Analysis of Hydrogen Production and Delivery Infrastructure as a Complex Adaptive System

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May 19, 2009

Project ID # an_08_tolley

Timeline

- Project start date: July 2005
- Project end date: June 2009
- Percent complete: 95%

Budget

- Total project funding
    - $3,616,634
- FY05-06
    - $1,626,901 budgeted
    - $700,000 funded
- FY07
    - $1,344,120 budgeted
    - $ 1,100,000 funded
- FY08
    - $1,200,000 budgeted
    - $1,200,000 funded
- **FY09**
    - $616,634 budgeted
    - $616,634 funded

Barriers

- Barriers addressed
    - Lack of understanding of the transition of a hydrocarbon-based economy to a hydrogen-based economy
    - Lack of consistent data, assumptions and guidelines
    - Lack of prioritized list of analyses for appropriate and timely recommendation
    - Lack of understanding of future market behavior

Partners

- RCF, prime
- Argonne National Laboratory
- BP
- Ford Motor Co.
- Protium Energy Technologies
- Industry Advisors

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Relevance

- Project Objectives

  - <u>Purpose:</u> Deal with the chicken-or-egg problem between supply of hydrogen fuel and purchase of hydrogen vehicles, using agent-based modeling. Overall aim is to answer the questions:

    "Will the private sector invest in hydrogen infrastructure?"
    "What, if any, policy assistance is needed?"

- 2008-2009 Objectives

  Add Finishing Touches to Model
  Carry Out Parameter Sensitivity Analysis
  Conduct Policy Analyses
  Do Model Validation
  Write final report

Approach: Brief Description of Model
Model of a Complex Adaptive System

Agent-based model explains investment in hydrogen infrastructure and purchase of hydrogen vehicles

- Investors supply infrastructure that makes hydrogen fuel available--depends on fuel demand
- Fuel demand is by drivers who purchase hydrogen vehicles--depends on fuel availability

Agent-Based

- Each actor "agent'" modeled individually
- Agents don't perfectly maximize—make approximations or use rules of thumb
- Agents interact over multiple periods—increasing their knowledge and changing their decision rules

Geographical Detail

- Agents are specified by location within city
- Decisions are influenced by location

Sequencing of Decisions over Time

- Agents learn from mistakes, neighbors, government programs
- Infrastructure and equipment may be abandoned (stranded assets)

Drivers—decide whether to buy a hydrogen vehicle

- Knowledge about hydrogen vehicles
- Attitudes toward hydrogen--greenness
- Socio-demographic characteristics
- Imitation of neighbors
- Concerned with inconvenience of refueling
- Worry about risk of running out of fuel

Investors—decide type of infrastructure to supply, how much, and where to locate

- Depends on cost of funds and willingness to take risks
- Build facilities based on expectations about complicated situations
- May make non-optimal decisions
- Learn from experience

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Technical Accomplishments and Progress

Outline of the Remainder of Today's Presentation

1. Performance and Financial Indicator Analysis for Individual Investors
    - a. **Independent Investor**
    - b. **Competing Investors**

2. Model Outcome Sensitivity to Parameter Variation
    - a. **Drivers**
    - b. **Investors**

3. Policy Scenarios

4. Model Validation

5. Major Project Conclusions

Technical Accomplishments and Progress, cont'd.

1. *Performance and Financial Indicators for Individual Investors*

- Results for an individual investor depend on the 140 parameter values used in a model run.

- For coherence, selected examples are presented here for representative situations, with model parameters at benchmark values.

- Because of the interest in early transition, results are shown up the 20th year. Due to the longevity of vehicles, full transition is ordinarily not achieved until 40th year.

Technical Accomplishments and Progress, cont'd.

 The **next** slide is for a single investor, e.g. large oil company. Investor provides all hydrogen fueling infrastructure, subject to threat of potential competition from other investors.

- Upper left:
  - Fueling capacity increases at an accelerating rate
  - The number of station locations occupied increases first at an accelerating and then at a decelerating rate
  - Capacity utilization per station is low at first as investor acts as a loss leader in order to discourage potential competitors, rising to surpass 70% very quickly,
- Upper right:
  - Cumulative Discounted Cash Flow for two polar scrap value cases, 0 asset depreciation versus 100% depreciation
  - With 100% depreciation, cash flow is increasingly negative during early investment years. It is insufficient to offset capital outlays and becomes increasingly negative for first 15 years, then begins to reverse, and beyond 20 years will turn positive as revenues exceed capital costs .
  - With 0 asset depreciation, recoupment of asset value offsets to some degree the negativity in early years
- Lower left:
  - Distribution of values of individuals stations increases with age of station, due to larger value within the investor's horizon the greater the number of years that the station operates
- Lower right:
  - Hydrogen fuel supply availability provided by investor greatly limits the rate of penetration of hydrogen vehicles

Technical Accomplishments and Progress, cont'd.
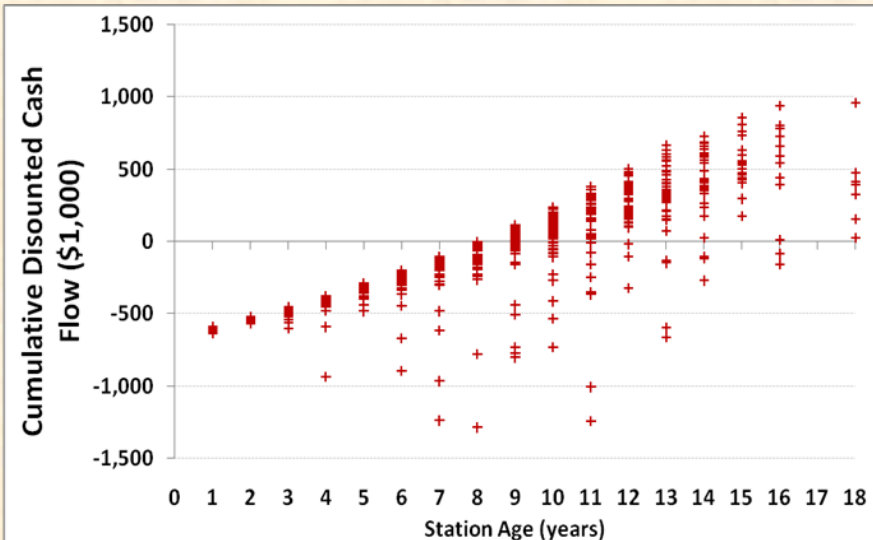
Rollout of the Supply Infrastructure, Benchmark Case:
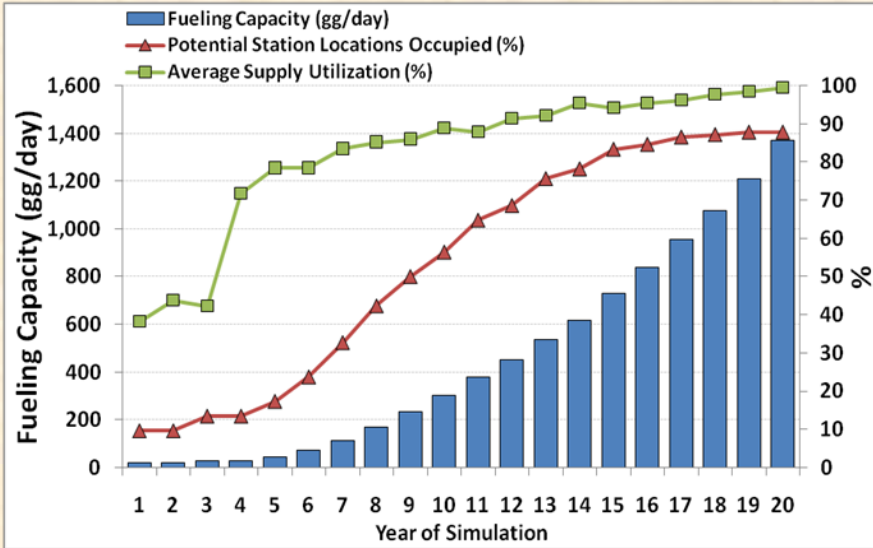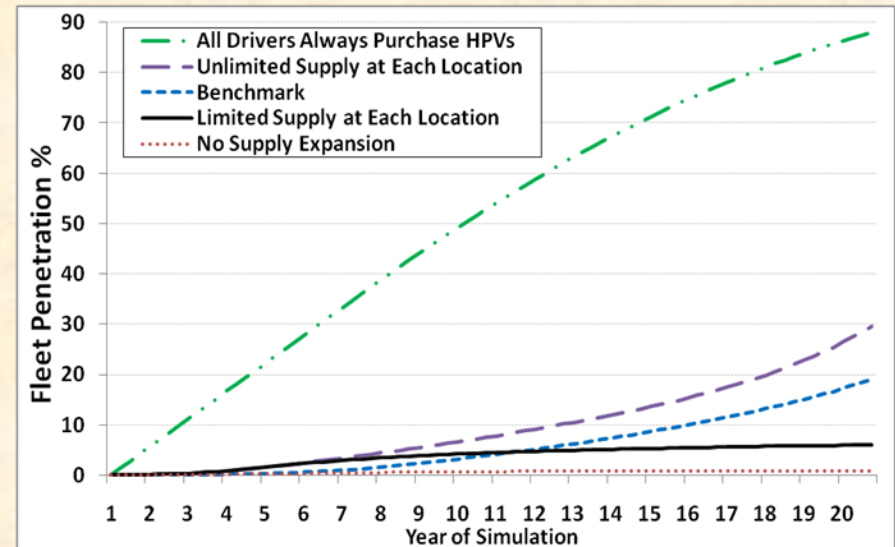

Investor Portfolio Valuation, Benchmark Case:
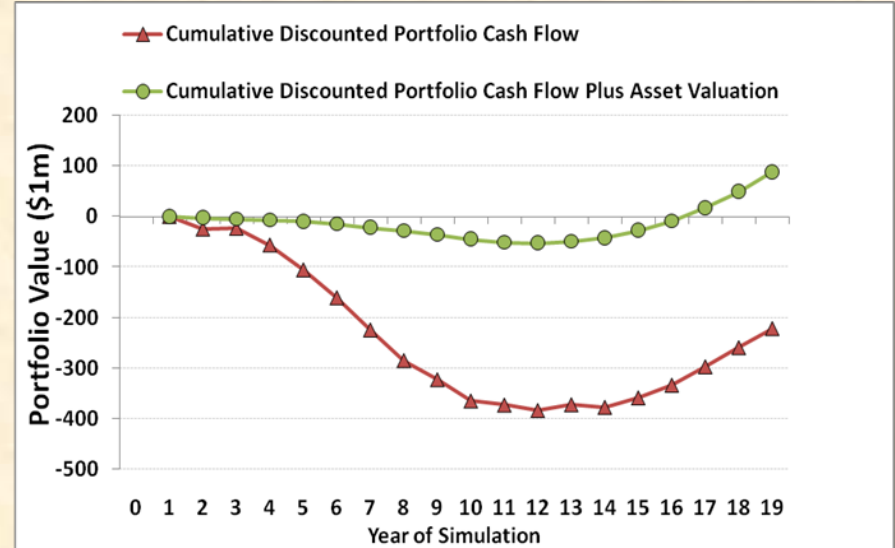
Investor Valuation of Individual Fueling Stations, Benchmark Case:

**Influence of Fuel Availability on Fleet Penetration Rates :**

Technical Accomplishments and Progress, cont'd.

The **next** slide is for individual investors under selected conditions of competition.

- Upper panels:

  - *Left*: If there is a single investor, for a selected location, supply (blue) tracks demand (red) closely.
  - *Right*: With 10 investors, supply gets ahead of demand in early years as investors fail to anticipate entry of other investors.

- Lower panels:

  - Two competing investors, one a loss-leader investor and the other a station-by-station investor.
  - *Left*: Cumulative Discounted Cash Flow for two polar scrap value cases, 0 asset depreciation versus 100% depreciation, for the loss-leader investor. Results similar to the lone single investor on the previous slide, except nearly half the capital outlays due to existence of other investor.
  - *Right:* Same, except for the station-by-station investor. This investor enters the market later than the loss-leader investor, because scared off by the loss-leader.
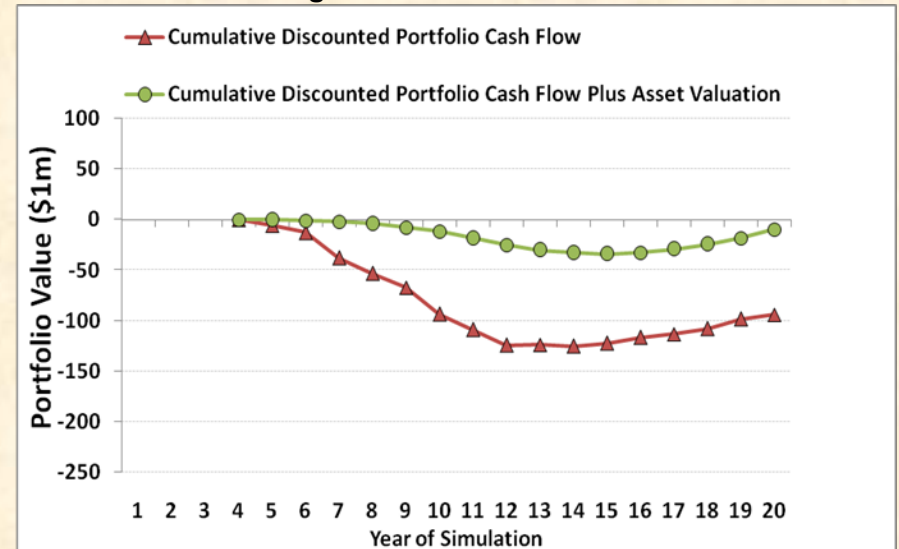
Technical Accomplishments and Progress, cont'd.

Capacity and Demand in Area 71 Under Single Investor and Ten Investors:
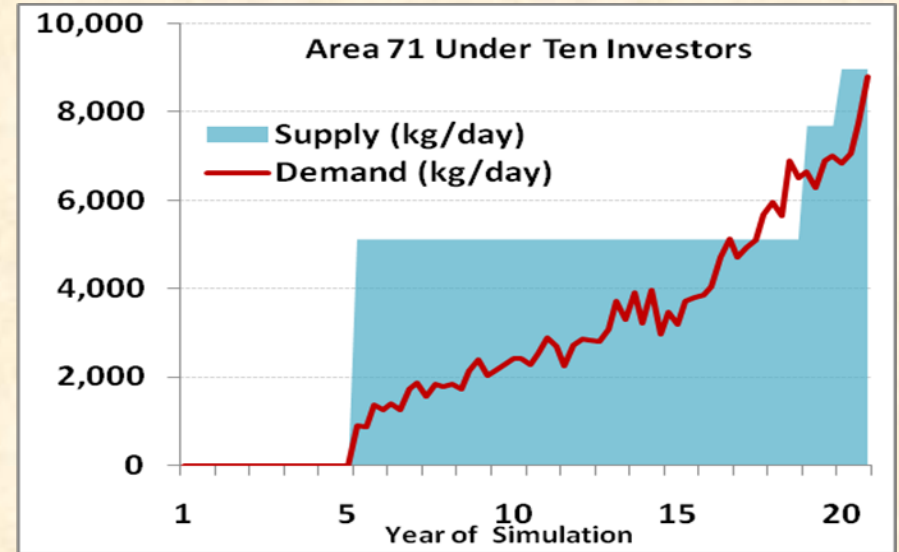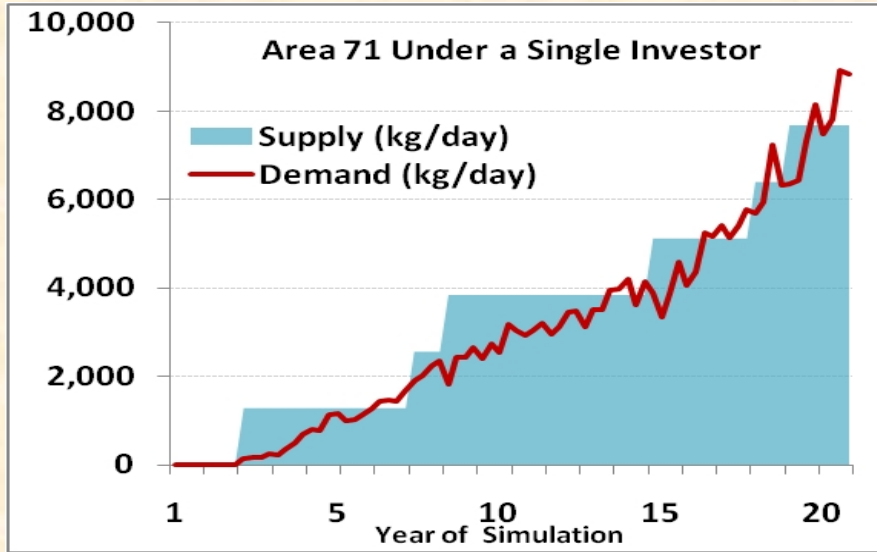
Loss-leader Investor Portfolio Valuation When Competing Against Station-by-Station Investor:
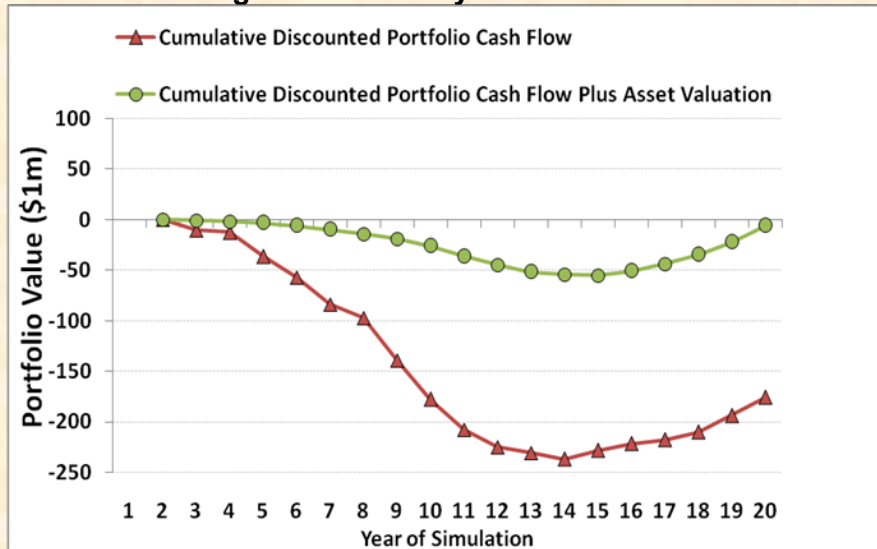
Station-by-Station Investor Portfolio Valuation When Competing Against Loss-leader Investor:

Technical Accomplishments and Progress, cont'd.
2. Model Outcome Sensitivity to Parameter Variation

The majority of the 140 parameters are from H2A, assumed to be known with sufficient accuracy not to require sensitivity analysis.

Sensitivity to Driver Agent Parameters

The **next** slide contains sensitivity results to 4 selected driver agent parameters as examples of the 9 driver agent parameters whose sensitivity we are considering.

- Clockwise from upper left:
    - Differences in bandwagon effect roughly converge by 20 years
    - Variations in familiarity premium require longest time to converge
    - Central tendency of taste for greenness has less impact on convergence time than does dispersion of greenness (bottom left)

Ultimate penetration tends to be robust to alternative driver parameter values.
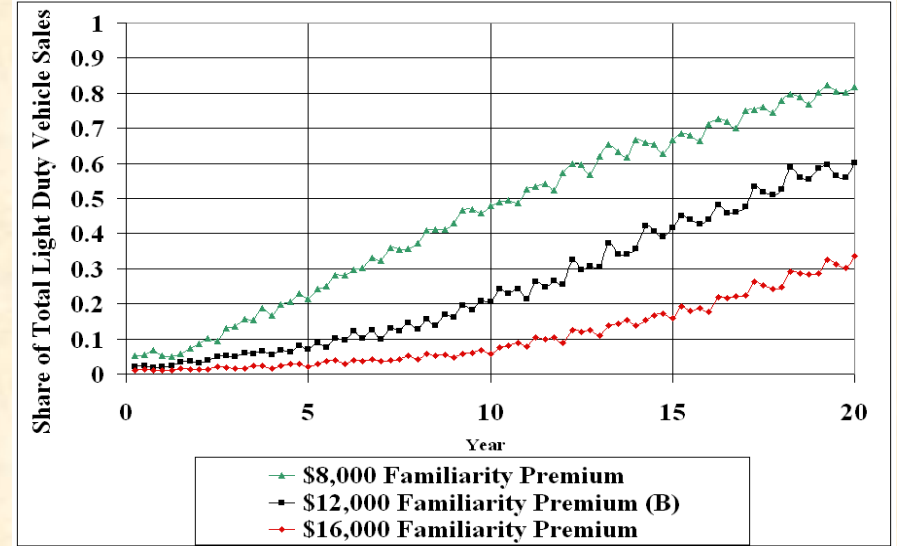
Intermediate penetration is affected and may differ within the 20 year period shown.

Technical Accomplishments and Progress, cont'd.
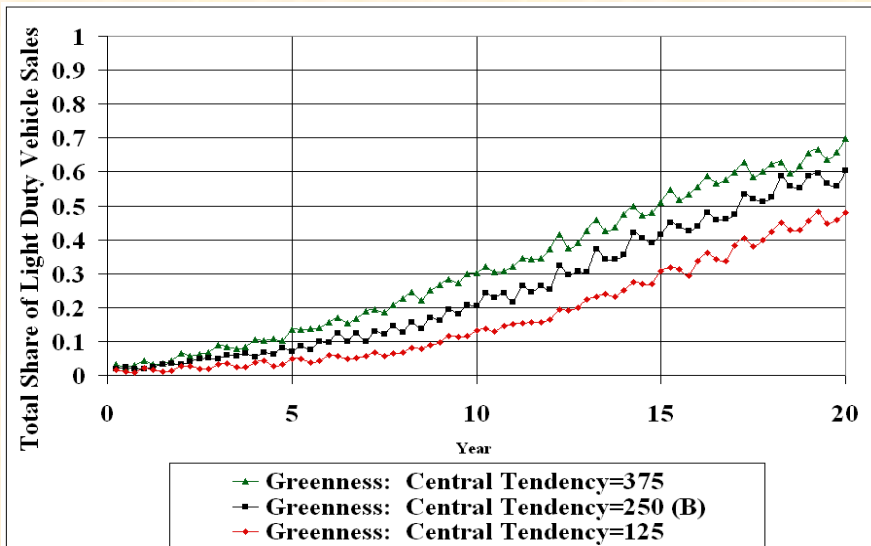
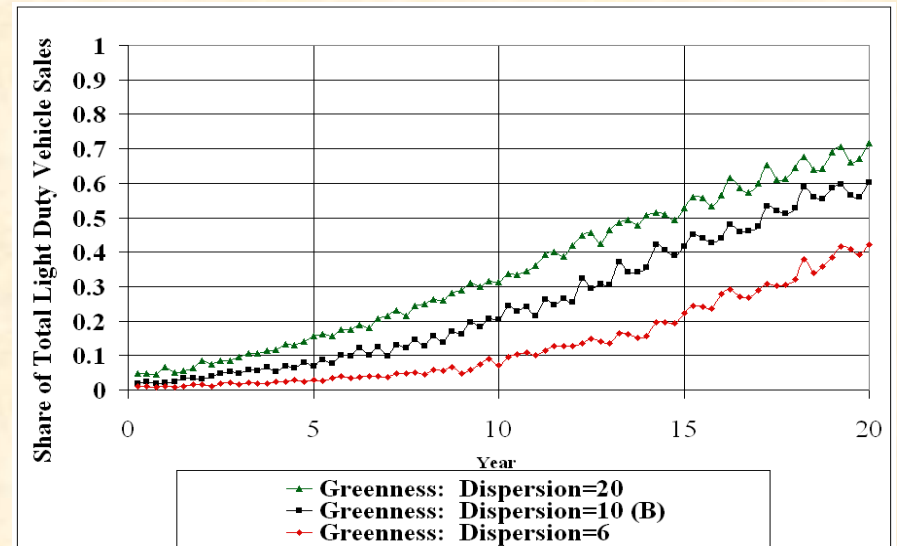**Driver Sensitivity to Bandwagon Effect:**
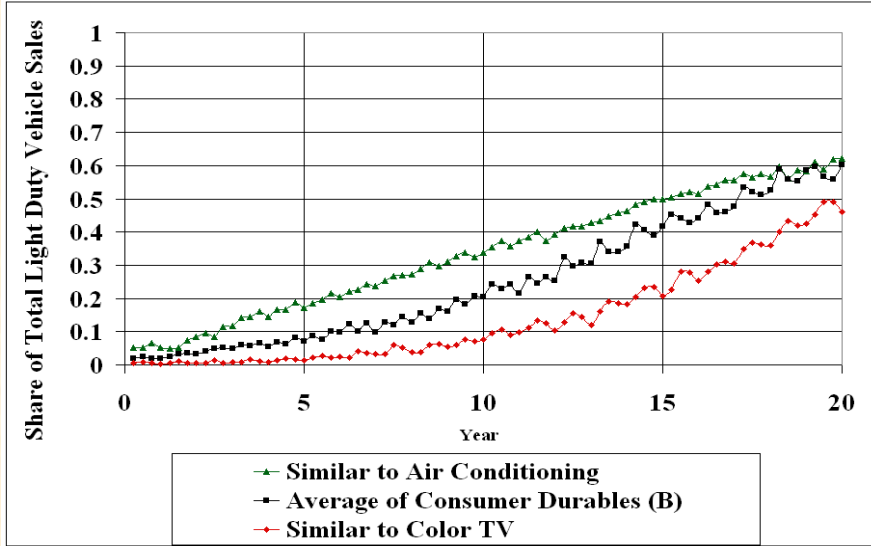
Driver Sensitivity to Familiarity Premium:

Driver Sensitivity to Greenness Central Tendency:

Driver Sensitivity to Greenness Dispersion:

B=Benchmark

Technical Accomplishments and Progress, cont'd.

Sensitivity to Investor Agent Parameters

The **next** slide contains sensitivity results to 4 selected investor agent parameters as examples of the 35 investor agent parameters whose sensitivity we are considering.

- Clockwise from upper left:

  - Sophistication of market analysis has little impact (observe all or only hydrogen vehicles?)
  - Sophistication of expectations formation (linear growth extrapolation or logistic?)
  - Upper management's risk aversion could kill the endeavor if it assigns a sufficiently high discount rate to expected profits
  - Smaller variation in staff discount rate has little impact

As with driver parameters, ultimate penetration tends to be robust to alternative investor parameter values.
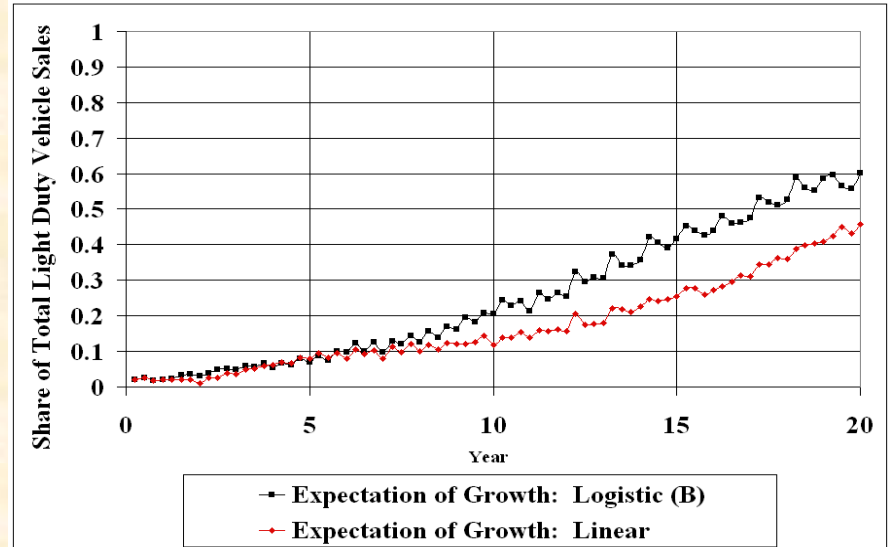
Intermediate penetration is affected and may differ within the 20 year period shown.

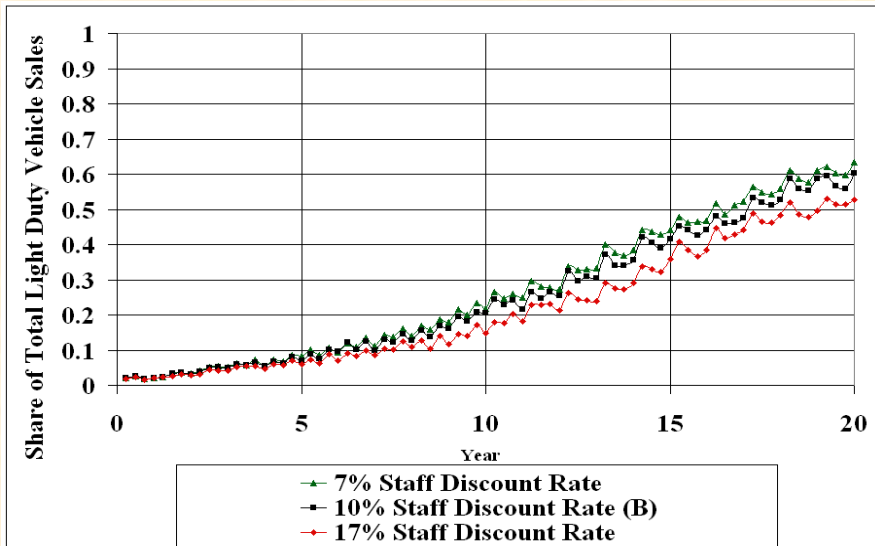# Technical Accomplishments and Progress, cont'd.

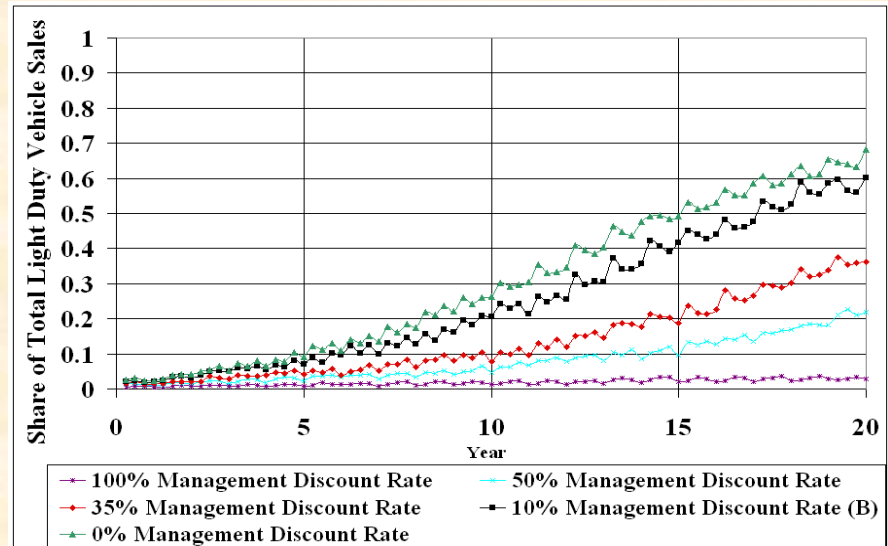

Investor Sensitivity to Demand Estimation Method:
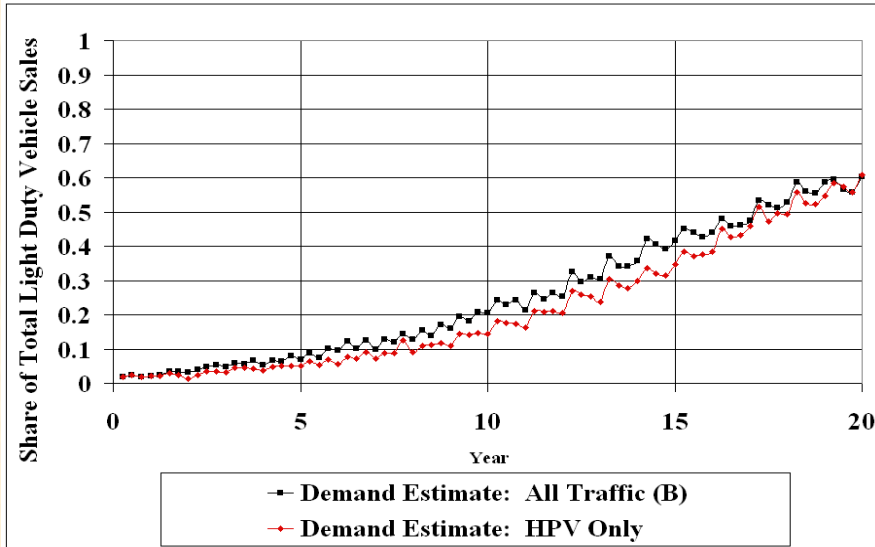
Investor Sensitivity to Linear or Logistic Growth Expectation:

Investor Sensitivity to Staff Discount Rate:

Investor Sensitivity to Upper Management Discount Rate:
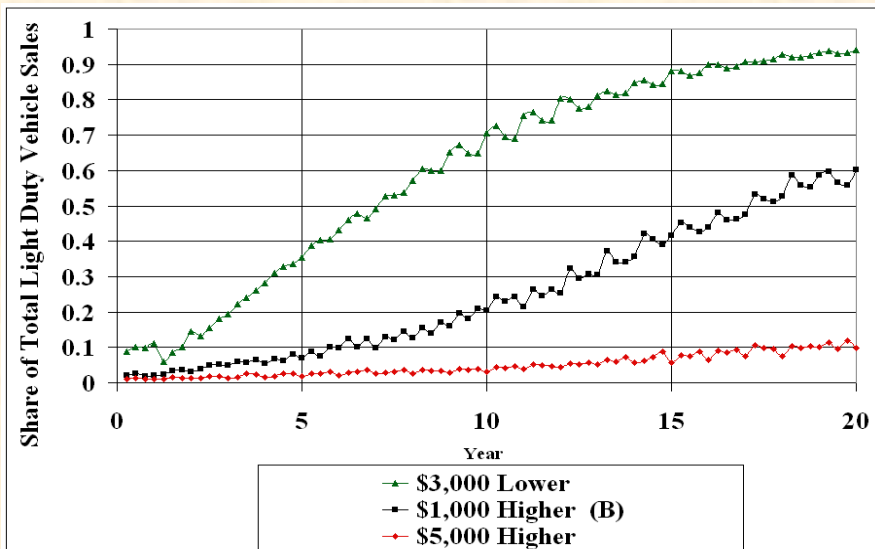
B=Benchmark

Technical Accomplishments and Progress, cont'd.

## *3. Policy Scenarios*

- Clockwise from upper left:

    - A sufficiently large price disadvantage of the hydrogen vehicle could kill the market

    - Gasoline prices are very important to both rapidity of market penetration and ultimate success

    - A tax credit for vehicle purchases could greatly hasten market penetration

    - Even a temporary tax credit, lasting 10 years, will substantially hasten market penetration
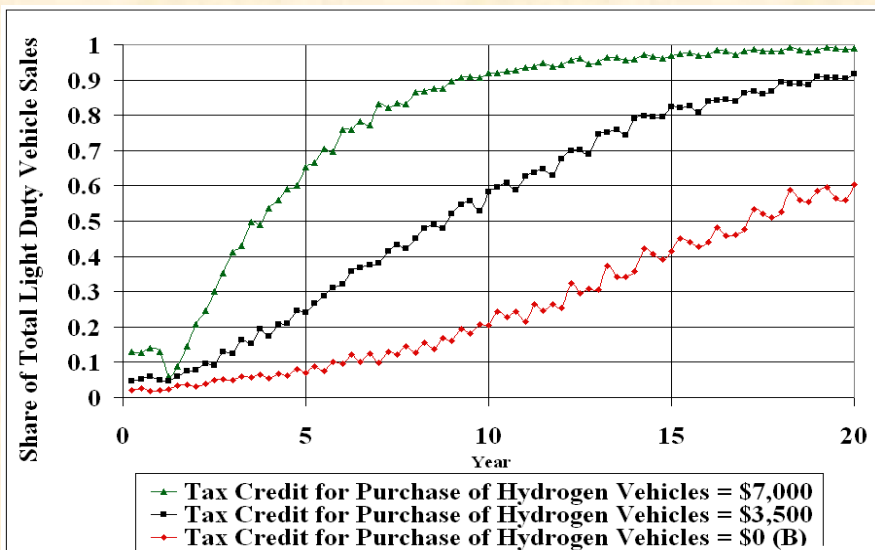
Technical Accomplishments and Progress, cont'd.

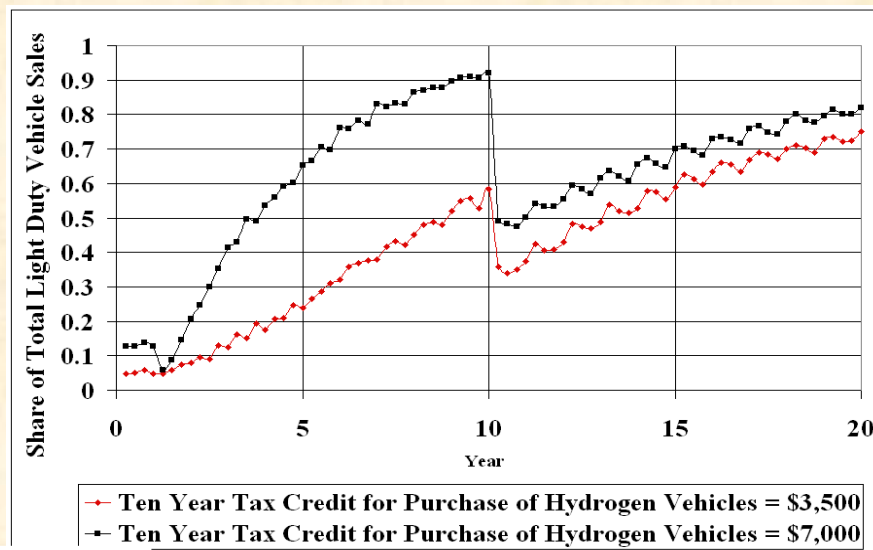**Sales Penetration Sensitivity to HPV Sticker Price Relative to GPV Price:**

HPV Sales Penetration Sensitivity to Gasoline Price:
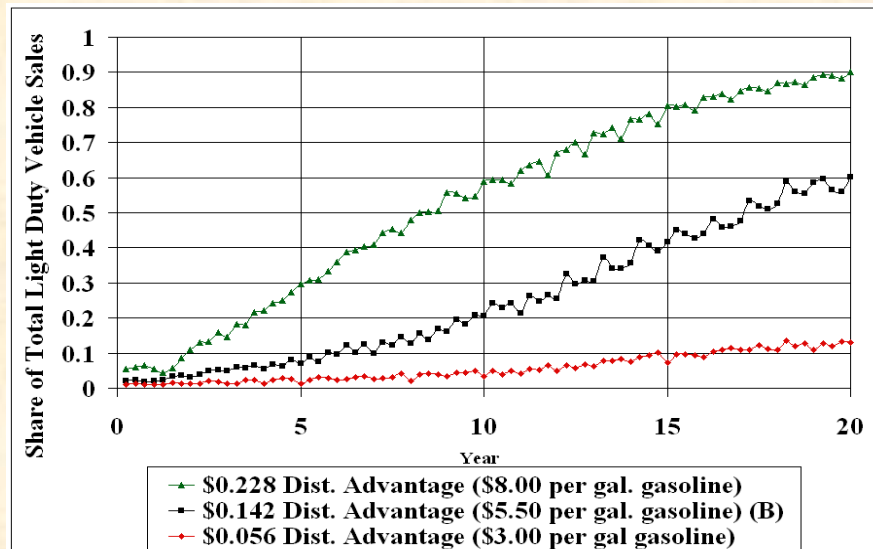
HPV Sales Penetration Sensitivity to Permanent Tax Credit:

HPV Sales Penetration Sensitivity to 10 Year Tax Credit:

B=Benchmark

Technical Accomplishments and Progress, cont'd.

4. Model Validation

- Internal Validation

  – Sensitivity analyses provide confidence intervals
  – Careful selection of parameter values from literature

- External Validation

  – Comparison of results with adoption of other technologies

    o **Time to asymptotic adoption**
    o **Shape of adoption path—generally logistic**

  – Review by industry cooperators
  – Examination by peer review panel

Technical Accomplishments and Progress, cont'd.

5. Major Project Conclusions

- Ultimate long-run penetration, normally well beyond the 20 year early transition period, tends to be robust to whether agents maximize perfectly.

- Penetration during the first ten years can be markedly affected by departure from strict maximizing behavior.

Answers to Original Questions:

"Will the private sector invest in hydrogen infrastructure?"

Answer: Yes, if parameter values, HPV production cost, and fuel prices are favorable.

"What, if any, policy assistance is needed?"

Answer: Government policies may be needed to speed up adoption to meet goals not achieved by market, e.g. more rapid reduction in foreign oil dependence.

Collaboration

- RCF, prime

- Argonne National Laboratory, direct collaboration

- BP, review and advice

- Ford Motor Co., review and advice

- Protium Energy Technologies, review and advice

- Industry Advisors, review and advice

Project Summary

Relevance: **Helps understand possible future market behavior**

Approach: **Agent-based modeling and simulation**

Technical Accomplishments & Progress:

         Operational model and simulation results; final report in preparation

Technology Transfer/Collaborations:

         Business and technology advice from oil, industrial gas, and automotive companies

Proposed Future Research: **Project completion date is June 30, 2009**