Joint DOE/NRCan Study of North American Transportation Energy Futures: DISCUSSION OF THE STUDY, PRESENTATION OF PHASE 2 RESULTS (May 2003)

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Outline of This Presentation

- Background
- Scenarios
- Models
- Analytical Results
- Underlying Cost Details
- Concluding Remarks
- Appendices

Note: Many of the slides contain "notes" which provide additional details. The presentation is available with or without notes slides.

Background for This Study

- In April 2000, DOE Undersecretary asked the Transportation office to undertake a study of transportation long-term futures.
- “Future U.S. Highway Energy Use: A Fifty Year Perspective”(dated May 3, 2001 and called **Phase 1**) is available at: **www.ott.doe.gov/future_highway.shtml**
- The **Phase 1** study had a limited scope, so a **Phase 2** was undertaken to address costs and resource limitations.

Phase 1 Features

- Six strategies to reduce oil use and carbon emissions were compared against a base case.
- Light vehicle oil use in 2050 was 27% to 96% less than the base case across the six strategies.
- No costs were estimated for the strategies.
- Feedback between the U.S. and World oil markets was not considered.

Phase 2 Features: "Joint DOE/NRCan Study of North American Transportation Energy Futures"

- Adds costs, sensitivity of oil price to conventional oil depletion to our analysis
- North American focus (U.S. and Canada only)
- Estimates the likelihood of an upcoming fuel transition for North America and the world
- Estimates the energy, oil, carbon and cost implications of alternative transportation futures
- Covers all modes, though the focus of this presentation is on highway vehicles only
- Alternative futures vary by vehicle and fuel technologies and total travel

Why the focus on 2050?

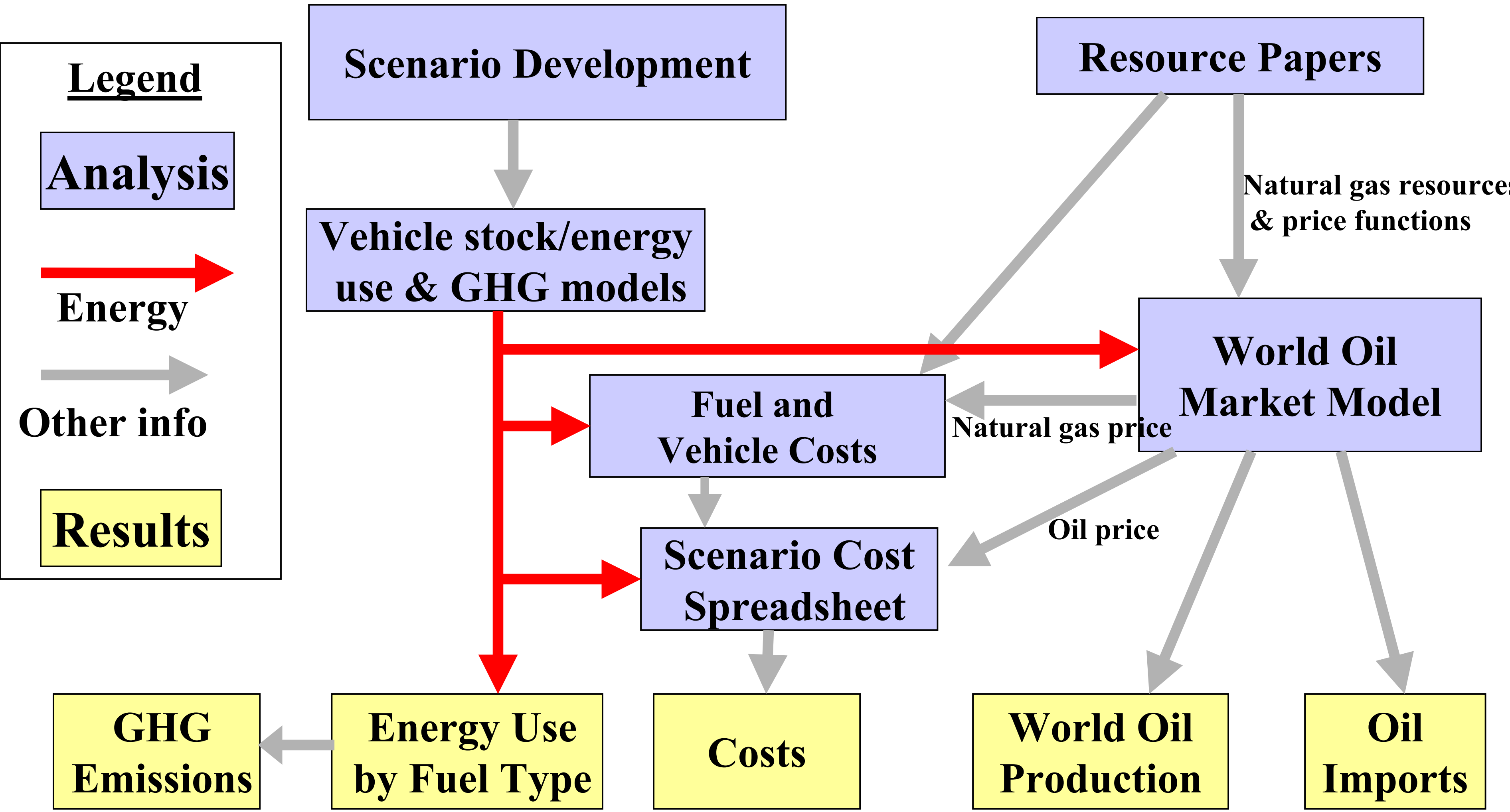
Very large uncertainties create skepticism about this long a time scale, but:

- Long time frame needed to examine a fuel transition:
  - Pessimistic estimates of conventional oil resources yield downturn as soon as 2010, but
  - More optimistic estimates push transition out to 2020-2040
  - It will take decades for full effect of new technologies to occur
- DOE's Office of Energy Efficiency and Renewable Energy is now focusing on a 50-year timeframe

Tools of the Study

- Scenarios of possible futures using rate of innovation, environmental responsiveness and degree of North American energy market integration as drivers
- Models for analysis of energy demand, greenhouse gas emissions, oil markets and costs
- Resource Papers on key topics to provide context, technical detail and cost data

Structure of the Analysis



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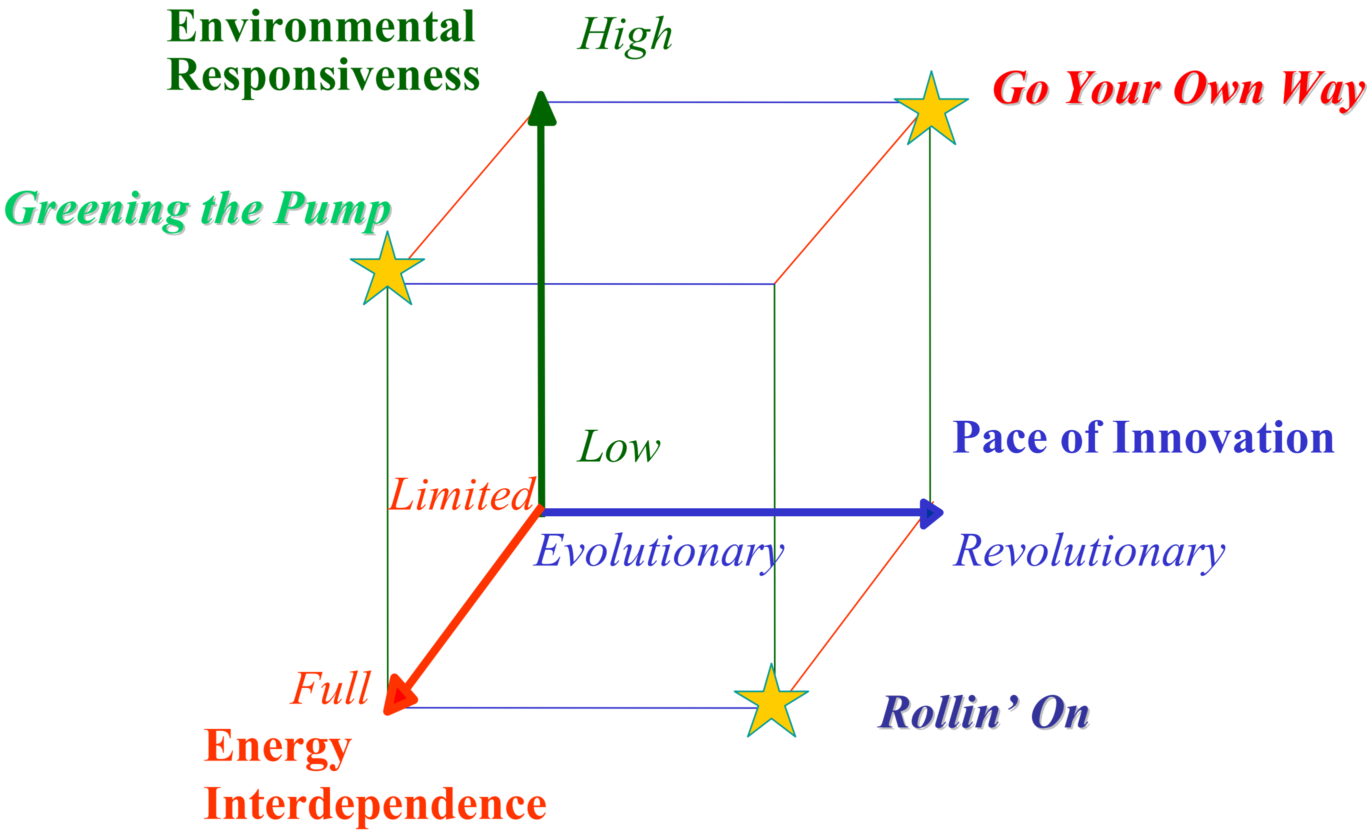
The 2050 Scenarios

- Visions of what the North America and World could look like
- Built from specific drivers:
  - The pace of innovation
  - Environmental responsiveness
  - Degree of U.S./Canadian energy market interdependence
- Scenarios provide the logic and context for further modeling assumptions
- Crucial point: many key scenario parameters, e.g. vehicle efficiency, are *assumptions*, not forecasts!

The 2050 Scenarios

	Market Interdepend-ence	Pace of Innovation	Environmental Responsive-ness	Average % GDP growth/year
Base Case (Fixed MPG)	Intermediate	Intermediate	Intermediate	2.6%
Greening The Pump (GtP)	Full	Slow	High	2.2%
Go Your Own Way (GYOW)	Limited	Rapid	High	3.0%
Rollin' On (RO)	Full	Rapid	Low	3.0%

The Scenario Drivers



Scenario Descriptions

Base Case

- Moderate level of innovation and environmental consciousness, some market integration
- Technological change continues, but fuel economy of LDVs and HDVs remains unchanged because of customer preferences for other vehicle attributes, e.g. performance.

Go Your Own Way

- Fast paced, revolutionary rate of innovation, a high level of environmental responsiveness and non-integrated energy markets within North America to the year 2050.
- Key energy-related assumptions: very high fuel economy, with major penetration of hybrids and fuel cells, high E85 use

Scenario Descriptions (continued)

Greening the Pump

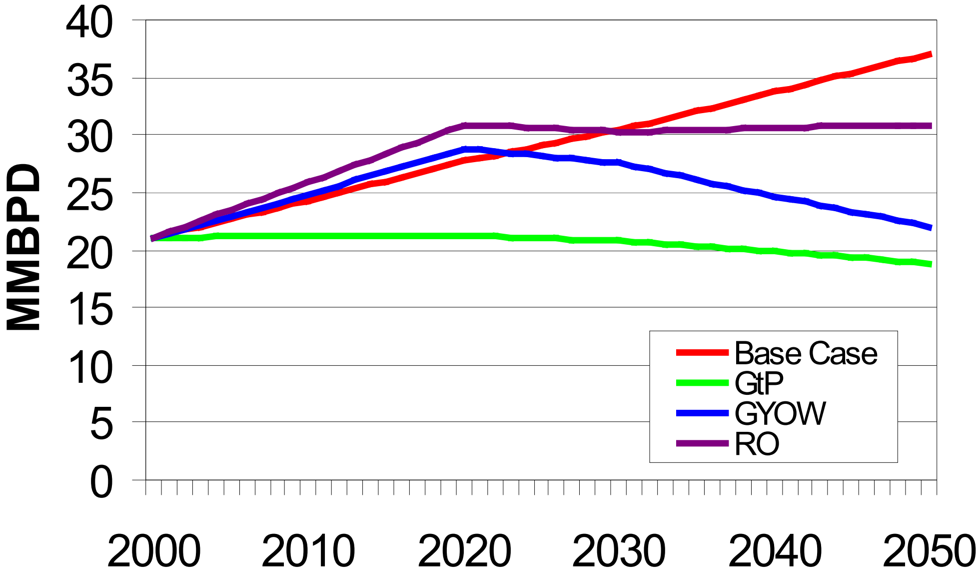
- Demand management is very successful in this low innovation, environmentally conscious world
- Environmentally friendly technologies that are existing or near deployment are quickly introduced into the market
- Key energy-related assumptions:
  - Reduced level of travel, rollback in light truck share
  - Moderately high fuel economy levels, high E85 use, focused on conventional technology

Rollin' On

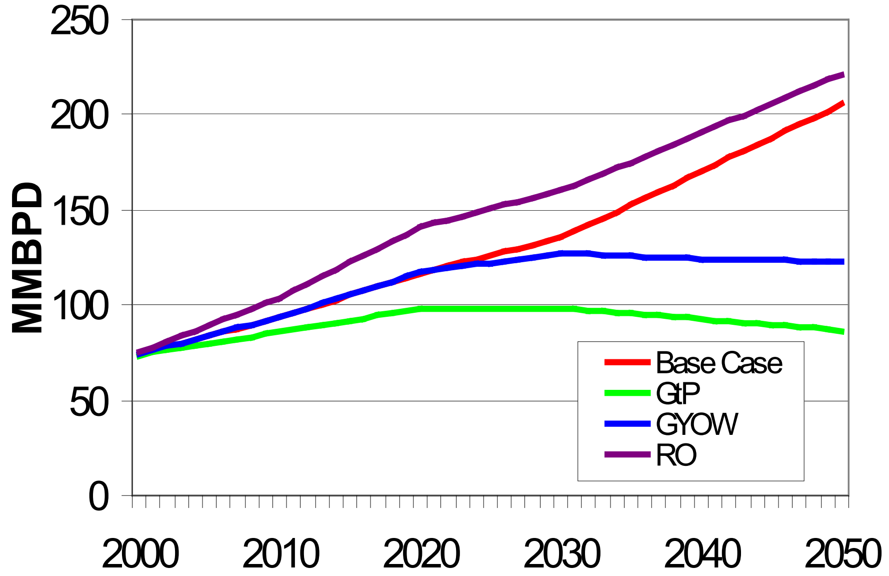
- Fast paced rate of innovation with the U.S. and Canada having a fully integrated market, with major focus on economic growth, not environmental consciousness.

Different World Oil Demand Scenarios from IIASA/WEC (IPCC) were tied to the North American Scenarios.

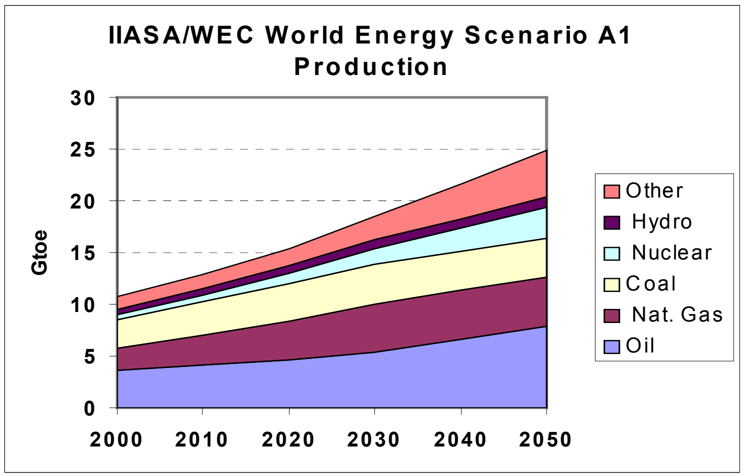
North American Oil Demand



World Oil Demand



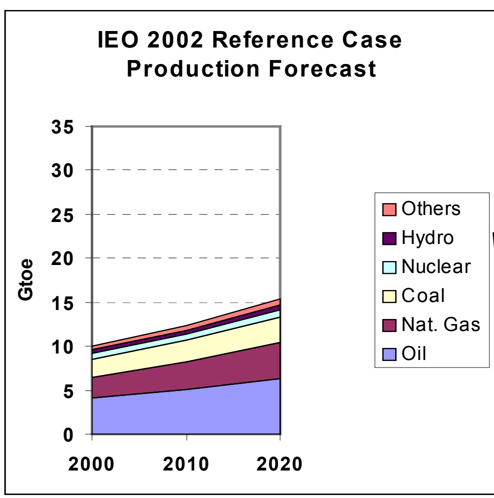
For the Base Scenario, the world energy projection begins as IIASA/WEC Scenario A1 and is adjusted to match the IEO 2002 Reference Case to 2020.

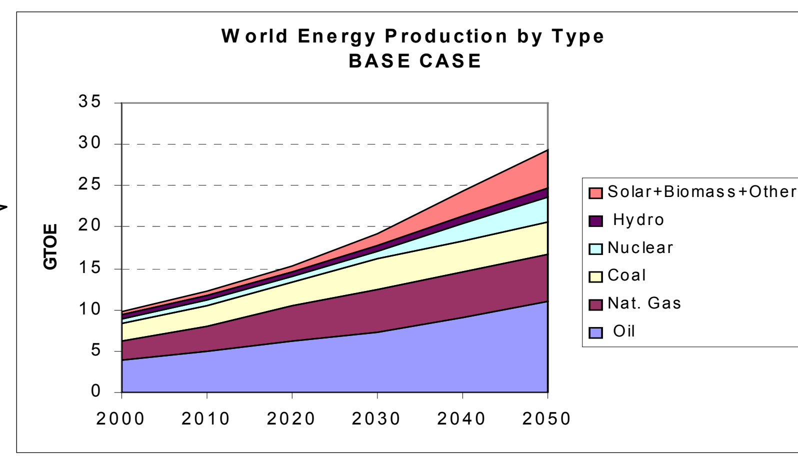


Optional Energy Intensity Adjustment

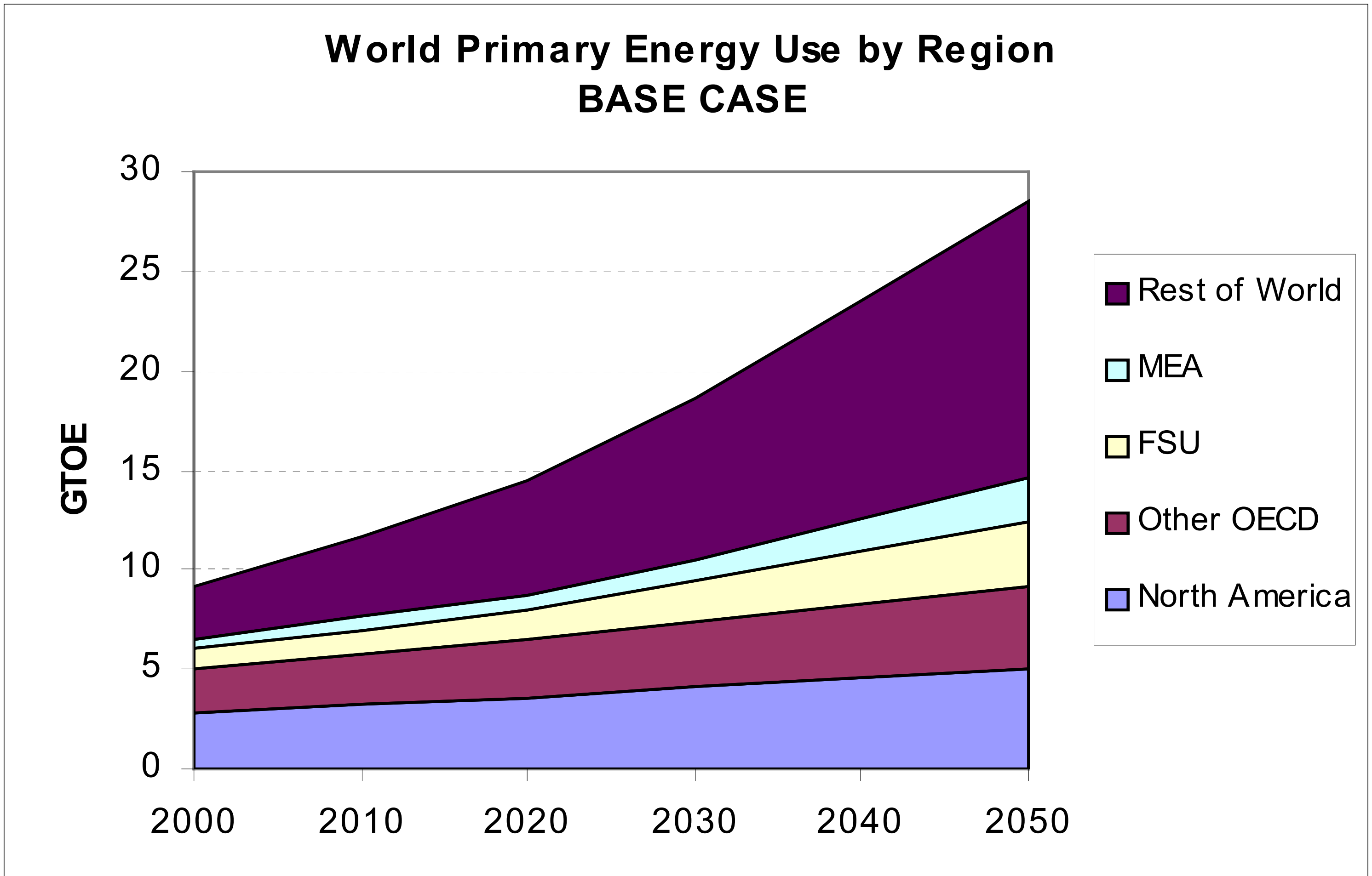
North American Champagne Forecast

World Oil Market Equilibration

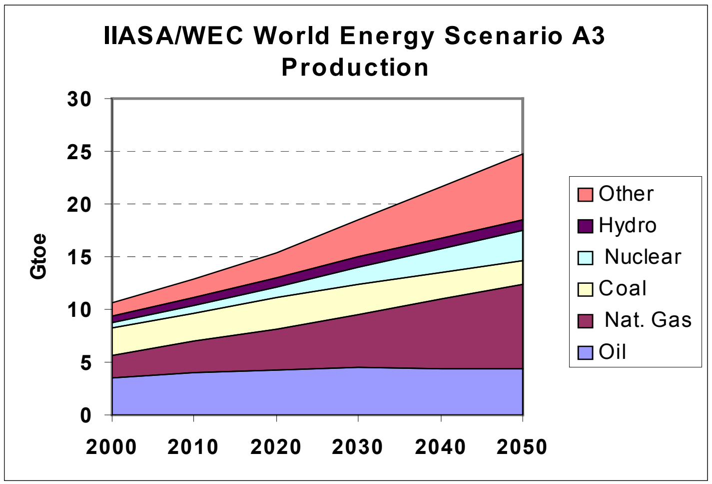


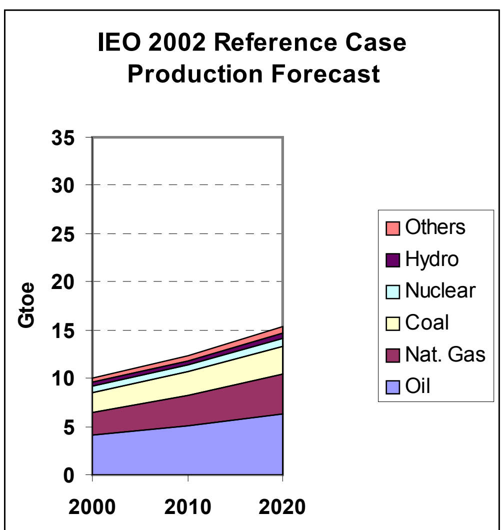


In the Base Case, energy use in North America and the developed economies grows steadily, but ROW energy use grows more rapidly.



The World GYOW Scenario begins as IIASA/WEC Scenario A3 and is adjusted to match the IEO Reference Case, thus raising Scenario A3's oil use significantly.





Optional Energy Intensity Adjustment

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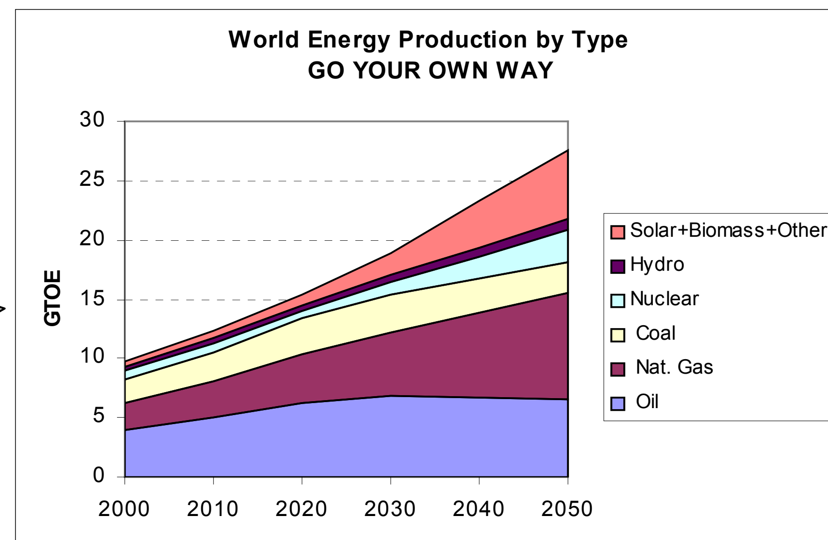
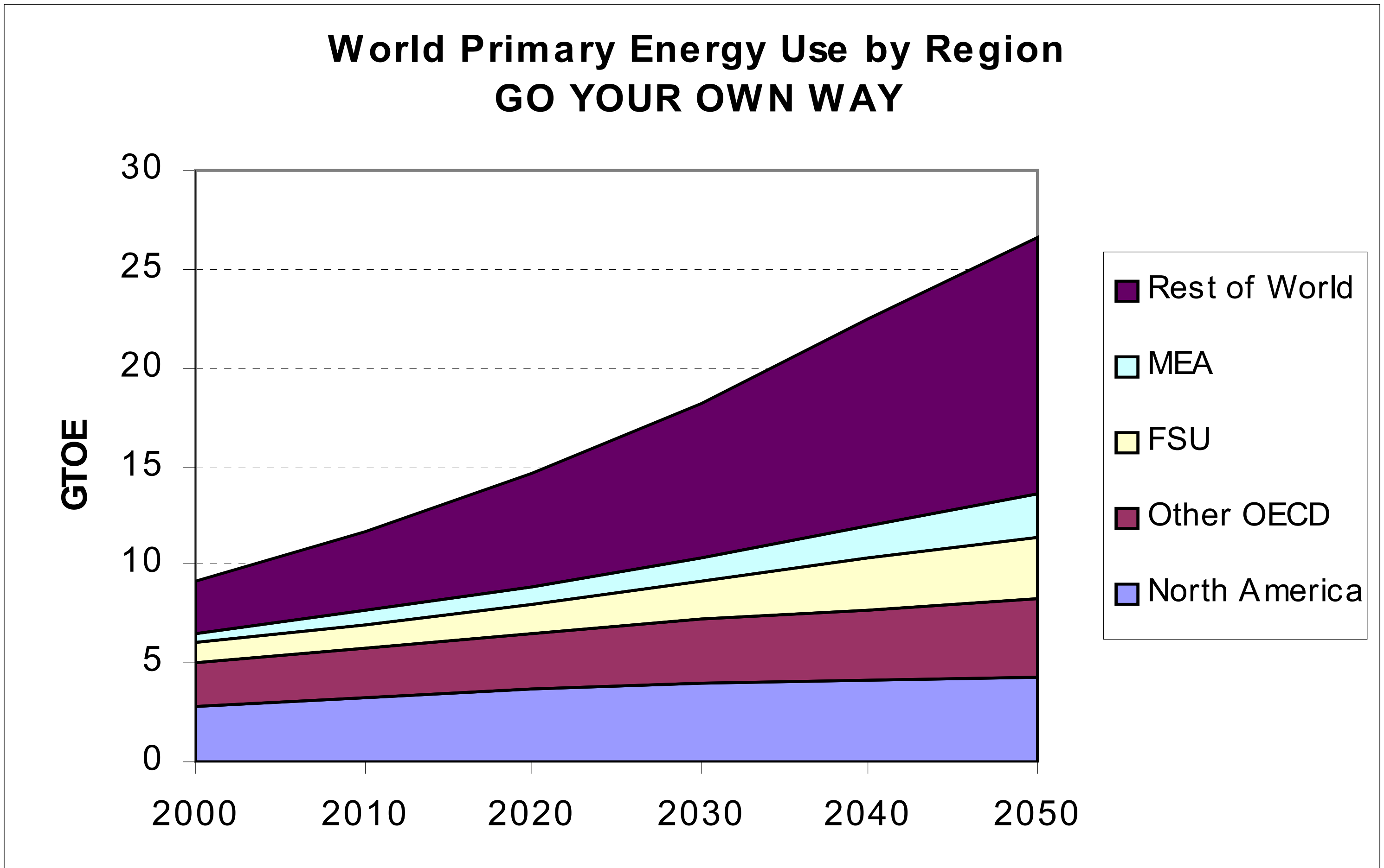


In the Go Your Own Way scenario, energy use in developed countries grows at an average annual rate of 1%/yr., while ROW energy expands at the rate of 3%/yr.



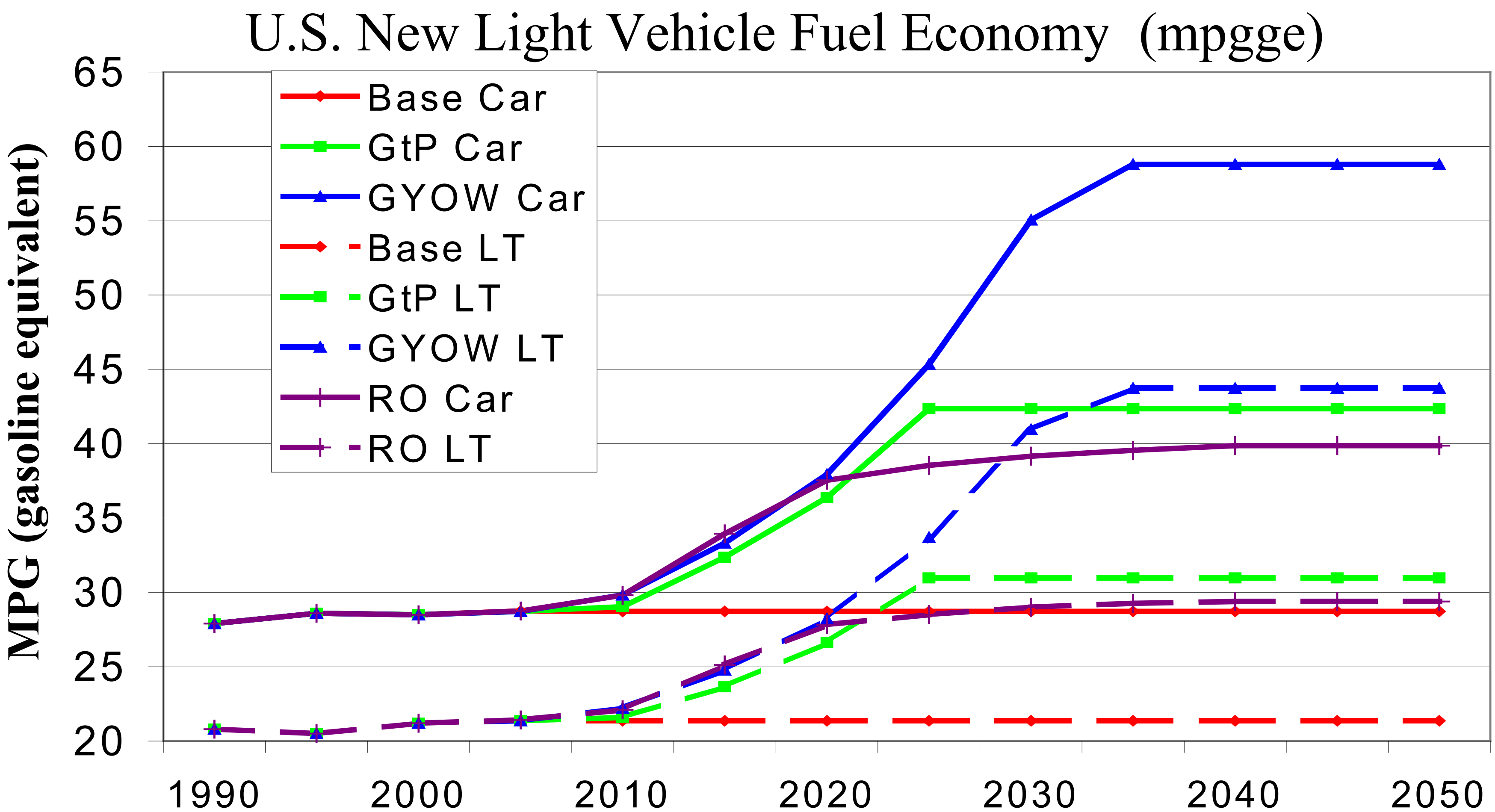
Selected Input Assumptions for U.S. Scenarios: Light Vehicles

Attribute	Base	GtP	GYOW	RO
Light Vehicle VMT	AEO 2002 rates to 2020 with further decline in rate of growth post-2020	15% less than Base by 2015	Same as Base	10% more than Base case by 2020
Light Vehicle Sales	AEO 2002 through 2020; 2015-2020 growth rate applied through 2050	Same as Base	Same as Base	Same as Base
New Car/Light Truck Split	50%/50% in 2010, then constant	62%/38% in 2050	42%/58% in 2050	Same as Base
New Car MPG/ Light Truck MPG	28.7/ 21.4 constant	42/ 31 in 2050	59/ 44 in 2050	40/ 29 in 2050
% Hybrids/ FCVs of New LVs	0%/0%	10%/0% in 2050	30%/50% in 2050	40%/ 0% in 2050
E10 in LVs	Continuation of current	Mandatory by 2020	Mandatory by 2020	5% in 2050
E85 in LVs	None	20% of LDVs sold use E85 in 2050	30% of LDVs sold use E85 in 2050	None
CNG/LPG in LVs	None	3% by 2025	None	None

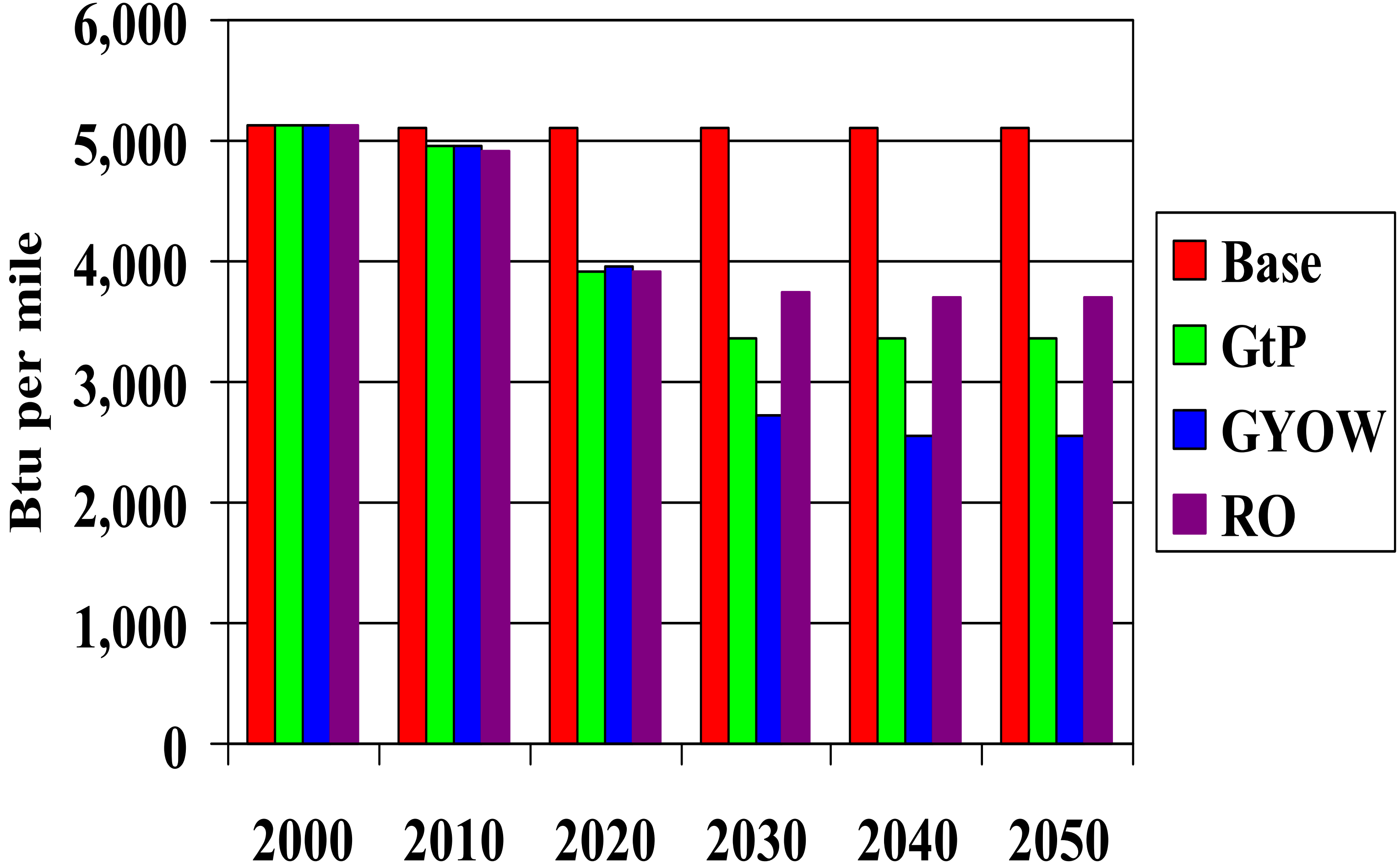
Selected Input Assumptions for U.S. Scenarios: Heavy Vehicles

Attribute	Base	GtP	GYOW	RO
Heavy Truck VMT as % of 2000 VMT	338% in 2050	269% in 2050	404% in 2050	129% in 2050
Medium Truck VMT as % of 2000 VMT	247% in 2050	208% in 2050	296% in 2050	507% in 2050
New HDV MPG	5.9 constant	7.2 in 2050	11.3 in 2050	8.1 in 2050
New MDV MPG	7.7 in 2010, then constant	11.6 in 2050	16.5 in 2050	11.3 in 2050
Heavy Truck sales as % of 2000 sales	204% in 2050	180% in 2050	340% in 2050	55% in 2050
Medium Truck sales as % of 2000 sales	195% in 2050	189% in 2050	235% in 2050	318% in 2050
Biodiesel in diesel	None	10%	10%	6%
Ethanol in diesel	None	10%	None	None

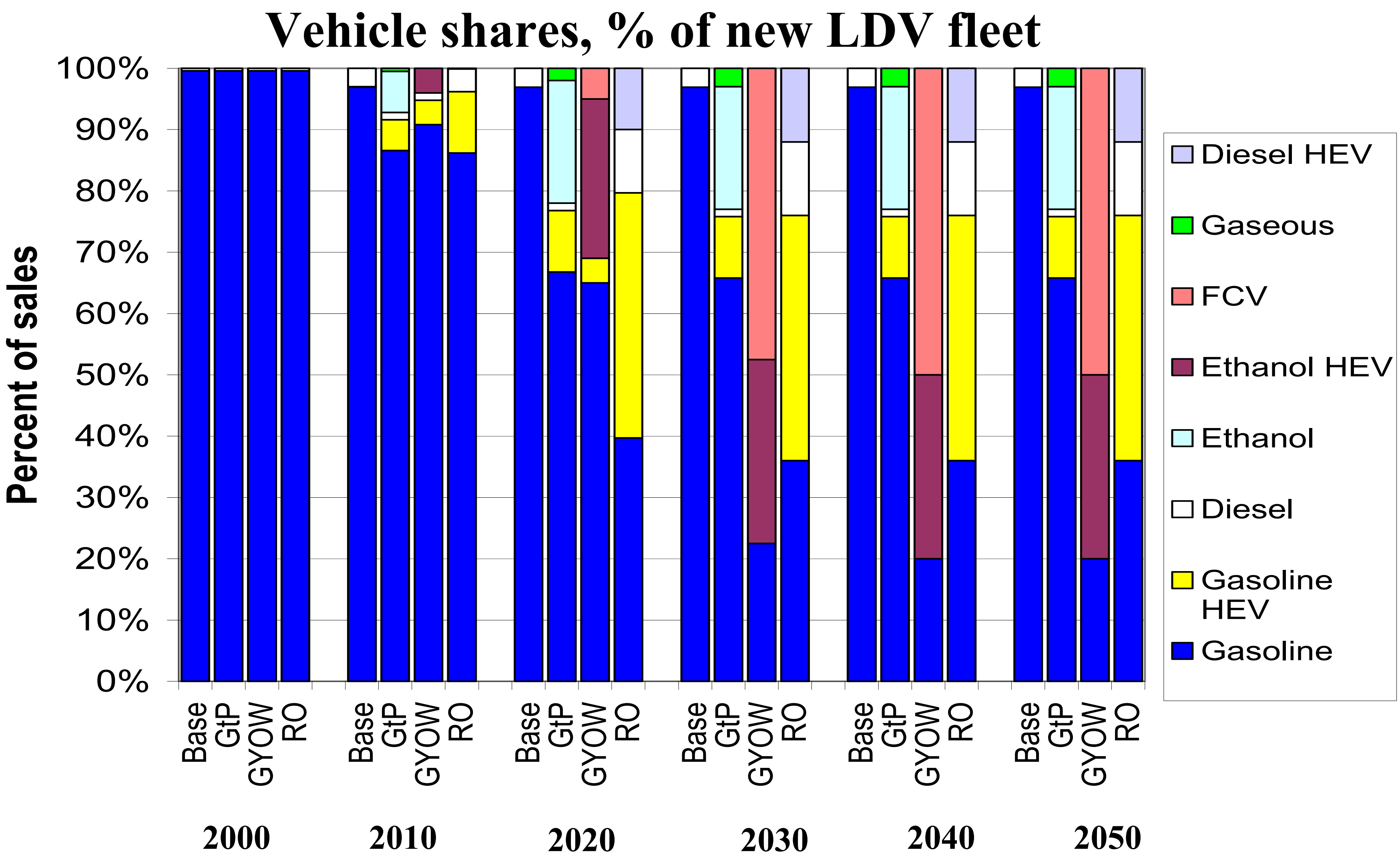
Fuel economy improvements start early, but then flatten out. GYOW has greater FE improvement over a longer time.



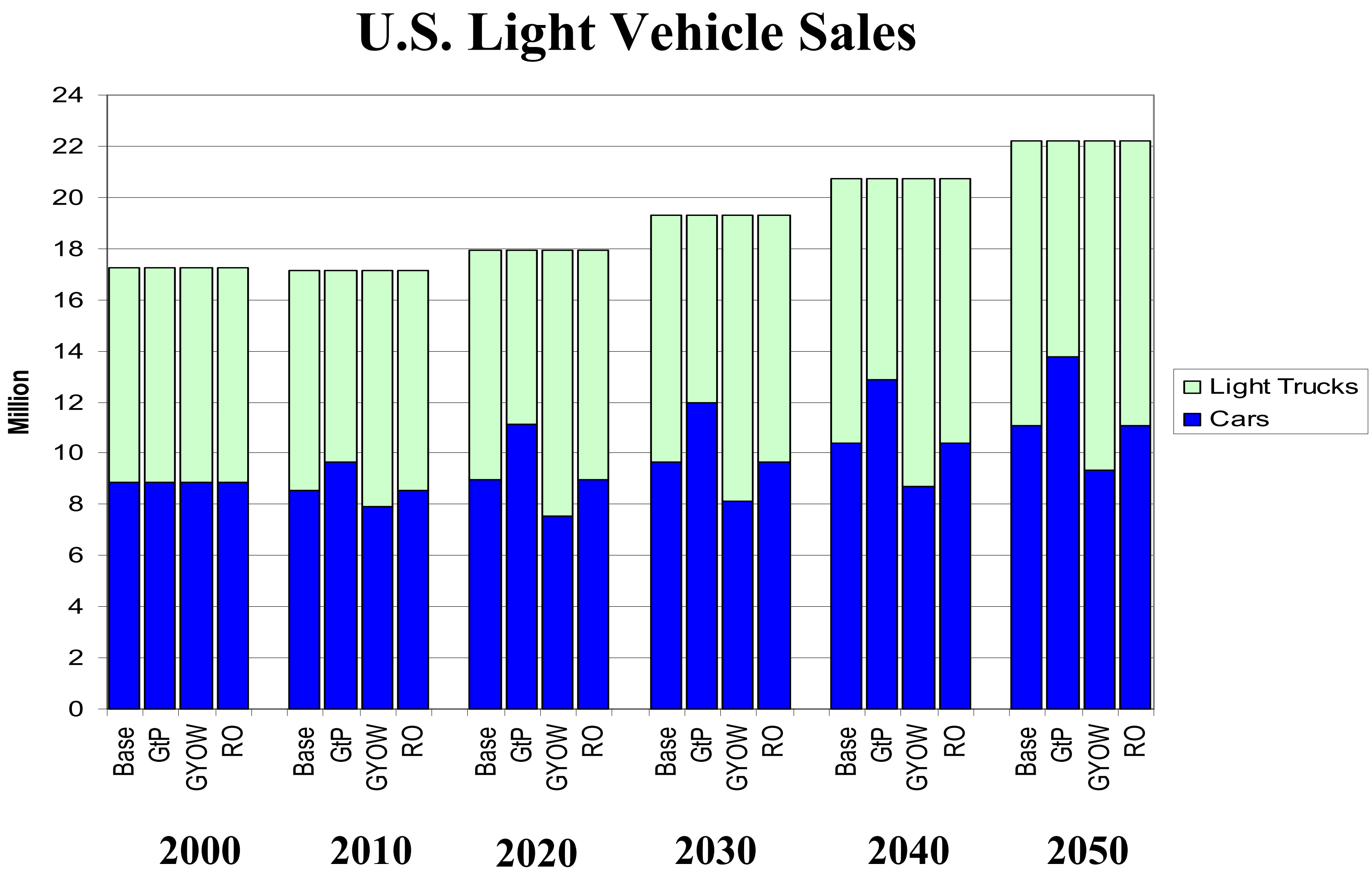
Assumed new LDV energy intensity drops sharply in GtP and GYOW.



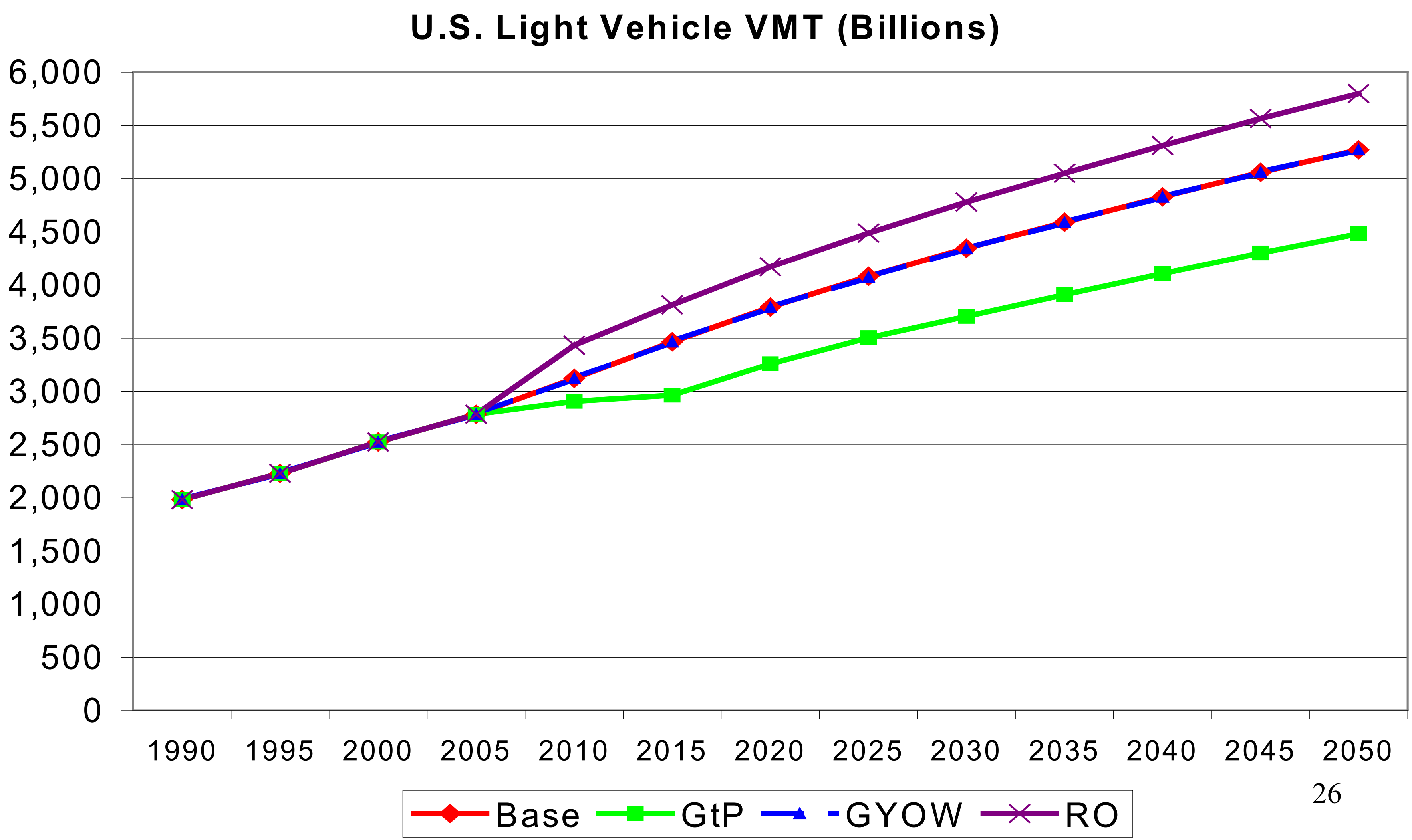
Light-duty FCVs only appear in GYOW, HEVs in GYOW, GtP and RO.



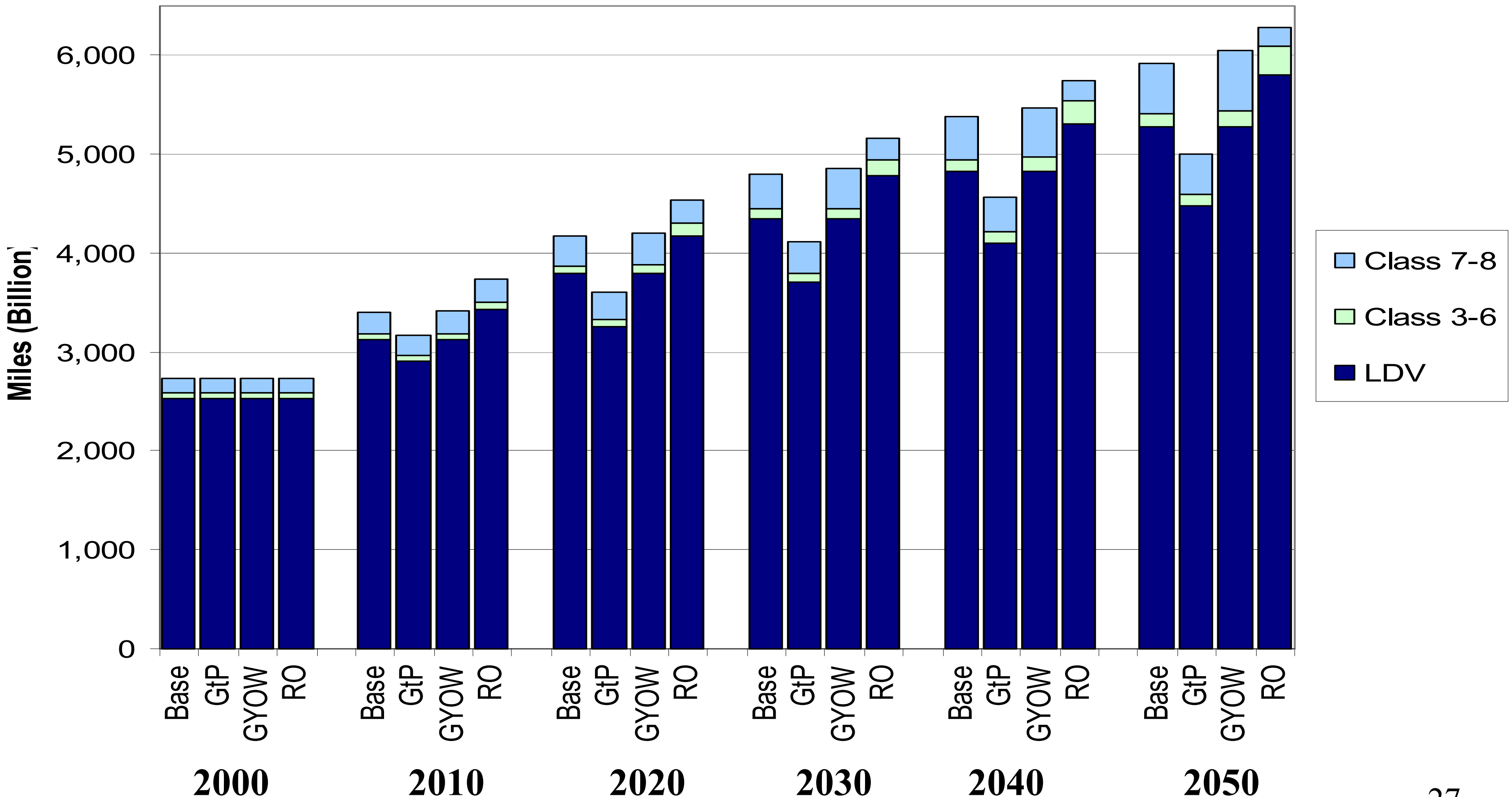
After 2020, the light truck share stabilizes at 50% in the Base Case and RO, 38% in GtP, 58% in GYOW.



For light vehicle VMT, Base case and GYOW are the same. GtP's LDV VMT is 15% lower, RO's is 10% higher than Base level in 2050.



In GtP, assumed VMT drops significantly from the Base Case. In GYOW, heavy vehicle VMT grows relative to Base (20% by 2050). In RO, LDV VMT grows 10%.



Selected Scenario Assumptions About World Oil and Natural Gas Resource Bases

- **Remaining recoverable natural gas resources in 2000**
  - **Base** **21,000 TCF**
  - **GtP** **20,000 TCF**
  - **GYOW** **27,000 TCF**
  - **RO** **28,000 TCF**

  includes unconventional

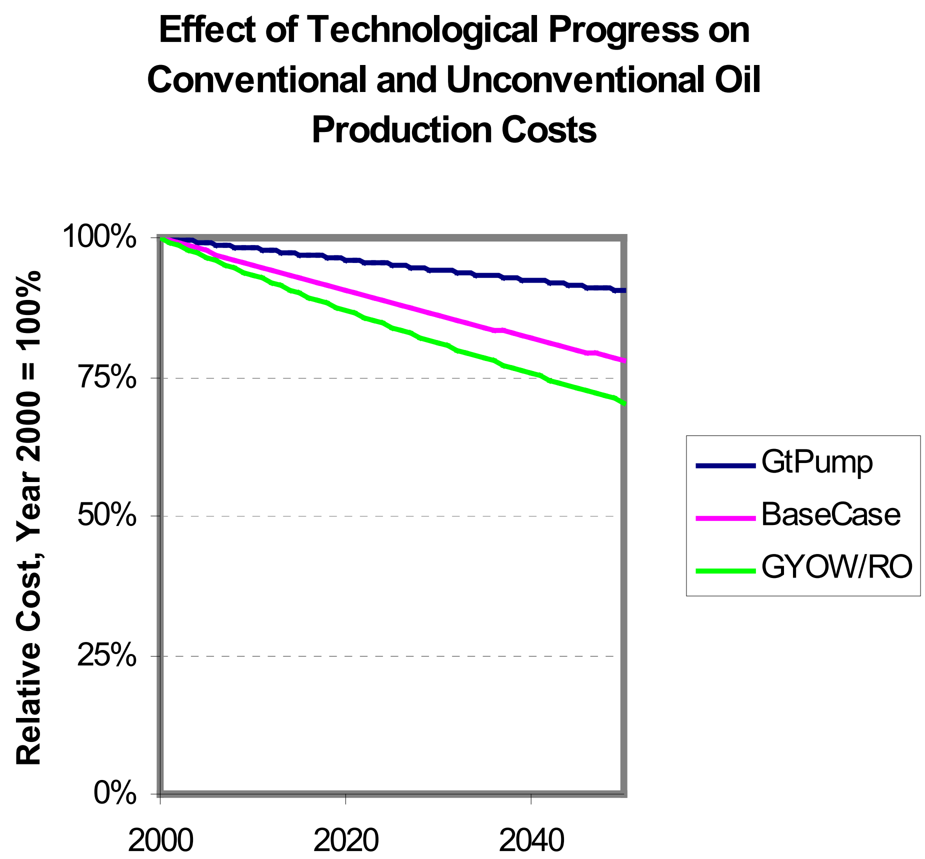
- **Remaining recoverable oil resources in 2000**
  - **Base** **5.4 trillion barrels**
  - **GtP** **4.5 trillion barrels**
  - **GYOW** **5.4 trillion barrels**
  - **RO** **5.6 trillion barrels**

  includes unconventional

(based on the 2050 ultimately recoverable resource)

All scenarios, including the Base Case, assume substantial technological advances that expand the resource base and lower supply costs.

- 0.2-0.7%/yr reduction in unconventional and conventional oil production costs.
- 0.2-0.7%/yr rate of reserve expansion.
- 0 to 75% of speculative resources developed.
- 75-95% of unconventional resources recoverable.



Scenarios were modeled using either an optimistic or pessimistic assumption of oil resources.

Variant	Source of Estimate	Speculative Resources	Reserve expansion Rate	Fraction of Unconv. Resources	Scenario
Pessimistic	Rogner	0%	0.2%/yr	75%	GtP
Optimistic	USGS 2000	50% 50% 75%	0.5%/yr 0.7%/yr 0.7%/yr	95%	Base GYOW RO

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Modeling and Analysis

- World Energy Scenarios Model (WESM)
- Hydrogen Infrastructure (CHAIN)
- ELSAS (Ethanol Production)
- Ethanol Distribution Cost Spreadsheet
- Biodiesel Production Cost Spreadsheet
- Vehicle Cost Model
- Scenario Cost Spreadsheet
- Champagne Model
- Genius Model

Models

World Energy Scenarios Model (WESM)

Tracks remaining conventional and unconventional oil and natural gas resources over time and estimates world oil price

Hydrogen Infrastructure (CHAIN)

Defines production and distribution paths for two H2 sources: Natural gas and Thermonuclear

Ethanol Production (ELSAS)

Calculates feedstock and non-feedstock costs of cellulosic ethanol production in the U.S., and includes learning improvements

Ethanol Distribution Cost Spreadsheet

Estimates new and converted equipment for transportation, storage, and distribution of ethanol

Models

Vehicle Cost Model

Develops estimates of vehicle costs to consumer based on fuel economy vs. cost curves (NAS/CAFE work used as checkpoint) and includes innovation cost reduction assumptions

Scenario Cost Spreadsheet

Pulls together the cost estimates developed by other models and adds fuel transportation and delivery costs where necessary

Champagne Model

Uses a stock model to estimate vehicle use and energy consumption for light vehicles, medium and heavy trucks, air, and other modes

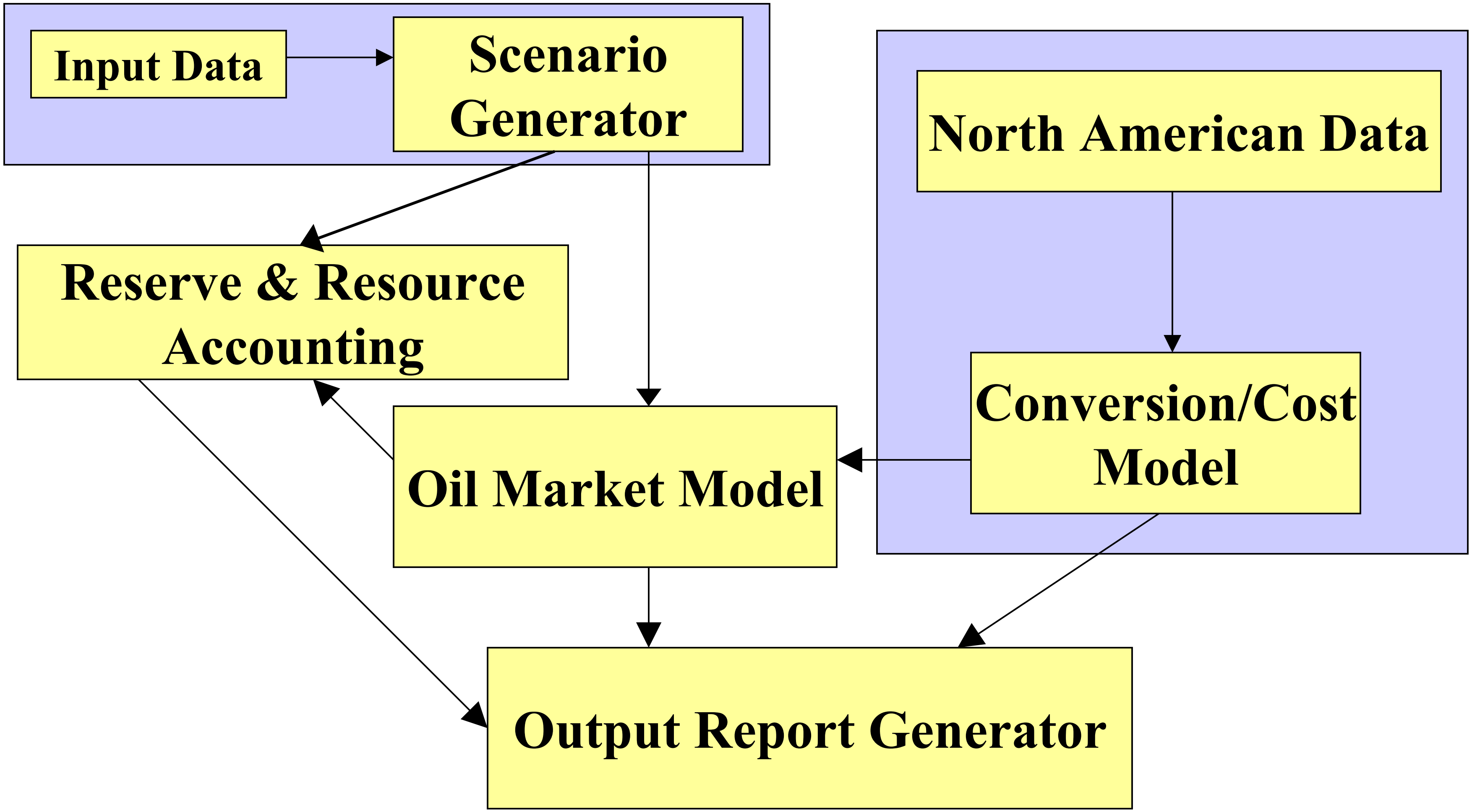
Genius Model

Estimates fuel-cycle greenhouse gases

World Energy Scenarios Model WESM (ORNL)

- Tracks remaining conventional and unconventional oil and natural gas resources over time
- Estimates production of unconventional oil
- Estimates world oil prices
- When scenario world oil demand is low, it is assumed that OPEC output is reduced accordingly
- World scenarios are based on IEO forecasts and IIASA/WEC long term scenarios

Structure of the WESM Model



WESM: Alternative Assumptions about OPEC Market Behavior

1. Reference assumption: When scenario world oil demand is low, OPEC output is reduced accordingly

   Result: Energy production will be restrained and prices held up by low oil availability

2. Alternate assumption is that OPEC production levels will track Base Case path, subject to resource constraints

   Result: Lower world oil prices than under the reduced output option

Hydrogen Cost Model - CHAIN (ANL)

- Defines production and distribution pathways
  1. Natural gas: NG production, compression, storage and transport; conversion to H2, transport and dispensing
  2. Nuclear: H2 production via nuclear water cracking process, transport and dispensing
- Determines total “tank-in” fuel requirement and share from each pathway
- Sizes pathway components
- Estimates component costs, including annual O&M
- Calculates pathway costs

Ethanol Cost Model -- ELSAS (TMS, Inc., and NREL)

• Model calculates feedstock and non-feedstock costs of cellulosic ethanol production in the United States

• Technology and learning improvements assumed over time increase the yield and lower the production costs

• A reference case and an aggressive production case offer two sets of production curves

• User inputs include production year, volume, and cumulative volume

• Model developed by TMS for DOE Biomass Program

Ethanol Distribution Cost Spreadsheet (NREL, ANL)

- Estimates new & converted equipment for transportation, storage and distribution
  - Trucks, rail cars and barges for transport from production plants to terminals
  - Terminal tanks, blending equipment, and rail spurs
  - Refueling stations
- Estimates capital costs
- Estimates per gallon transport cost, refueling station markup for E10 and E85
- Uses analysis by Downstream Alternatives, Inc. as a starting point

Vehicle Technology Cost Model (TA Engineering, Inc.)

- Develops generalized estimates based on published/accepted fuel economy vs. cost curves
  - NRC work used as checkpoint/ comparison
- Includes innovation-cost reduction assumptions
- Prepares long-term trend relationships for each technology and scenario
- Current version includes Autos, Light Trucks, and Medium and Heavy Trucks

Scenario Cost Spreadsheet (ANL)

- Pulls together the following estimates developed by other models:
  - Fuel volumes by fuel type by scenario
  - Fuel prices by scenario
  - Vehicle sales by vehicle type by scenario
  - New vehicle costs by scenario
- Adds fuel T&D costs where necessary
- Calculates total costs for each scenario by year and cumulatively

Champagne and Genius Models (NRCanada, ANL)

- Tracks roll-in of new vehicles and fuels and vehicle retirement, yielding (changing) overall fleet characteristics, fuel use
- Quantifies Canadian and U.S. transportation use by demand, technologies and fuels
  - Light duty vehicles (cars and light trucks)
  - Medium and Heavy Duty Trucks
  - Buses, other vehicles, as well as rail and air
- For each segment, calculates fuel use and (using the Genius model) highway GHG emissions

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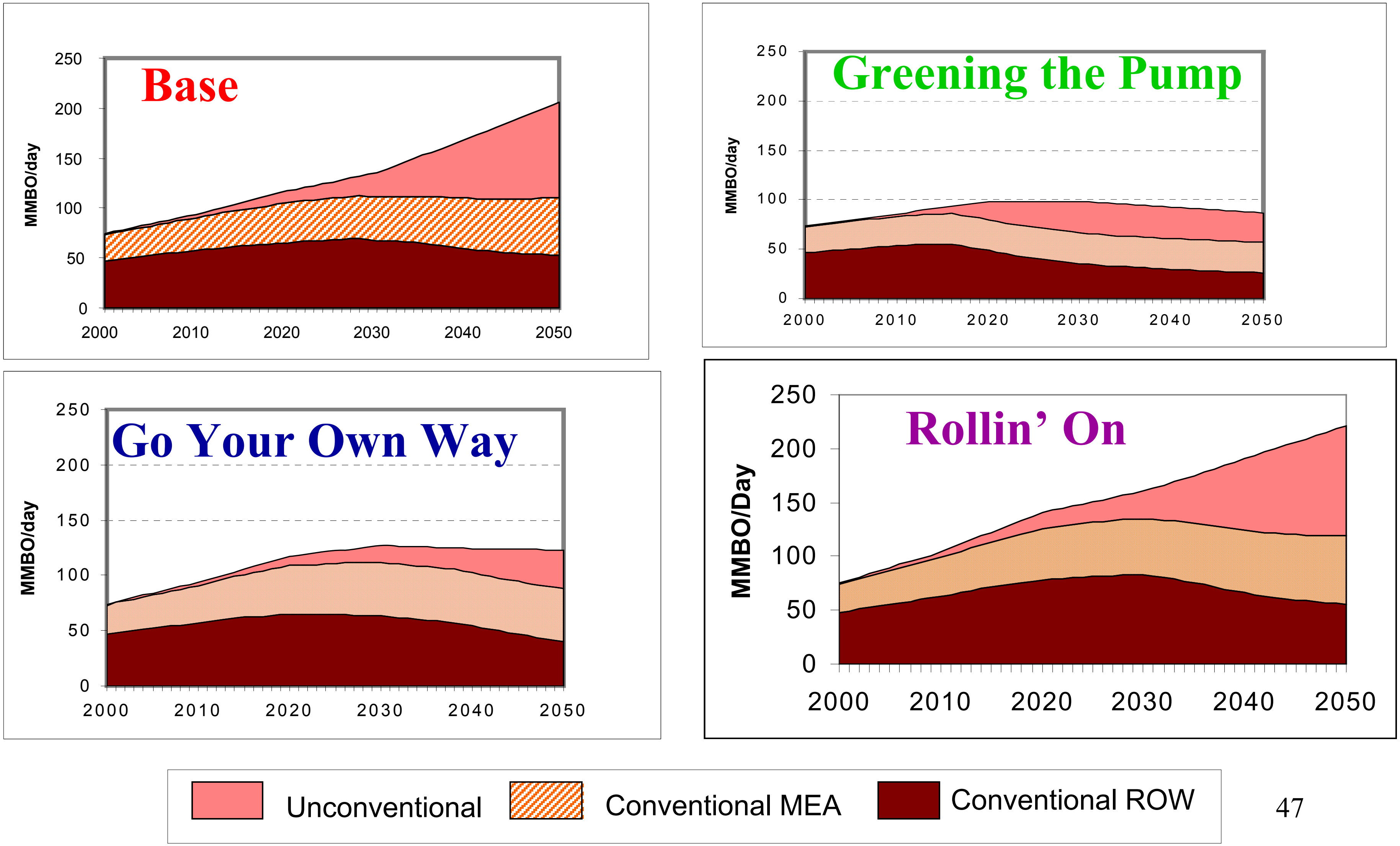
Analytic Limitations and Uncertainties

- Model limitations: limited feedback between world and North America, no feedback for gas, etc.
- High levels of uncertainty in key variables:
  - Ultimate world oil and gas resources, and resource costs
  - Future oil prices (depend on OPEC behavior)
  - Technology costs and impacts
- Need for sensitivity analysis, skeptical evaluation of (and appropriate interpretation of) results – a process still ongoing.

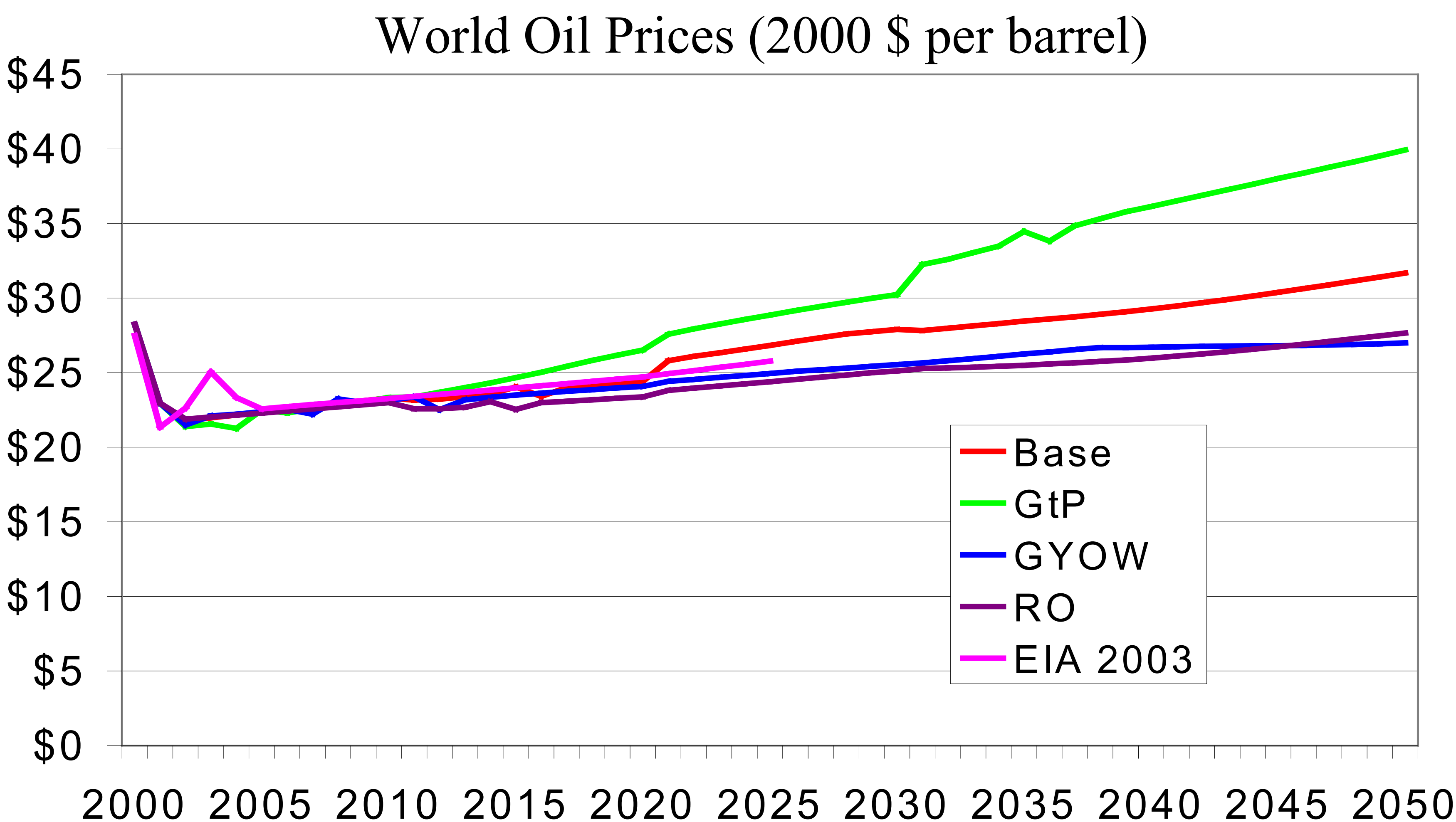
Dealing With Analytical Limitations and Uncertainties

- Conduct sensitivity analysis of key (uncertain) variables
- Interpret extreme results not as "what we expect to happen," but instead as "first order effects" that:
  - **may be warning signs of impending resource or environmental problems,**
  - **may indicate the need for significant policy changes, or**
  - **may be reduced by effects not captured by our models.**
- Review key results with these questions in mind:
  - **What "real world" feedback effects could change the result?**
  - **Does our analysis capture these effects?**

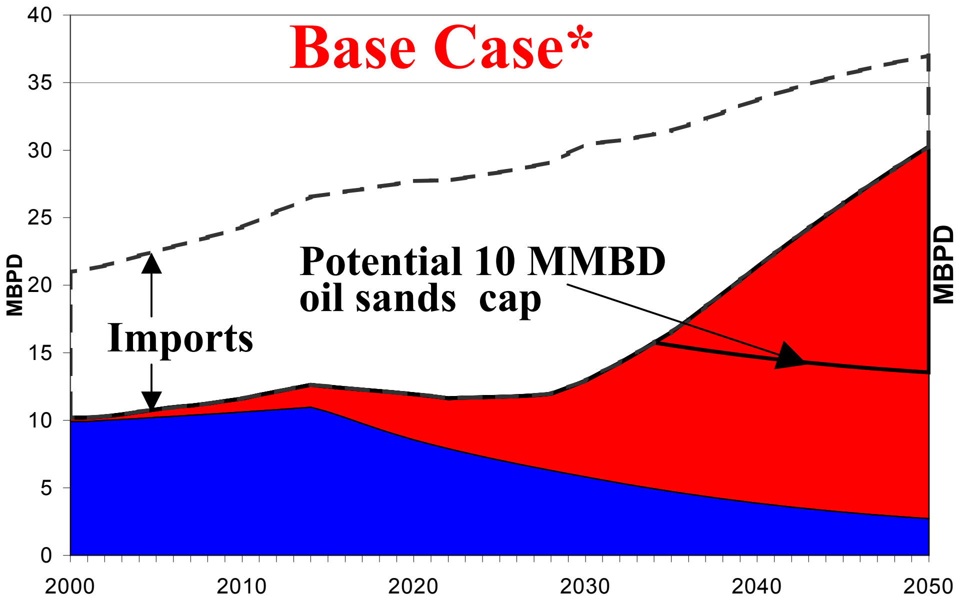
World conventional oil production peaks before 2050 in all scenarios.

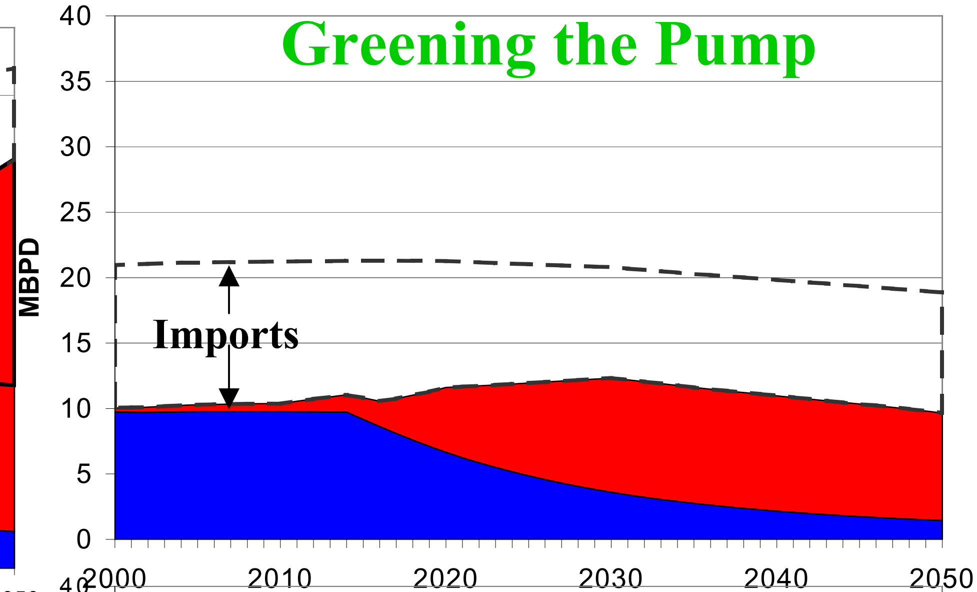


In 2050, oil prices range from $27/barrel in GYOW to $40/barrel in GtP.

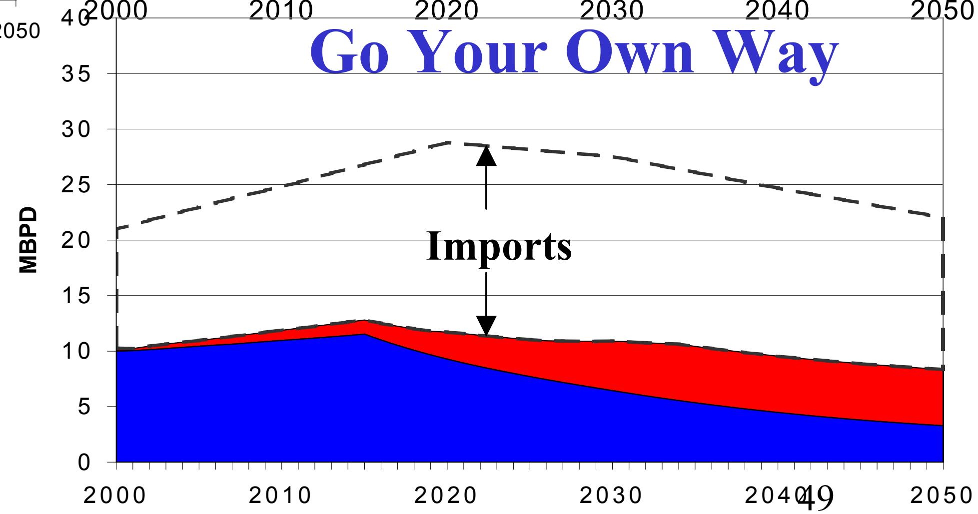


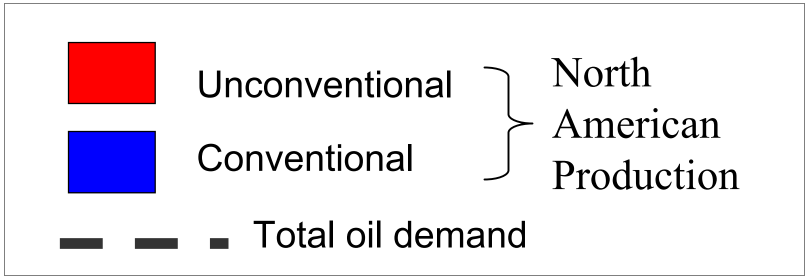
Beyond 2020, NA oil production is all about Canadian oil sands… Is this level of production feasible?



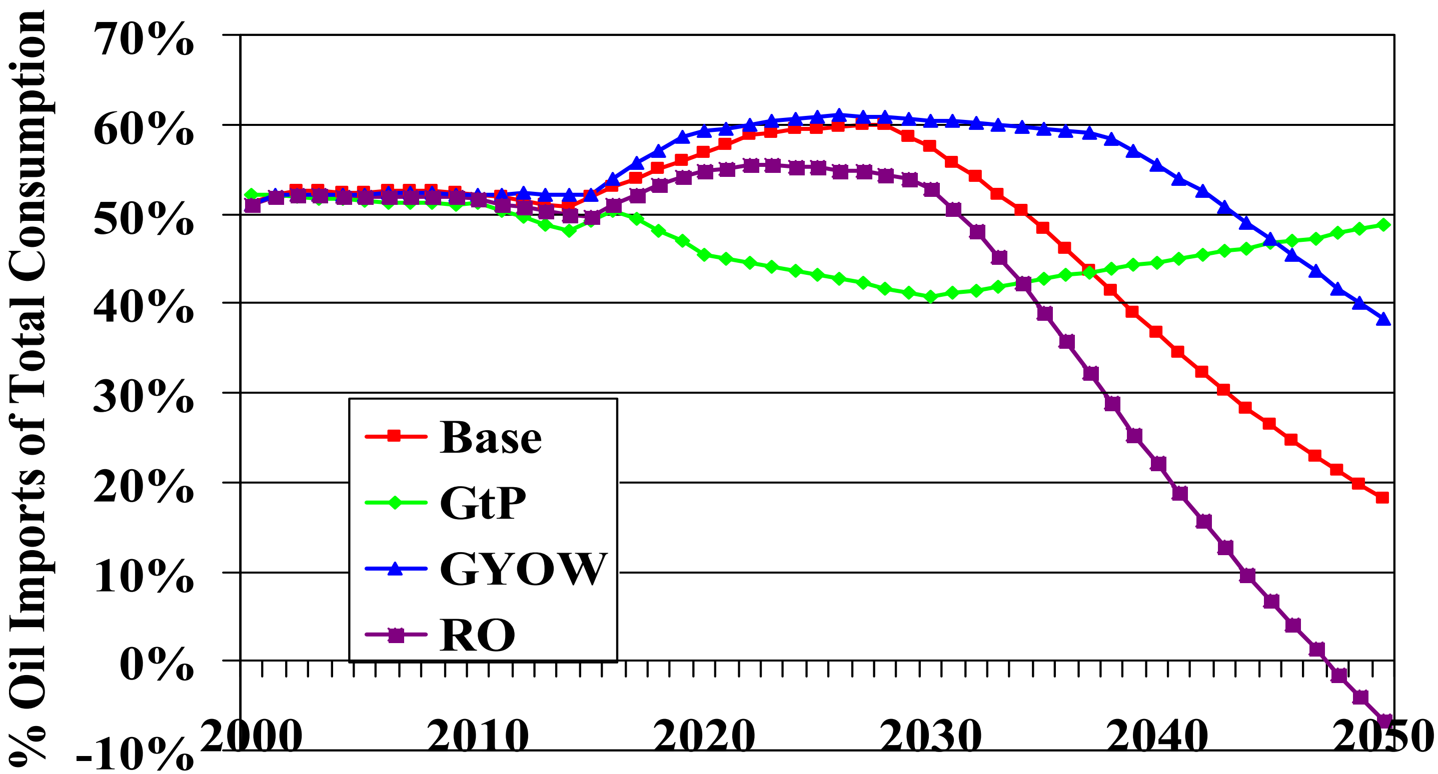


* Rollin On production is very similar to Base Case production

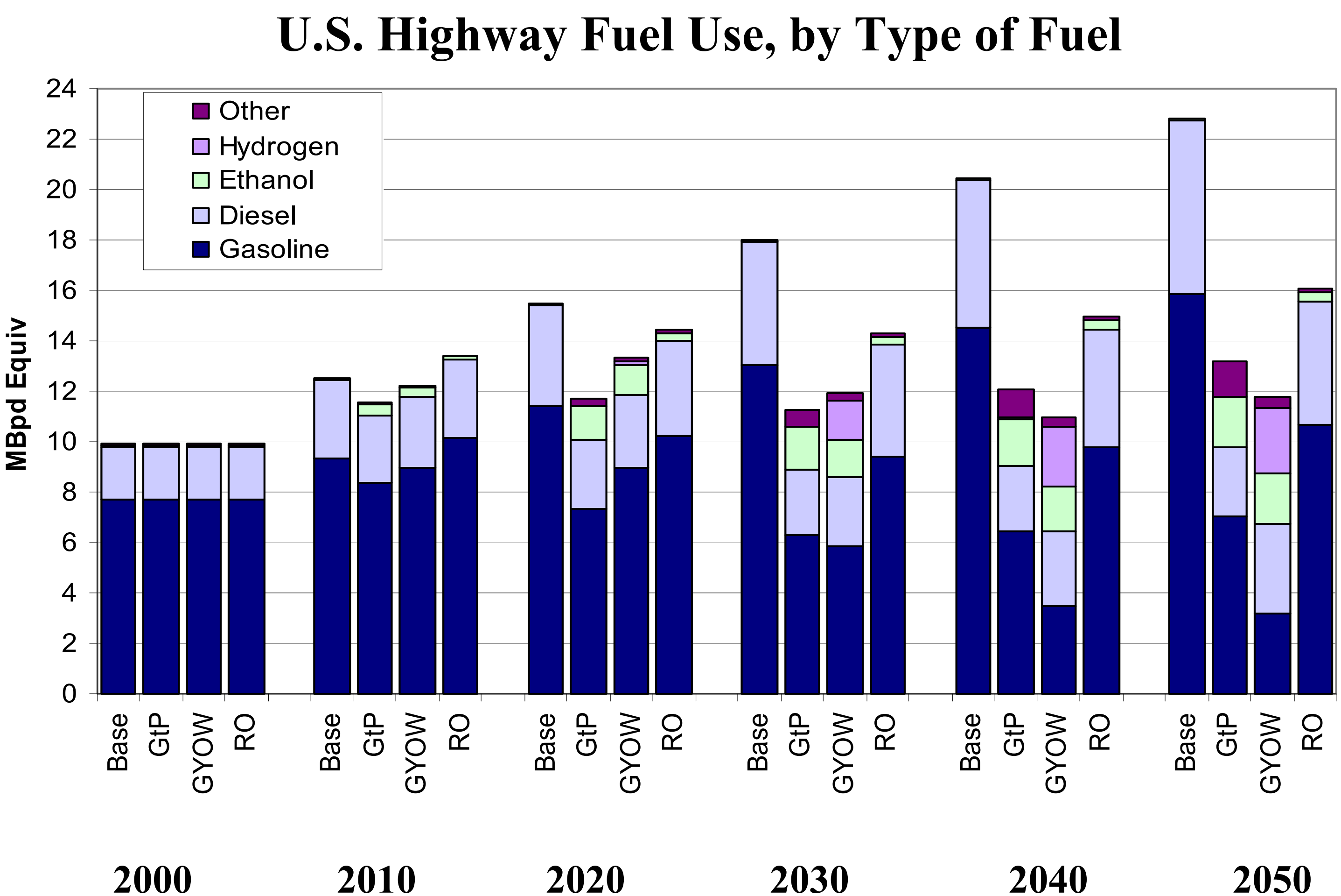




In GtP, NA oil import share eventually becomes *higher* than in the Base Case because lower world oil demand depresses unconventional (including Canadian) production.

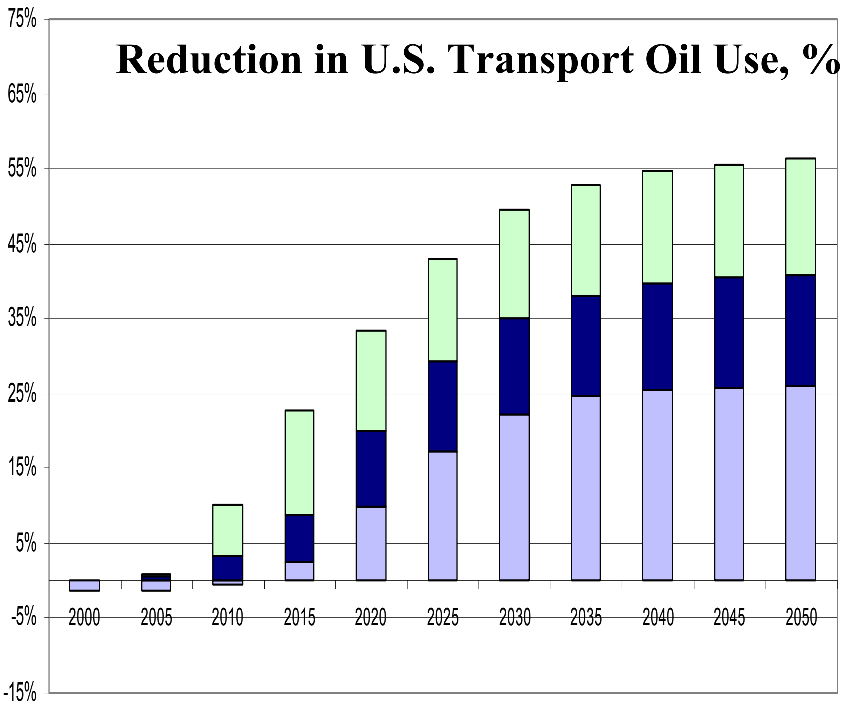


Although oil-based fuels remain crucial, both H_2 and E85 play major roles in GYOW, and ethanol is important in GtP.



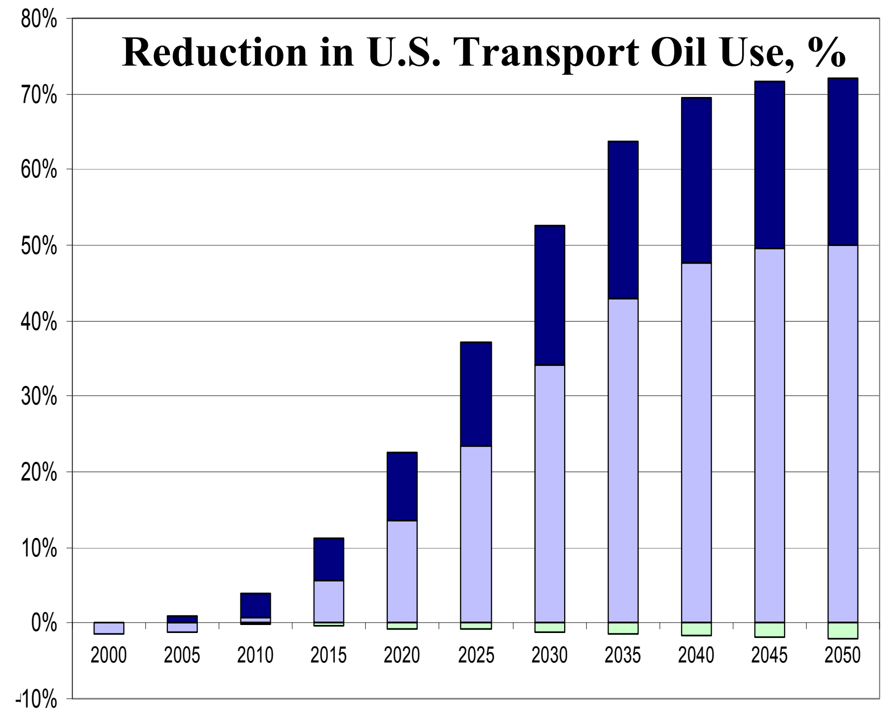
Oil reduction can be achieved with changes in behavior and/or with technological advances.

GTP: Includes Some Behavior Changes

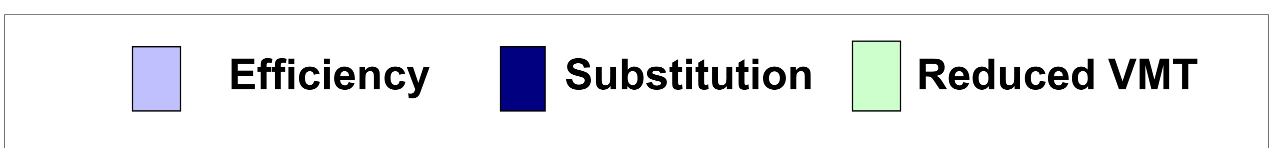


Greening the Pump

GYOW: All Technology Changes

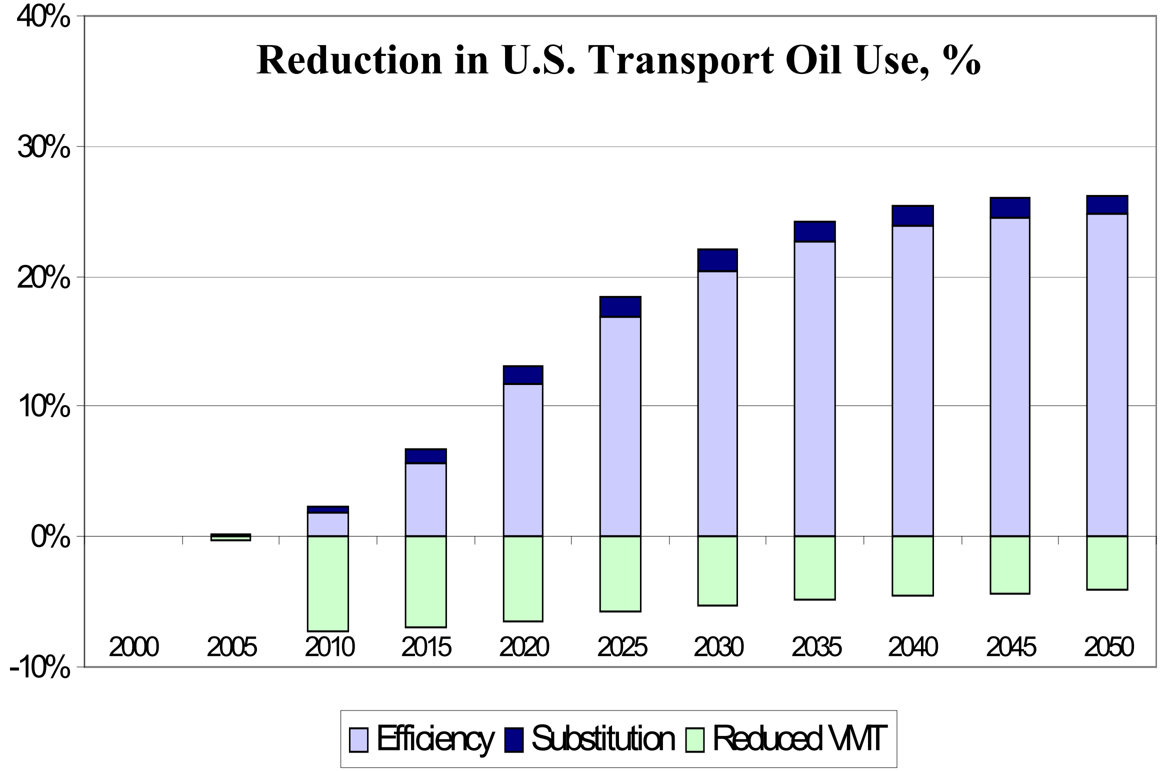


Go Your Own Way



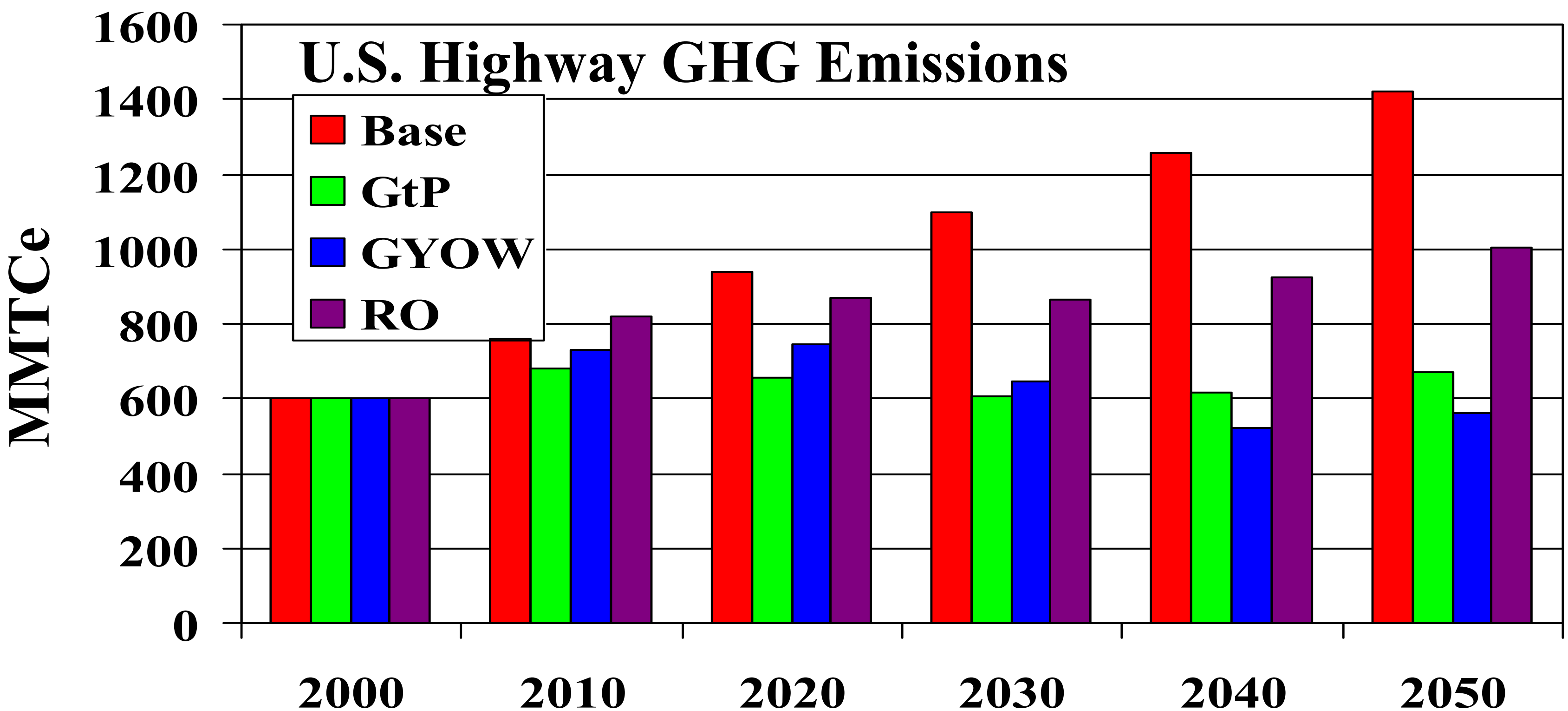
Oil reduction can be achieved with changes in behavior and/or with technological advances (continued).

RO: Technology changes, with increased vmt

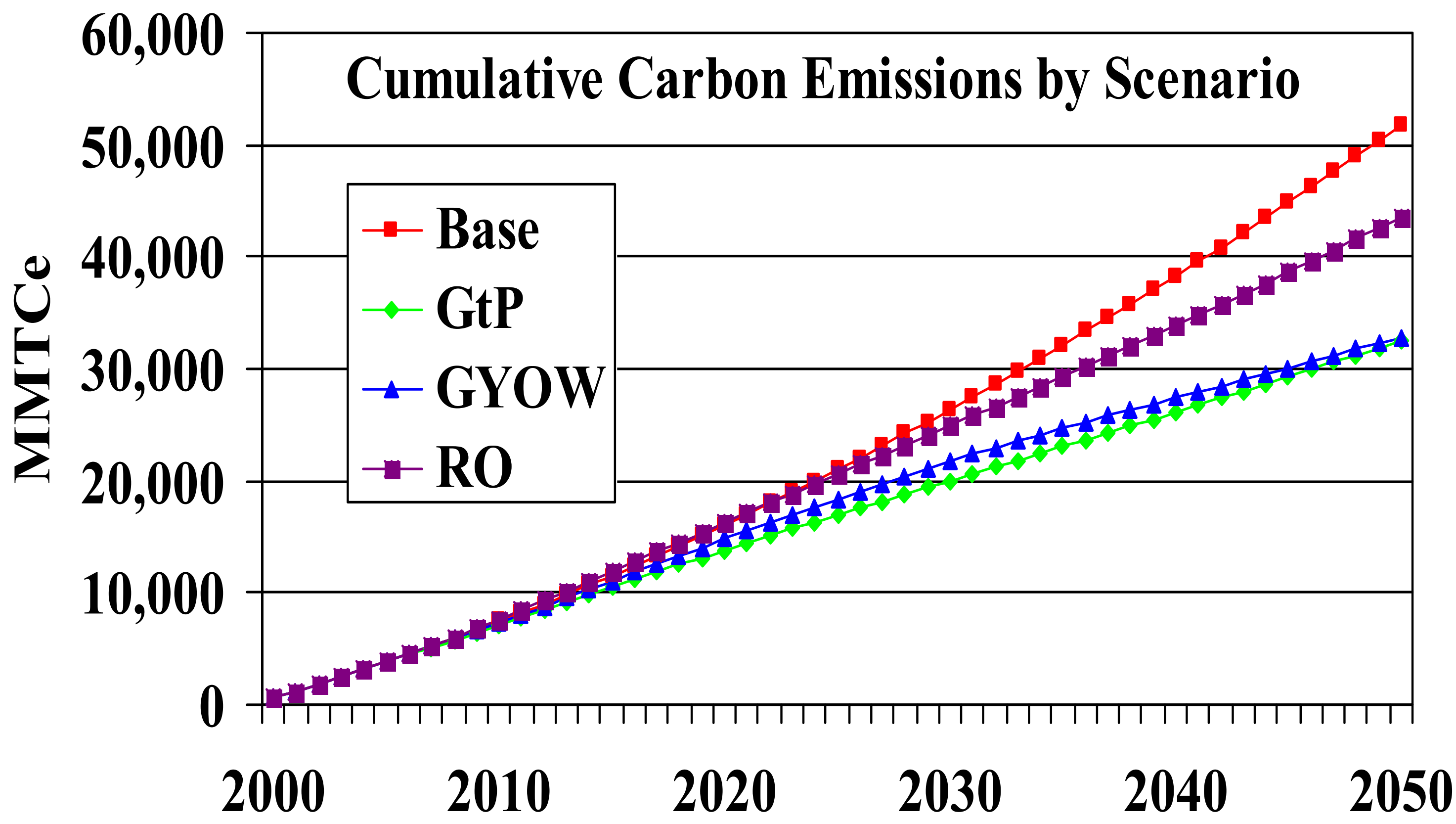


Rollin' On

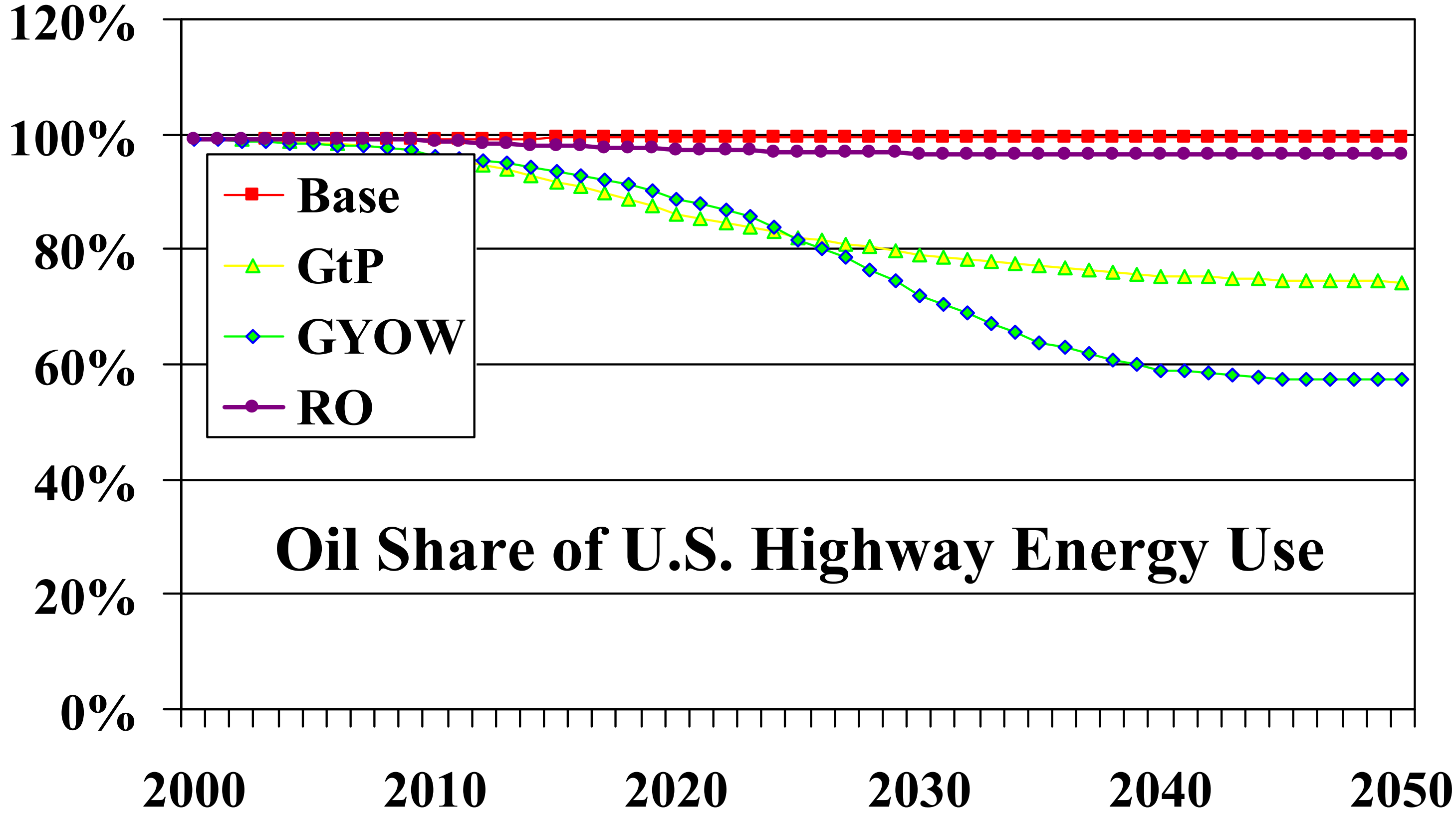
GtP achieves the greatest annual GHG reductions early in the 2000-2050 time frame and GYOW later in that time period.



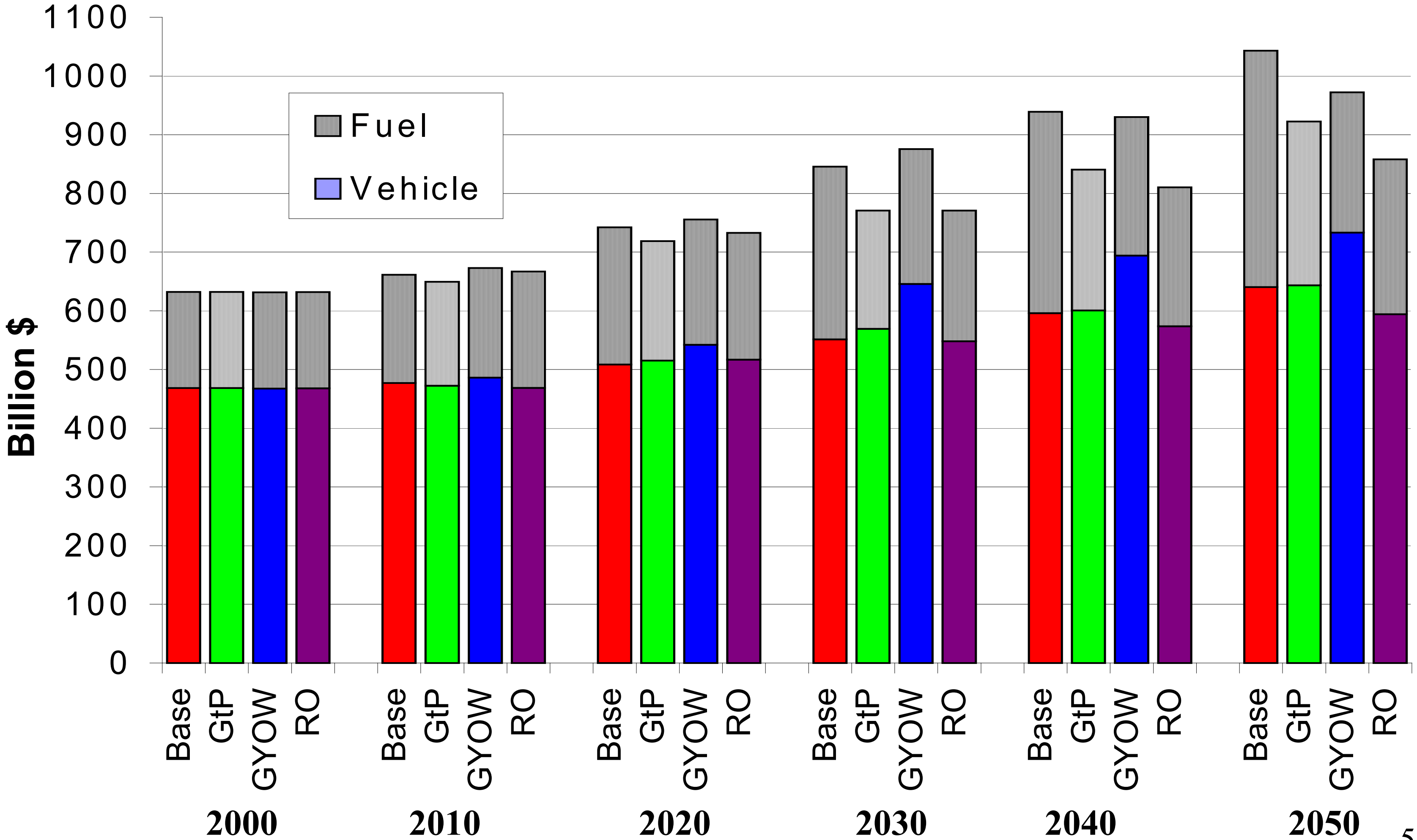
GtP's and GYOW's cumulative GHG emissions from highway vehicles to 2050 are both 37% lower than the Base Case emissions.



Even in the most optimistic case, oil continues to dominate highway transportation energy use.



With the optimistic technology price assumptions, total (vehicle and fuel) costs vary only moderately across scenarios.



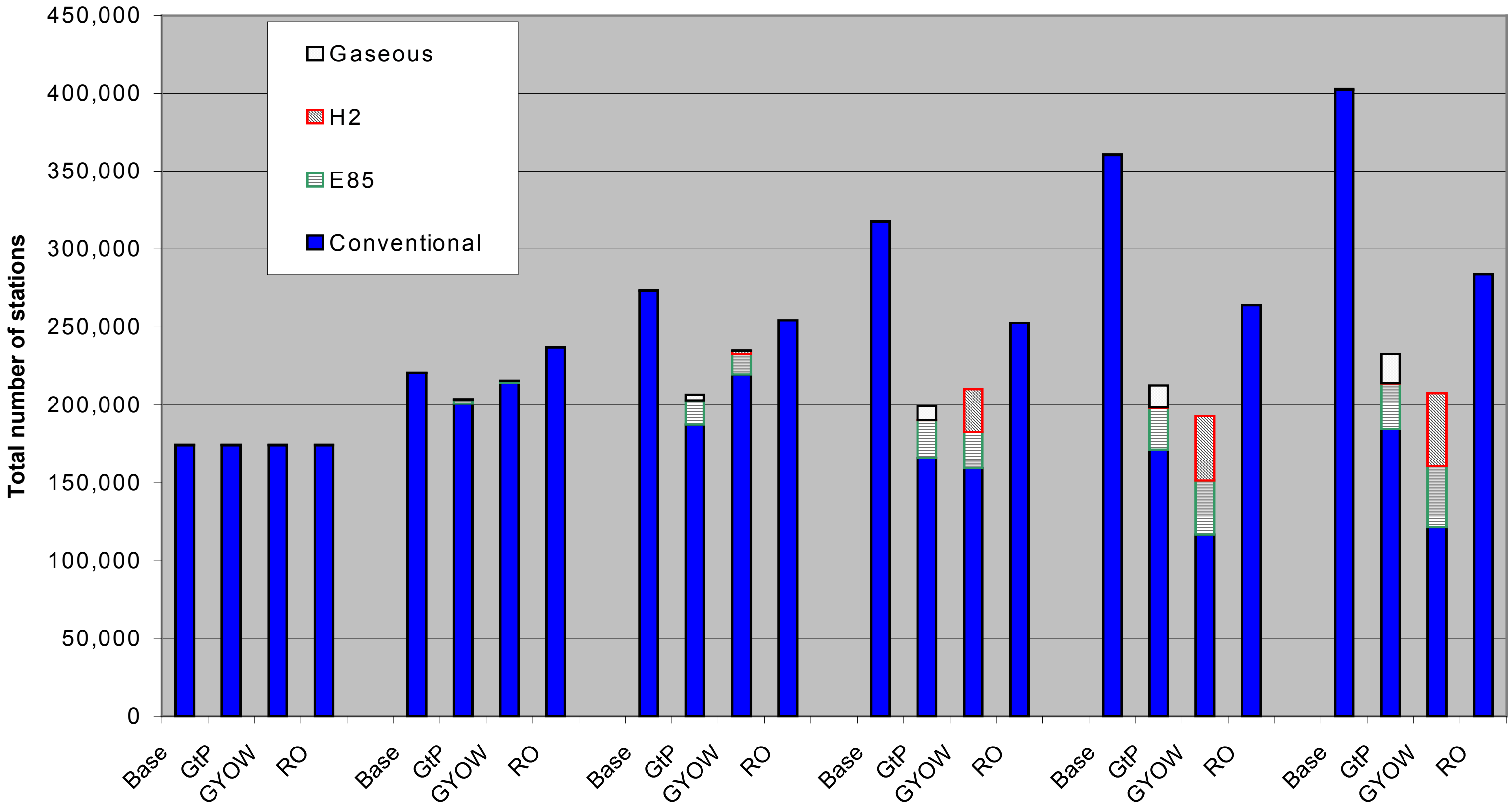
Cumulative costs for 2000-2050: GtP and RO costs are lower than the Base Case while GYOW costs are similar or slightly higher than the Base Case.

Scenario Costs (Undiscounted, trillion 2000$)

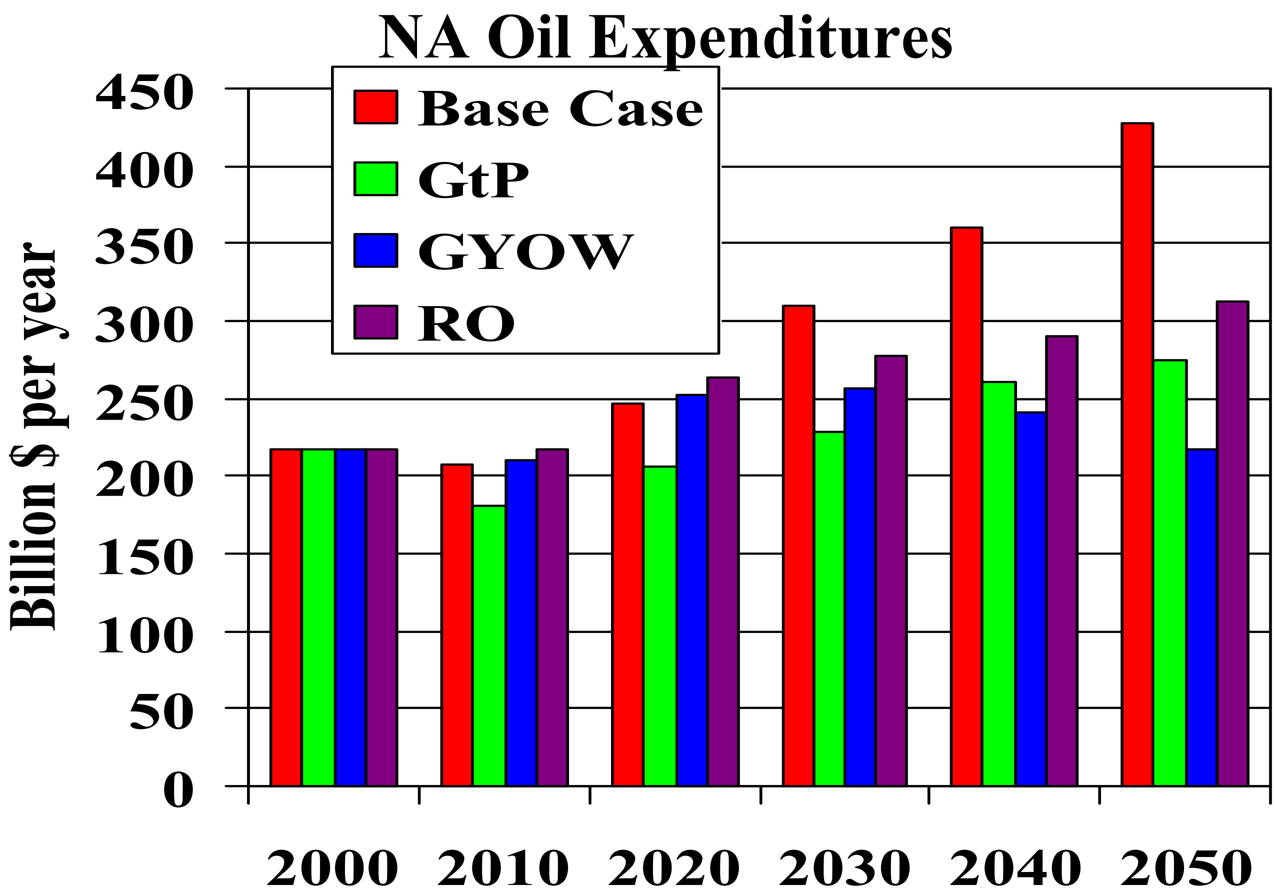
	Vehicles	Fuel	Total	% Change
Base Case	\$27.3	\$13.5	\$40.8	
Incremental Costs				
Greening The Pump	+\$0.2	-\$3.0	-\$2.8	-7.0%
Go Your Own Way (Original)	+\$2.6	-\$2.8	-\$0.2	-0.7%
Go Your Own Way (Higher costs)	+\$3.7	-\$2.50	+\$1.2	+2.8%
Rollin' On	-\$0.6	-\$2.6	-\$3.2	-7.9%

Despite their strong reliance on alternative fuels, GYOW & GtP may *reduce* refueling infrastructure requirements through fuel demand reduction.

Refueling Stations by fuel type based on fixed GGE capacity/station



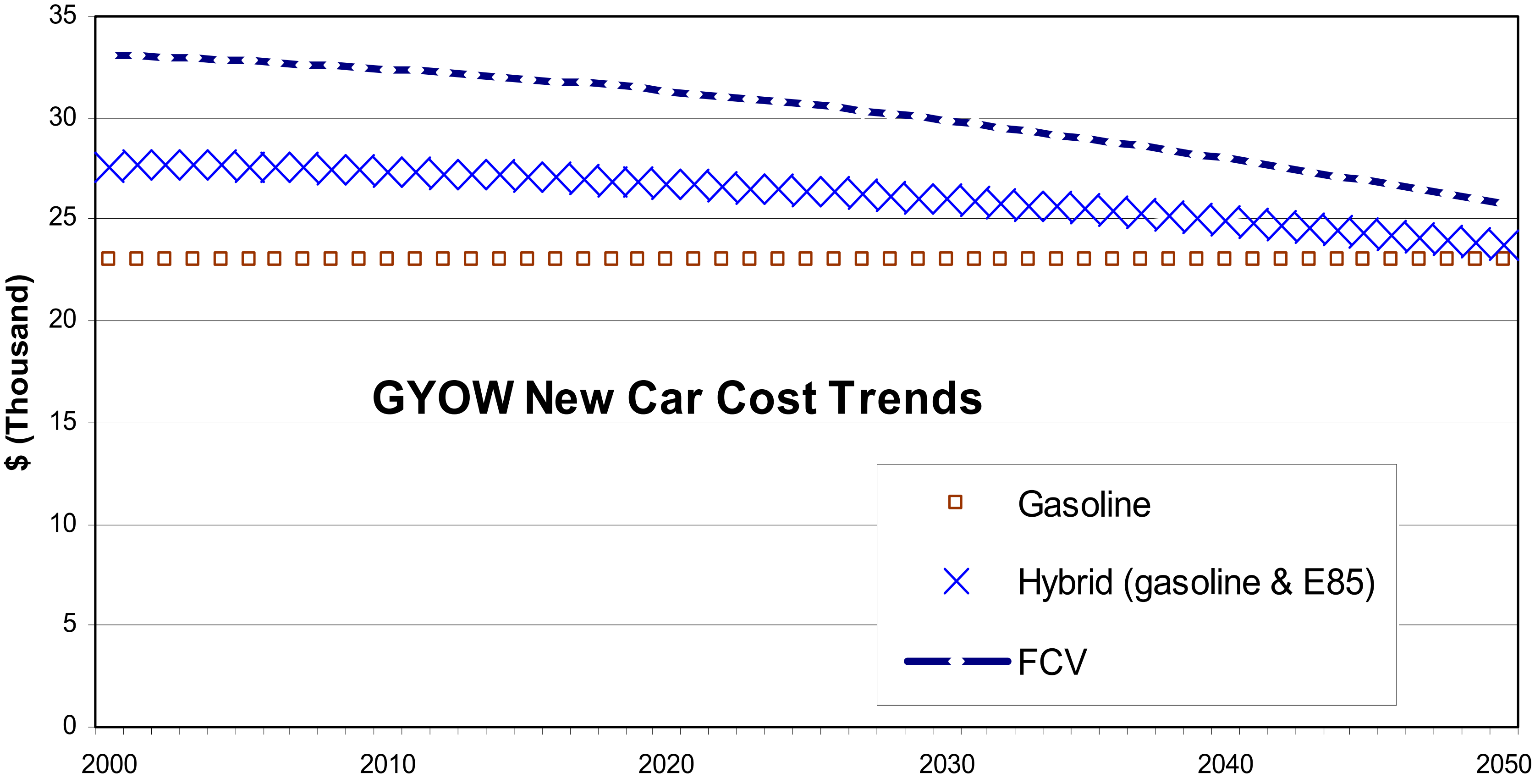
High efficiency, alternative fuels, and, for GtP, vmt reductions sharply cut oil expenditures, greatly reducing NA economic and strategic vulnerability.



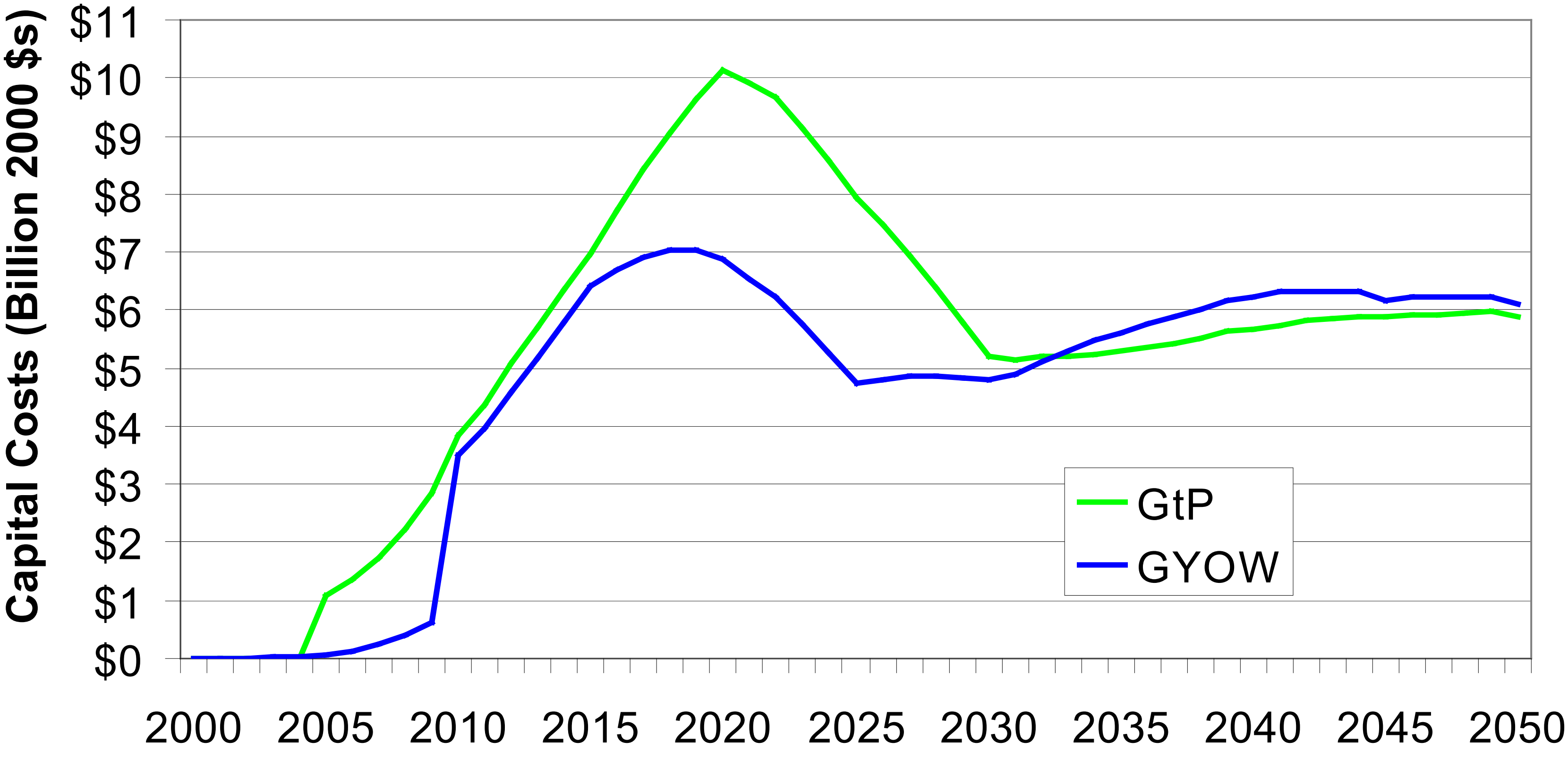
Outline of This Presentation

- Scenarios
- Models
- Analytical Results
- **Underlying Cost Details**
- Concluding Remarks
- Appendices

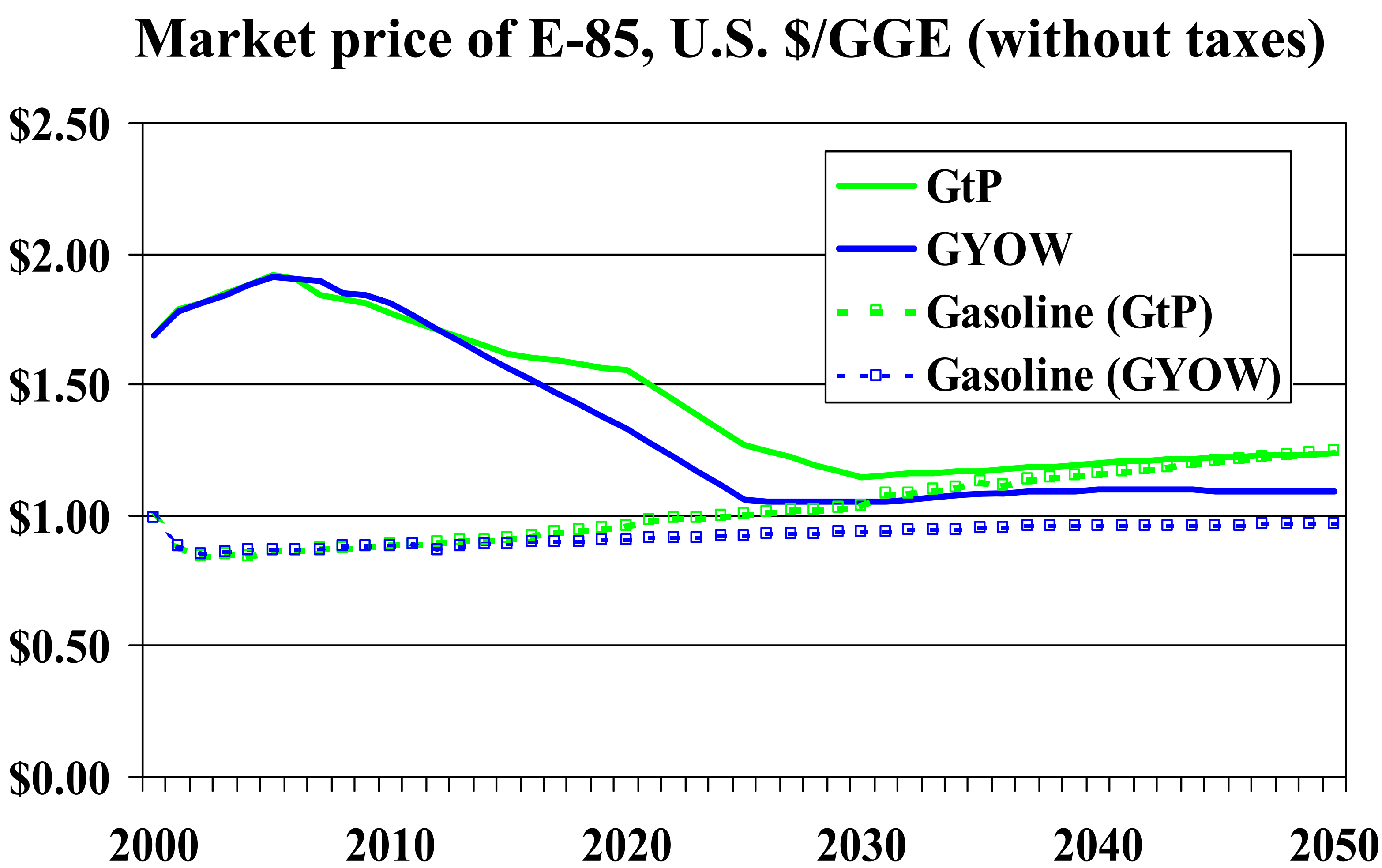
In GYOW, advanced vehicle costs are assumed to drop over time -- but FCVs still cost $2k+ more than ICE vehicles in 2050.



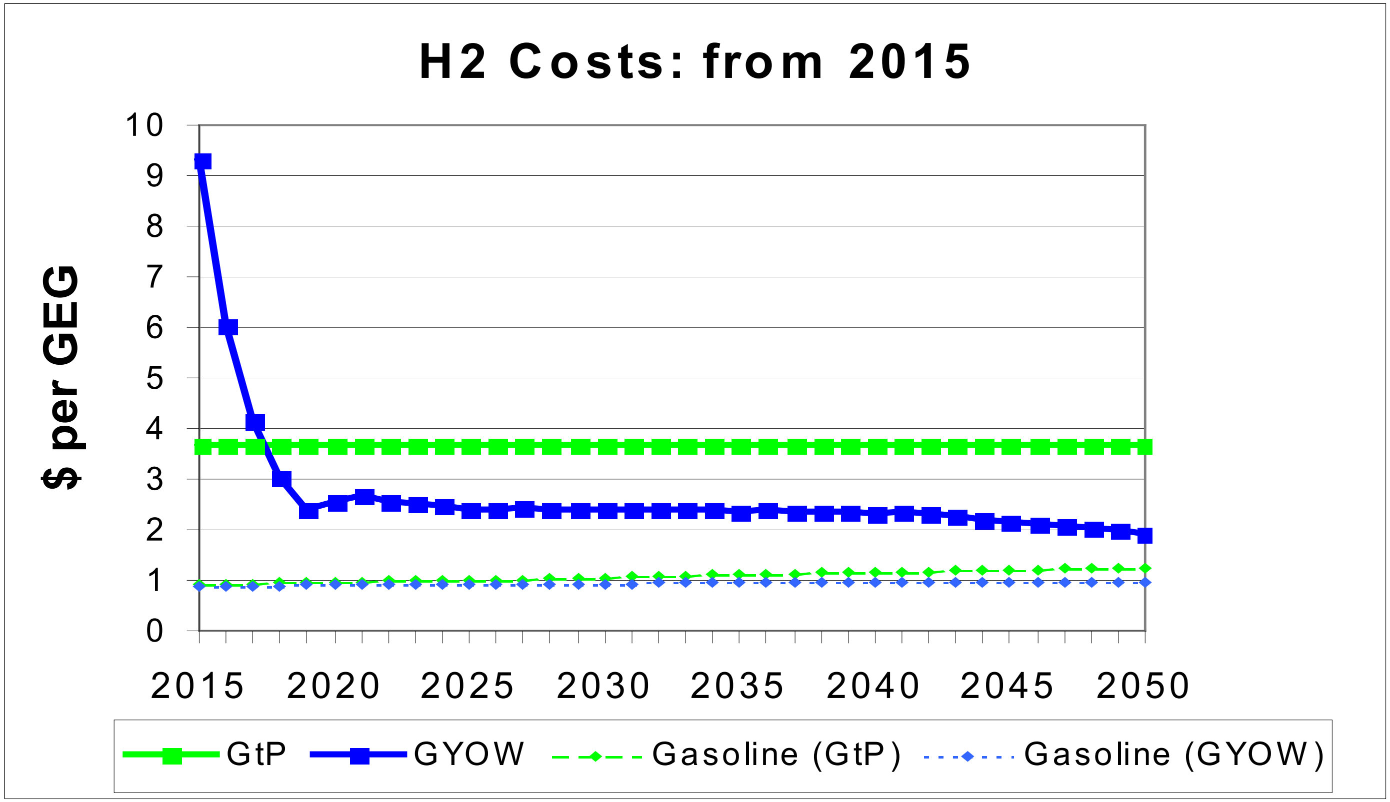
Capital costs for the ethanol infrastructure peak early in both GtP and GYOW.



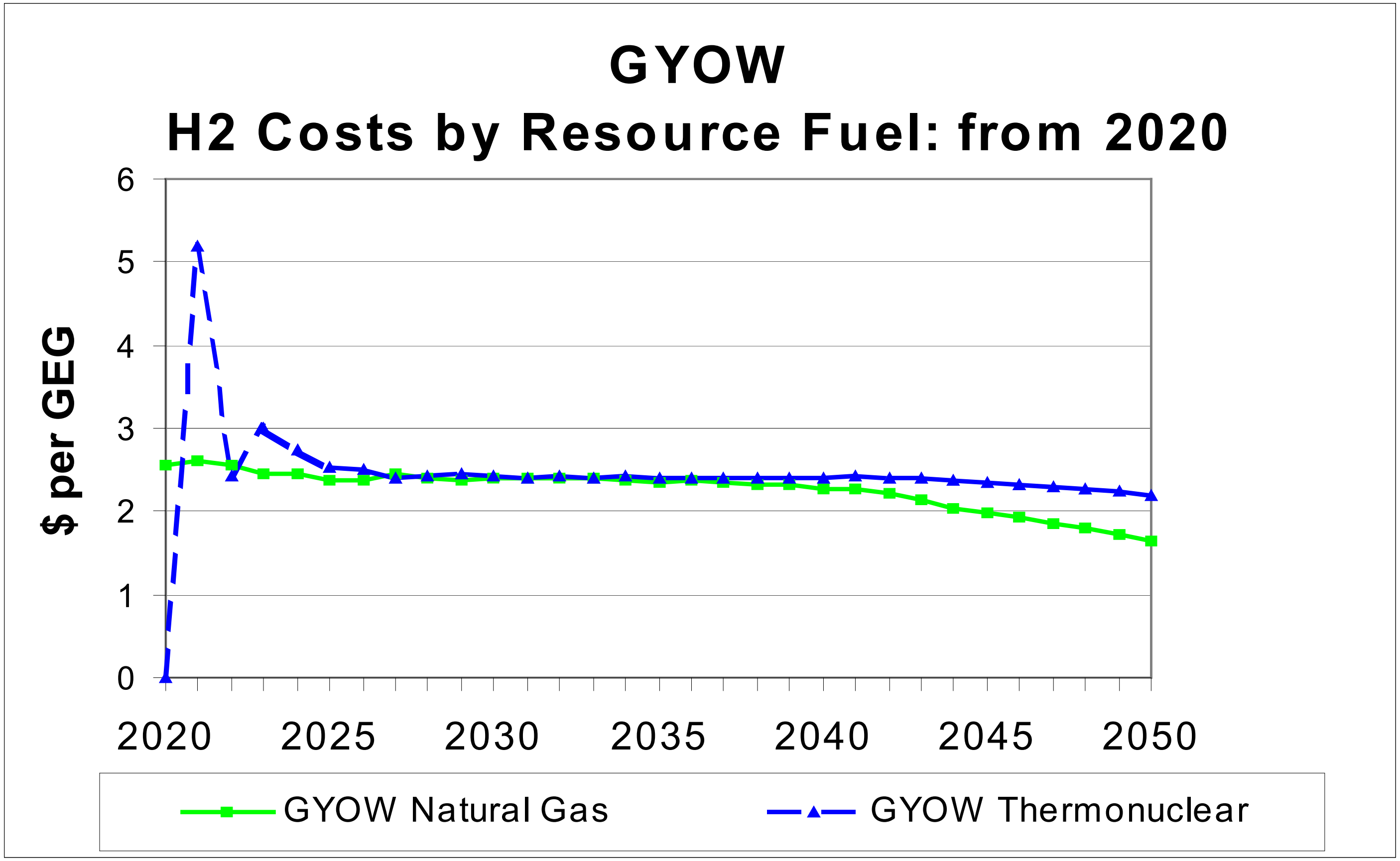
In the U.S., the cost of E-85 is driven down substantially in both GtP and GYOW.



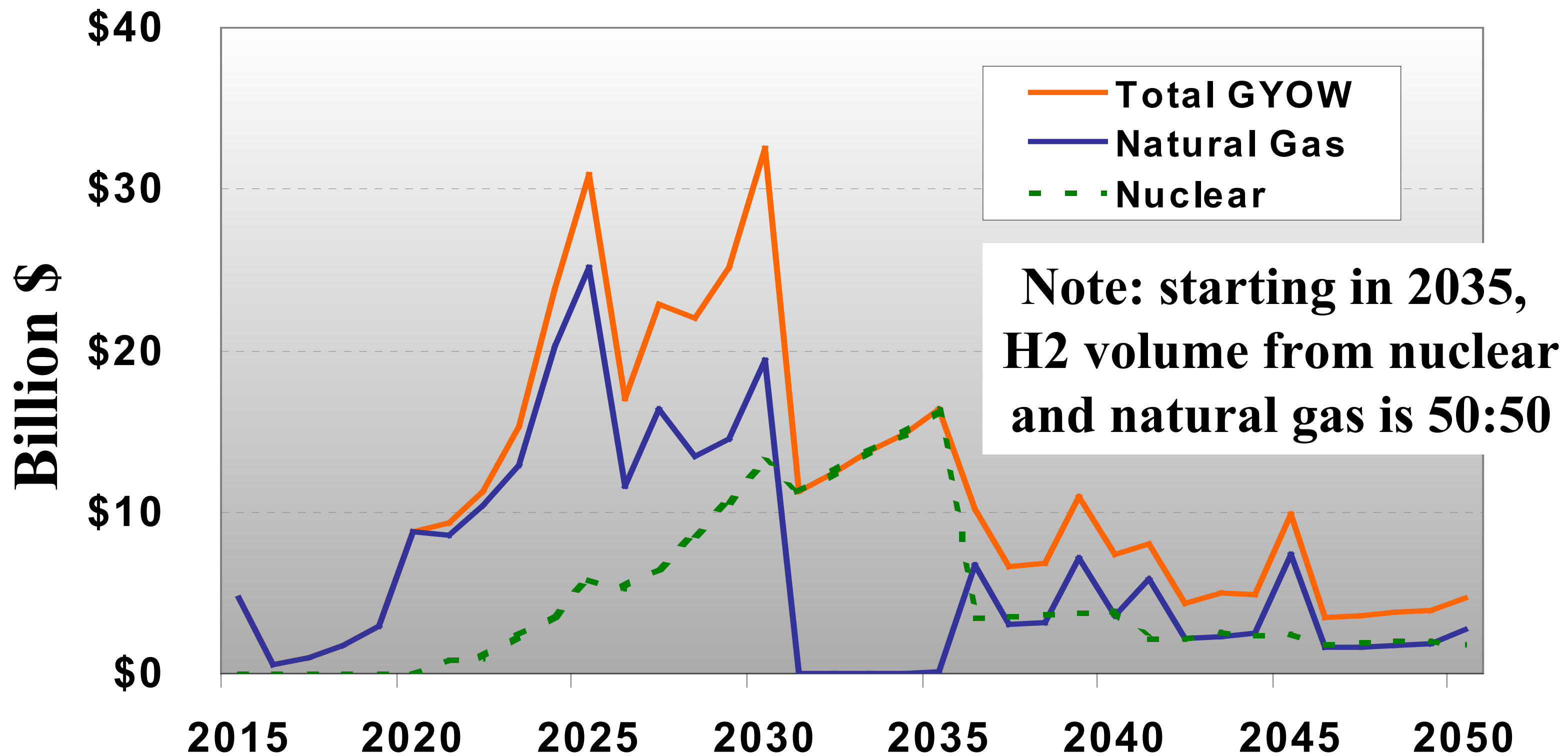
GYOW's high H_2 production levels require expensive new infrastructure but eventually drive unit prices lower.



In GYOW, H2 production from thermonuclear is the more expensive H2 option in the latter years of the scenario.

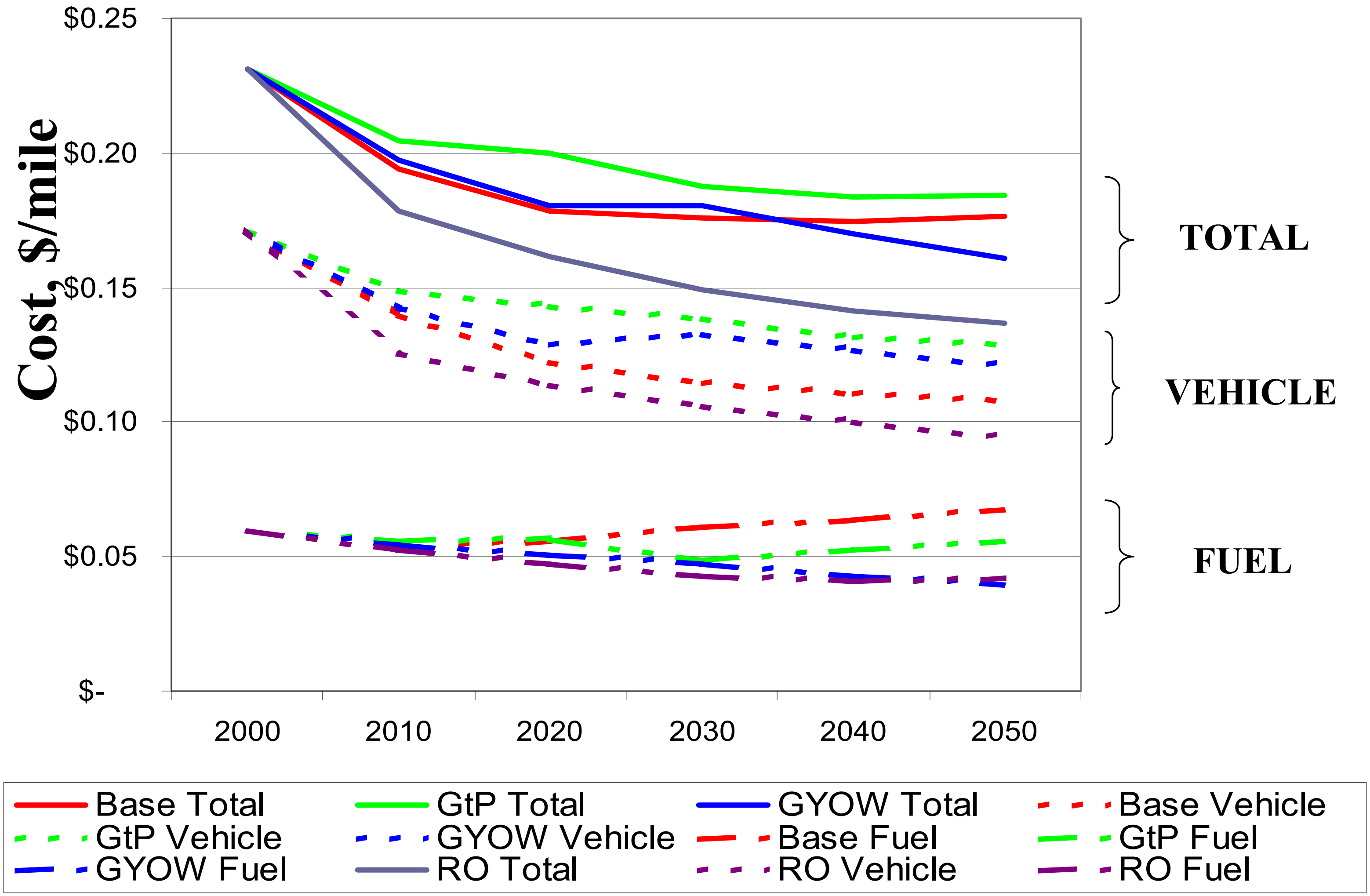


Capital costs of GYOW H2 infrastructure peak in the 2020-2030 timeframe.



Cumulative costs estimated to be nearly $400 billion

GtP has the highest total per mile costs of all scenarios. RO has the lowest.



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Concluding Remarks

- For two different environmentally-driven scenarios – different views of what the future will look like -- we have illustrated similar potential for reducing NA oil use and greenhouse gas emissions at relatively similar total costs, but through different means and with different timing of benefits.
- A transition from conventional to unconventional oil, or other transportation fuel substitutes, beginning before 2050 appears to be necessary. This transition raises a variety of issues about energy security, capital availability, environmental consequences, and so forth.

Concluding Remarks (continued)

- Oil from Canadian oil sands may be an important contributor to future North American supply, but considerable uncertainty remains – especially about long-term costs and the potential for large increases in production.
- Transitions to ethanol and/or hydrogen as fast as in these scenarios will require large early capital investments.

Capabilities Gained

- The 2050 project team has gained the capability to model a variety of oil, gas, and alternative fuel resource production and conservation issues.
- Specifically, we developed or used models for the following:
  - Effects of increased oil and/or gas resource base and varying OPEC production behavior
  - Cost of H2 production and distribution from natural gas and thermochemical processes
  - Cost of cellulosic ethanol production and distribution
  - Vehicle costs across scenarios

Some Criticisms of this Study

- Some very sudden or rapid changes are difficult to defend. For example:
  - In GYOW , H2 FCV sales increase quite rapidly
  - In GtP, VMT drops 15% in a short time
- Oil sands production allowed to grow without constraints
- Fixed fuel economy base case
  - Commonly used within EERE, but
  - Yields maximum savings, gains from new technologies and policies – could be considered biased
  - Need to consider the possibility of using EIA projections or some other alternative reference case

Possible Next Steps

- Obtain peer review and respond to comments
- Sensitivity analysis to address likely challenges and underlying uncertainties:
  - Different vehicle technology and/or fuels costs
  - Different oil and gas resource estimates
  - Limitations on Canadian oil sands
  - Various Hydrogen FC penetration levels
- Evaluation of additional hydrogen production pathways

Possible Next Steps (continued)

- Focus on the U.S. and develop scenarios more aligned with U.S. concerns and interests
- More in-depth examination of transition to alternative fuels and technologies, including shape of refueling infrastructure
- Employ more flexible vehicle stock, fuel use, and GHG models (VISION, GREET)
- Obtain input from industry experts (BP, ExxonMobil) and others (environmental groups) who are interested in the same topics and have valuable insights

Publicly Available Documents from 2050 Study

- *White Paper on Natural Gas Resources*, S.E. Plotkin, Argonne National Laboratory, 2002
- *Running Into and Out of Oil: Scenarios of Global Oil Use and Resource Depletion to 2050*, D.L. Greene, et al, Oak Ridge National Laboratory, July 23, 2002
- *Long-Term Energy Scenario Models: A Review of the Literature and Recommendations*, D.L. Greene, Oak Ridge National Laboratory, February 28, 2001
- *Ethanol Pathways in the 2050 North American Transportation Futures Study*, E. Steiner, National Renewable Energy Laboratory, 2002
- *Technology Cost Resource Paper*, J. Moore, TA Engineering, Inc., December, 2002
- *Total Scenario Cost Spreadsheet*, M.K. Singh, ANL, 2002

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Appendices

A. WESM Results
B. Ethanol and Biodiesel
C. World Natural Gas Resource and U.S. Gas Price Estimates
D. Technology Cost Model Overview and Assumptions
E. Additional Scenario Cost Details

Appendix A:
WESM Results

David Greene, Oak Ridge National Laboratory

Definitions of Oil Use and Resources

- Oil Use
  - **High: IAASA/WEC Case A1**
  - **Low: IAASA/WEC Case C1**
- Oil Resources
  - **High: Higher USGS estimate, 90% of speculative resources, 95% of unconventional resources**
  - **Intermediate: Rogner estimate, 50% of speculative resources, 75% of unconventional resources**
  - **Low: Laherrere mean estimate, lower speculative resources**

In WESM, the date of oil peaking is more sensitive to the assumed growth of world oil use than to the magnitude of the resource base.

Date of Oil Peaking

	MAGNITUDE OF OIL RESOURCES		
OIL USE	High	Intermediate	Low
High	2038	2036	2029
Low	2020	2016	2012

Appendix B: Ethanol and Biodiesel

By Elyse Steiner, National Renewable Energy Laboratory

Cellulosic Ethanol Basics

- Starch-based ethanol produced mainly from corn– an expensive feedstock with competing uses

- Cellulosic ethanol expected to be produced from:
  - agricultural residues
  - municipal wood waste
  - forest residues
  - bioenergy crops

- E-10 fuel (10% ethanol, 90% gasoline by volume) can be used by all US conventional light vehicles

- E-85 fuel (85% ethanol, 15% gasoline by volume) can only be used in “Flex-fuel” vehicles

- Energy content is 2/3 that of gasoline on a per gallon basis

Ethanol in the 2050 Study

Greening the Pump

- 100% of gasoline is E-10 blend by 2020
- 20% of new light vehicles consume E-85 in 2050
- Production volume reaches 49 million gallons in 2050 and the production cost is $0.69 per gallon

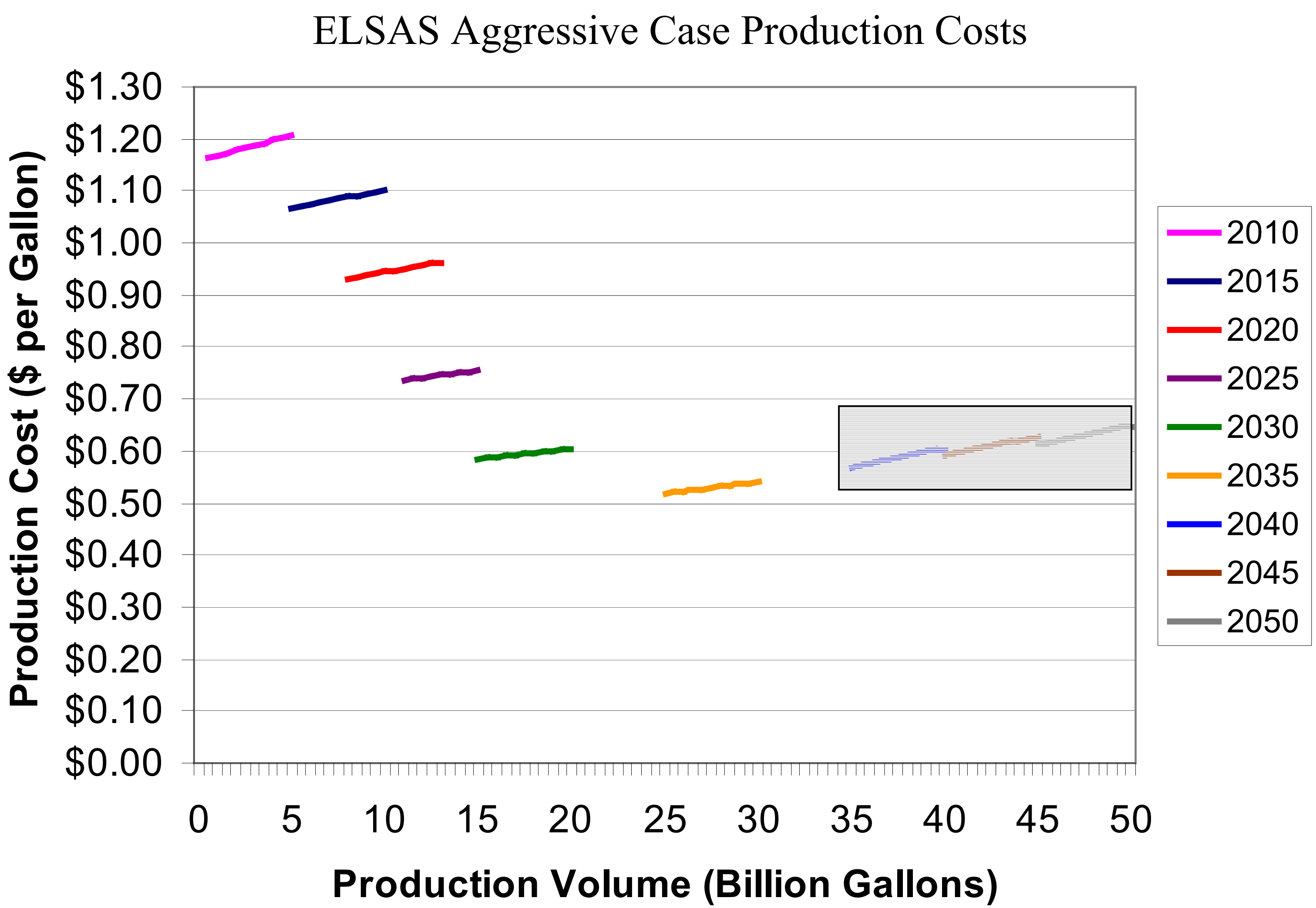
Go Your Own Way

- 100% of gasoline is E-10 blend by 2020
- 30% of new light vehicles consume E-85 in 2050
- Production volume reaches 50 million gallons in 2050 and the production cost is $0.61 per gallon

Key Assumptions Used in Ethanol Production Cost Calculations

Year	Cellulosic Volume (Billion gallons)	Production Cost ($/gallon)	Feedstock Cost ($/gallon)	Capital Cost ($/gallon)	Tax Credit ($/gallon)	Yield (Gallon/ dry ton)	# of Plants
Greening the Pump							
2010	6.9	$ 1.16	$ 0.42	$ 0.52	$ 0.37	77	123
2030	36.4	$ 0.63	$ 0.47	$ 0.11	$ 0.19	106	162
2050	45.4	$ 0.69	$ 0.53	$ 0.11	$ -	106	154
Go Your Own Way							
2010	5.9	$ 1.20	$ 0.41	$ 0.55	$ 0.37	77	107
2030	31.7	$ 0.57	$ 0.41	$ 0.11	$ -	106	147
2050	44.3	$ 0.61	$ 0.45	$ 0.11	$ -	106	150
Rollin' On							
2010	0.0	$ -	$ -	$ -	$ -	0	0
2030	3.4	$ 0.98	$ 0.28	$ 0.49	$ 0.19	106	15
2050	4.5	$ 0.83	$ 0.28	$ 0.39	$ -	106	15

At high volumes, production costs start to rise because more expensive feedstocks are needed.

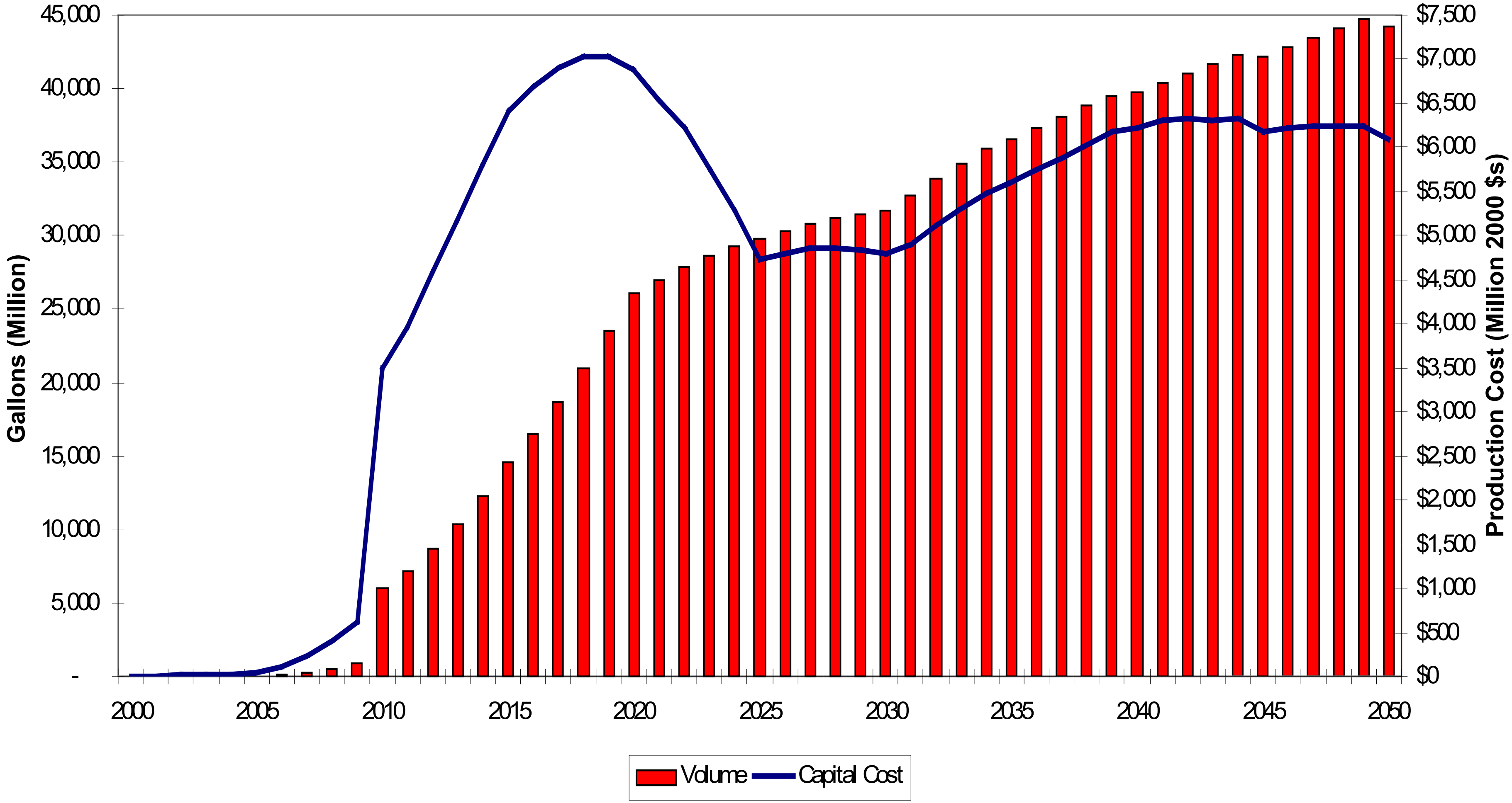


Capital Distribution Costs for GtP

(Million 2000$s)

	Bioethanol plants	Vehicles to tranpsort ethanol to terminals	Terminal equipment (tanks, blending equipment,etc)	E-10 stations	E-85 stations	Total
2010	$ 3,534	$ 59	$ 54	$ 8	$ 173	$ 3,828
2030	$ 4,076	$ 90	$ 58	$ -	$ 981	$ 5,205
2050	$ 5,084	$ 80	$ 46	$ -	$ 677	$ 5,888
Cumulative	$ 232,591	$ 3,501	$ 2,129	$ 166	$ 37,759	$ 276,146
Share	84.2%	1.3%	0.8%	0.1%	13.7%	100.0%

Capital costs for ethanol production are very high in early years relative to volume.



Biodiesel Basics

- Can be made from vegetable oils, grease or animal fats
- Used in heavy and light vehicles that run on diesel fuel
- Reduced CO, PM, NMHC, and air toxic exhaust emissions, but increased NOx emission
- Current production cost not competitive with diesel
- Similar to ethanol, biodiesel will commonly be blended with diesel, not used straight

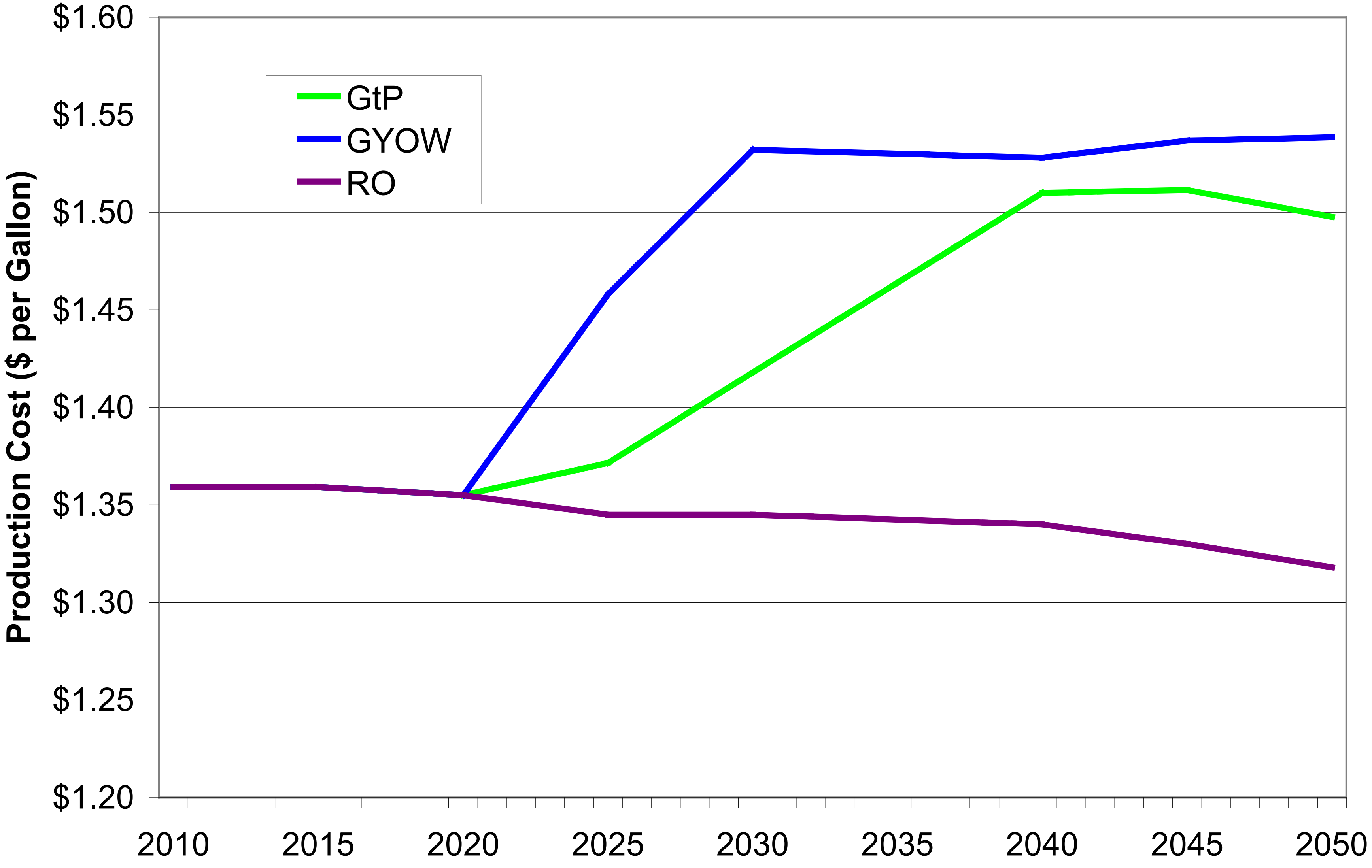
Biodiesel in the 2050 Study

- Assumed 50% made from soybean and 50% from yellow grease initially
- Canola oil and mustard seed oil added when market for other feedstocks depleted
- Market prices for commodity feedstocks subject to fluctuations. The following 2001 prices were used:
  - Soy: $0.143/ lb.
  - Yellow grease: $0.105/ lb.
  - Canola: $0.175
- Mustard seed not yet commercialized; DOE program funding current R&D

Biodiesel Cost Calculations

- Biodiesel from vegetable oils (B100) = $0.366 + (8.1 * $/lb feedstock)
- Biodiesel from yellow grease and animal fat (B100) = $0.35 + (8.008 * $/lb feedstock)
- Capital and operating costs assumed to decrease gradually over time
- Spreadsheet model calculated average cost based on percentage of each feedstock type used in production
- From NREL and Ocean Air data

Biodiesel Production Costs



Appendix C
World Natural Gas Resource and U.S. Gas Price Estimates

Steven Plotkin
Argonne National Laboratory

Range of Current Resource Estimates

- U.S. : 1258 TCF (PGC) – 2225 TCF (GTI advanced)
- Canada: 90+ TCF (USGS) – 670 TCF (NPC)
- Mexico: 60+ TCF (CRE) – 80 TCF+ (USGS)
- World: 13,649 TCF (USGS) conventional

  (with about 5,000 TCF undiscovered)

PGC: Potential Gas Committee
GTI: Gas Technology Institute
USGS: US Geological Survey
NPC: National Petroleum Council
CRE: Comision Reguladora de Energia

2050 Study Scenario Estimates of World Gas (Remaining) Resources

- **High innovation → more, cheaper supply**
- **High environmental consciousness → some resources are off limits**
- **Integration of U.S., Canadian energy trade → no effect on resource base**

scenario drivers

- **<u>Rollin' On</u>: high innovation, low environmental consciousness** — **25,000 TCF**
- **<u>Greening the Pump</u>: low innovation, high environmental consciousness** — **18,000 TCF**
- **<u>Go Your Own Way</u>: high innovation, high environmental consciousness** — **23,000 TCF**
- **<u>Base Case</u>: low innovation, env't** — **20,000 TCF**

Long-term U.S. Natural Gas Prices

- **Accurate projection is impossible**
- **Factors affecting U.S. wellhead prices to 2050**
  - **Size of the world gas resource base**
  - **U.S. economic growth rates**
  - **Changes in energy intensity, esp. in gas sectors**
  - **World rates of natural gas use**
  - **Development of a worldwide gas trading system**
  - **Improvements in gas finding, production, and transport technology, esp. for small fields**
  - **Development of methods to exploit gas hydrates**
  - **Cost reductions in gas backstops, e.g. coal gasification with sequestration**

Long-term Gas Prices (continued)

- EIA sees \$3.25/MMBtu by 2020
- Backstop prices:
  - Coal gasification w/sequestration: current estimates ~ \$7.00/MMBtu, expected declines to \$6.00/MMBtu
  - Methane hydrates – not estimated, production method unclear
- Assumptions:
  - Worldwide trading system (i.e., LNG): robust within a decade or two, prices equilibrate, wide supply choices

Handling Gas Prices in the 2050 Study:

- **Coal gasification is a backstop source: assume \$6.00/MMBtu by 2025, \$5.50 by 2050 for high innovation; not available for Greening the Pump due to environmental objections.**
- **In Rollin' On and Go Your Own Way, depletion of North American resources leads to \$3.50MMBtu (import price) by 2025 until 50% worldwide depletion, rising to \$5.50/MMBtu backstop by 70% (\$6.00 for Base Case)**
- **Greening the Pump has no backstop: gas price reaches \$6.50/MMBtu by 80% worldwide depletion and remains there.**

Appendix D
Technology Cost Model Overview and Assumptions

December 12, 2002

James S. Moore, Jr.
TA Engineering, Inc.
j.moore@ta-engineering.com

Technology - Vehicle Class - Scenario Matrix

Vehicle Class	Diesel	Hybrid Electric	Fuel Cell	Ethanol	Natural Gas
Autos	GtP (Conv.), GYOW (Conv.) RO (Conv.)	GtP, GYOW, RO	GYOW	GYOW	- -
Light Trucks	GtP (Conv.), GYOW (Conv.) RO (Conv.)	GtP, GYOW, RO	GYOW	GYOW	- -
Medium Trucks	GtP (Conv.), GYOW (Conv.) RO (Conv.)	GtP, GYOW, RO	GYOW	- -	GtP
Heavy Trucks	GtP (Conv.), GYOW & RO (Conv. & Adv.)	- -	- -	- -	- -
Buses	GtP (Conv.), GYOW (Conv.) RO (Conv.)	- -	- -	- -	GYOW

Vehicle Technology Cost Methodology

- Develop generalized estimates based on published cost curves for fuel economy improvement
- Include innovation-cost reduction assumptions
- Develop long-term trend relationships for each technology and scenario

Cost Curves for Fuel Economy Improvement

- Reviewed literature reference sources
  - “Scopes” relative to technologies, time frames and assumptions varied
  - Fuel cell technology cost estimates showed no discernable pattern
- Literature information was analyzed based on percentage changes in cost and fuel economy
- Results from 2002 National Research Council study on CAFE standards were used to improve consistency of resource values.

Effects of Innovation

- Innovation results in step-change reductions in relative cost of advanced technologies.
- Investigations sought a ‘model’ to use to illustrate the potential impacts that occur during a *50-year* period.
  - Cost trends that have occurred in the semiconductor industry provided an interesting ‘template’ to consider

Effects of Innovation (continued)

- 'Moore's Law':
  - Circuits per chip = $2^{(\text{year} - 1975)/1.5}$
- Expressed in terms of cost reduction effect:
  - Production Cost Effect = $2^{(-\text{elapsed time in years})/1.5}$
- Cost reduction equation form modified for ***longer life-cycle products***:
  - Production Cost Effect = $2^{(-\text{elapsed time in yrs})/10}$
    - Note that the innovation cycle has been changed from 1.5 years to 10 years. Can be changed to represent other time spans.

Pros and Cons of Methodology

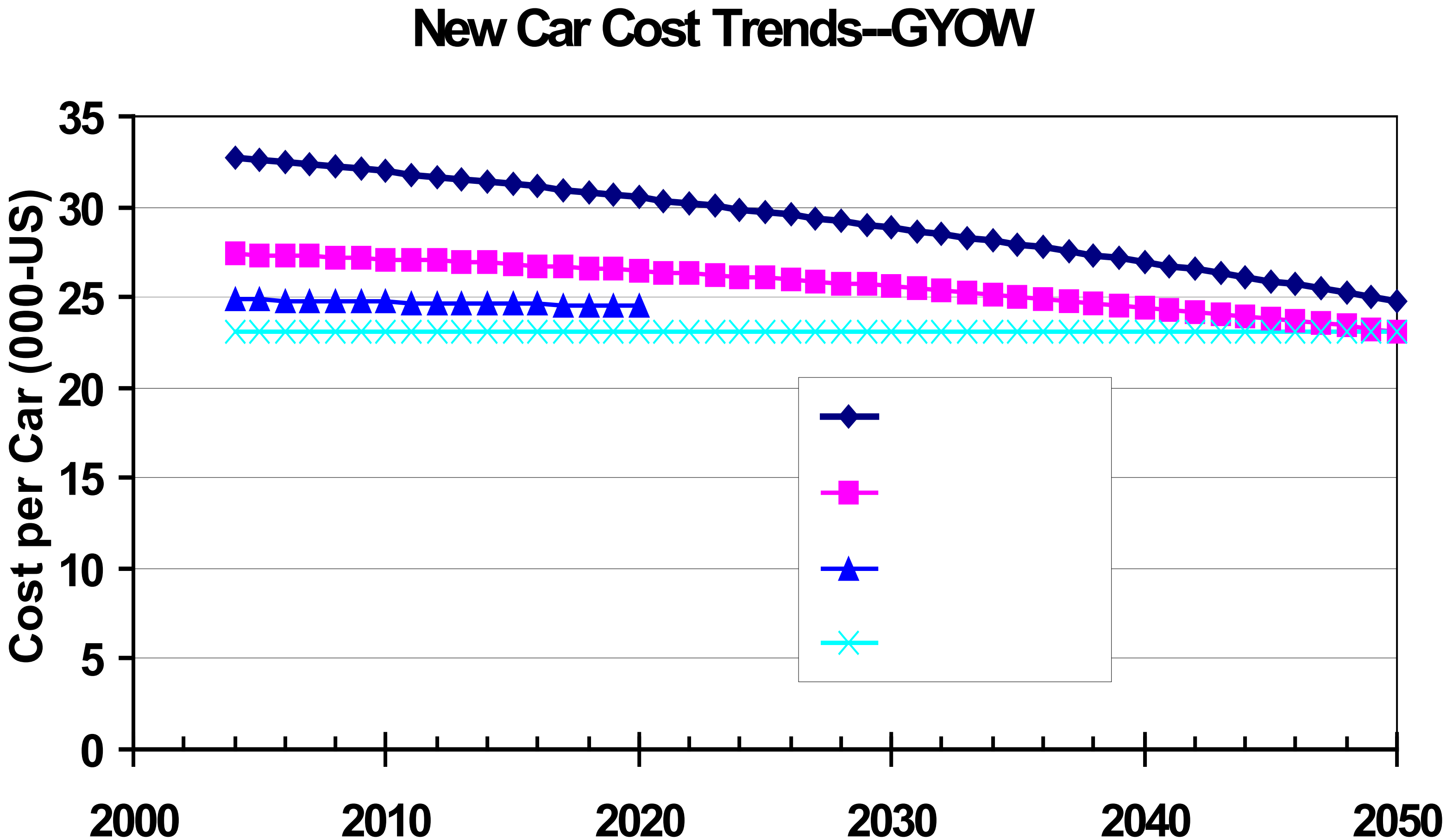
Pros:

- Confirmed empirically w/in Semiconductor Industry
- Some analysis has addressed applicability to other sectors
- A radical change from traditional auto design and production techniques will be needed to achieve market penetrations

Cons:

- Not well understood theoretically
- Negative secondary cost effects have been noted but not quantified
- Semiconductor industry may be highly atypical

Representative Results: GYOW



Medium & Heavy Truck Baseline Costs, $

Weight Class	Low	High	Average	Percent of Sales
Class 3	26,000	30,000	28,000	48.0%
Class 4	33,200	40,000	35,467	19.3%
Class 5	33,000	41,000	36,450	11.9%
Class 6	35,000	51,000	44,150	20.9%
Sales Weighted Average Cost	30,100	37,623	33,818	- -
Class 7-8			130,000	

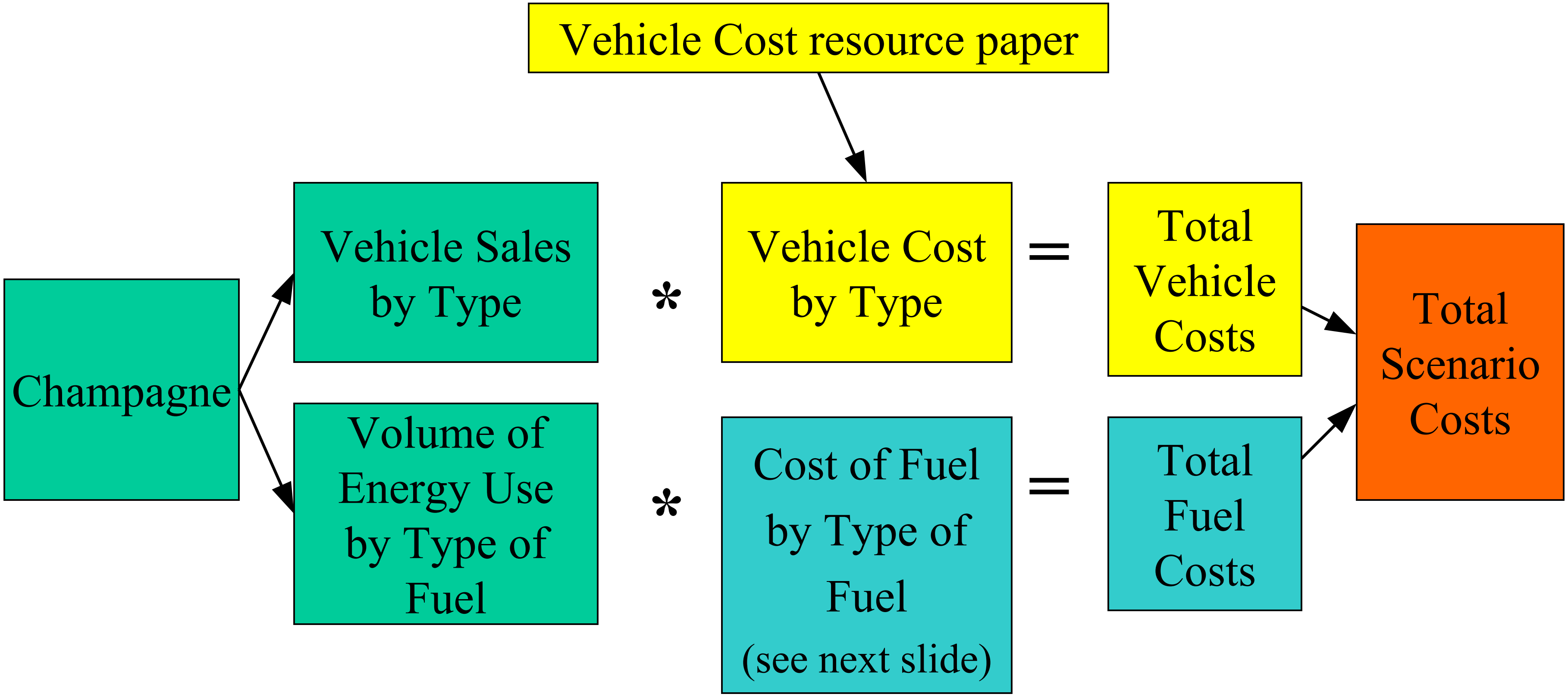
Key References for Vehicle Technology Cost Analysis

1. "On the Road in 2020, A Life-cycle Analysis of New Automobile Technologies", MIT Report No. MIT EL 00-003, October 2000
2. "Guidance for Transportation Technologies: fuel Choice for Fuel Cell Vehicles", Arthur D. Little, Inc., Report No. 35340-00, February 6, 2002
3. "Engineering-Economic Analyses of Automotive Fuel Economy Potential in the United States", Greene, D. L. and DeCicco, J., ORNL/TM-200/26, January 2002
6. "Social Cost Comparison Among Fuel Cell Vehicle Alternatives", Contadini (ICS-UC Davis)
7. "A Critical Evaluation of Electric Vehicle Benefits", Litman (Victoria Transport Policy Institute), Nov. 1999
8. "Integrated Analysis of Hydrogen Passenger Vehicle Transportation Pathways", Davis et al (DTI), March 1998
9. "Integrated Analysis of Hydrogen Passenger Vehicle Transportation Pathways", Davis et al (DTI), March 1998
10. "Technical and Economic Assessment of Hydrogen as a Fuel for Fuel Cell Vehicles", Ogden et al, 1998
11. "Program Analysis Methodology—Quality Metrics 2002", DOE-OTT, May 2001
12. "Effectiveness and Impacts of Corporate Average Fuel Economy Standards," National Research Council, National Academy Press, Washington, D.C., 2002
13. .Schaller, B., "The Origin, Nature, and Implications of Moore's Law; The Benchmark of Progress in Semiconductor Electronics", http://mason.gmu.edu/~rschalle/moorelaw.html.
14. "Transportation Energy Data Book" (Edition 21), Stacy C. Davis (Oak Ridge National Laboratory), ORNL 6966, October 2001
15. www.usedtrucklocator.com, PACCAR Financial New and Used Truck Locator, March 2002
16. **www.truckpaper.com**, March 2002

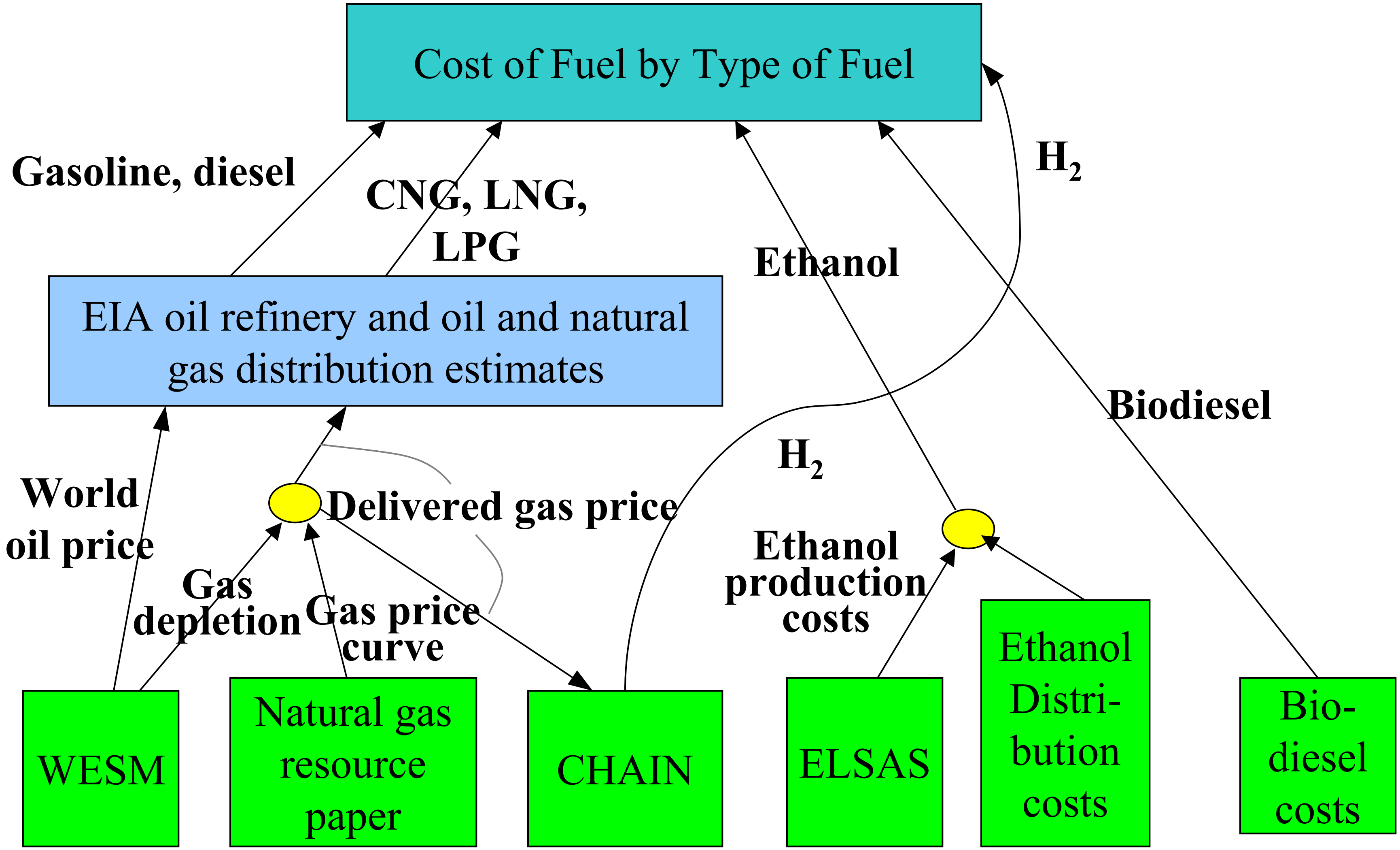
Appendix E
Additional Scenario Cost Details

Derivation of Total Scenario Costs

(Derived for each year (2000-2050) and then accumulated over time, for each scenario)



Derivation of Cost of Fuel Estimates



Cumulative cost estimates for 2030-2050: GtP and RO costs are substantially lower than the Base Case in the latter years of the analysis.

Scenario Costs (Undiscounted, trillion 2000$)

	Vehicles	Fuel	Total	% Change
Base Case	$12.5	$7.3	$19.8	
Incremental Costs				
Greening The Pump	+$0.1	-$2.2	-$2.1	-10.6%
Go Your Own Way (Original)	+$2.0	-$2.3	-$0.3	-1.4%
Go Your Own Way (Higher costs)	+$3.0	-$2.1	+$0.9	+4.5%
Rollin' On	-$0.5	-$2.2	-$2.7	-13.7%