2009 DOE Hydrogen Program Review

Modeling the Transition to Hydrogen

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Overview

Timeline

- Start Oct. 2005
- End: Sept. 2010
- Percent complete 80%

Budget

- Total project funding $2.4M
  - DOE share 100%
- Funding for FY08: $600k
- Funding for FY09: $600k

Barriers Addressed

- Lack of understanding of the Transition from a Hydrocarbon-based Economy to a Hydrogen-based Economy.
- Lack of integrated market model of all major components of the Hydrogen Fuel and Vehicle System
- Need for improved analysis of future fuel and vehicle markets, using consistent data

Partners

Interactions/ collaborations

- **NREL, ANL, DTI**
- **GM, Ford, Chrysler**
- **UTC, PlugPower, Ballard**
- **Energy & Environmental Analysis, Inc.**
- **U.C. Davis STEPs/Hydrogen Program**
- **IEA & IPHE**

Project management by ORNL

Objectives and Relevance

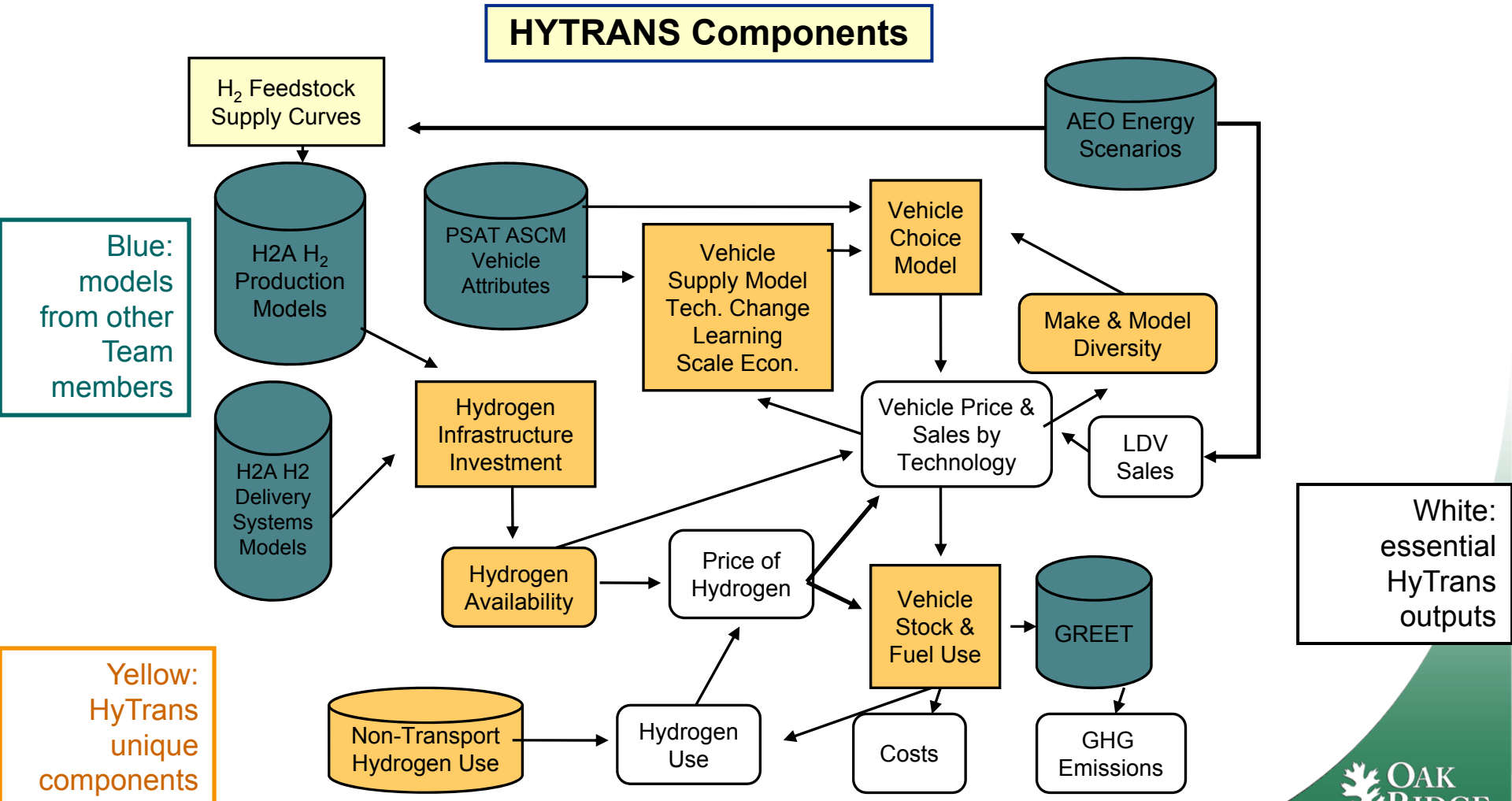
Objectives

- **Update and extend the HyTrans integrated market model.**
  - to latest AEO, latest versions of H2A, HDSAM and GREET models;
  - incorporate new vehicle technology characterizations, and include PHEVs
- **Assess potential impacts on the hydrogen transition of not meeting program R&D goals for on-board hydrogen storage.**
- **Consider synergies between Transportation and Stationary Power FC applications in early transition.**
- **Develop and execute a new round of credible transition scenarios**
  - incorporating HyTrans model enhancements, non-automotive fuel cell market, international linkages, and representations of uncertainty

Relevance

- **Addressing barrier**
  - Need for improved analysis of future fuel and vehicle markets, using consistent data
- **Contributing to the Systems Analysis goal**
  - "…providing a sound basis for estimating the potential value of research and development efforts."
- **Addressing barrier**
  - Lack of integrated market model of *all* major components of the Hydrogen Fuel and Vehicle system
- **Supporting Systems Analysis goal:**
  - "identify and evaluate transition scenarios, consistent with developing infrastructure and hydrogen resources." p. 4-1
  - Long-term analysis of "ultimate potential for hydrogen and fuel cell vehicles"

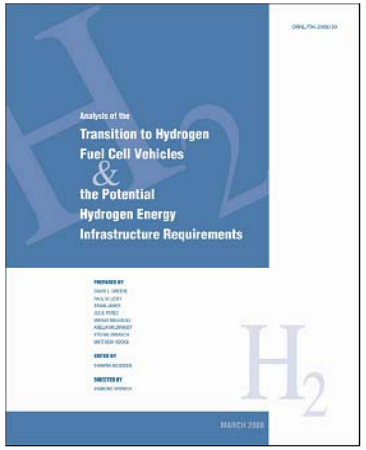
Approach: HyTrans integrates established data and models with new components, to simultaneously represent key agents: 1) fuel supply, 2) vehicle manufacture, 3) consumer choice.



Approach

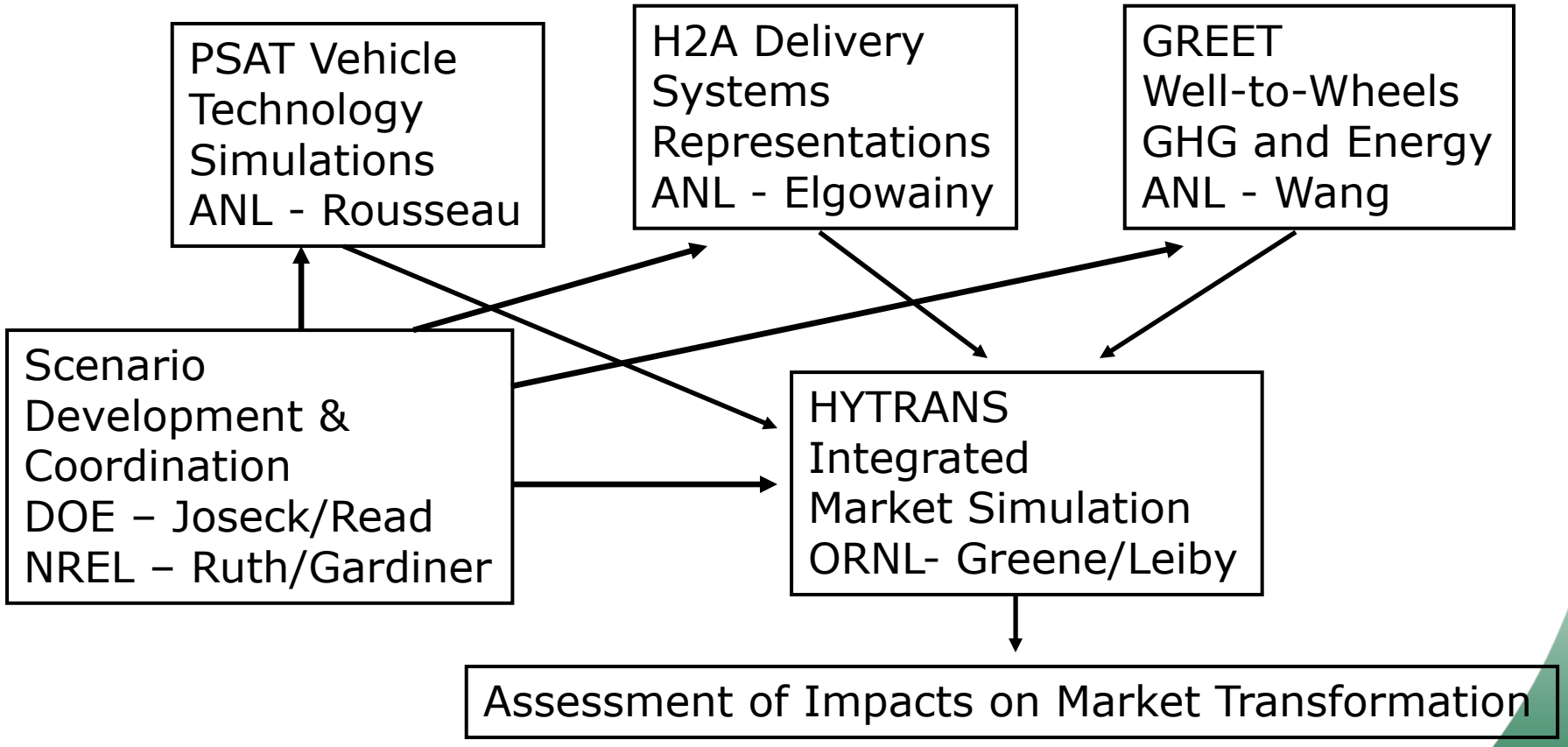
- **Market Simulation Model Development**
  - HyTrans market simulation model integrates key components in a multi-period non-linear optimization framework. (Addresses the “chicken or egg” sequencing problem.)
  - Team approach to careful scenario construction & evaluation
- **Domestic and International Collaboration**
  - With US colleagues, exchange data and approaches, apply standardized, shared model components
  - With EU colleagues, compared and contrasted premises, methods and assumptions, surveyed H2 transition models and advanced vehicle technology characterizations.
- **Extension to Stationary Applications:**
  - Constructed a non-automotive PEM cost model including learning-by-doing and scale economies
  - Extending to scenarios with distributed H2-CHP & infrastructure

Technical Accomplishments and Progress



- **Previous accomplishments (FY08)**
  - Completed integrated HyTrans model
  - Completed and published first U.S. hydrogen transition scenario analyses, in collaboration with DOE and other systems analysis team members
- **FY09 accomplishments to date**
  - Enhanced and updated HyTrans
    - Calibrate to AEO 2008
    - Update to new versions of H2-A, HDSAM and GREET
    - Incorporate new vehicle technology data including PHEVs
  - Initial applications to scenarios with partial technological success (e.g. in storage)
  - Participated in TSPI Team planning and workshops

The hydrogen storage technology risk assessment is a team effort.

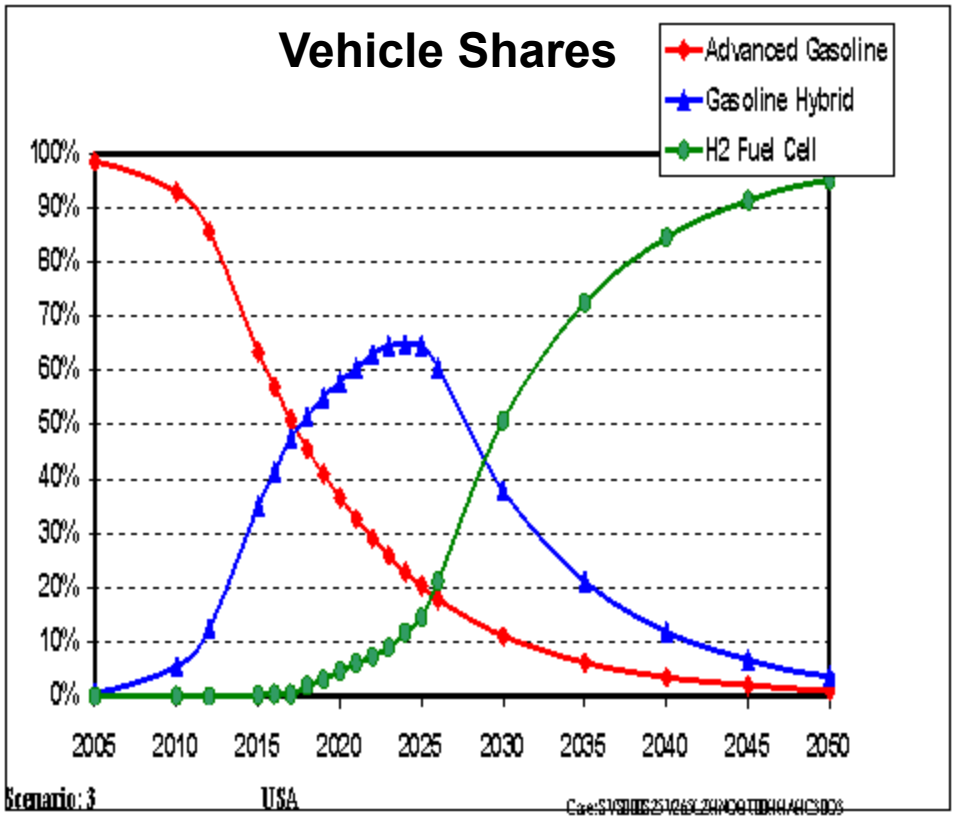


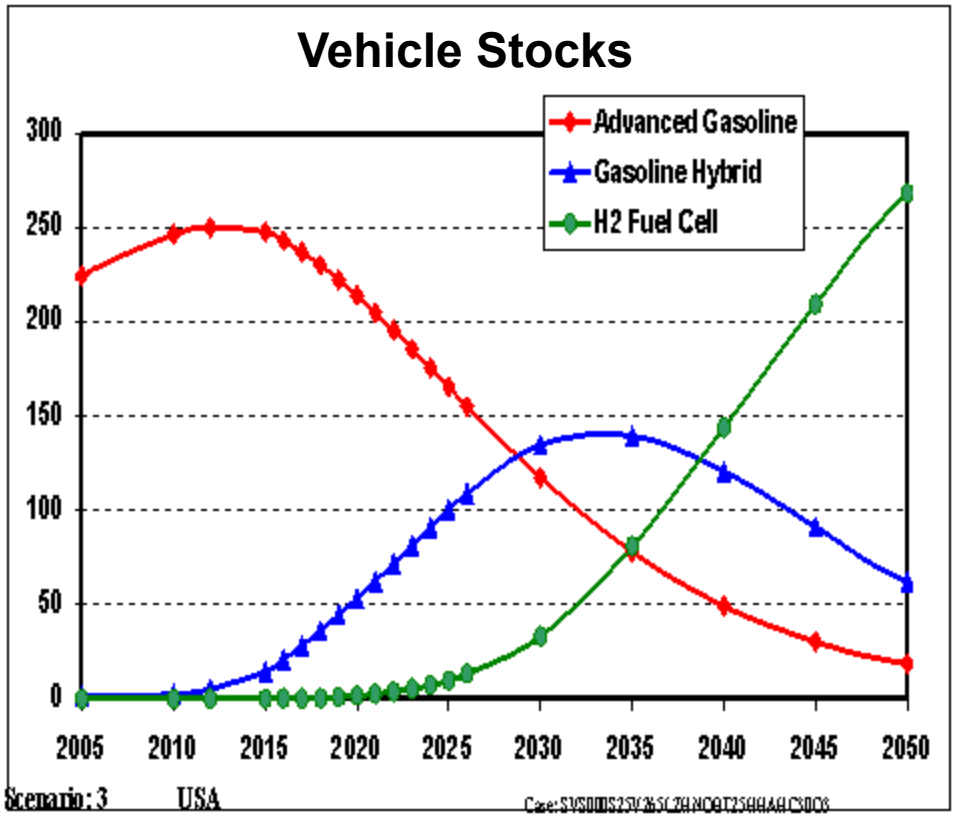
The results shown next are incomplete and for illustrative purposes only.

- Only change is storage cost
  - No change in vehicle design (e.g., on-board storage volume), only change in storage cost.
  - No change in delivery system (e.g., liquid hydrogen dispensing).
- H2A and PSAT characterizations of key technologies will be added.
  - 5,000 psi, 10,000 psi
  - Cryo-compressed hydrogen
  - Liquid on-board storage
- These necessary inputs will come from the analysis team.

Strong Transition to H2-FCVs *if* DOE 2015 High Tech Goals are Met, and Strong Early FCV Deployment Program

Preliminary: Results based on Prior (2008) HyTrans Version

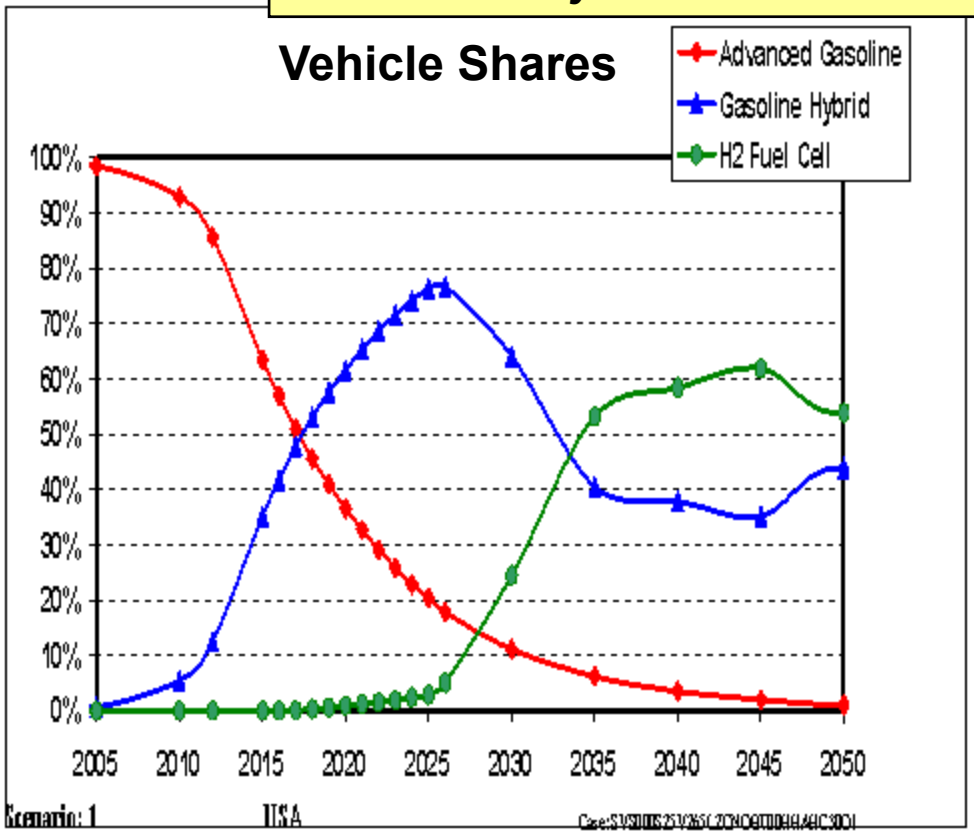


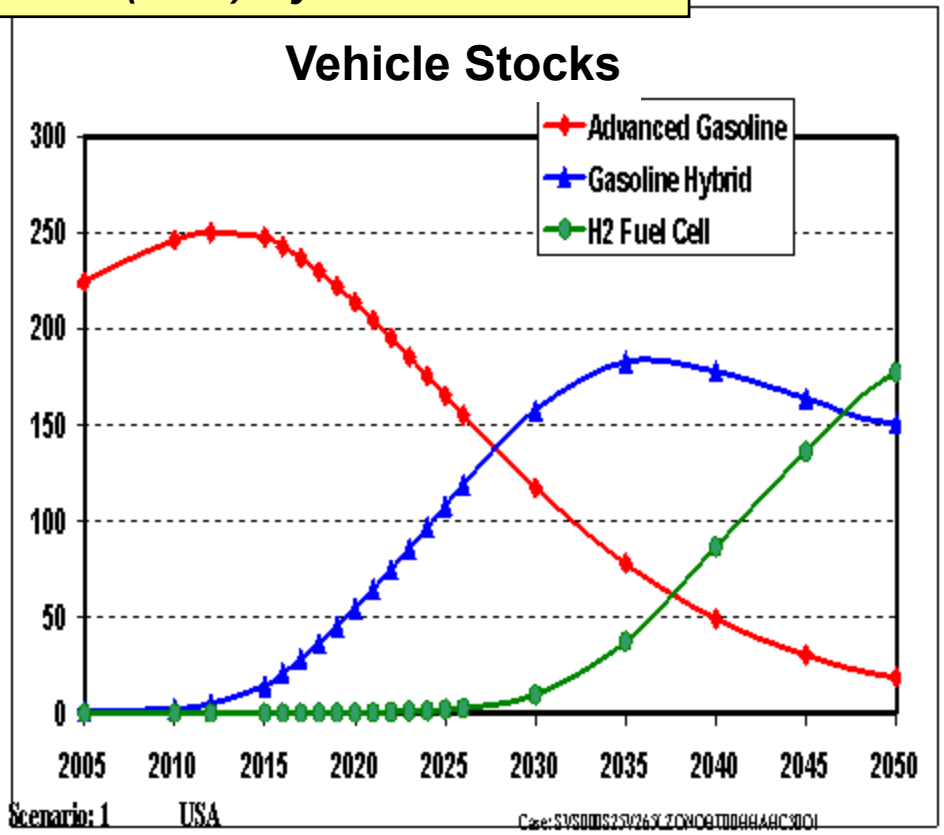


- Scenario 3, High price, technologies meet DOE 2015 High Tech Goals

Transition May Still be Sustainable, Although Partial, if DOE 2015 High Tech Storage Goals *Not* Met (*$17/kWh*)

Preliminary: Results based on Prior (2008) HyTrans Version

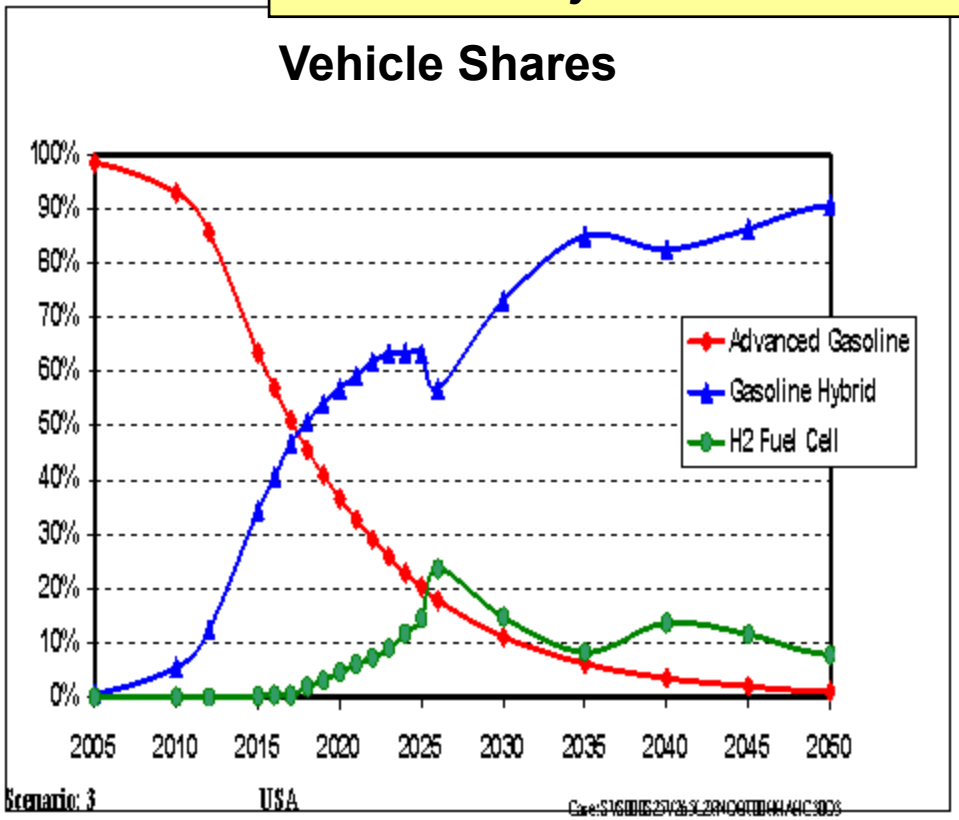


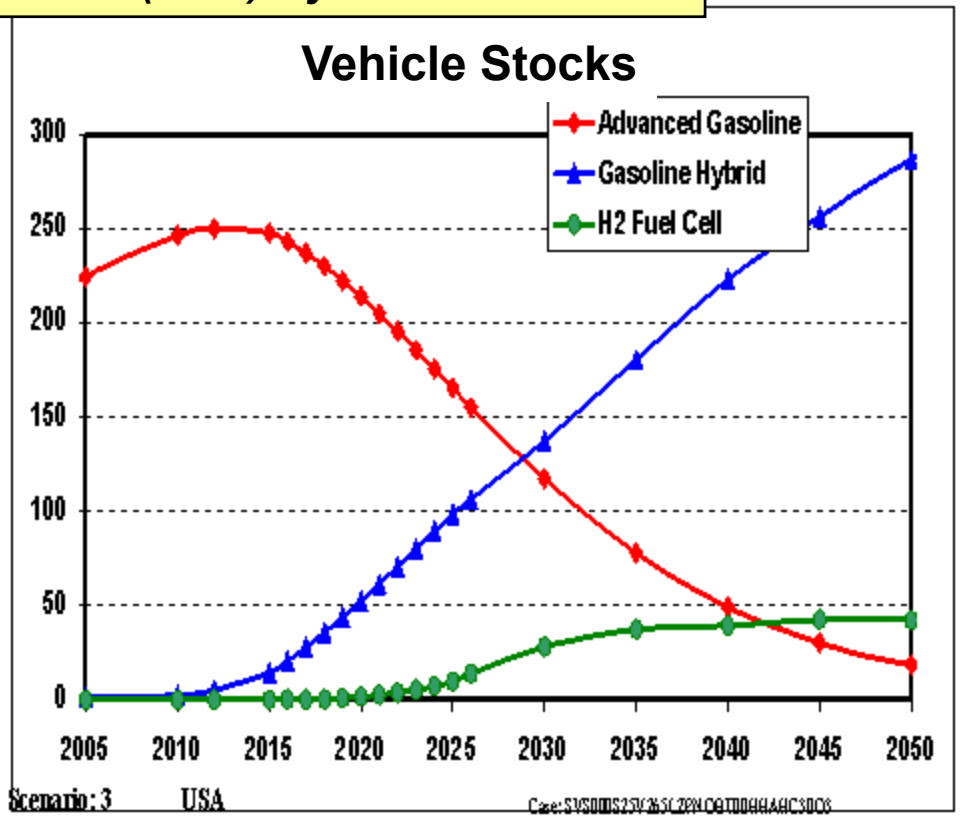


- Scenario 1, High price, technologies meet DOE 2015 High Goals for all except storage costs (which is $17/kWh rather than $2/kWh)

If DOE 2015 High Tech Goals Met *Except Storage Cost,* Transition May Falter if Storage Costs Very High *($27/kWh)*

Preliminary: Results based on Prior (2008) HyTrans Version





- Scenario 3, High price, technologies meet DOE 2015 High Goals for all except storage costs (which is $27/kWh rather than $2/kWh)

Cautionary Interpretation

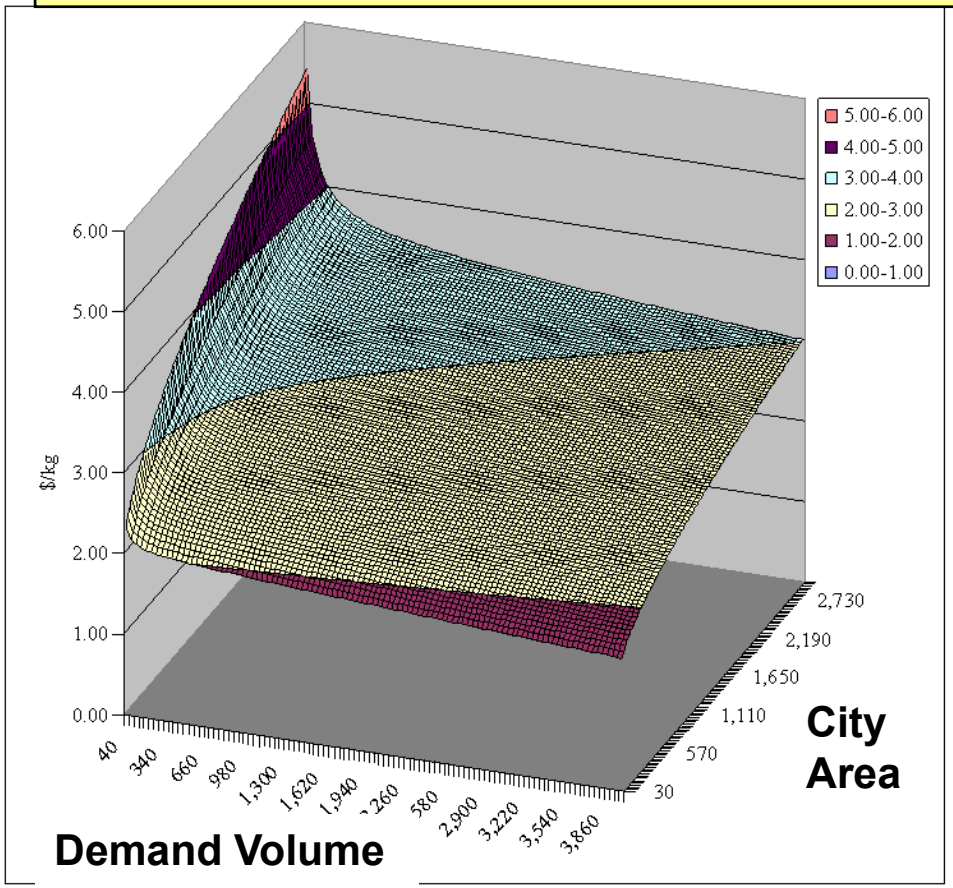
- These incomplete results are based on last years model and data (EIA, H2A, etc.)
- Are only a preliminary indication that the transition may be sustainable, even with higher storage costs.
  - Depends on oil prices and early deployment scenario size.
- However, significant increases in the costs of key vehicle technologies (storage and/or fuel cell) can cause the market transition to be incomplete or unstable
- All of these results bear more careful and rigorous study
  - This is the purpose of our work task with the H2 Storage Technology team.

Completed FY09 Storage Scenario Results Will Reflect:

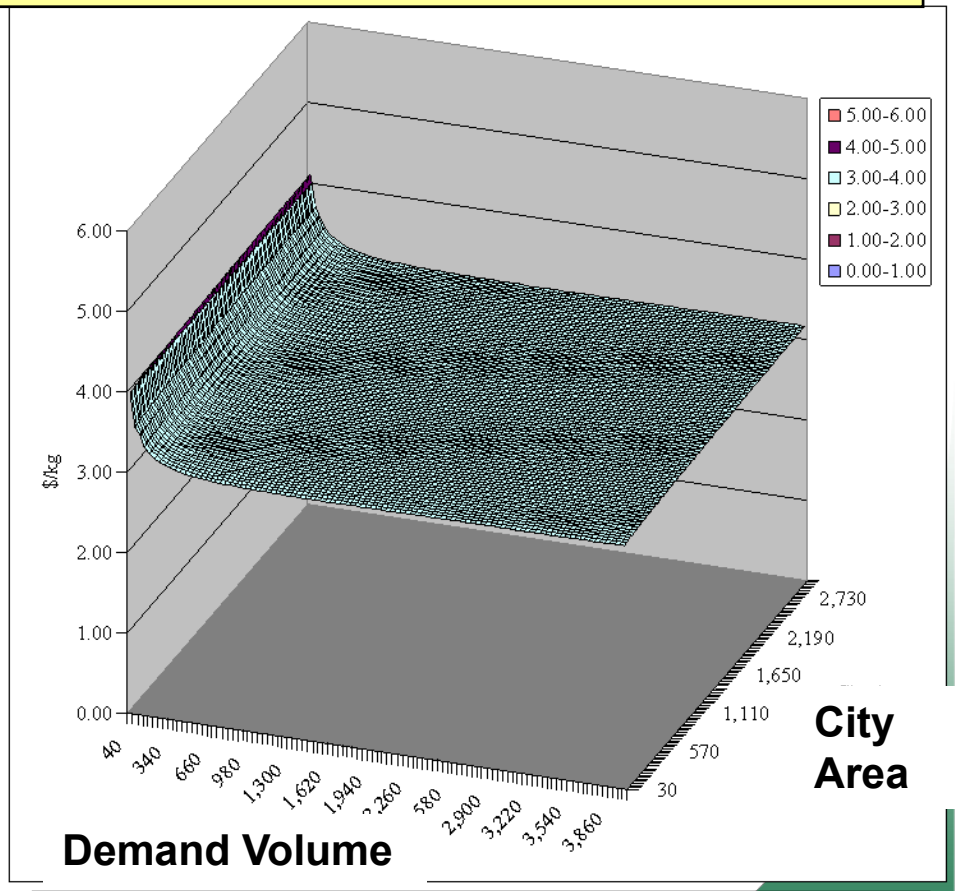
- HyTrans updating:
  - 2008 Annual Energy Outlook (High, Reference Oil Prices)
  - 2008 H2A Production and Delivery Models, 2008 GREET Model
  - Updated PSAT vehicle technology and cost characterizations, including PHEVs
- On-board Storage System Impacts
  - Include vehicle cost, range & space impacts
  - Include delivery pathway cost impacts
  - WTW GHG and energy use (MPG) impacts
  - Alternative storage tech cases, as recommended by Storage Tech Team

FY09 Progress: Model Updated with Reduced Form Cost Curves for Infrastructure Developed From Newest H2A/HDSAM Models

E.g. Smooth Delivery and Forecourt Costs as Function of Demand Volume and Area (Very different shapes by mode)



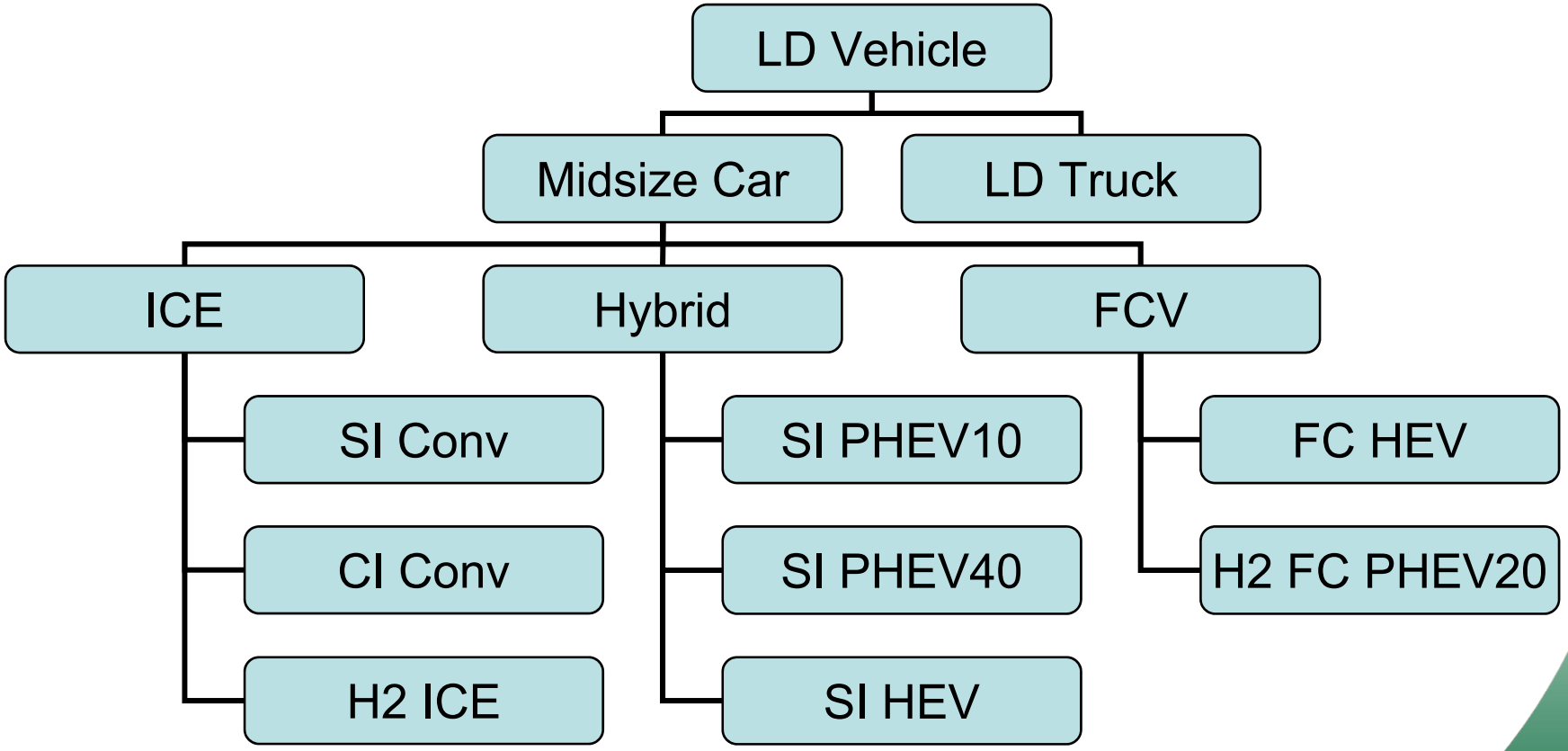
Delivery Cost: Pipeline Mode



Delivery Cost: Liquid (Cryo) Truck Mode

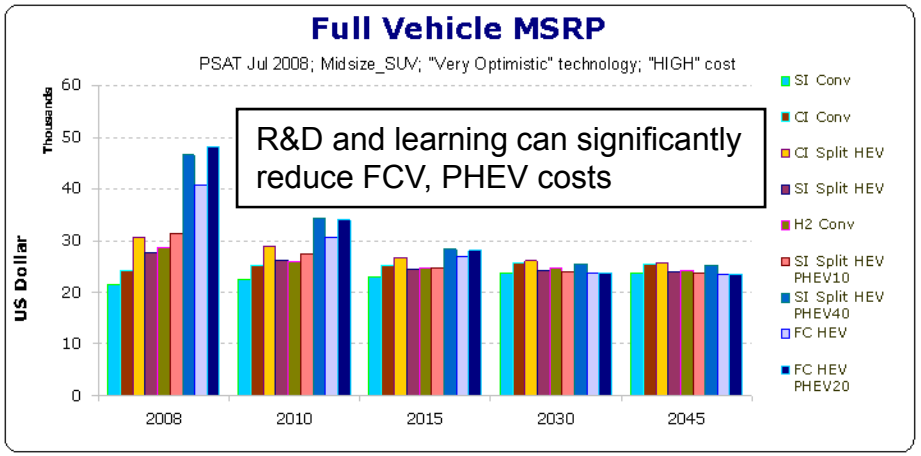
Case: 1000 kg/day station, 31 miles plant to city, 10% Summer Surge, 8% Friday Peak

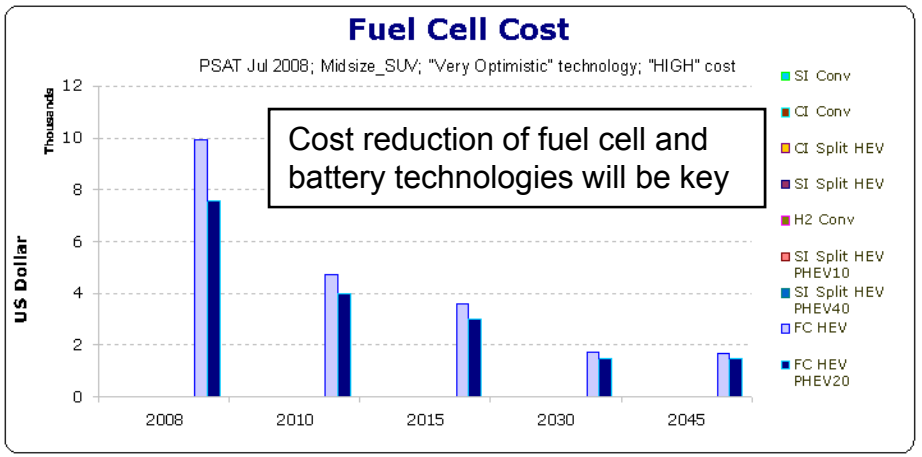
FY09 Progress: Expanded Vehicle Choice Set (Include various PHEV, FC-PHEV)

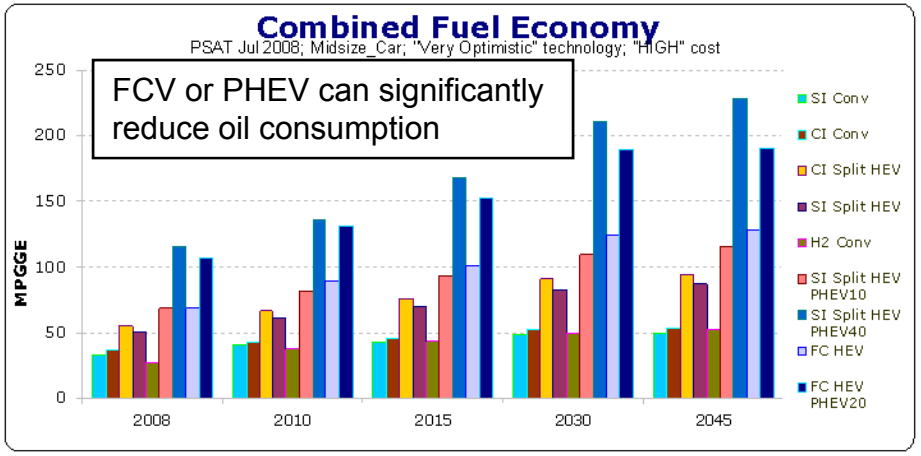


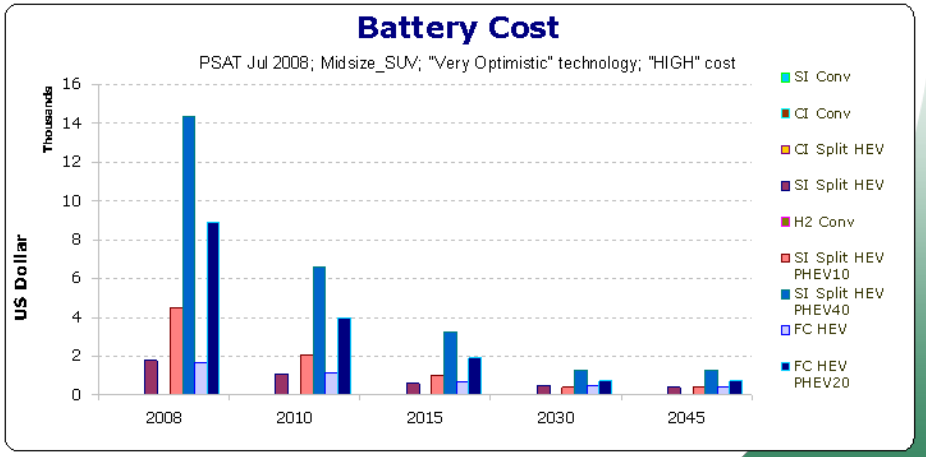
Note: LD Truck class includes the same 8 powertrain technologies as the Midsize Car class. These 2 classes currently merged.

FY09 Progress: Surveyed and Synthesized Vehicle Characteristics & Cost Estimates, From DOE and Others









Data source: PSAT July 2008, Vehicle Characterization 04072009.xls

Vehicle "Characteristics" include Performance, Efficiency, Range, etc.

Collaborations

- **Collaboration Partners**
  - NREL, ANL, DTI (DOE Systems Analysis Team members): each develop key component models (H2A, HDSAM, GREET, PSAT), shared approaches and consistent data
  - GM, Ford, Chrysler, UTC, PlugPower, Ballard (Manufacturers): provide information on costs, possible roll-out scenarios, and expert review of approaches used.
  - University Calif. Davis: extensive interaction including personnel exchange on visiting assignment
  - IEA & IPHE (International Organizations): data comparison, validation, international scenario development
- **Participation in Joint Initiatives**
  - DOE Transportation and Stationary Power Integration Team
  - DOE Crosscutting Analysis Team
  - HyWays/IPHE Team

Future Work

- **FY09:**
  - Complete analysis of storage technology cases
  - Develop model-capability and scenarios to integrate early H2 transportation and stationary power (CHHP) in early market
    - In coordination with TSPI Team
    - Opportunities for shared fueling infrastructure
    - Possible shared technological progress and learning spillover
  - Incorporate global trends & explicit representation of uncertainty
    - Facilitate alternative assumptions and sensitivity analysis
- **FY10:**
  - Extended scenario and sensitivity analysis to support benefits assessment (cost/GHG/energy security)
  - Publish documentation for updated and enhanced HyTrans, make model available to other modelers.
  - Publish peer-reviewed report on the GHG and oil dependence impacts of the transition to hydrogen-powered transportation.

The integrated market assessment will analyze the potential impacts of missing the storage cost goals under a range of assumptions.

- Sensitivity to oil and energy prices
- Sensitivity to success of alternative advanced technologies
- Sensitivity to fuel cell stack costs and hydrogen production and delivery costs
- Impacts on sustainability of transition
- Impacts on the costs of the transition

Project Summary

- **Relevance**: Addresses need for transformational and long-run analysis of H2 and FCV market potential, using valid and consistent data from program. Supports benefits analysis and GHG/energy security impacts analysis.
- **Approach:** Develop dynamic market simulation model, integrating fuel production and delivery pathways, vehicle technologies and production costs, consumer choice.
- **Technical Accomplishments and Progress**: Demonstrated applicability to early market transformation strategies and long-run transition scenarios. Model updated, extended technology set to PHEVs, FC-PHEVs.
- **Collaborations**: Active partnerships with other modeling teams at national labs, UC Davis, and industry; information exchange with vehicle and fuel-cell manufacturers.
- **Proposed Future Research**: Apply completed HyTrans model to further assess impact of partial technological success (in storage), and synergies between stationary and transportation FC applications in early market. Careful scenario and sensitivity analysis to support benefits assessment.

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Supplemental Slides

HyTrans model developed in response to the NAS' call to better understand what a transition to hydrogen powered vehicles would require.

- **NAS 2004 Hydrogen Economy report**
  "…the DOE should map out and evaluate a transition plan consistent with developing the infrastructure and hydrogen resources necessary to support the (NAS) committee's hydrogen penetration scenario (Scenario 3 of the analysis) or another similar demand scenario. The DOE should estimate what levels of investment over time are required…"
- **Engage the stakeholder community in creating a vision of how the market transformation could happen.**
- **Create useful systems analysis tools capable of representing the "chicken or egg?" dilemma.**
- **Test whether DOE's program goals are sufficient to enable the transition.**

HyTrans models excess "transition costs" incurred in overcoming the natural market barriers to a new transportation fuel.

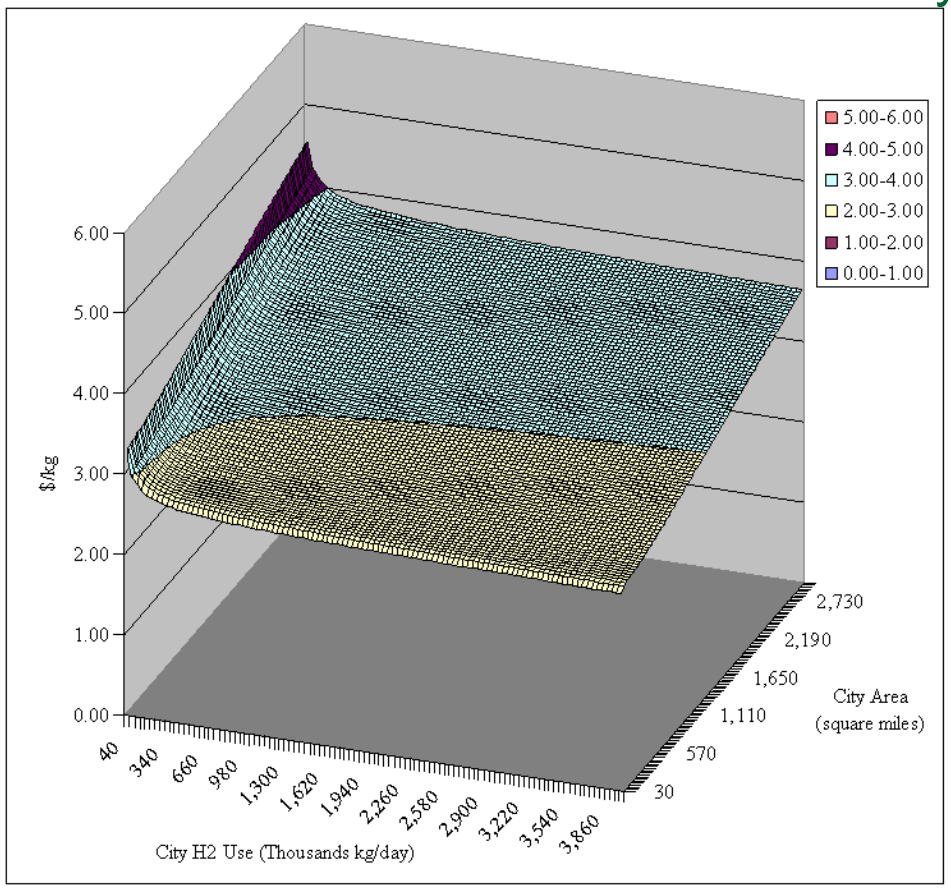
- **Limited fuel availability**
- **Limited make and model availability**
- **Scale (dis)economies**
- **Learning-by-doing**
- **All are represented in HyTrans**

HyTrans draws on or incorporates models and data from a variety of sources.

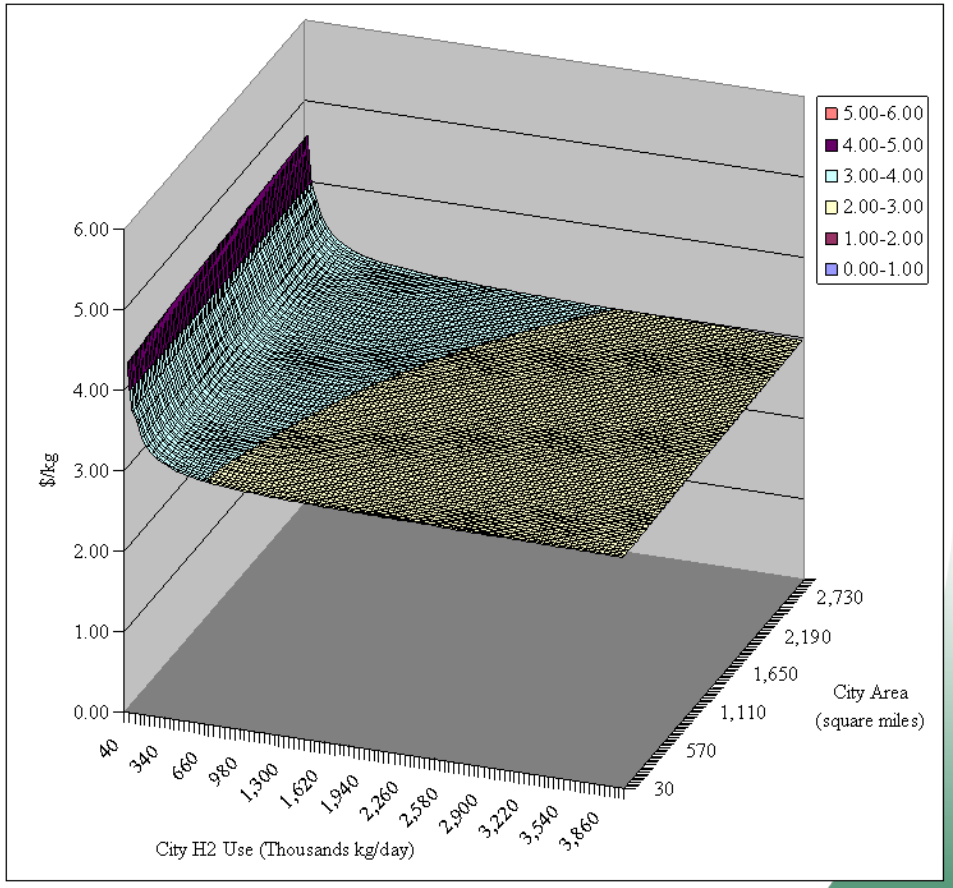
- **H2A**
  - Hydrogen Production
  - Hydrogen Delivery
- **PSAT & ASCM**
  - Fuel economy
  - 2010/2015 cost & performance goals
- **ORNL Vehicle Choice Model**
  - Fuel availability
  - Make & model diversity
  - Price, fuel economy, etc.
- **Vehicle Manufacturing Cost Estimates (assisted by OEMs)**
  - Scale Economies
  - Learning-by-doing
- **GREET GHG emissions**
- Calibrated to **NEMS AEO 2006** through 2030, the extrapolated to 2050 & beyond.

Progress: Developed Reduced Form Cost Curves for Infrastructure From H2A/HDSAM

1000 kg/day station, 31 miles plant to city, 10% Summer Surge, 8% Friday Peak



Delivery Cost: Hybrid Pipeline/Tube Truck Mode



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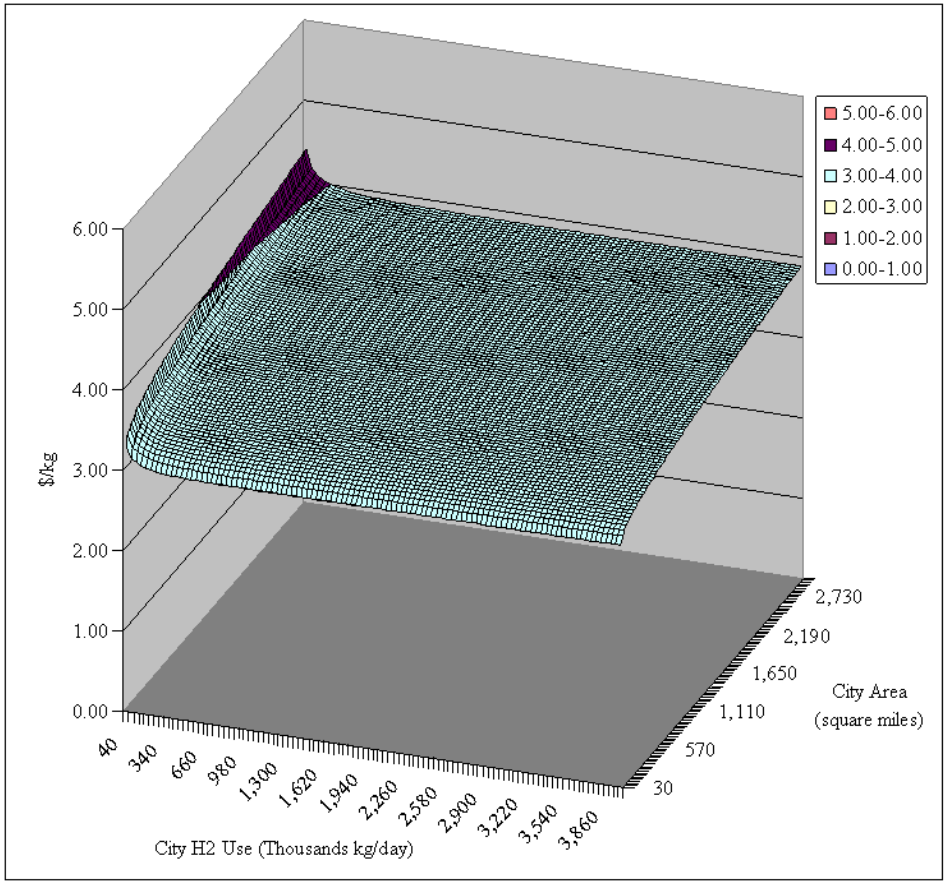
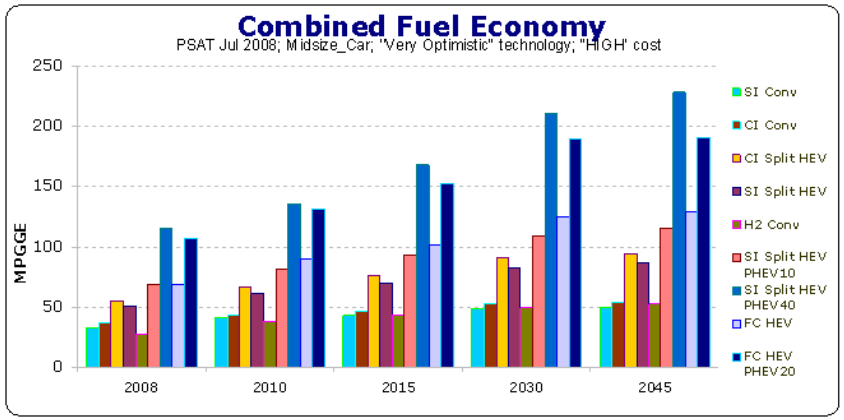
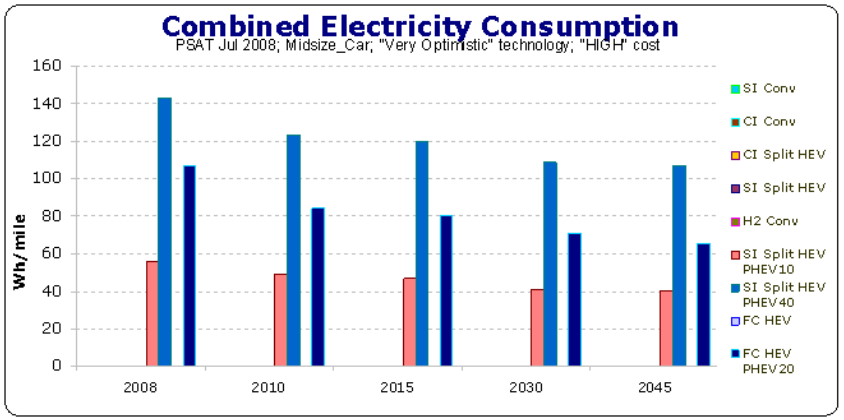


Delivery Cost: Tube Truck Mode

Progress: Estimates of Vehicle Energy Use

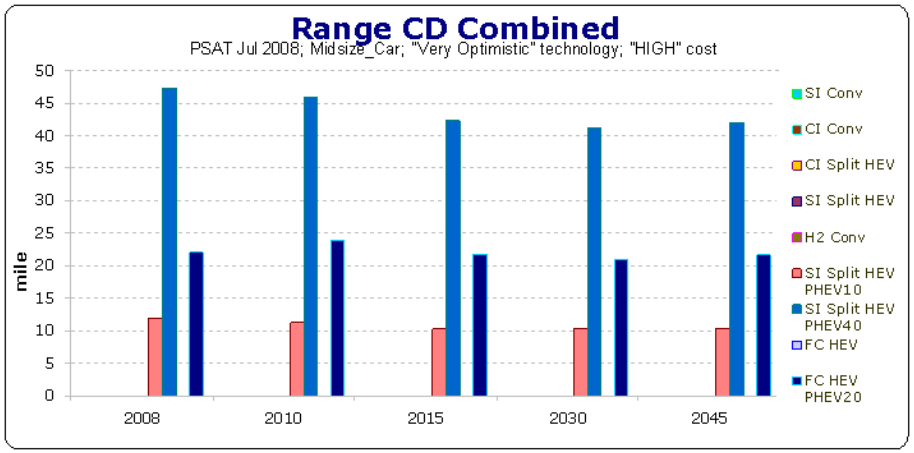




- If commercially successful, PHEV or FCV can significantly reduce oil consumption from transportation
- The introduction of PHEV can help utilize off-peak electricity and provide generation capacity for grid regulation or as spinning reserve.

Data source: PSAT July 2008, Vehicle Characterization 04072009.xls

Progress: Consider Range of Electric Drive Designs



- PHEV can provide electric driving via its blended CD mode, in which most of the propulsion energy comes from electricity rather than gasoline
- In general, bigger battery leads to longer CD mode, but also more vehicle weight and higher vehicle price.
- The desired CD range also depends on driving pattern of the individual consumer

Data source: PSAT July 2008, Vehicle Characterization 04072009.xls

Major Topic is Technological Progress

- Technological progress during the transition
  - Learning and scale for vehicles & major components
- Storage technological success and the market for H2-FCVs
- Learning for stationary FC systems
  - FY08 study of back-up power and MHVs
- Learning and scale spillovers between early stationary and transportation applications
- International context of tech progress