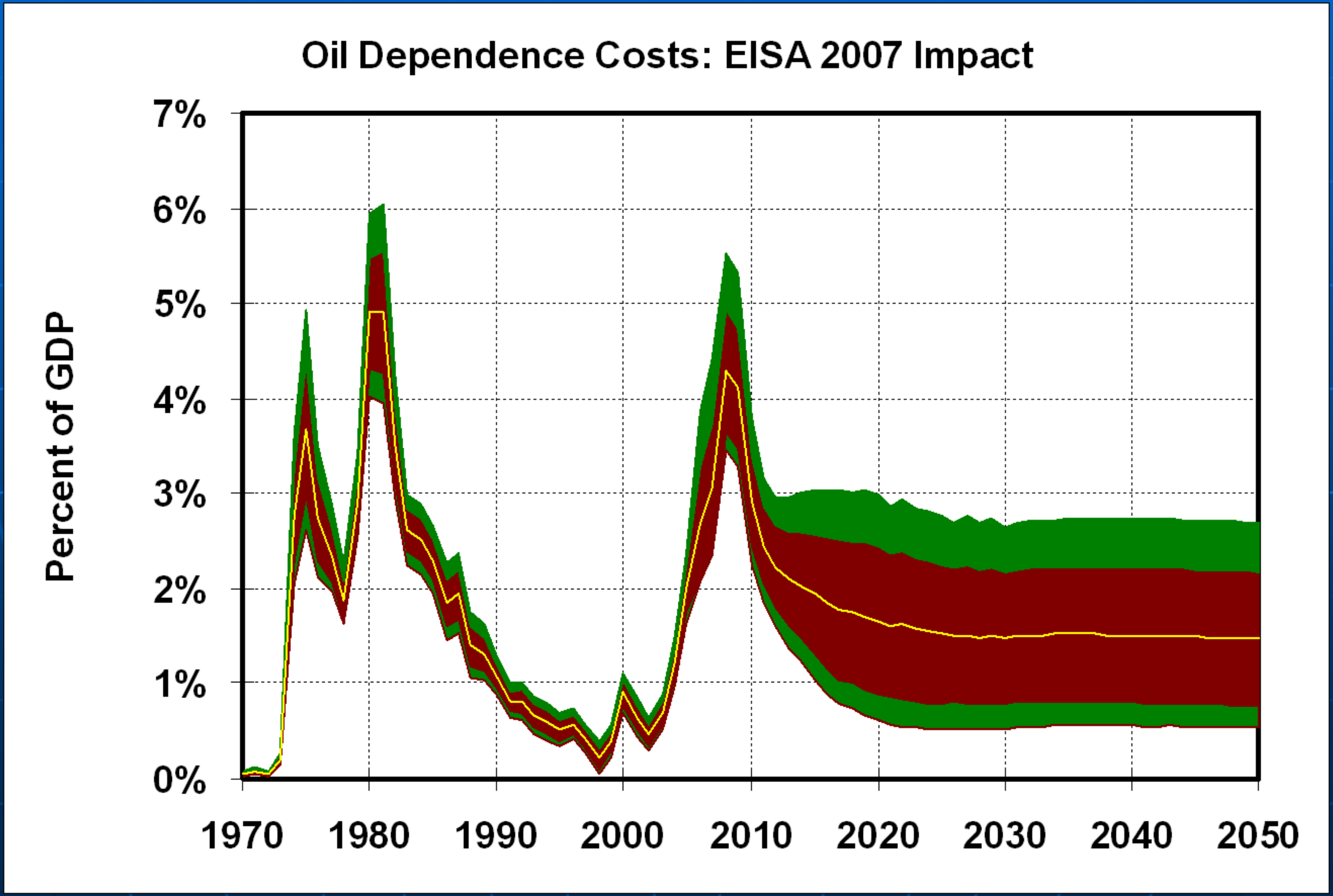
Supply

- Expand oil drilling to the ANWR and deep offshore areas by 2 mmbd.
- Produce 1 mmbd petroleum fuels from coal.

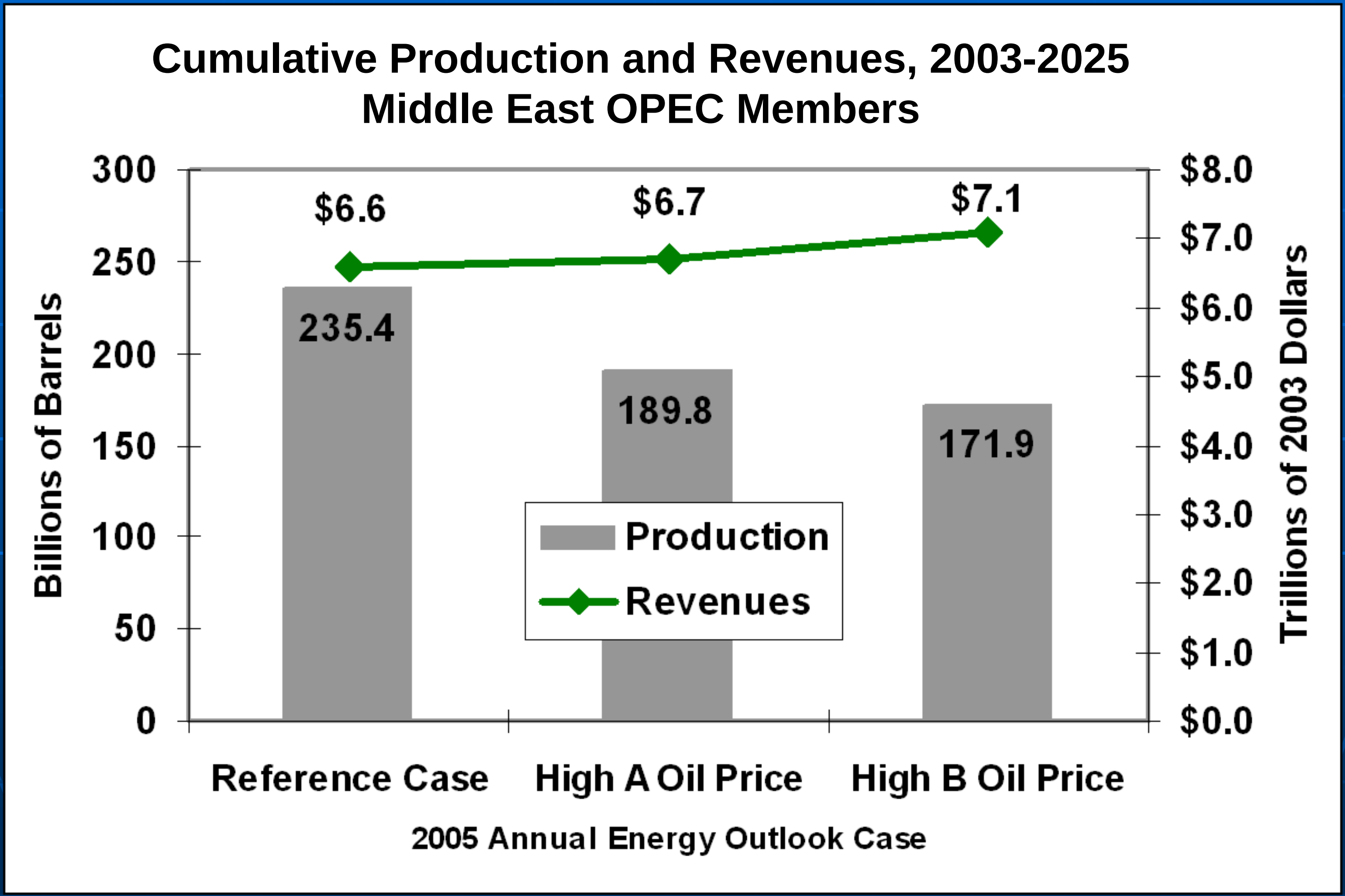
CO_2 dominates transportation's GHG emissions (EPA, 2006).



A 40% increase in LDV fuel economy would reduce expected costs by almost ½% of GDP and decreases the 95th percentile by 1%.



But OPEC is not and will not “fill the gap” because OPEC can make more money by leaving the oil in the ground.

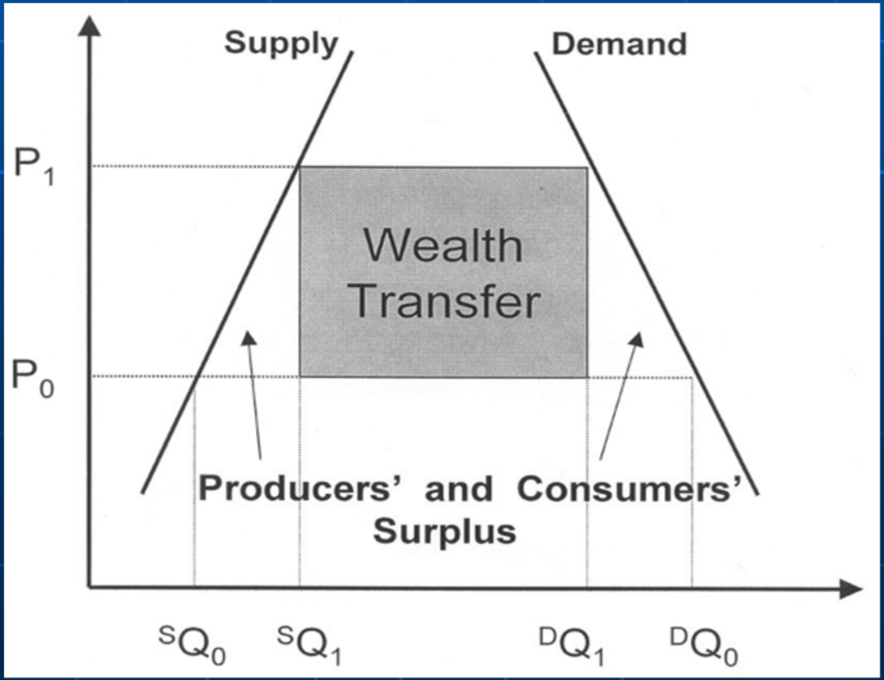


U.S. DOE/EIA, Annual Energy Outlook 2005.

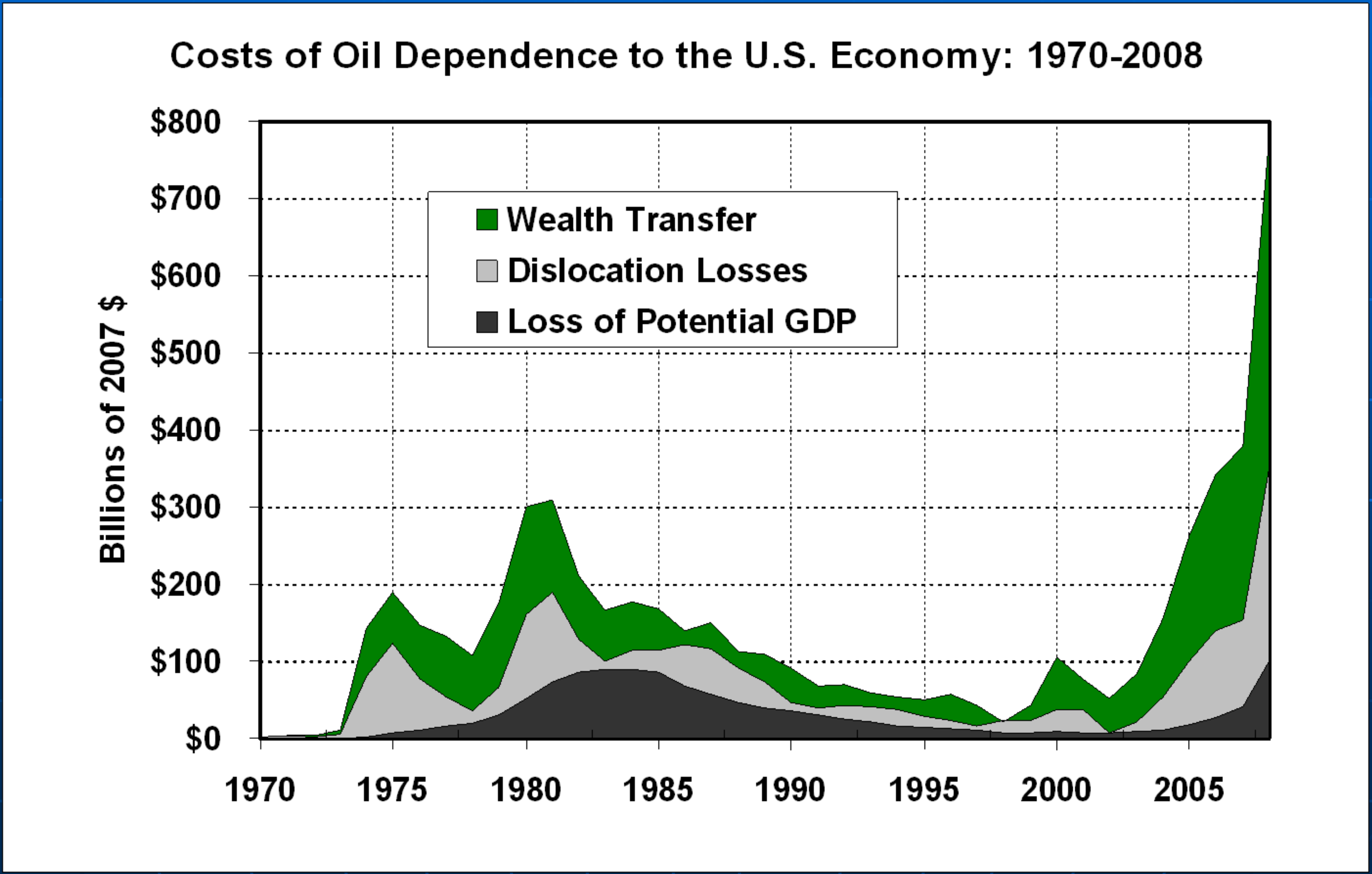
What does oil dependence cost?

1. Loss of potential GDP = producers' & consumers' surplus losses in oil markets (dynamic).
2. Dislocation losses of GDP due to oil price shocks.
3. Transfer of wealth due to monopoly pricing and price shocks (requires counterfactual competitive price).

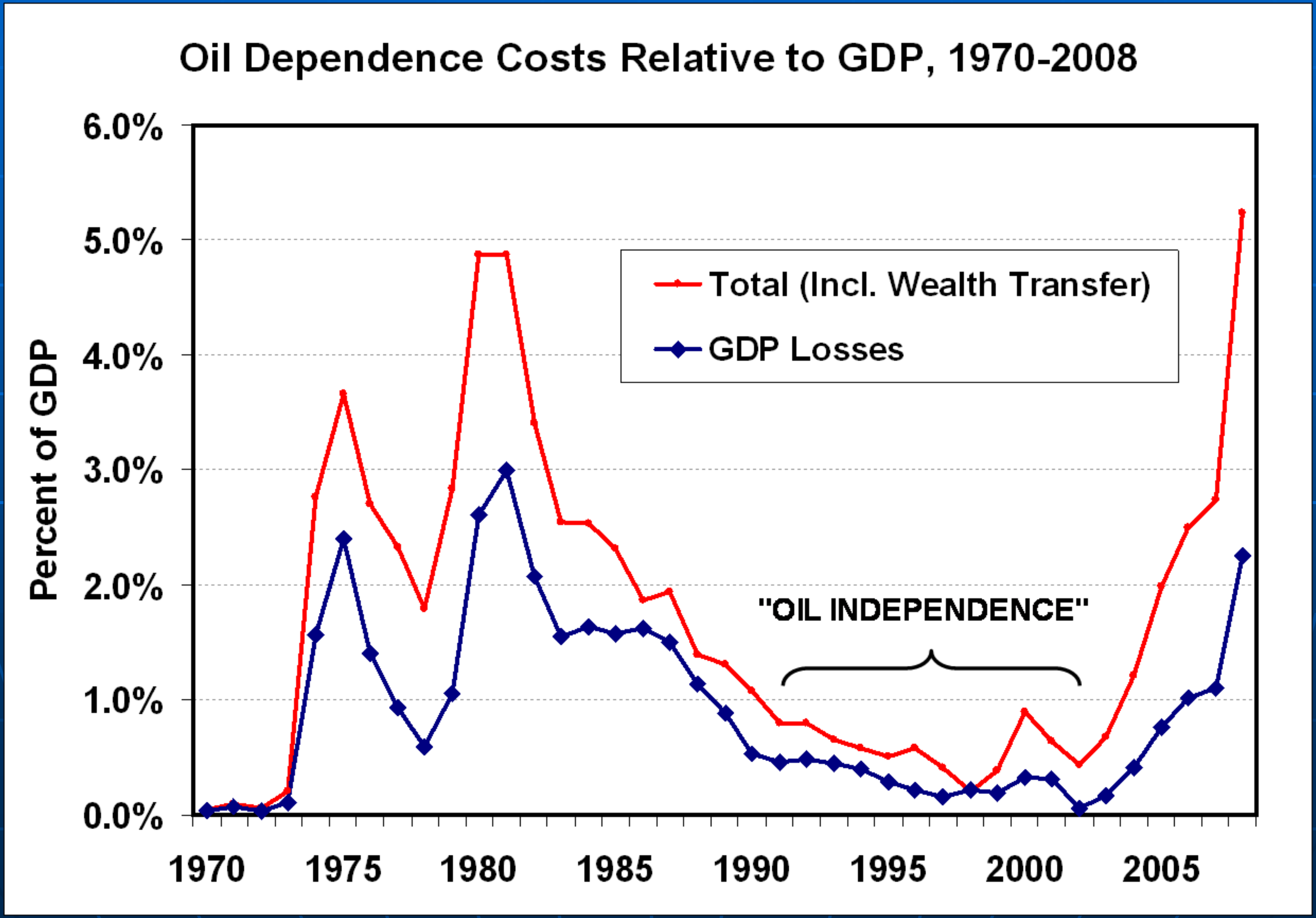
Transfer of wealth is not a loss of GDP but a change in the ownership of GDP. It can occur in disrupted and undisrupted markets and occurs whether or not OPEC is the cause of the disruption.



Oil dependence can be usefully measured retrospectively and prospectively by its direct economic costs.



I think we have already experienced "energy independence"…for a while.



What is oil dependence?

Oil dependence is primarily an economic problem with significant national security implications caused by,

- use of market power by oil producing states,
- importance of oil to the economy and,
- lack of economical substitutes for oil.

What is oil (energy) independence?

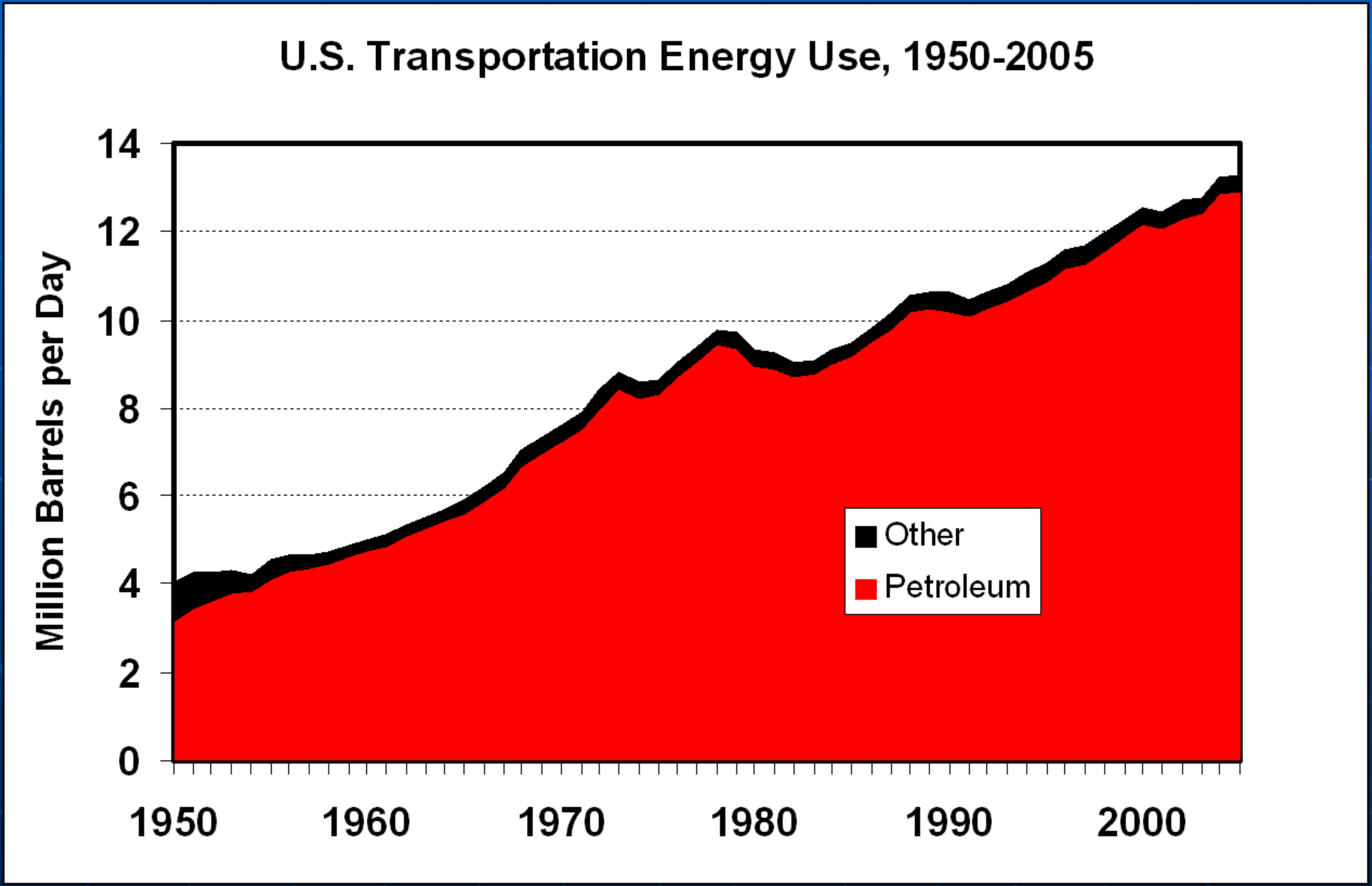
- Use no oil?
- Import no oil?
- Let’s consult the dictionary.
- A state in which a consuming nation’s actions are “not subject to restraining or directing influence by others” as a consequence of its need for oil.

The Oil Security Metrics Model estimates future U.S. oil dependence costs, incorporating key uncertainties.

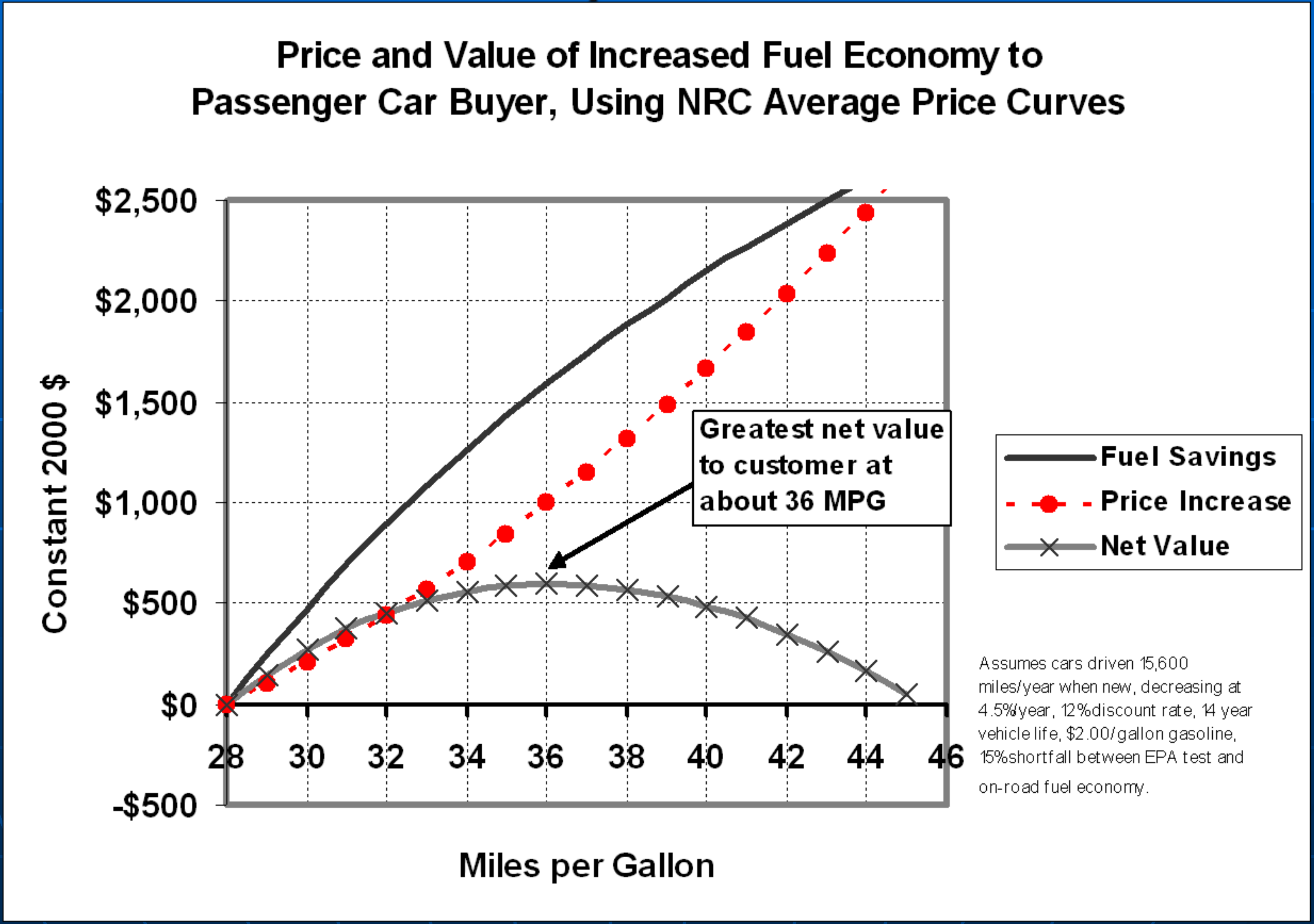
- Uncertainty about future oil resource availability and OPEC's willingness to expand output represented by the Energy Information Administration Annual Energy Outlook High, Reference & Low Oil Price Projections.
- Simulates potential supply disruptions, with a stochastic model calibrated to historical deviations of OPEC supply from AEO projections.
- Policies & technologies change both the level of oil demand & its response to oil prices. Both are estimated.
- 10,000 simulations are run to characterize alternative oil futures and allow for uncertainties in key parameters.

Greene, D.L. and P.N. Leiby, 2006. *The Oil Security Metrics Model*, ORNL/TM-2006/505, Oak Ridge National Laboratory, Oak Ridge, Tennessee, May.

Our transportation system runs on petroleum (> 6,300 gals/sec) and uses more than any other nation's entire economy.

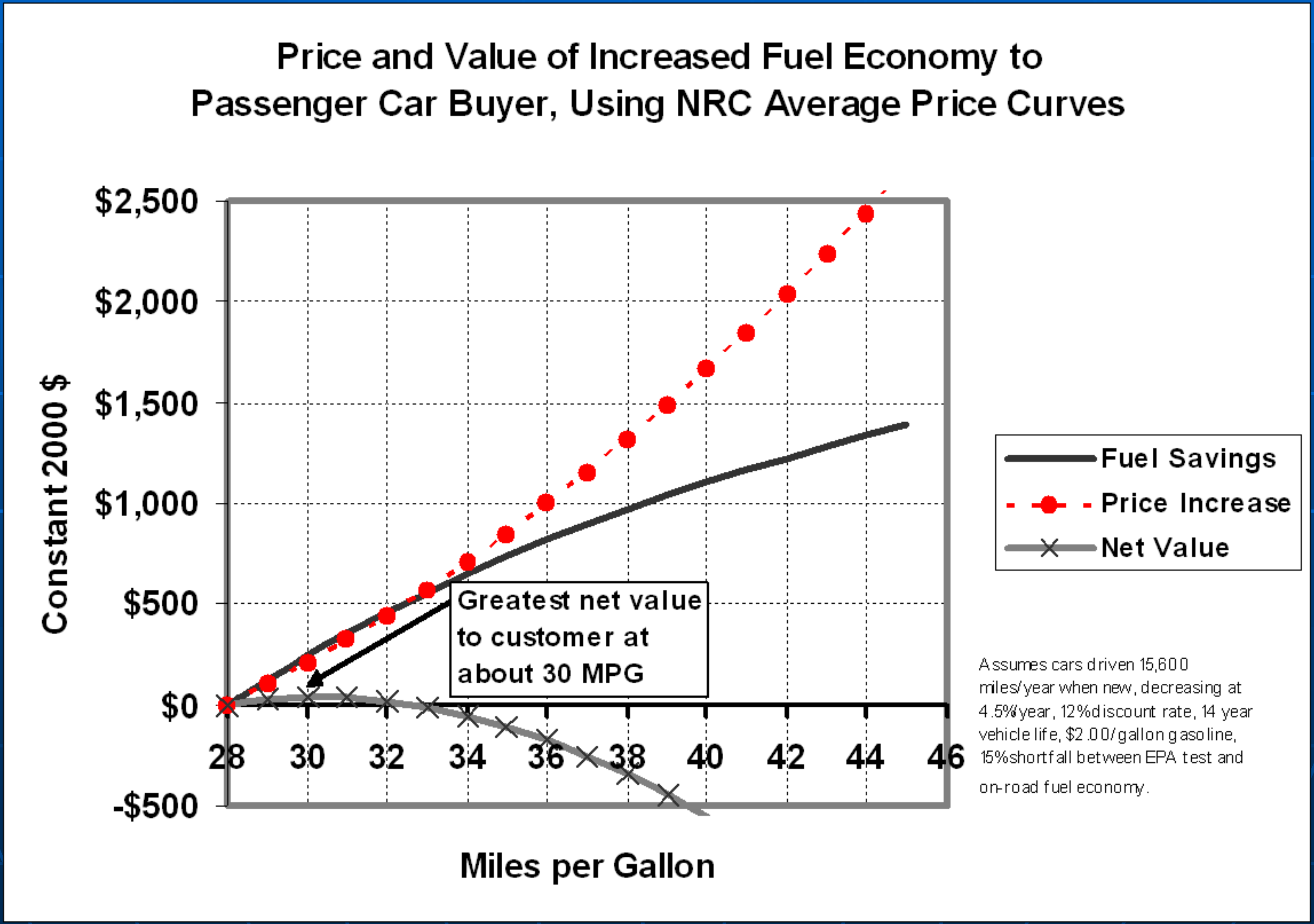


Setting MC = MV maximizes net value to the consumer. Net value varies only a little near the optimum.



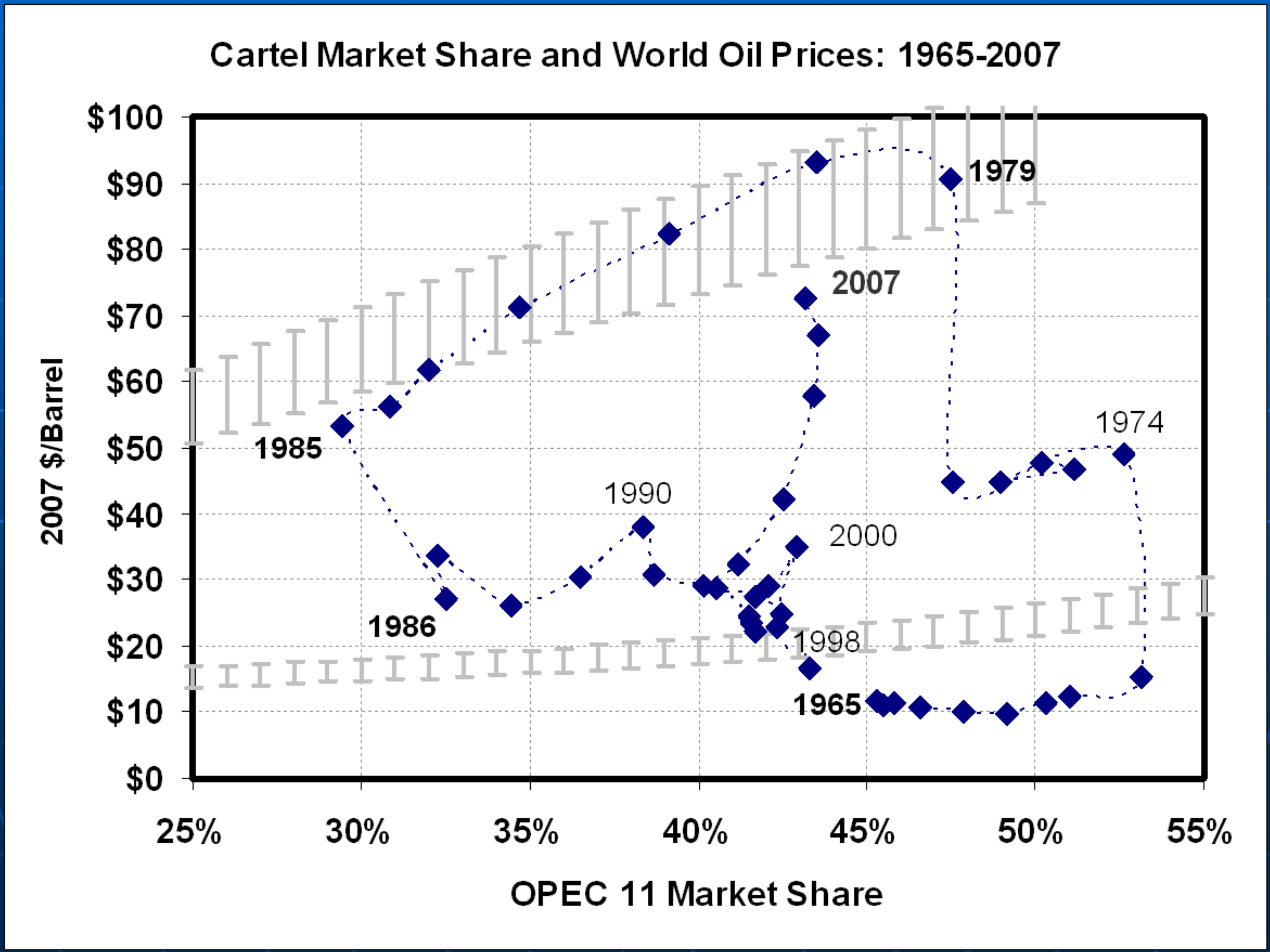
Source: Calculated from data in NRC, 2002.

Manufacturers assert that consumers are willing to pay for 3-years worth of fuel savings. Shortsighted consumers would not be interested in increased fuel economy at $2.00/gallon.

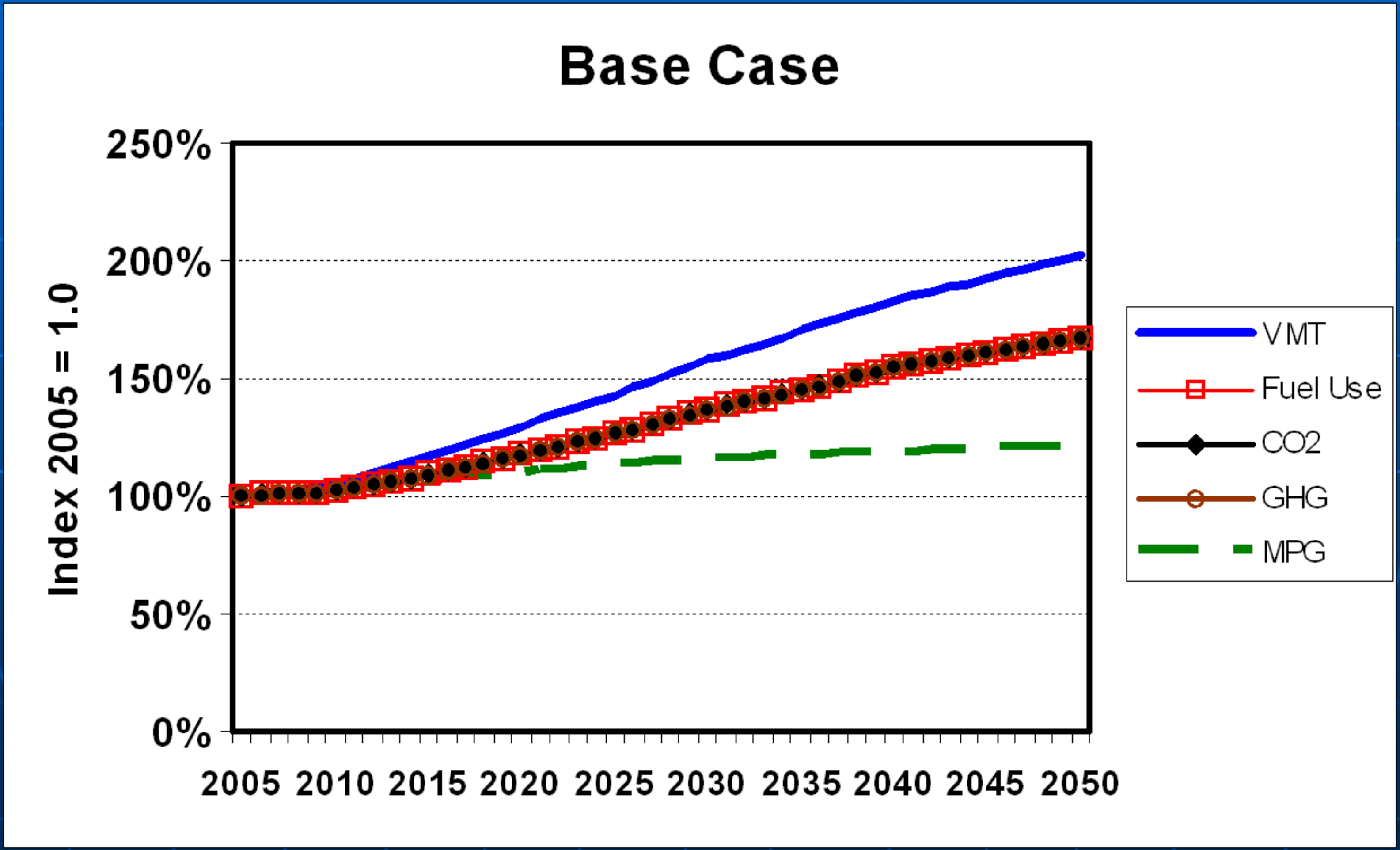


Source: Calculated from data in NRC, 2002.

Even the static version of von Stackelberg's model has impressive explanatory power.



The base case (AEO 2007) projects a doubling of light-duty vehicle (LDV) travel by 2050, with fuel use and CO_2 emissions increasing by two thirds.



In addition, if we could triple light-duty vehicle fuel economy by 2050 that would reduce CO_2 emissions below their 2005 levels.