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

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Project ID # AN5

Timeline

- Project start date: July 2005
- Project end date: June 2009
- Percent complete: 60%

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
  - $645,613 budgeted
  - $1,200,000 anticipated
- **FY09**
  - $616,634 anticipated

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

Project Purpose

- Purpose: 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?"

Inputs:

- Feedstock and capital costs of producing hydrogen fuel
- Risk profiles of investors
- Learning behavior
- Cost and performance characteristics of vehicles
- Drivers' refueling behavior
- Fuel prices – hydrogen and gasoline
- Government policies (tax credits, pilot programs, government risk sharing, other)

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)

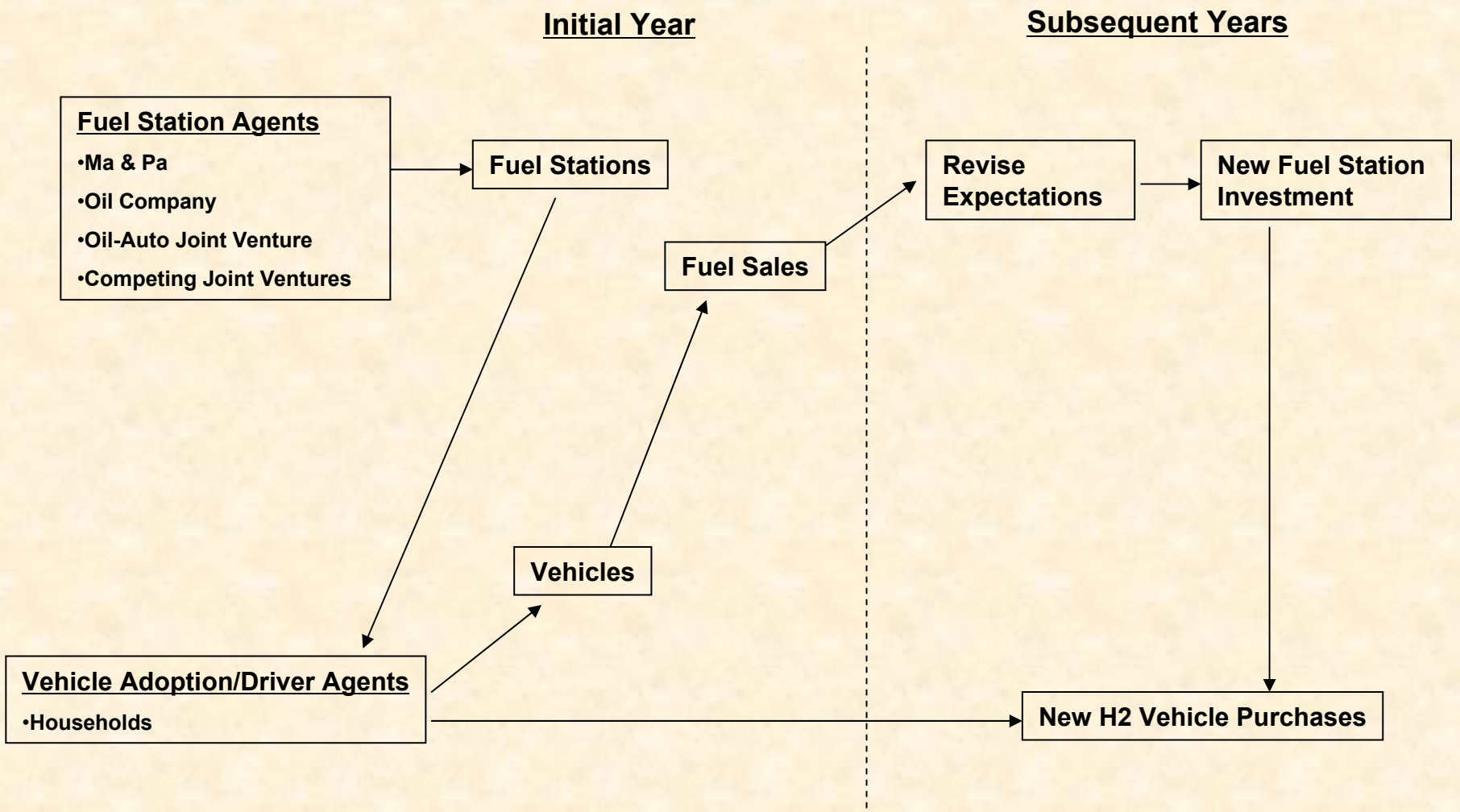
Drivers—decide whether to buy a hydrogen vehicle

- 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

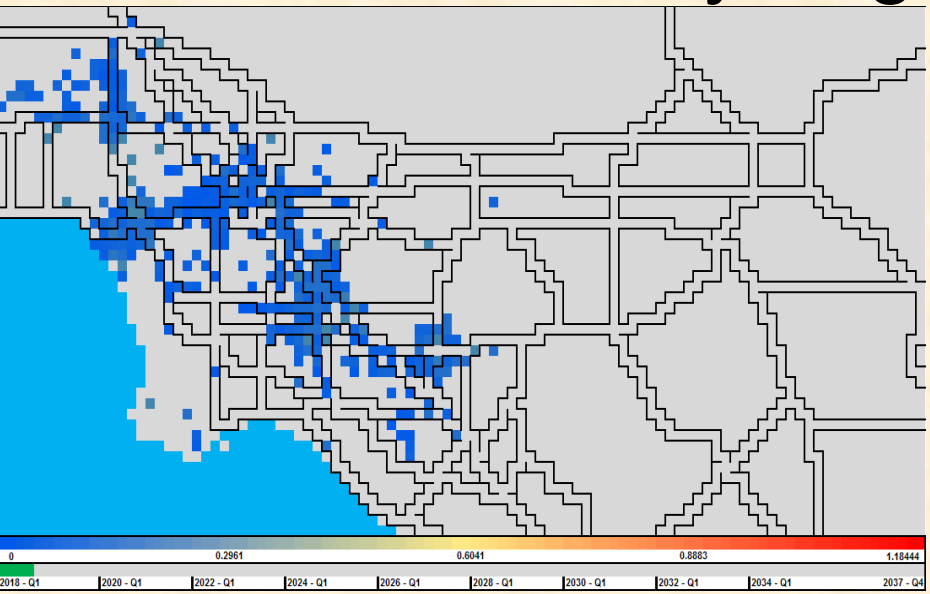
Investors—decide type of infrastructure to supply, how much, and where to locate

- 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

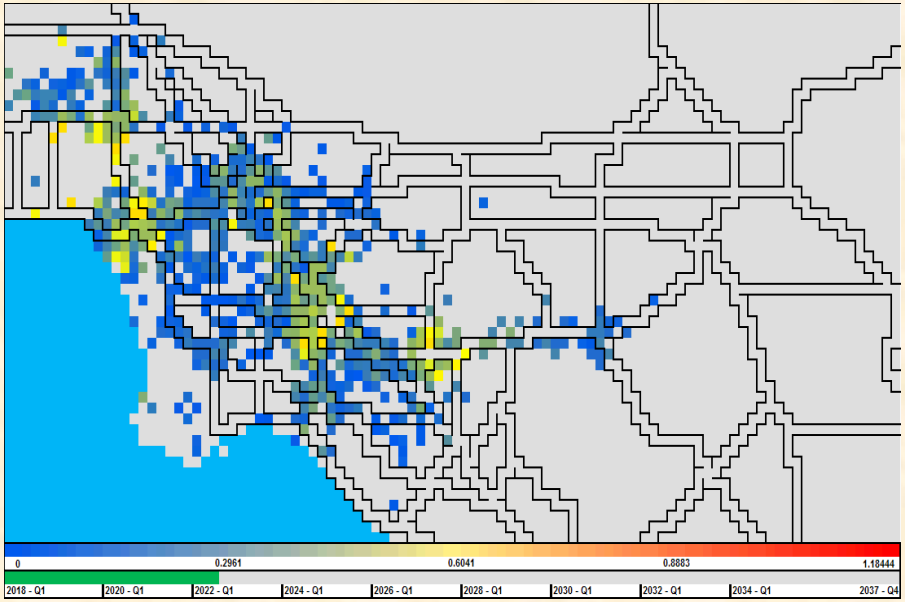
Decision Sequence in Model



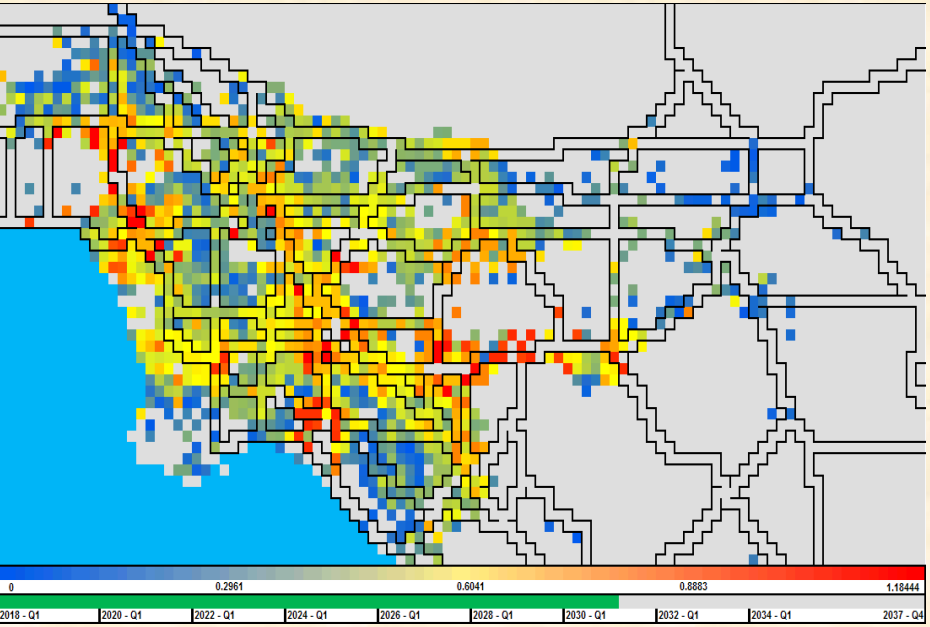
Stock of Hydrogen Vehicles in L.A.



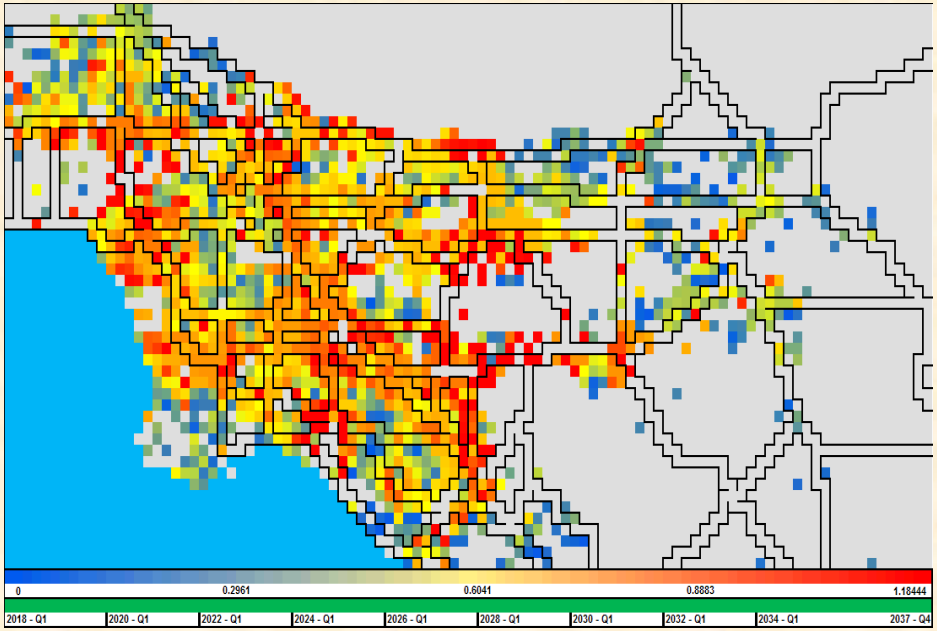
2018



2020



2030



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Project Accomplishments to Date

Prior to FY2008

Constructed Driver and Investor Modules

Obtained Preliminary Results

Today's presentation is on FY2008 progress:

- **1. Centralized H2 Production**
- **2. Upper Management**
- **3. Model Validation**
- **4. Policy Analysis**

1. Centralized Production Option

Production and Distribution at Fueling Site

- $2M SMR units, 1,500 kg per day capacity, at fueling site
- One station is small enough to allow maximum utilization (70% of capacity)
- Levelized cost is the same regardless of year built.

Centralized Production

- $181m SMR units
- 379 K kg per day
- at varying capacity
- 100 km from L.A.
- Levelized cost is raised by need to cover early unused capacity

Distribution from Centralized Site

- $13.6b Delivery and Dispensing System
- Transmission pipeline to city, 2 urban trunk lines
- Service pipelines to fueling stations
- Geologic storage, compressors, dispensing station

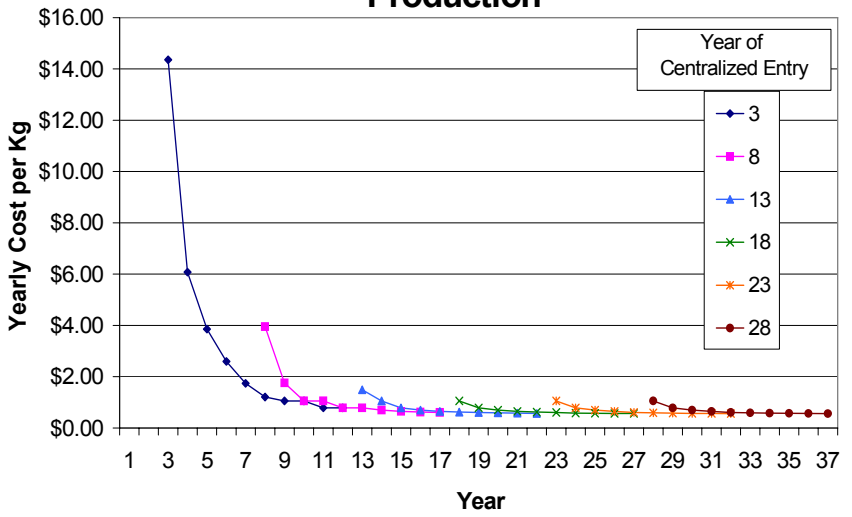
Switch to centralized occurs when economies of scale make levelized cost of centralized lower than distributed cost

Year of Entry Of Centralized Production

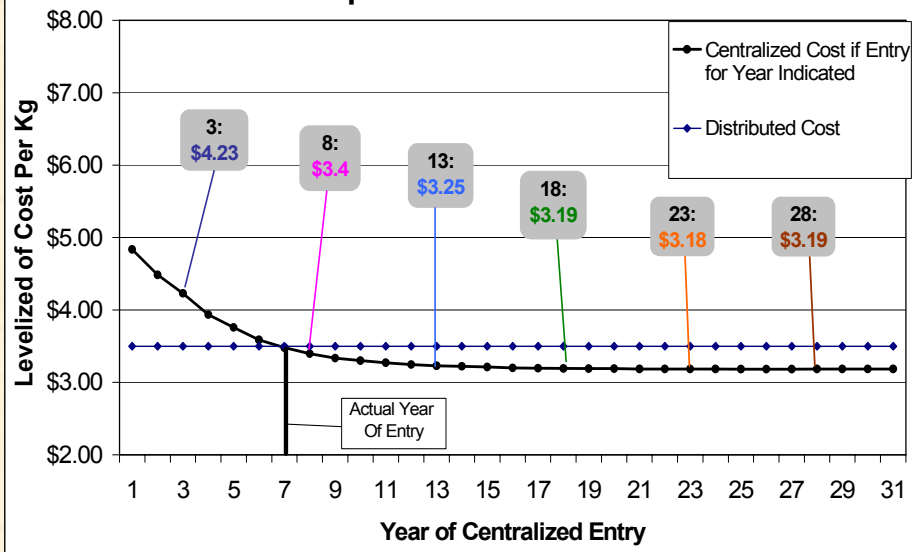
Cost functions based on H2A show how the year of entry of centralized production will occur sooner:

- The more rapid is market demand growth
- The fewer distributed stations that are built prior to centralized entry, since existing distributed stations take away volume that would otherwise lower losses on unused centralized capacity
- The higher is the cost of distributed production

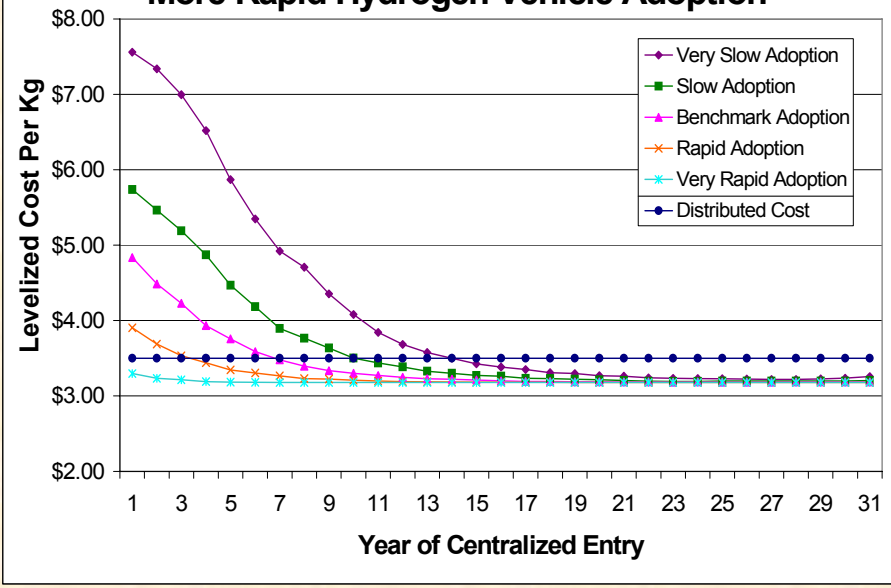
(1) Costs of Unused Centralized Capacity Are Raised by Early Entry of Centralized Production



(2) Levelized Price Needed to Repay Centralized Costs Competes with Distributed Price



(3) Year of Centralized Entry is Lowered By More Rapid Hydrogen Vehicle Adoption

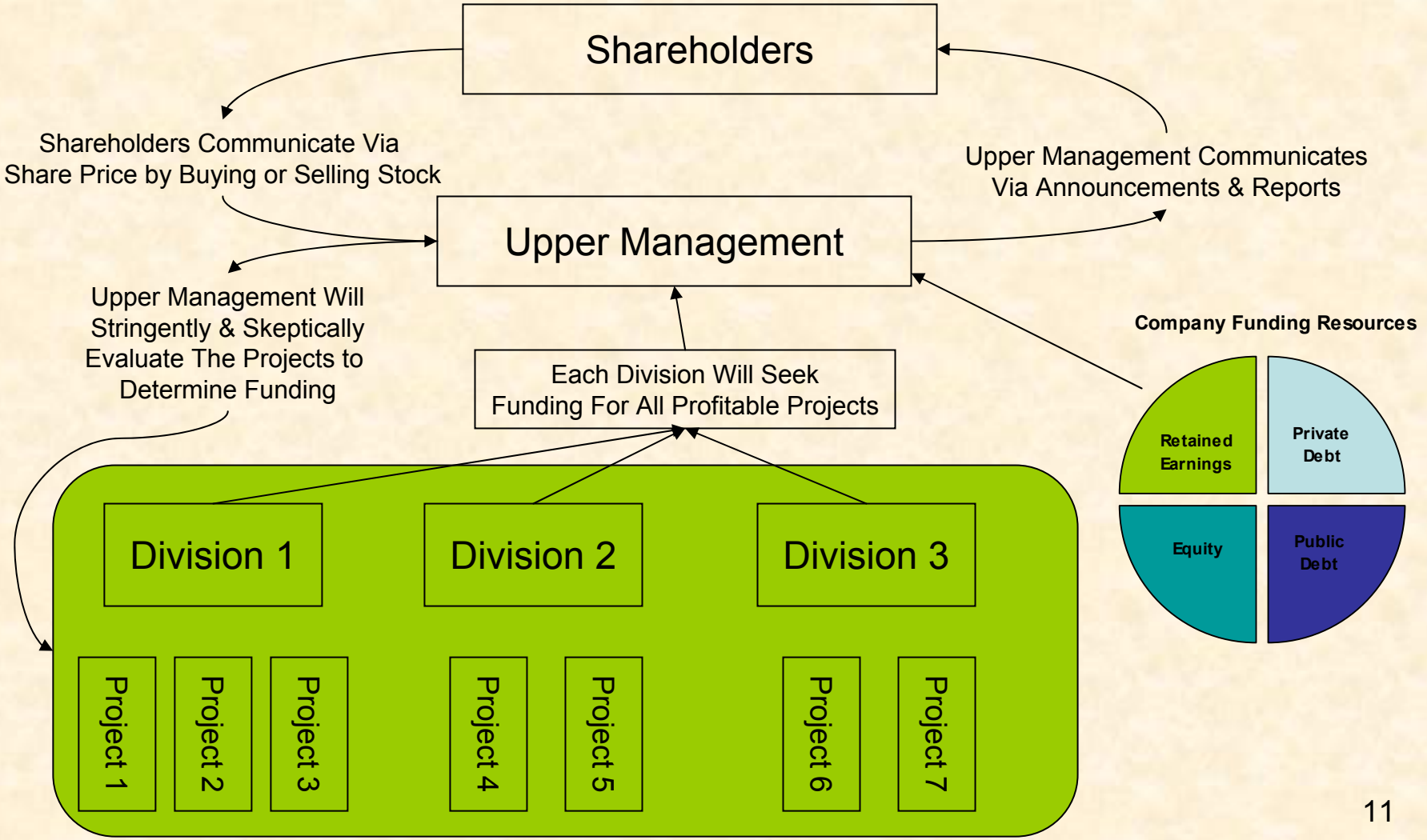


(4) Year of Centralized Entry is Lowered By Higher Distributed Price

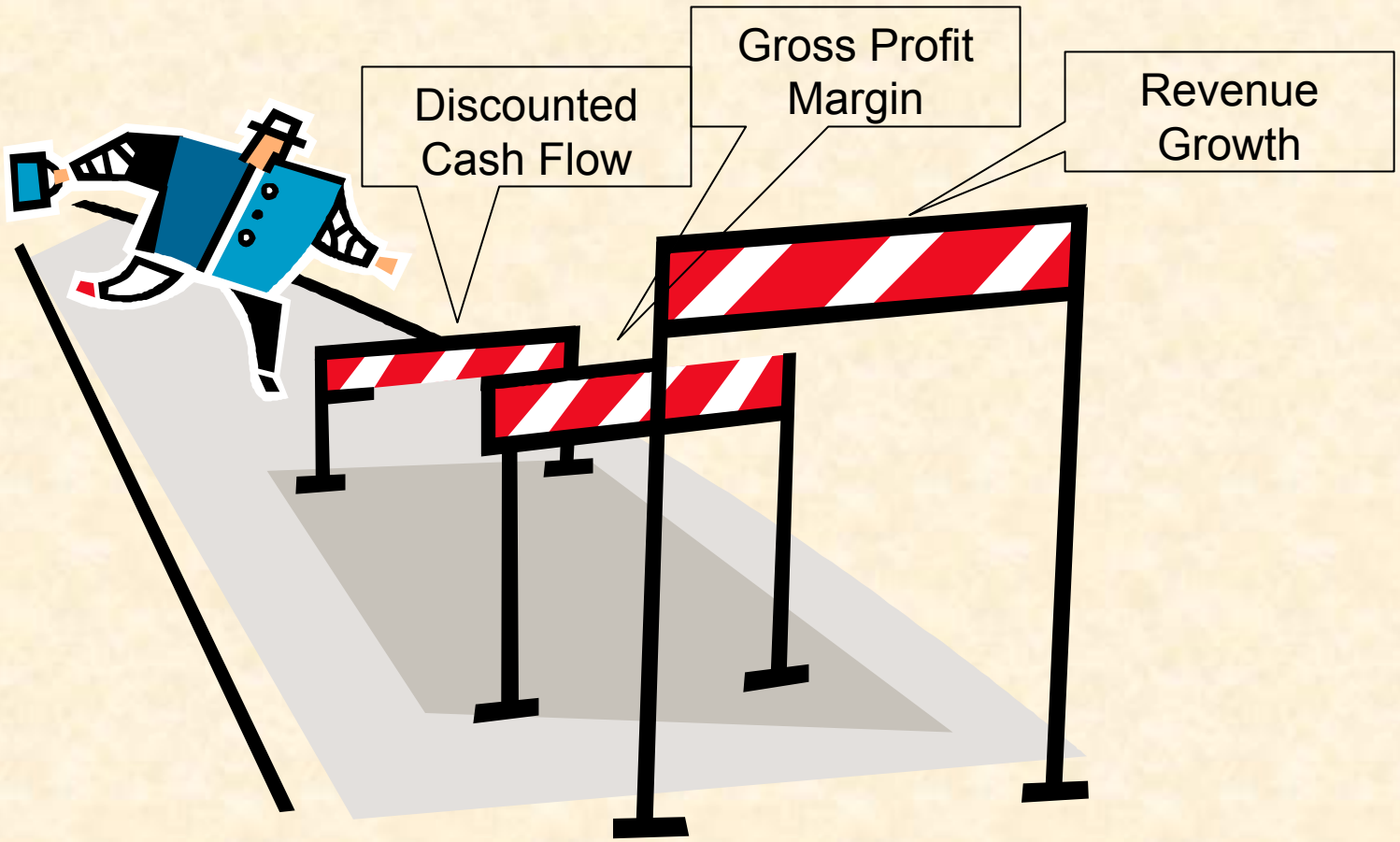
Distributed Price	Vehicle Adoption Rate				
	Very Slow	Slow	Benchmark	Rapid	Very Rapid
>$7.56	1	1	1	1	1
$5.50	6	2	1	1	1
$3.50	**14**	**10**	**7**	**4**	**1**
<$3.19	-	-	-	-	-

2. Role of Upper Management in Infrastructure Provision

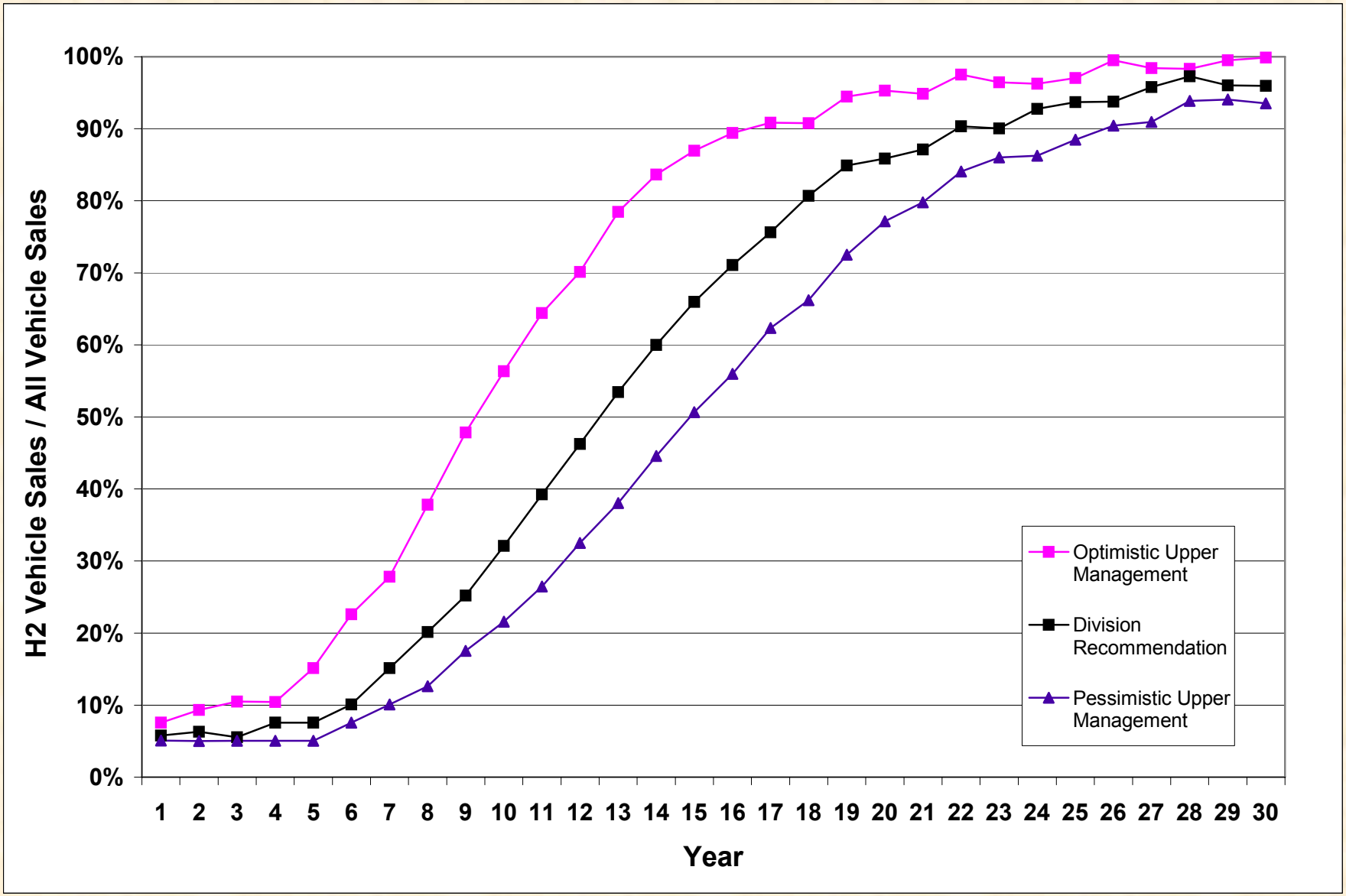
Profitability Estimates By Technical Staff May Be Over-ruled by Upper Management



In Addition to Standard Analysis, A Project Must Jump Hurdles Reflecting Broader Company Goals



Upper Management Optimism or Pessimism Gives Estimates Different From Staff



* Based on discussion with industry partners on how companies view risk

3. Model Validation

Sensitivity Analysis

- Narrow Confidence Intervals are Obtained for Sensitivity of Vehicle Adoption Path to 126 Cost Parameters
- High, Medium, and Low Scenarios are Needed for 7 Driver and Investor Parameters. Strategy: Plan for Medium Scenario. Be Prepared to Shift Policy if Other Outcomes Occur

External Validation

- ABM model replicates general pattern of adoption path experienced by previous similar innovations

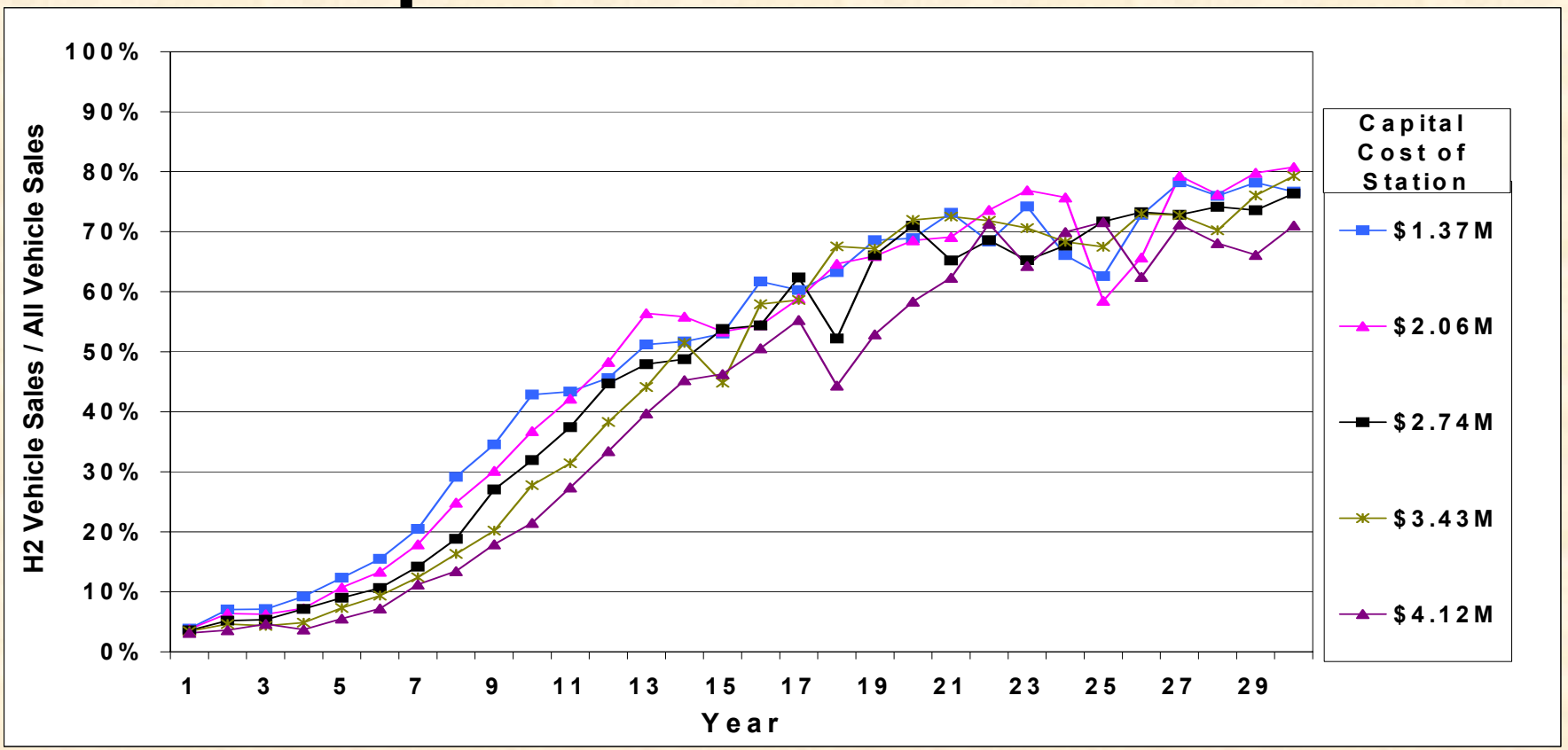
Industry Cooperators

- Industry advisors give feedback and ideas for realism

Peer Review

- Team to be assembled during final year

Sensitivity of Market Penetration to Capital Cost of Fuel Station

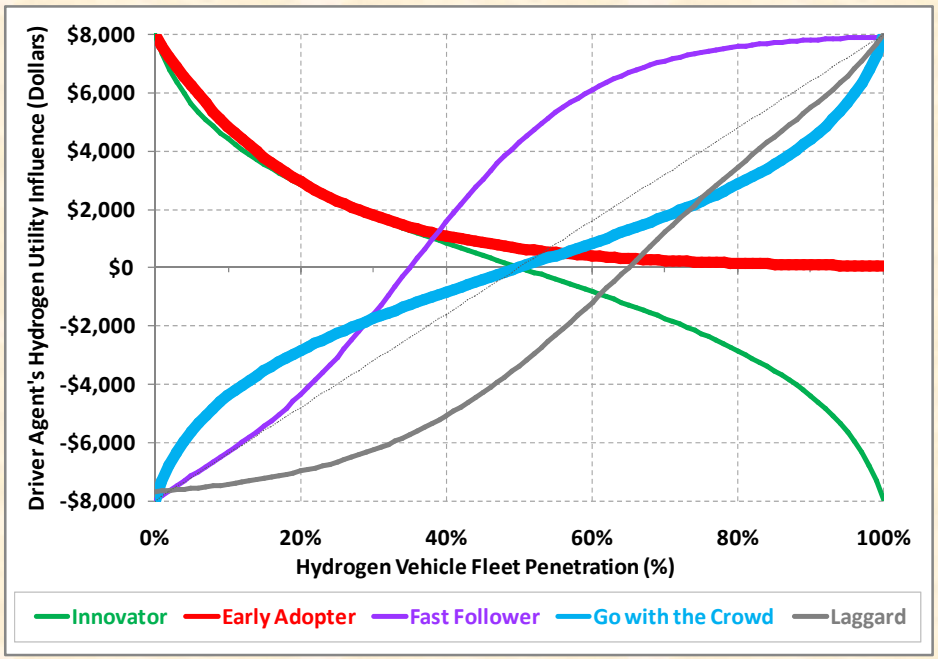


Scenario	Capital Cost of Station	Percent market share by			
		5th year	10th year	20th year	30th year
Highest Penetration	$1.37M	12.3%	42.9%	68.9	76.7%
Middle Penetration	$2.74M	9.0%	31.9%	71.0%	76.4%
Lowest Penetration	$4.12M	5.5%	21.5%	58.4%	71.0%

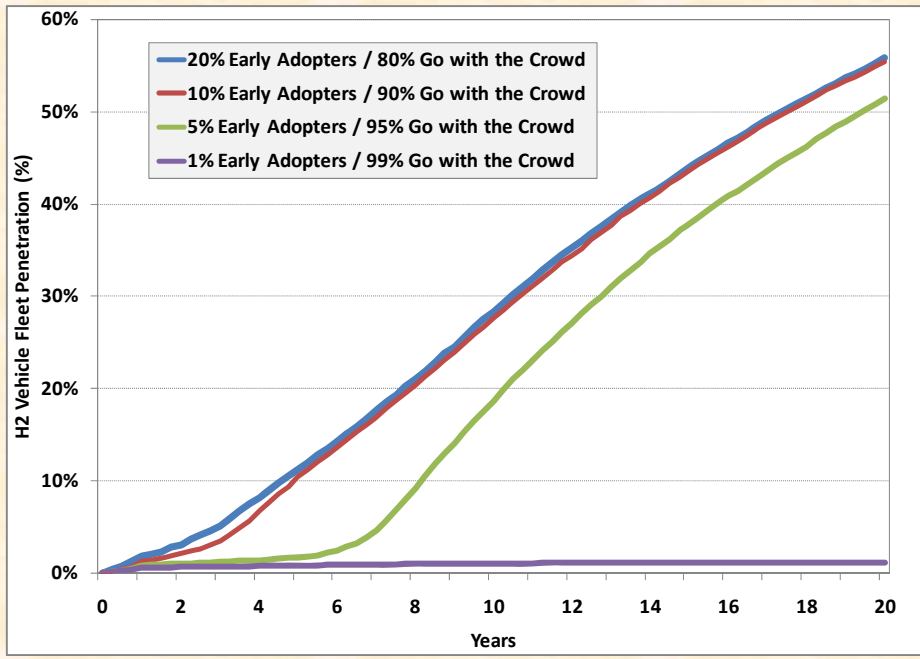
Sensitivity of Market Penetration to Early Adopter Assumptions

- The population contains a mix of adopter types. Early adopters obtain greater utility from acquiring new technologies, such as H2 vehicles. Go-with-the-crowd adopters only copy what others have done.
- A mass of early adopters (5-10%) are needed to start early vehicle adoption

Input: Different Adoption Propensities



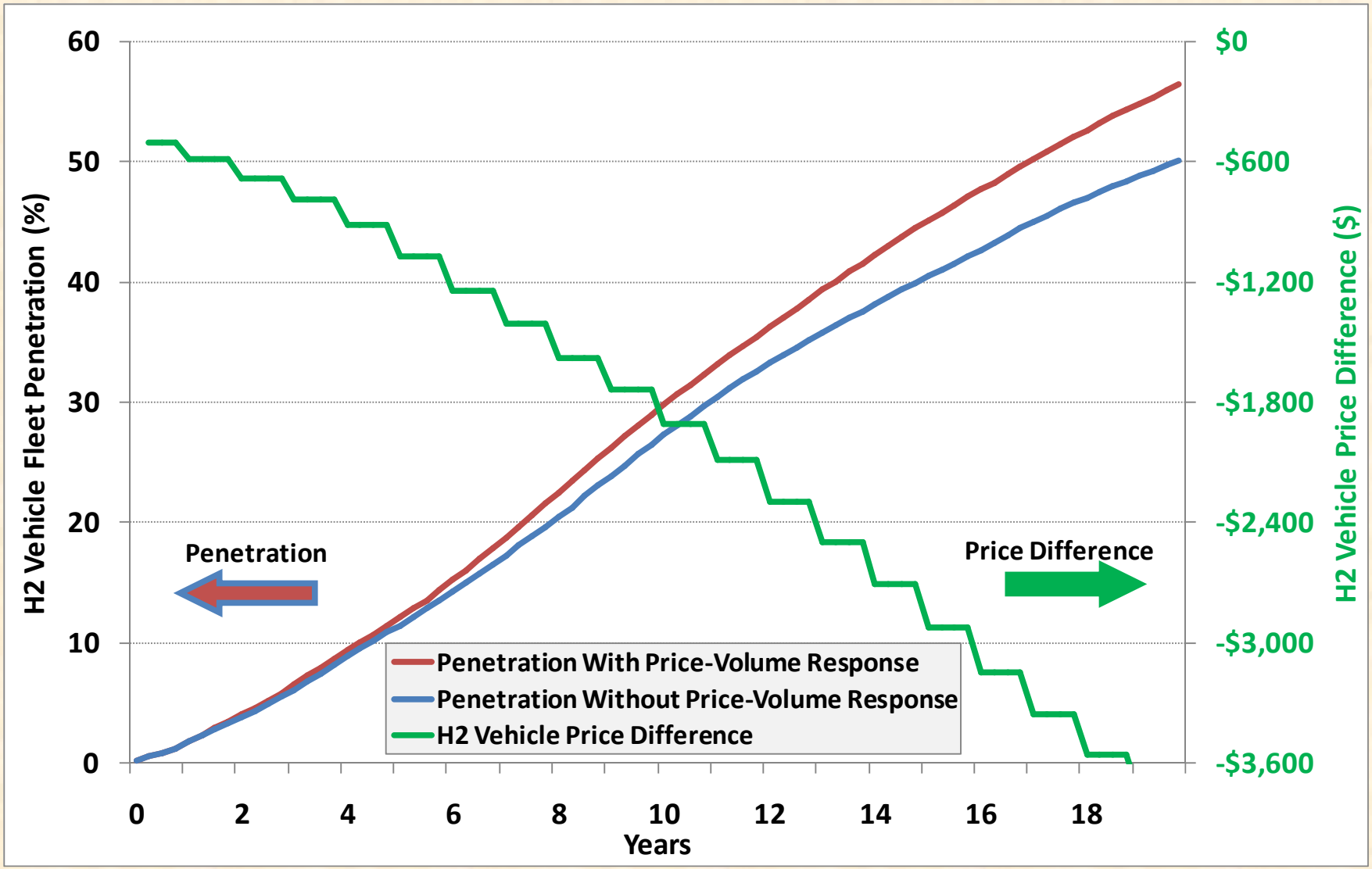
Penetration Depends on Adopter Mix



4. Policy Analysis

- Government assistance including tax credits, pilot programs and government risk sharing can help achieve early adoption goals.
- Policy scenarios answer question: What policies are required to reach adoption goals?
- One of several examples is tax credit on purchase of hydrogen vehicle

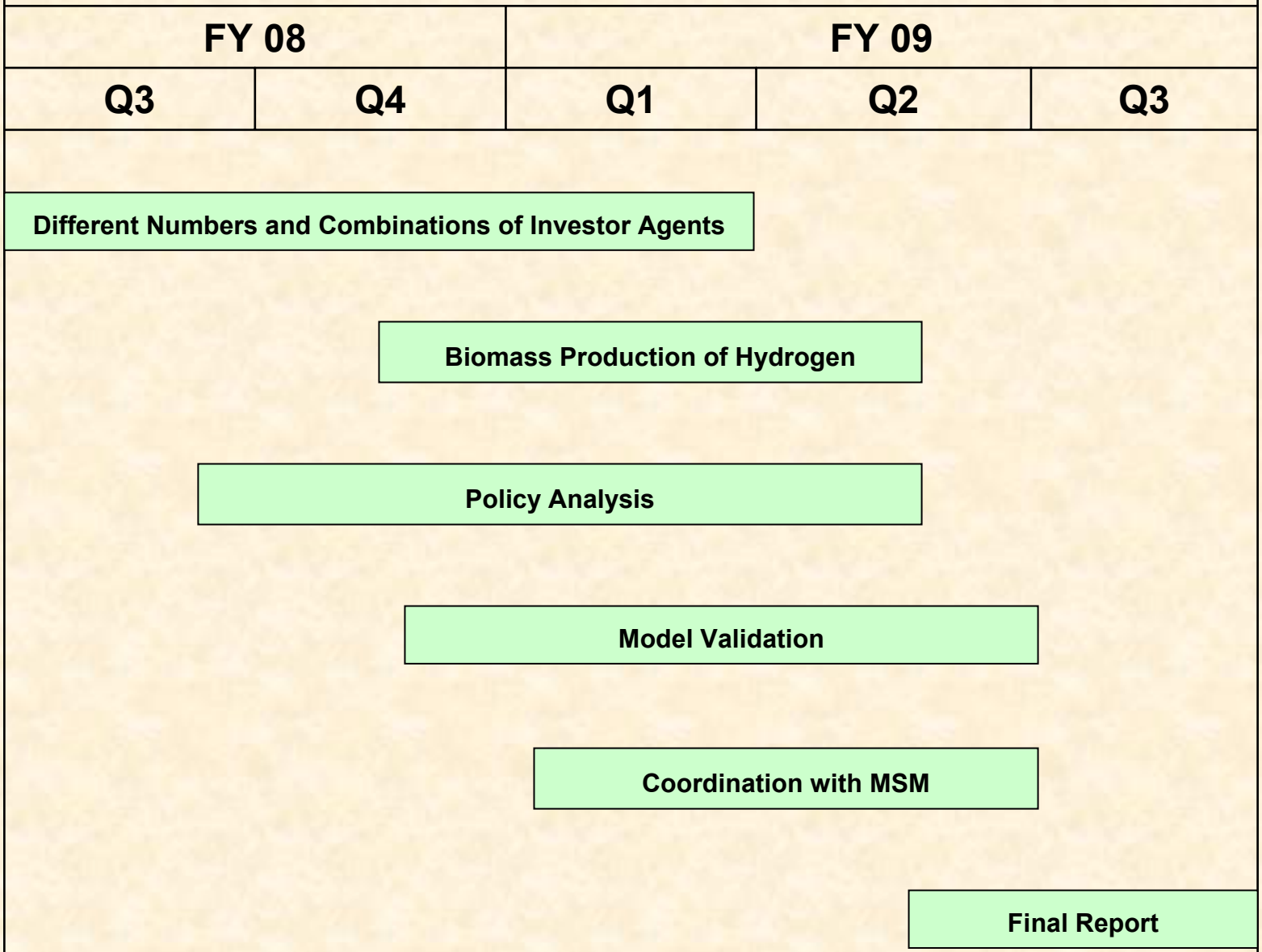
Sensitivity of Market Penetration to H2 Vehicle Price-Volume Response



Summary

- ✓ Chicken is Investor. Egg is car driver. Later interaction.
- ✓ Will the private sector invest? Yes. Eventually.
- ✓ Adoption depends on rules of thumb, risk aversion, attitudes and learning, in addition to traditional cost considerations. Gradually approaches optimum.
- ✓ Model explains transition from distributed to centralized production.
- ✓ Model is policy tool to evaluate tax credits, pilot programs and government risk sharing aimed at speeding adoption.
- ✓ Model is being validated by sensitivity tests, replication of other innovations, industry opinion and peer review.

Future Work


FY 08
FY 09
Q3
Q4
Q1
Q2
Q3
Different Numbers and Combinations of Investor Agents
Biomass Production of Hydrogen
Policy Analysis
Model Validation
Coordination with MSM
Final Report