

# **Hydrogen Transition Modeling and Analysis HyTrans v. 1.0**

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**Project # AN3**

# **We have been working on this challenging task for almost 1 ½ years.**

## **Timeline**

- **Start: 10/1/2004**
- **Finish: 10/31/2007**
- **Status: 40% completed**

## **Budget**

- **FY04 - \$540K**
- **FY05 - \$450K**

## **Barriers**

- **Transition Scenarios**
  - “By 2007, identify and evaluate transition scenarios, consistent with developing infrastructure and hydrogen resources, including an assessment of timing and sequencing issues.” p. 4-1

## **Partners**

- **ANL – Pipelines & delivery**
- **NREL & H2A – Production & delivery**
- **UC Davis - Expert review**

# **HyTrans' objective is to model the market transition to a H<sub>2</sub> vehicle system in a way that is useful for R&D planning, cost-benefit analysis, policy analysis and envisioning.**

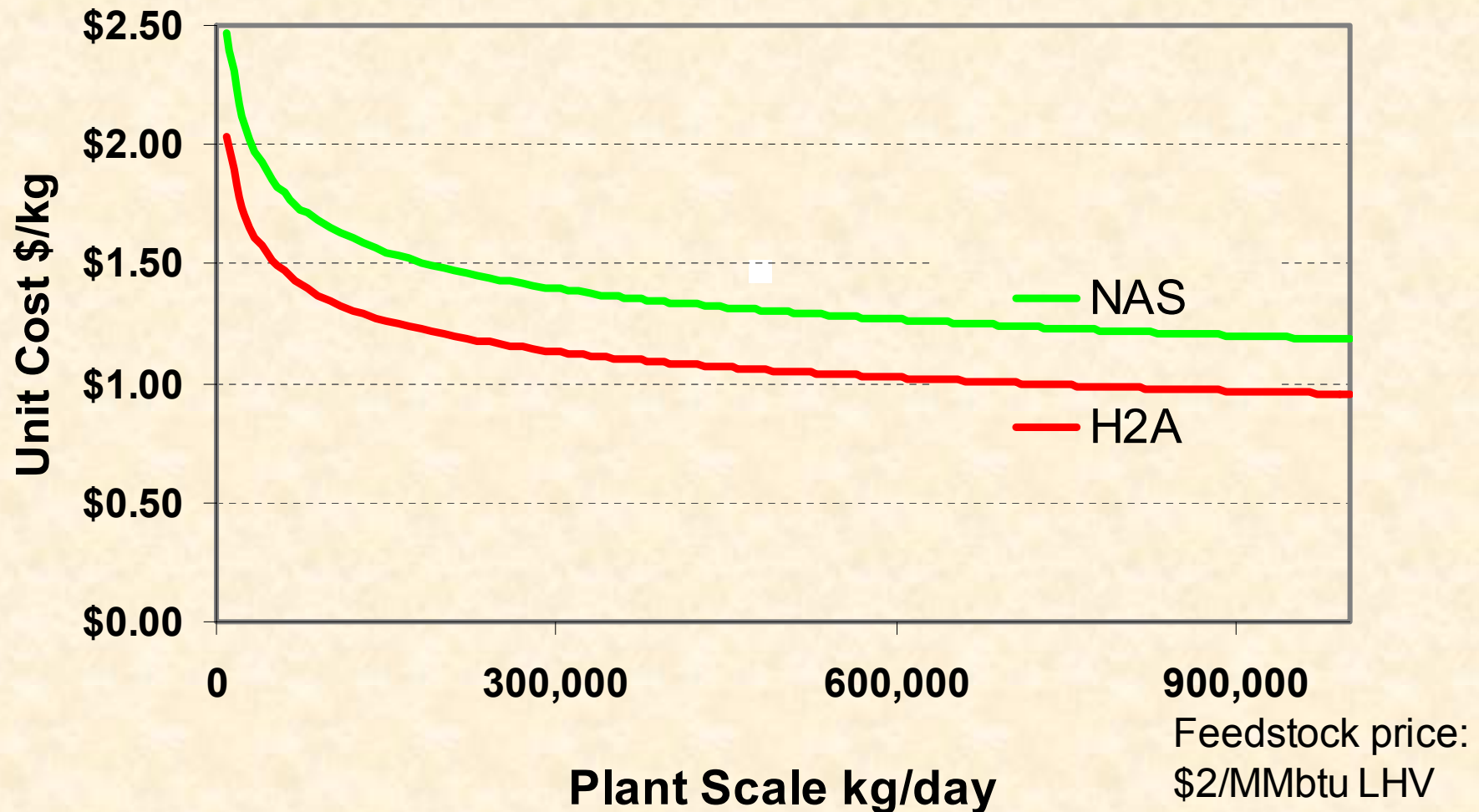
- **Integrates all main H<sub>2</sub> market components**
  - Hydrogen Production
  - Hydrogen Delivery
  - Vehicle Production
  - Consumer Choice
  - Hydrogen Use
- **Determines a market equilibrium solution**
  - Maximizes total consumption benefit minus production, distribution, and other costs
  - Estimates amounts and timing of costs, benefits, levels of investment and activity, production and consumption, key environmental impacts.
  - Sensitive to technological goals and supporting policies.

# **Our method is economic modeling via non-linear optimization.**

- **Production pathways: cost functions**
- **Vehicle production: cost functions**
- **Consumer demand: NMNL**
- **3 fuel demand density regions**
- **Key dynamic elements:**
  - Learning-by-doing
  - Technological change
  - Scale economies
  - Fuel availability
  - Diversity of vehicle choices
- **Generalized Algebraic Modeling System**

# Hydrogen production cost functions derived from H2A and NAS 2004 have been incorporated.

## H2 Production Costs: Biomass Gasification



# A H2 Supply Pathway comprises three parts.

## Delivery

**Compression/Liquefaction+Storage  
+Dispensing+Transporting+Storage  
+Compression/Vaporization**

## Production

**Centralized SMR  
Coal Gasification  
Biomass, etc.**

**Forecourt  
(Store + Dispense)**

**Retailing of  
Compressed  
Gas**

Pipeline

Truck Compressed Gas

Truck Liquefied

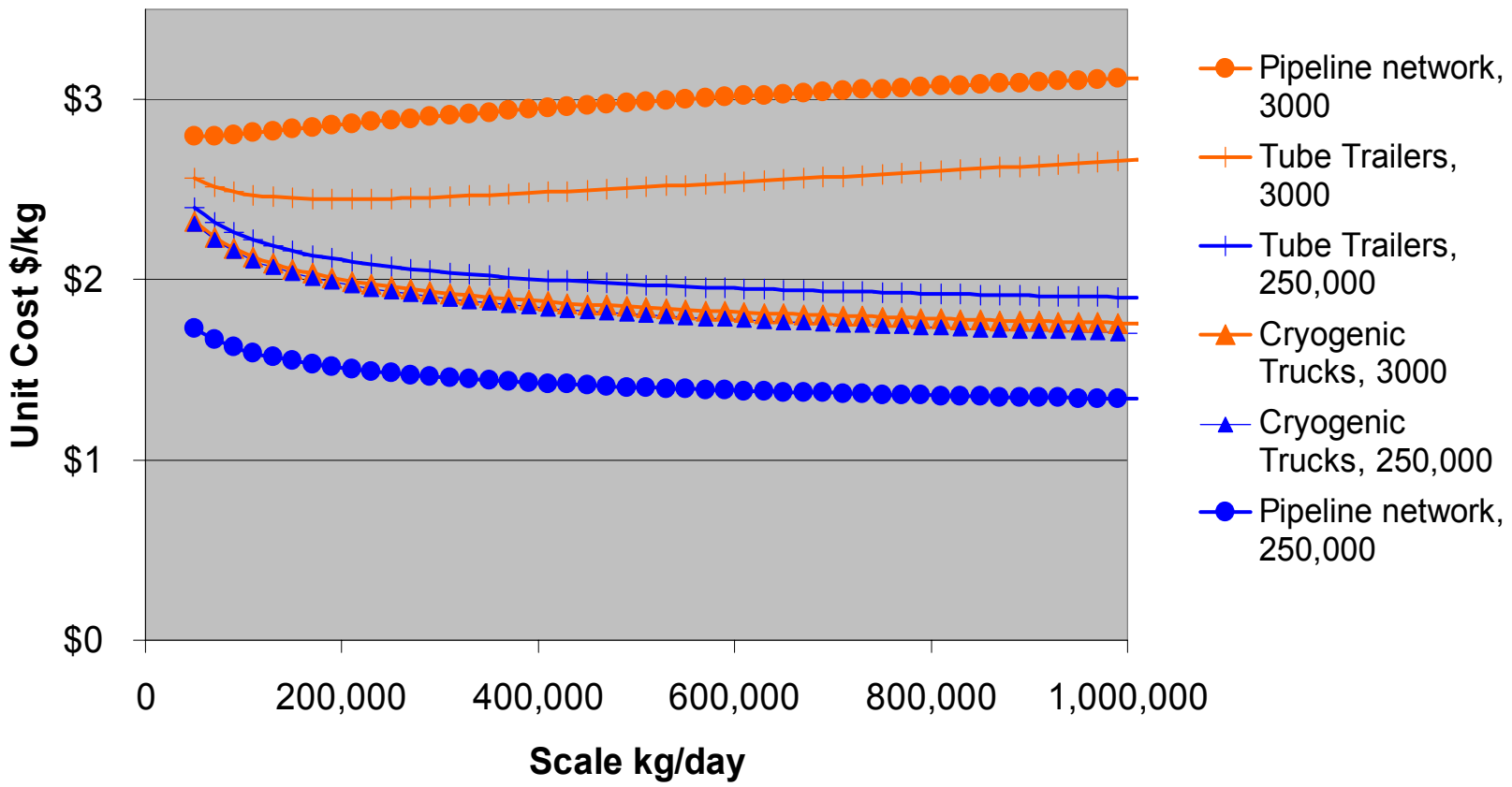
**Forecourt SMR  
Forecourt Electrolysis  
Many Others...**



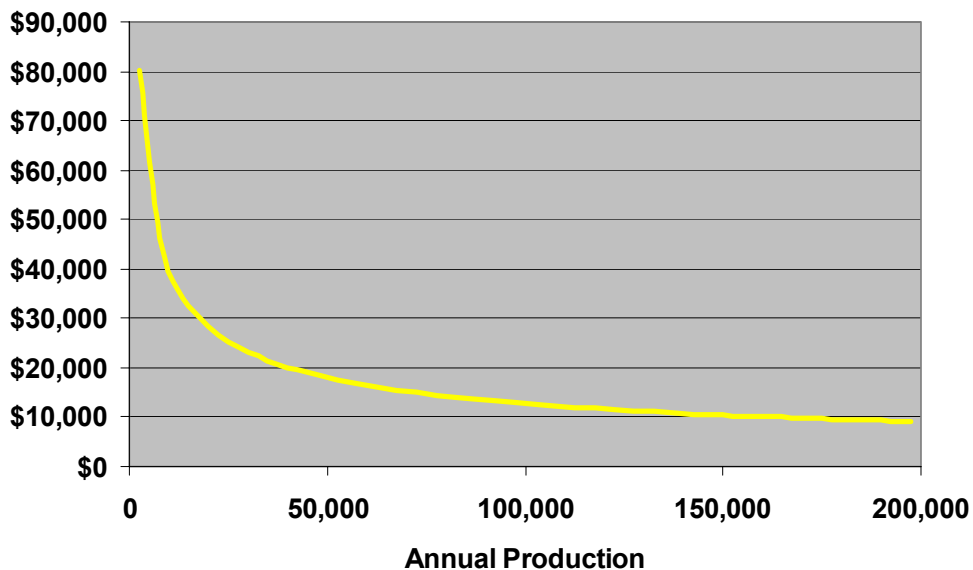
# Demand density affects the competitive positions of production/delivery pathways.

(H2 delivered to vehicle excl. taxes)

Delivered Unit Cost, Future Coal Gasification  
H2 demand density: 3,000 and 250,000 kg/sqkm/yr

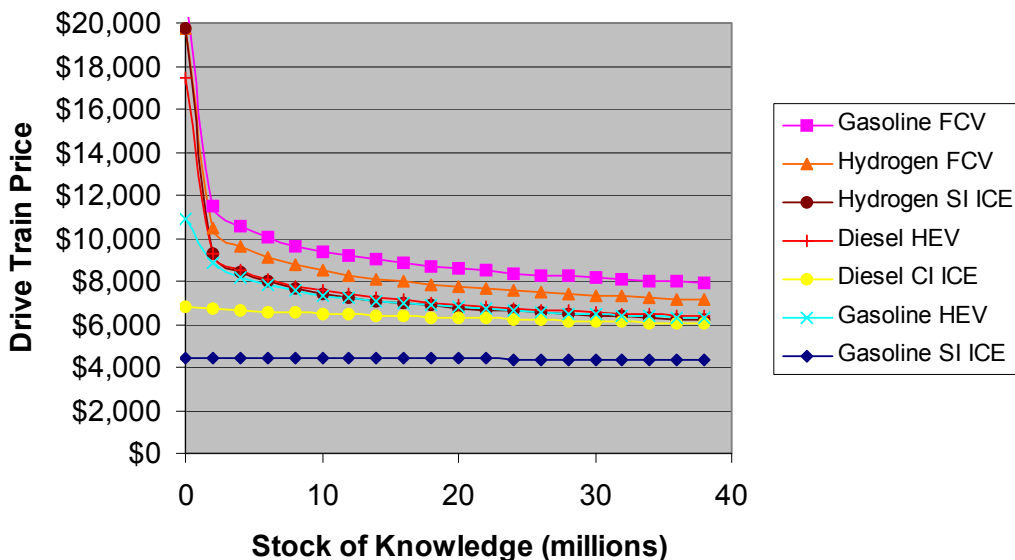


### Scale Economies with Elasticity of -0.5



### Scale w/ Annual Production/Plant

### Asymptotic Learning Model

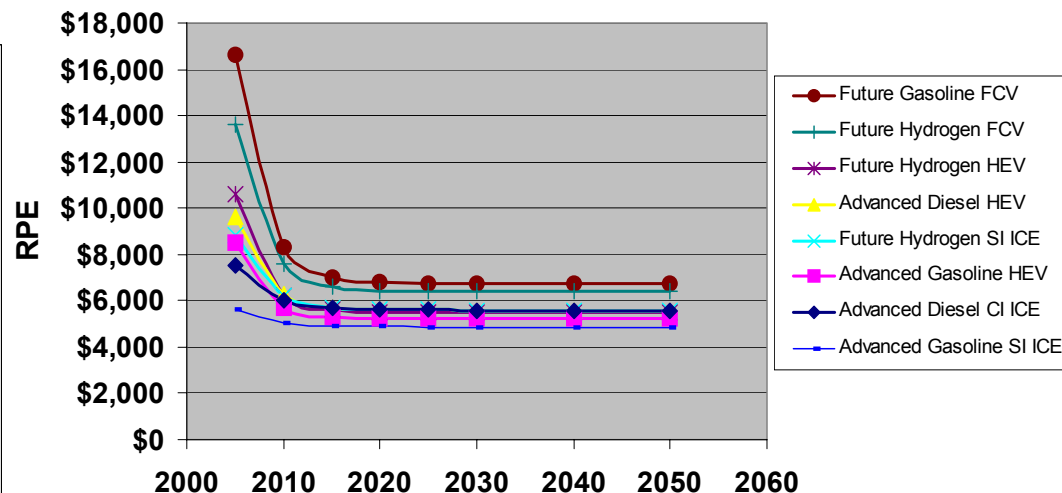


# Vehicle technologies improve by 3 mechanisms.

$$\text{Retail Price} = \text{Scale} \times \text{Learning} \times \text{Tech Change} \times \text{Scenario Price}$$

### Effect of Technological Change on Incremental Prices Advanced Vehicle Technologies

DOE Freedom Car Goals Scenario



### Tech Change w/ Passage of Time (Yr)



### Learning & Unlearning w/ Stock on Road



# **We have completed a preliminary working version of HyTrans.**

- **Implemented and tested all major components in GAMS**
- **Translated H2A and NAS hydrogen production models into HyTrans equations**
- **Developed and implemented a temporary delivery model**
- **Developed, implemented and calibrated representations of technological change, learning-by-doing and scale economies.**
- **Produced preliminary, test transition scenario runs**

**The results I will present today are preliminary not definitive and should not be interpreted as conclusions about the hydrogen transition.**

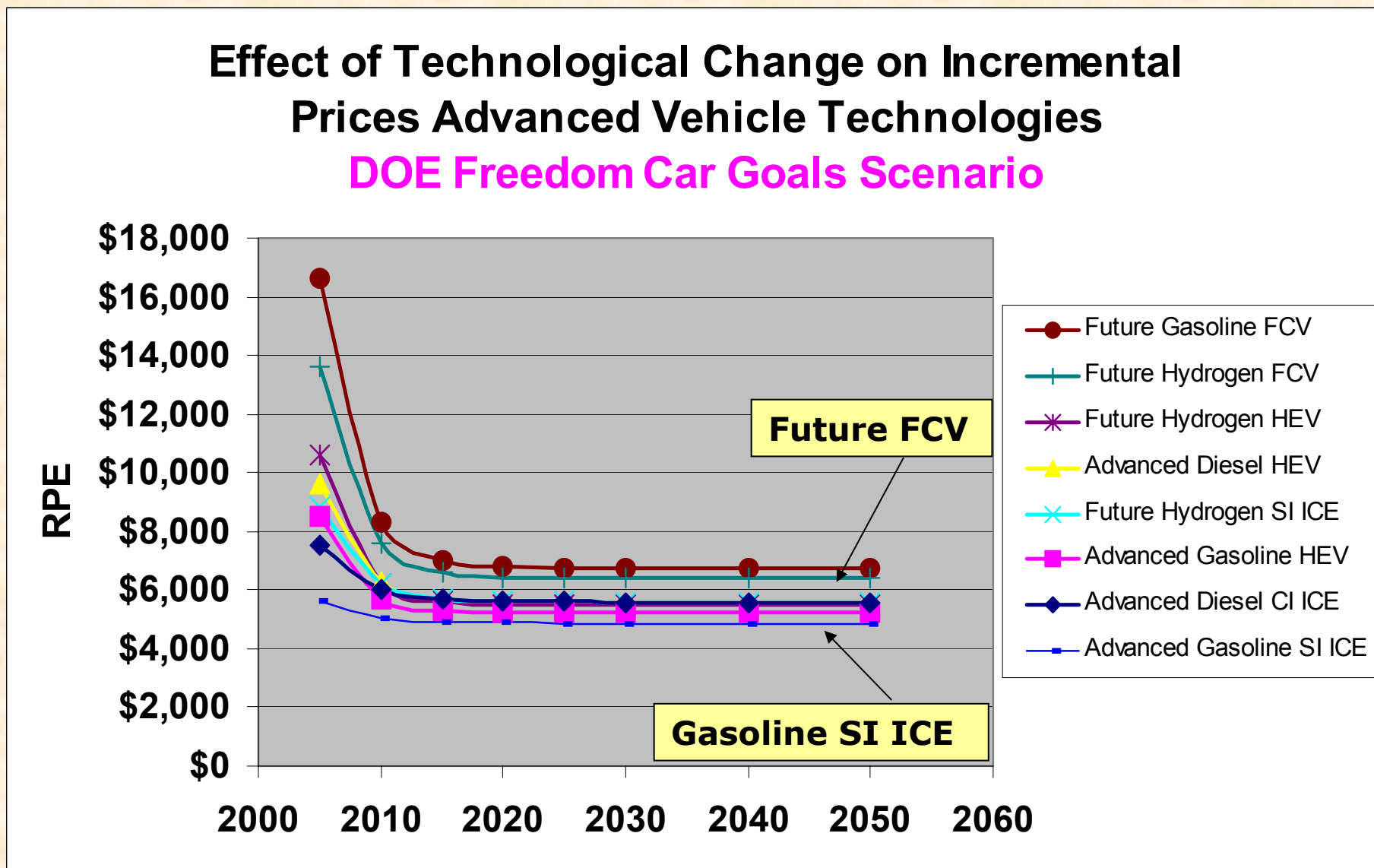
- **HyTrans is still under development and review.**
- **Scenarios to be presented today do not reflect HFCIT program goals via H2A models (will soon).**
- **NAS production technologies used; results presented below based on restricted sets of production options.**
- **Geographical regions, several major improvements are needed.**
- **Results illustrate feasibility of optimization methodology, kinds of analyses that will be possible.**

# I will show some preliminary results from three scenarios.

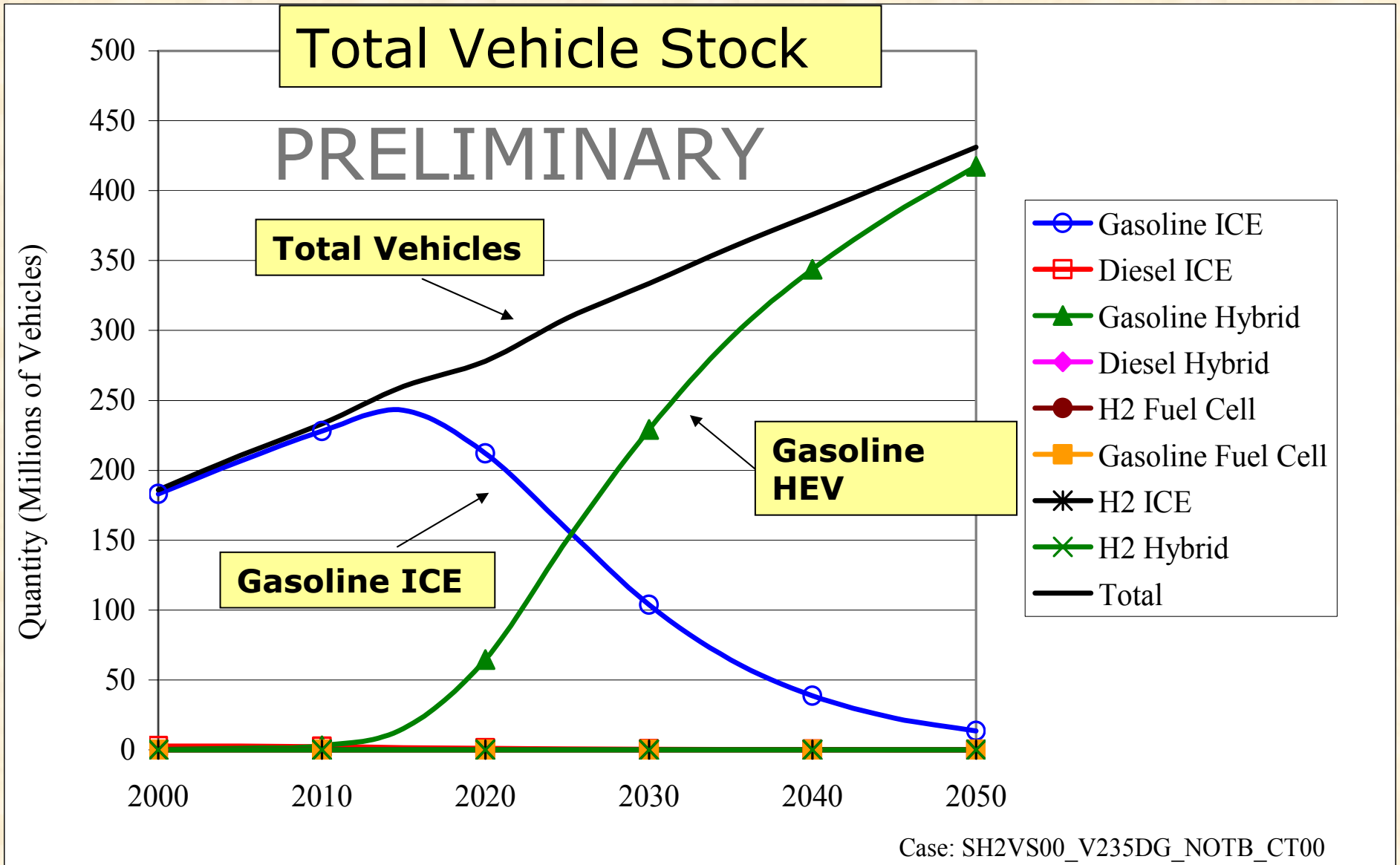
- **Based on AEO 2004 Reference Case & extrapolated.**
- **Two policy drivers**
  - Vehicle subsidies
  - Fuel subsidies
- **1: DOE Freedom Car Goals Met**
- **2: Alternative Vehicle Technology Evolution**
- **3: Carbon Emissions Limitations**
- *ALL scenarios here rely on NAS (2004) H2 production cost estimates – H2A models will be incorporated in the near future.*

# SCENARIO 1

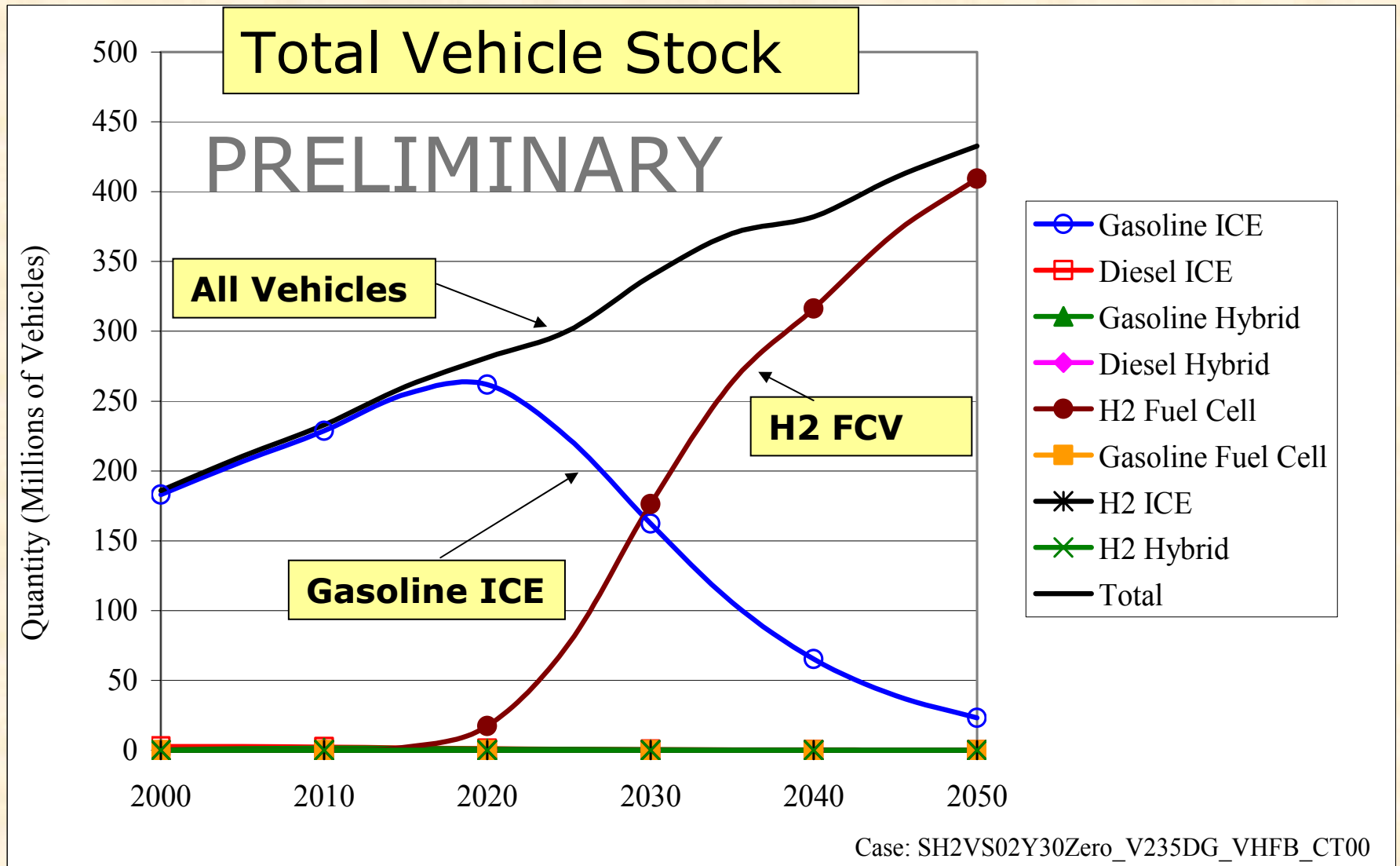
The DOE Vehicle Technology Program Goals scenario anticipates rapid progress for all technologies.



# Given no new policies, HyTrans sees a shift to gasoline hybrids in scenario 1.



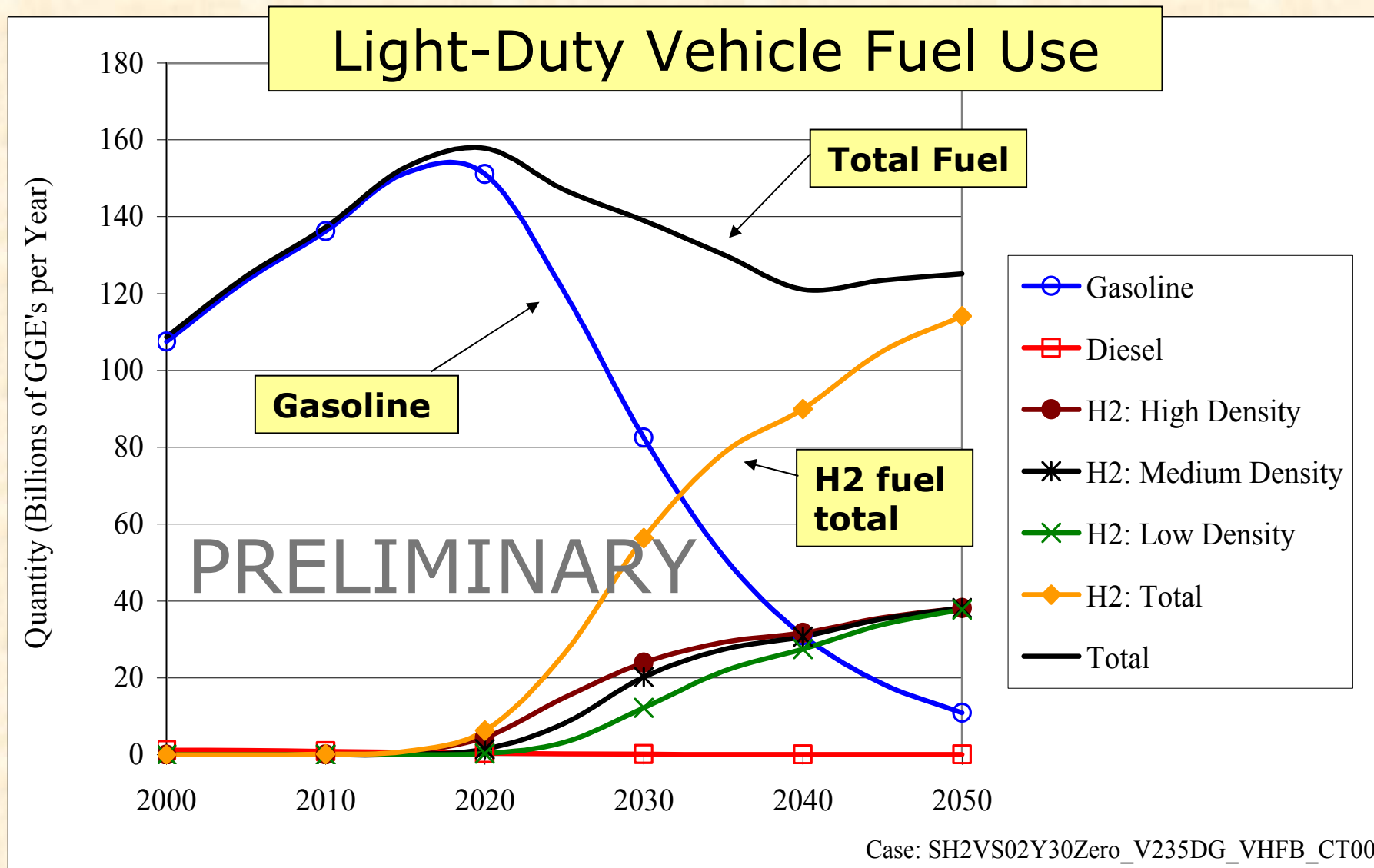
# A temporary H2-vehicle subsidy of \$2,000 until 2030, and \$0 afterwards produces a sustainable transition to hydrogen-powered light-duty vehicles.





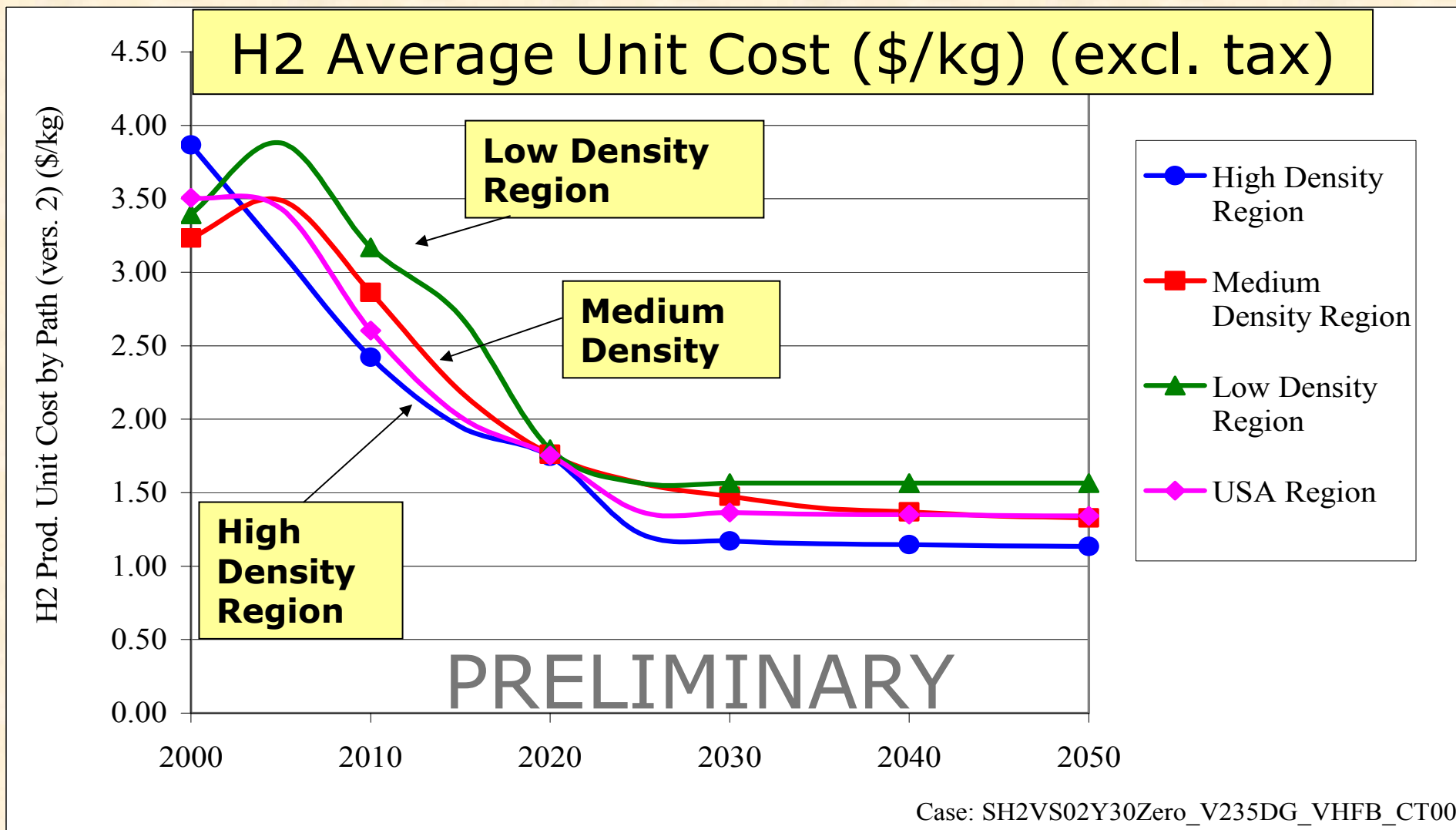
# The transition to H<sub>2</sub> reduces vehicle fuel use in the face of steadily growing travel demand.

(Scenario 1: \$2,000 H<sub>2</sub> Vehicle Subsidy, \$0 After 2030)



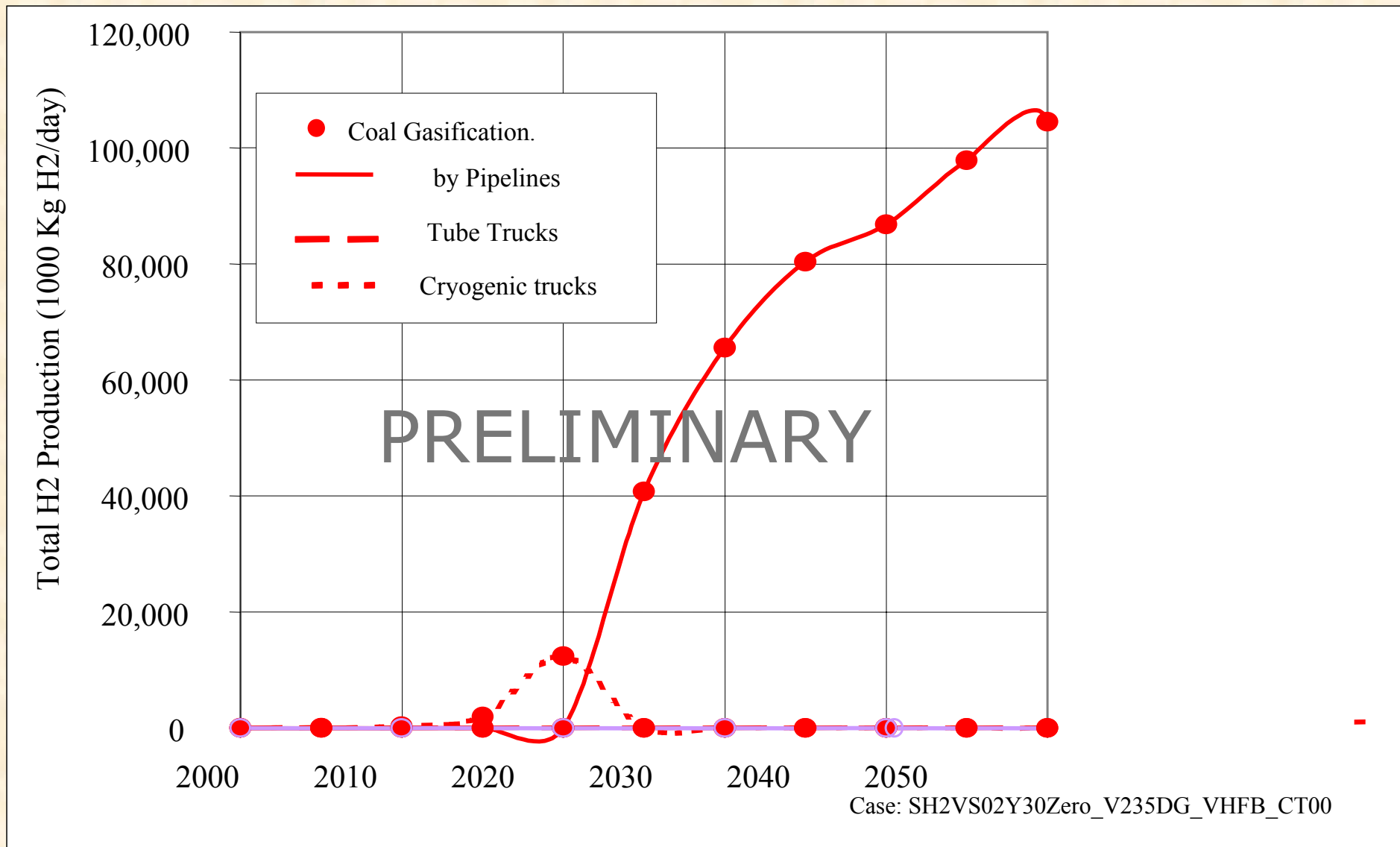
# Delivered H<sub>2</sub> costs fall over time with technological progress, scale economies and market share.

(Scenario 1: \$2,000/H<sub>2</sub>-Veh Subsidy, \$0 After 2030)



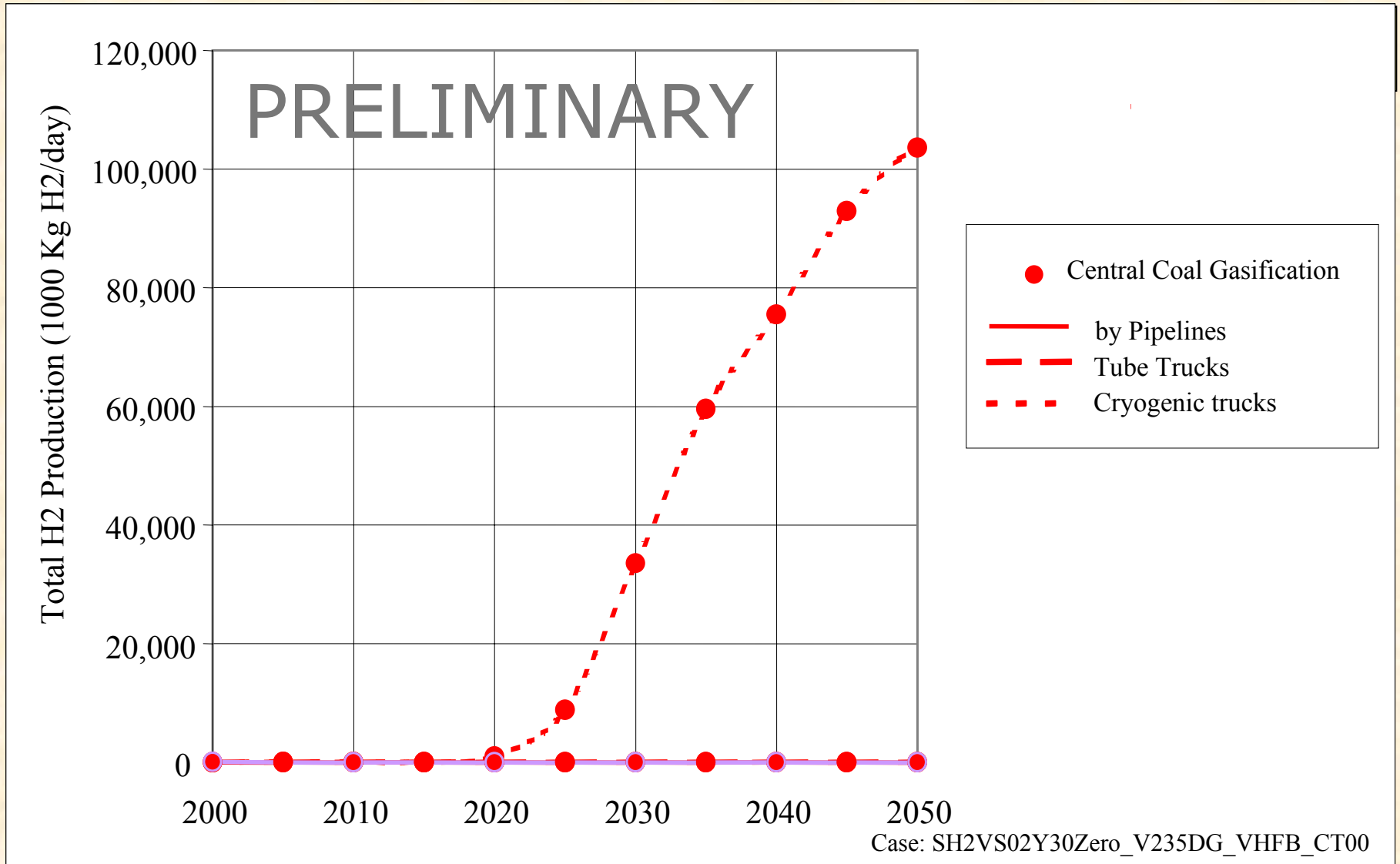
# With centralized production, higher density regions start with truck and shift to pipeline as hydrogen's market share grows.

(Scenario 1: \$2,000/H<sub>2</sub>-Veh Subsidy, \$0 After 2030)



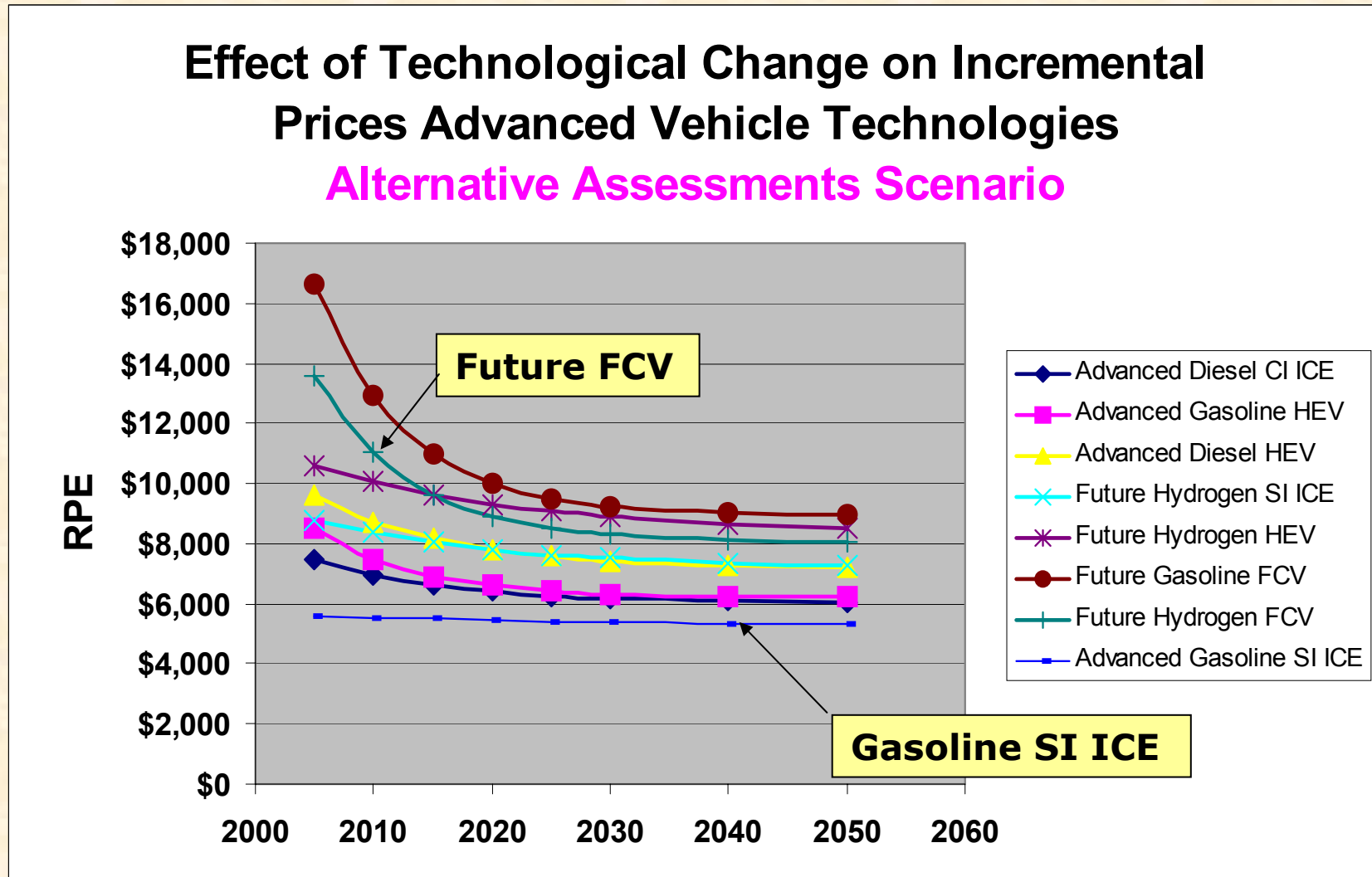
# The low density (intercity) region relies on cryogenic-trucking throughout.

(Scenario 1: \$2,000/H<sub>2</sub>-Veh Subsidy, \$0 After 2030)



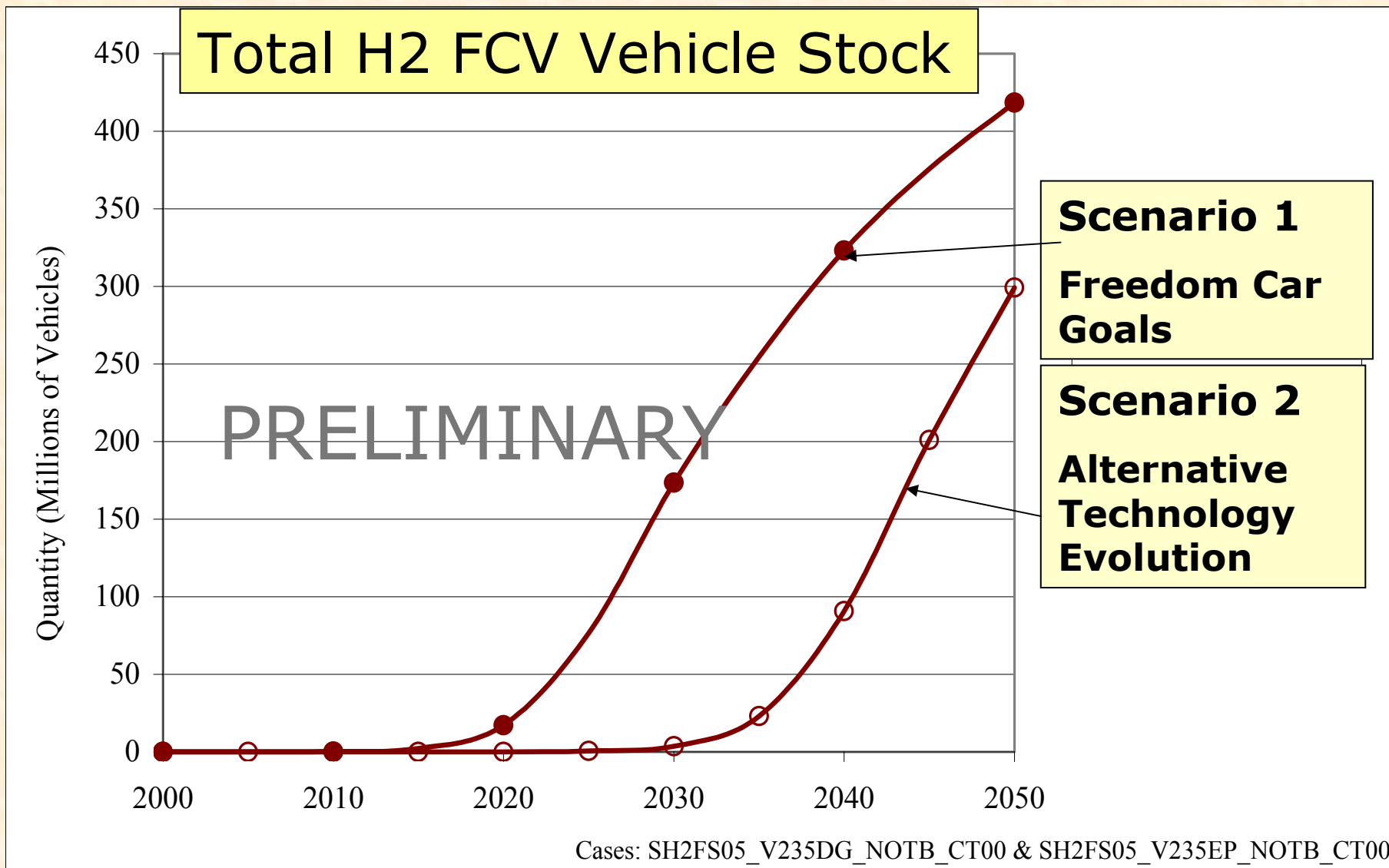
## SCENARIO 2

We derived the **Alternative Vehicle Technology Case** from published studies. It is less favorable for some technologies, certainly for FCVs.



# Given the same fuel subsidy policy, the hydrogen transition occurs later in scenario 2.

(Scenarios 1 & 2: \$0.90/GGE H2 Fuel Subsidy)



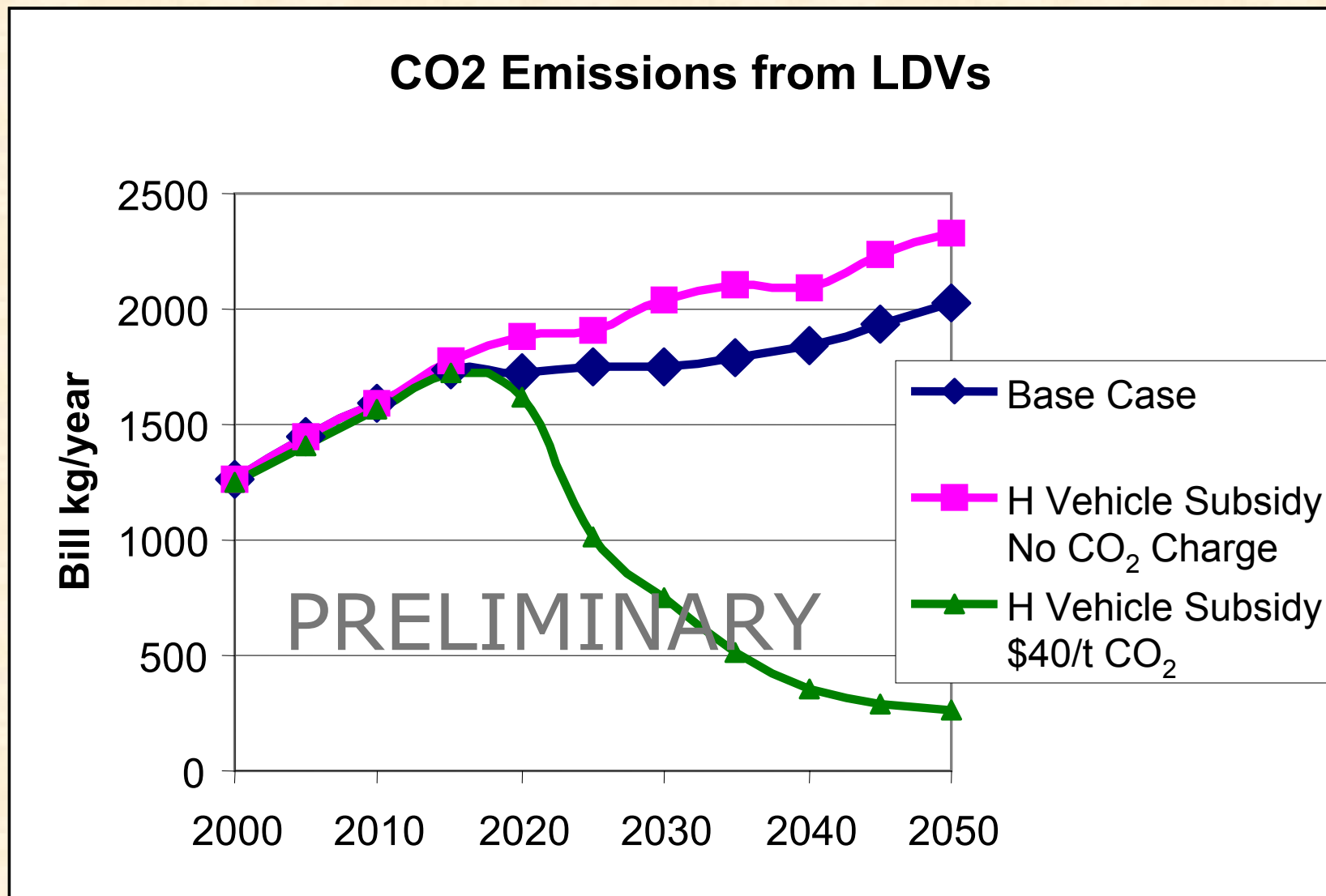


# **SCENARIO 3: Carbon emission Limits**

**How do the vehicle technology program goals change the ability to reduce CO<sub>2</sub> emissions from light-duty vehicles?**

- **REET 1.6 Supplemented by other sources (REET update in Spring)**
- **Represent carbon limits in the form of carbon taxes (cap and trade)**
- **Add vehicle subsidies, as well**
- **DOE Vehicle Technology Program Goals**

# Transition to H<sub>2</sub> creates an opportunity for massive reductions in C emissions.



# HyTrans is making significant progress.

- **Plausible answers to:**
  - Is a stable transition achievable?
  - When?
  - How long will it take?
- **Can begin to test key policies**
- **Will be able to produce potentially useful cost and benefit measures**
- **Close to useful visions of the transition**
- **Beginning to generate insights about R&D goals**
  - Good enough?
  - Effects of competing technologies

# Several important deficiencies remain to be addressed in FY 2005.

- **Size of the optimization problem, nonconvexities and resulting multiple equilibria are pushing the state of the art of nonlinear optimization software.**
  - Test alternative global solvers (e.g., BARON)
  - Continue development of hybrid scenario/optimization methods
- **Lack of geographic regions makes it difficult for renewable H sources to penetrate the market.**
  - Develop and implement representation of NEMS regions in collaboration with Singh and Wood.
- **Representation of fuel availability needs improvement**
  - Intercity (Melaina methodology)
  - Variable station sizes

# Future Work

- **Remaining FY 2005**
  - **Report on sensitivity analysis: 6/30/2005**
  - **HyTrans documentation: 9/30/2005**
  - **Report on Plausible Hydrogen Transition Scenarios, Policies, Costs and Benefits: 9/30/2005**
- **FY 2006**
  - **Linkages to Macro Model**
  - **Representation of regional differences affecting choice of production technology**

# THANK YOU.

OAK RIDGE NATIONAL LABORATORY  
U. S. DEPARTMENT OF ENERGY





# Presentations and papers

**”Modeling the Demand for Hydrogen by Light-Duty Vehicles: HyTrans Methodolgy”, UC Davis Workshop on Hydrogen Demand Modeling, Institute for Transportation Studies, UC Davis, Davis, CA, June 21, 2004.**

**“HyTrans: a dynamic equilibrium model of market transitions to hydrogen”, presentation to the National Research Council Committee on Hydrogen, Washington DC, January 24, 2005**

**“Analyzing Transitions to Hydrogen Powered Vehicles with HyTrans, National Hydrogen Association Conference, Washington, DC, March 30, 2005.**

**“Modeling the Transition to Hydrogen: Early Experience with the HyTrans Model”, 13<sup>th</sup> Annual EIA Midterm Energy Outlook and Modeling Conference, Washington, DC, April 12, 2005.**

## Draft Reports

**“HyTrans Hydrogen Transition Model: Building Version 1,” Draft report, Center for Transportation Analysis, Oak Ridge National Laboratory, Oak Ridge, Tennessee, March.**

**“Incorporating H<sub>2</sub>A Production, Delivery and Forecourt Models into HyTrans”, draft report, National Center for Transportation Research, Oak Ridge National Laboratory, Oak Ridge, Tennessee, December 20, 2005.**

**“Initial Hydrogen Transition Scenarios Developed Using the HyTrans Model”, Progress Report, National Transportation Research Center, Oak Ridge National Laboratory, Oak Ridge, TN, March 29, 2005.**