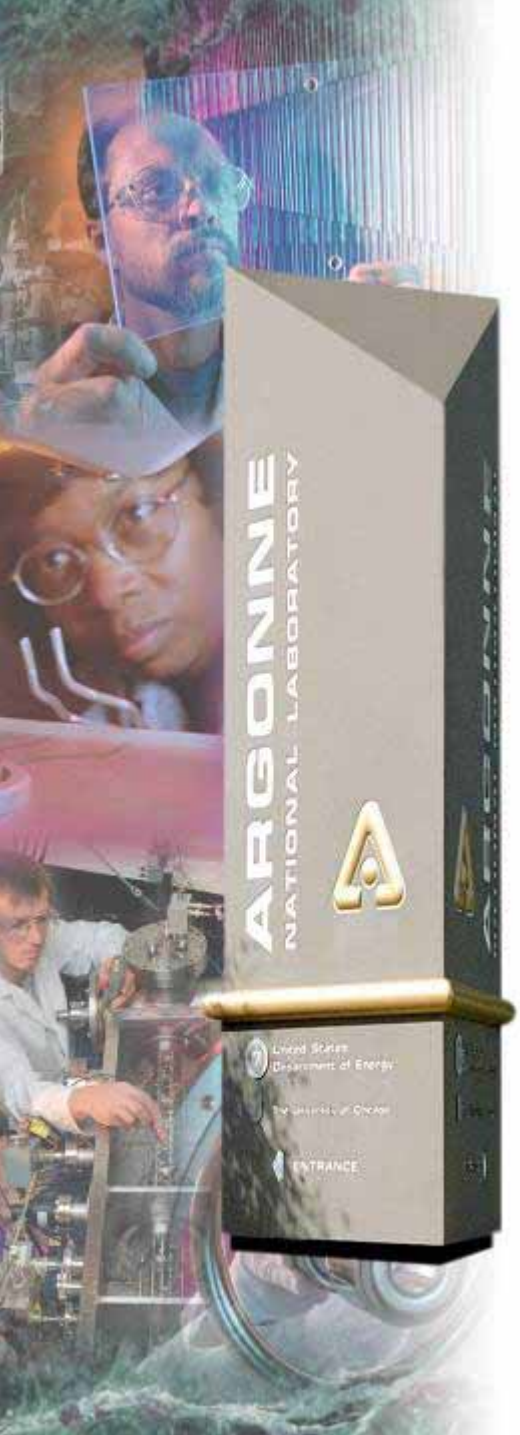

Hydrogen Infrastructure: Requirements and Issues

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Windsor Workshop
Transportation Technologies Fuels Forum
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Toronto, Canada

Argonne National Laboratory

Office of Science
U.S. Department of Energy

A U.S. Department of Energy
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This Presentation Will Focus on:

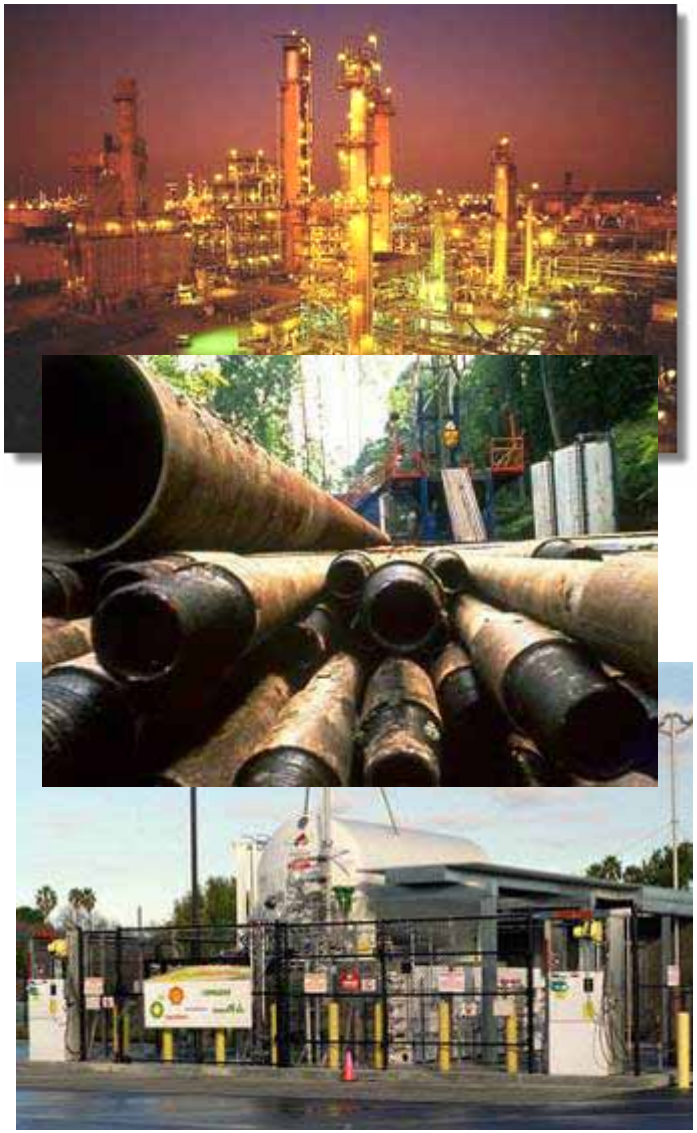
- **Investment requirements for a hydrogen infrastructure to serve transportation vehicles**
  - Magnitude
  - More complicated than IRR
- **Hydrogen market as a complex system itself and *vis a vis* other energy markets**
  - Multiple players with different objectives
  - Players interact with each other and environment, adapt, and evolve behavior
- **Agent-based modeling as a tool to analyze co-evolution of hydrogen supply and demand**

Recent H_2 Studies Have Used Relatively Simple Fuel Chain Models to Estimate Cost

- **Example: National Research Council Report - *The Hydrogen Economy: Opportunities, Costs, Barriers and R&D Needs***
- **Example: Joint US-Canadian 2050 study with infrastructure modeling by Argonne National Laboratory using the *CHAIN* model (Cost of Hydrogen under Alternative Infrastructures)**
- **Example: DOE's H2A effort to model hydrogen production, delivery and dispensing using consistent, industry-vetted financial assumptions**

Results Suggest H_2 Infrastructure May Cost $500 Billion or More Over 30-50 Years

- In real, undiscounted dollars
- Excluding unit cost reductions from "learning"
- Without reference to context, i.e., not compared to other large investments which may be obviated by a hydrogen infrastructure and not related to other large infrastructure transitions

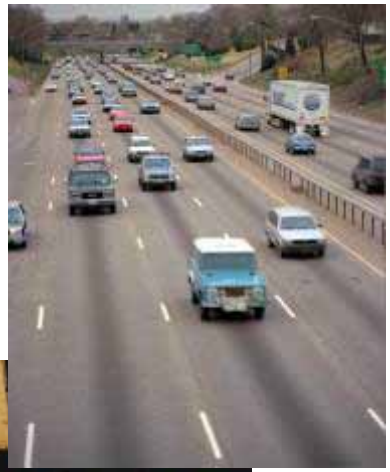


Other Large Infrastructures Have Had Similar Investment Requirements

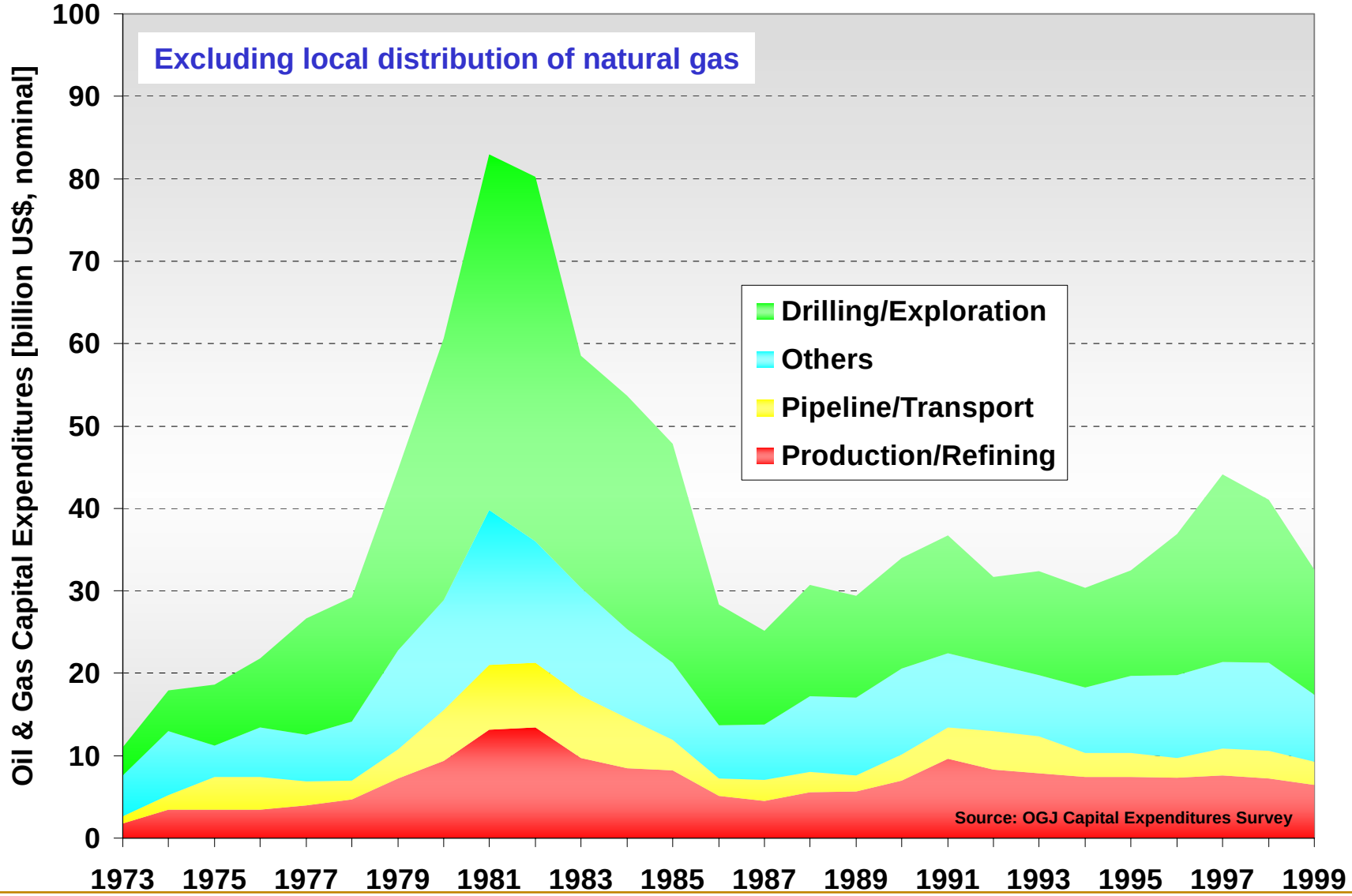
- **US Interstate highway network, FHWA**
  - $129 billion (nominal) 1958-1991
  - $576 billion (2003 dollars)

- **US air traffic control network upgrade $51 billion (1981-2007), GAO**

- **Telecommunications and fiber optic networks**

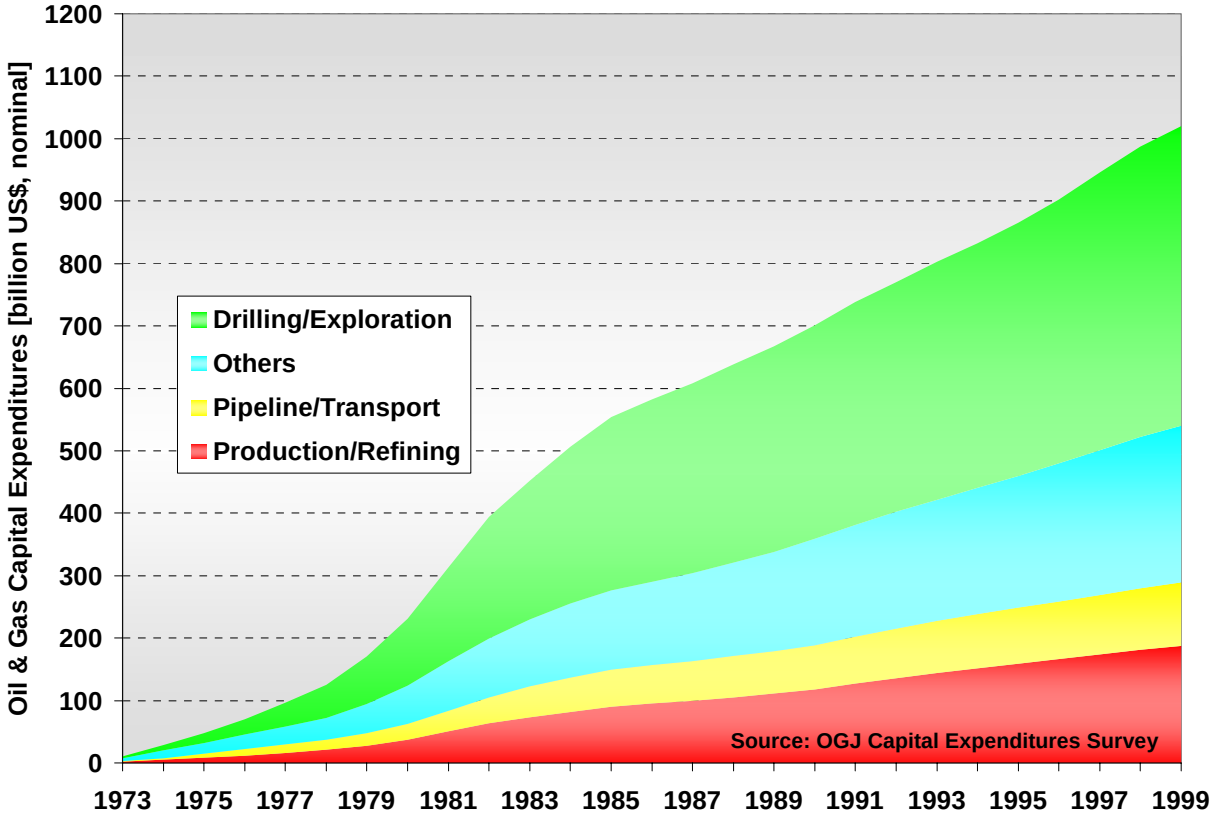


North American Oil and Gas Industry Invests Heavily in Infrastructure, Especially Exploration and Drilling



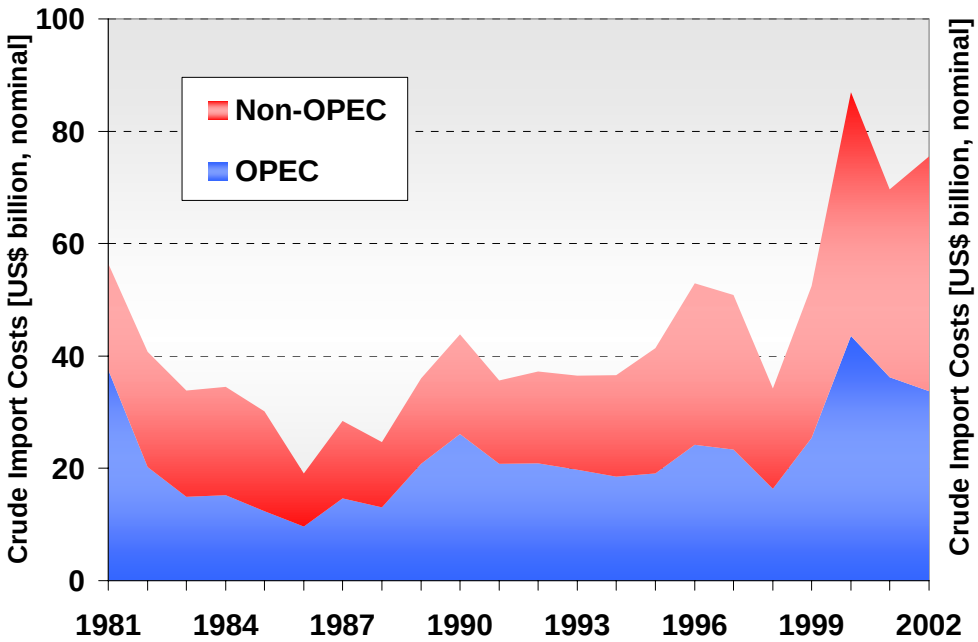
Cumulative Investments Exceed $1.0 Trillion Nominal ($1.9 Trillion Real) between 1973 and 1999

- **Drilling and exploration accounted for nearly half, $480 billion**
- **Over the next 30 years, IEA estimates another $1.7 trillion will be needed worldwide, just to make up for declining non-OPEC production**



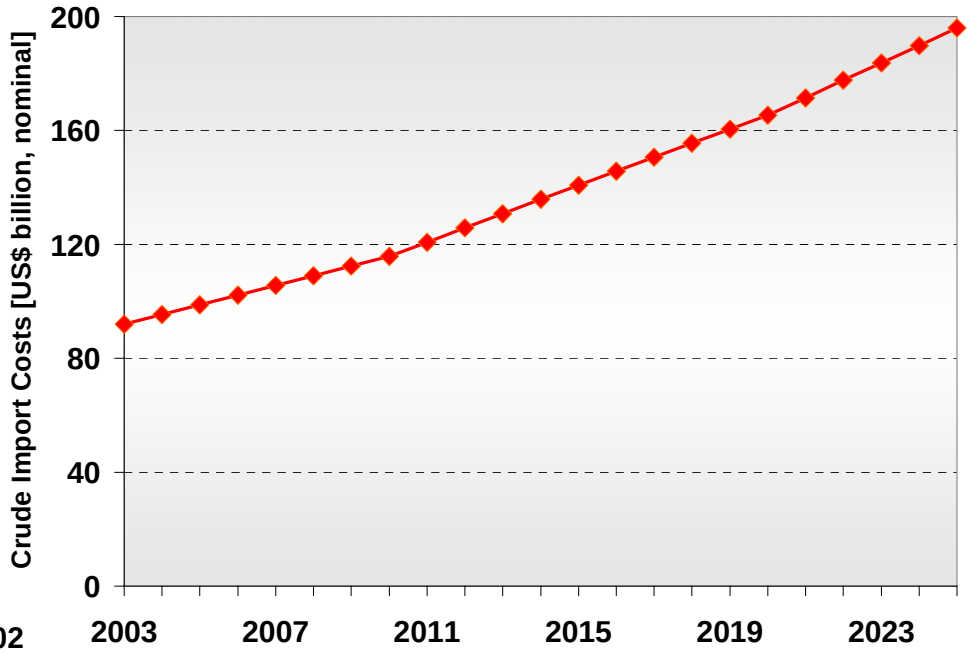
US Spending for Imported Oil Has Been of Similar Magnitude: $958 Billion Nominal (1981-2002)

$1.3 Trillion 1981-2002 (2003 dollars)



Crude oil only
Source: DOE-EIA, Petroleum Supply Annual

$3.4 Trillion 2003-2025 (2003 dollars)

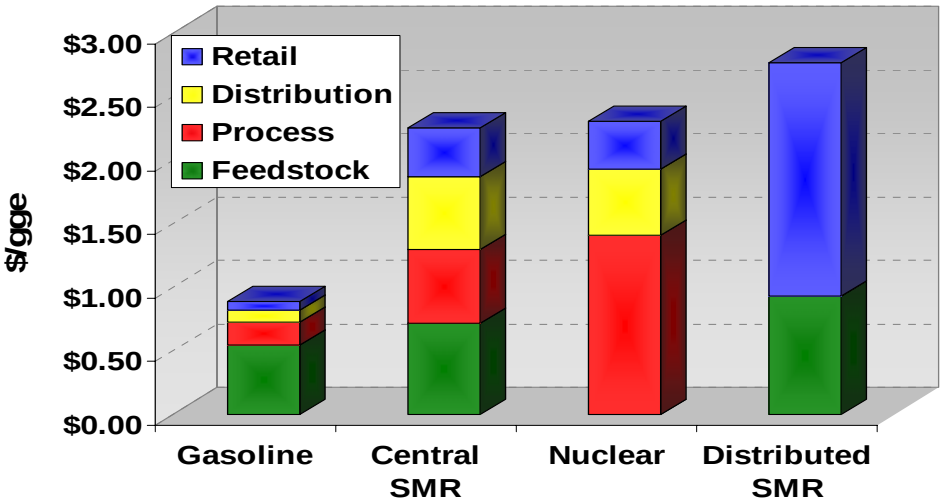


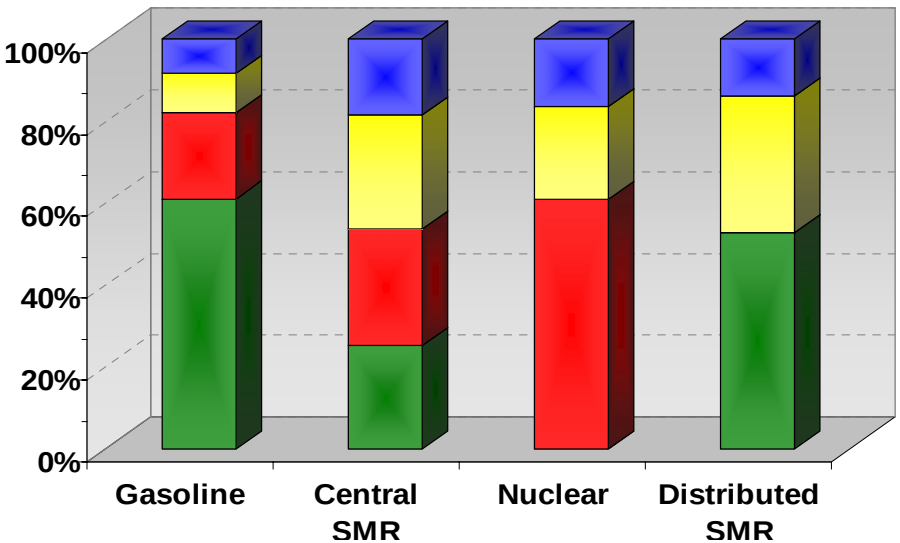
Crude oil and refined products
Source: DOE-EIA, AEO2004

What Does This Tell Us?

- **Oil and gas industry has track record of significant infrastructure investment**
- **Magnitude of that investment is not significantly different from what would be required for a hydrogen infrastructure, but the FOCUS is**
  - Oil and gas exploration and drilling are high risk
  - Success/failure are quickly known
  - Rewards are short-term
- **Hydrogen infrastructure investments may be quite different**
  - Greater market, competitive, technological uncertainty
  - Cost/benefits accruing to different players
  - Rewards are long-term

Gasoline Is Highly Dependent on Cost of Feedstock H_2 Cost Depends on Processing and Distribution





- Gasoline ~$1.00-1.25/gal untaxed ($28-40/bbl crude)
- H_2 >$2.50/gge at high volume, much more at low volume
- Feedstock >60% for gasoline vs. 25-35% for NG-based H_2, much less for coal or nuclear
- Distribution <10% for gasoline vs. 20-25% for centralized H_2
- Production ~20% for gasoline vs. >60% for H_2 from nuclear, ~25% from NG.
- Levelized costs decline as infrastructure is "built out"

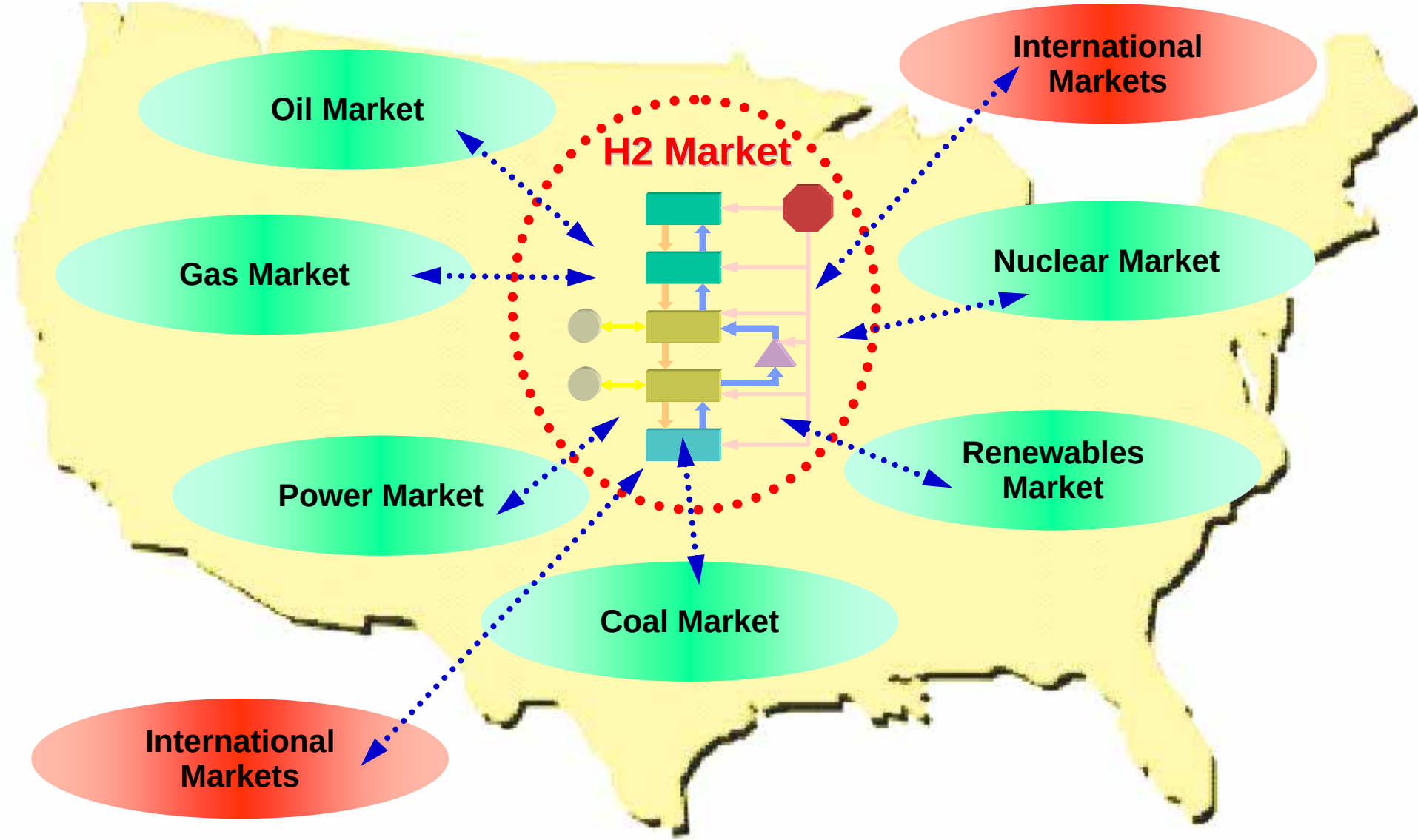
Hydrogen Infrastructure Investments Are Unlikely to Follow Oil and Gas Industry Example

- **Like oil drilling, hydrogen production and distribution are high risk, but success is uncertain until market develops and rewards are long-term at best**
- **Other options more likely to appeal to industry short-term preferences:**
  - Gas-to-liquids
  - Heavy oil
  - Oil sands
- **Rather than postulating scenarios of hydrogen infrastructure investment, need to better understand behavior and identify conditions in which investment might occur**

Current Modeling Attempts Provide an Incomplete Picture of the Challenge of a Hydrogen Transition

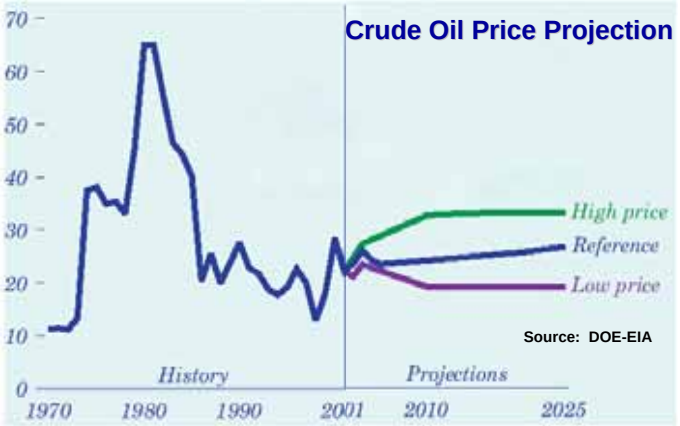
- **Transition will evolve as a result of complex interactions between multiple players across the supply chain**
- **Players have different objectives, strategies, business profiles, and risk preferences**
- **Each maximizes own objectives**
  - Objectives are often conflicting
- **Players' decisions based on a mix of private and public information**
- **Players learn and adapt to real or perceived changes in behavior of others or operating environment (dynamic)**

Complexity Increases if H_2 Market is Modeled as Part of the Larger Energy Market

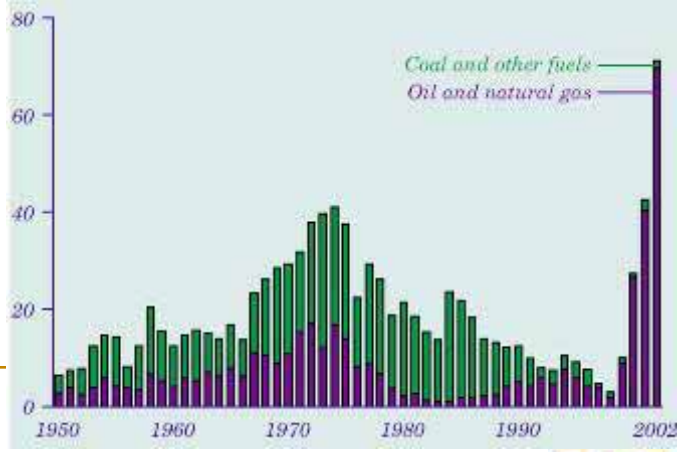


Current Energy Systems Models Do Not Adequately Capture Underlying Complexities

- **Existing simulation and optimization tools are limited in accounting for volatility and uncertainty prevalent in today's energy markets**
  - Single decision-maker
  - Perfect foresight
  - Rational decision-making
  - Energy markets in equilibrium



- **Straight-line projections ignore dynamics, uncertainties, potential for sudden shocks and disruptions, market imperfections, and emerging strategies by market participants**
  - California power restructuring
  - Recent crude oil & natural gas price volatility
  - Rush to natural gas for power generation and recent collapse



Agent-Based Complex Adaptive Systems Is an Intuitively Appealing Method for Analyzing Large Energy Systems

- **Complex adaptive systems consist of *numerous heterogeneous* entities (players) that *interact* with each other and their environment often in *non-linear* ways, *adapt* to change and evolve their behavior**

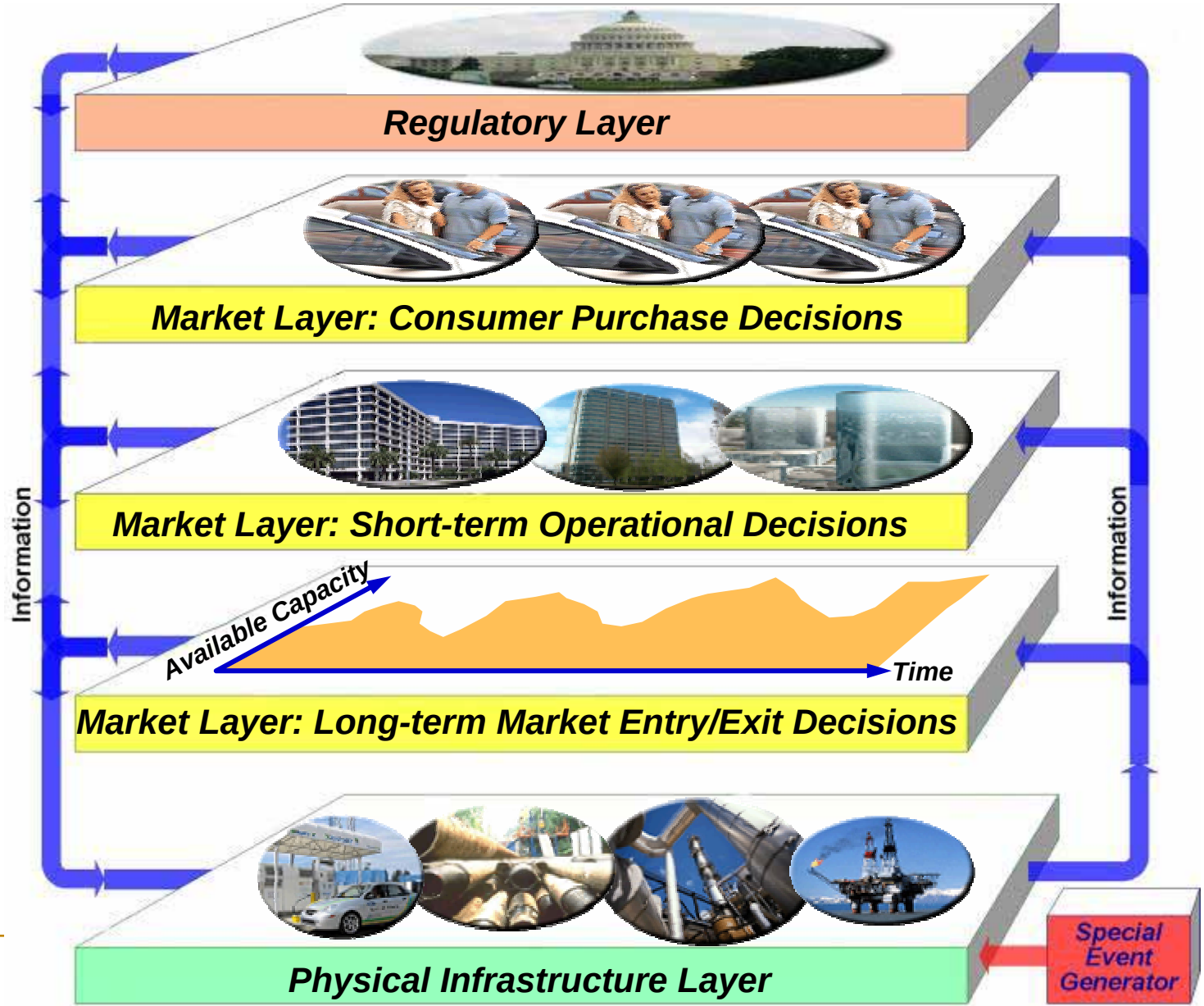
- **Agent-based modeling and simulation (ABMS) simulates the behaviors and interactions of large numbers of entities (*agents*) and studies the macro-scale consequences of those interactions**

What is an Agent?

- **An agent is an individual with a set of characteristics or attributes**
  - A set of rules governing behavior or “decision-making” capability, protocols for communication
  - Responds to the environment
  - Interacts with other agents in the system

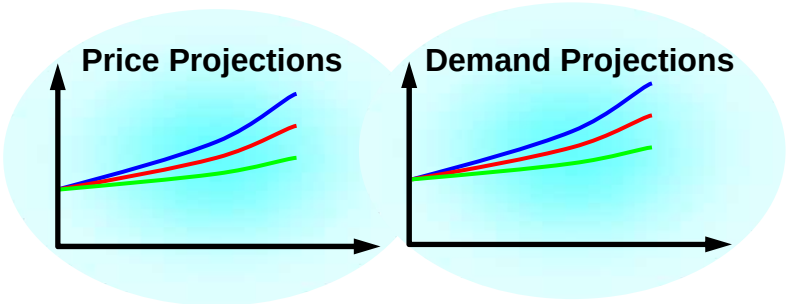
- **Agents are diverse and heterogeneous**
  - Each has own internal decision model, strategies, and objectives that can vary in complexity (simple to elaborate)
  - Each agent tries to find its own optimum (as compared to traditional models with a single decision maker trying to optimize the entire system, “social optimum”)

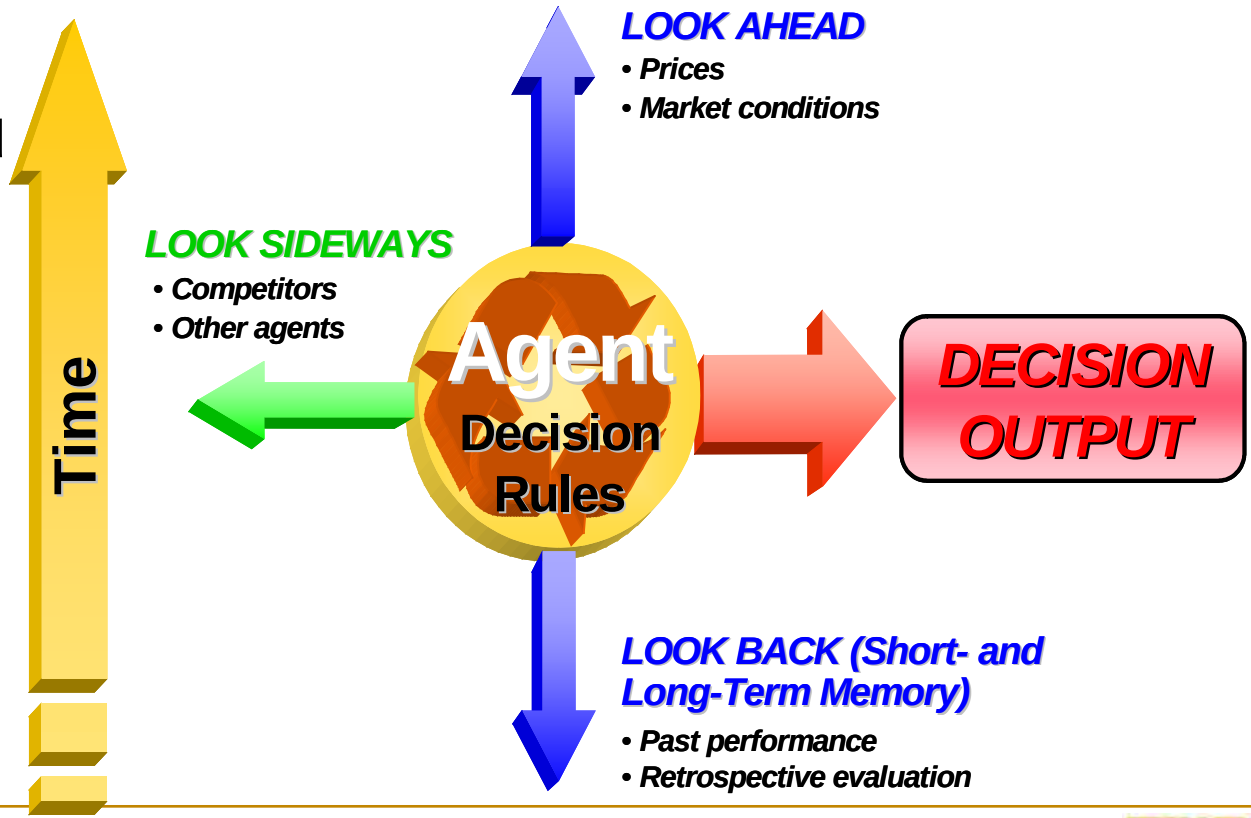
H_2/Energy Market Agents Make Decisions in a Complex and Multidimensional Environment



H_2/Energy Market Agents Consider Information on the Past, Present, and Future in their Decisions

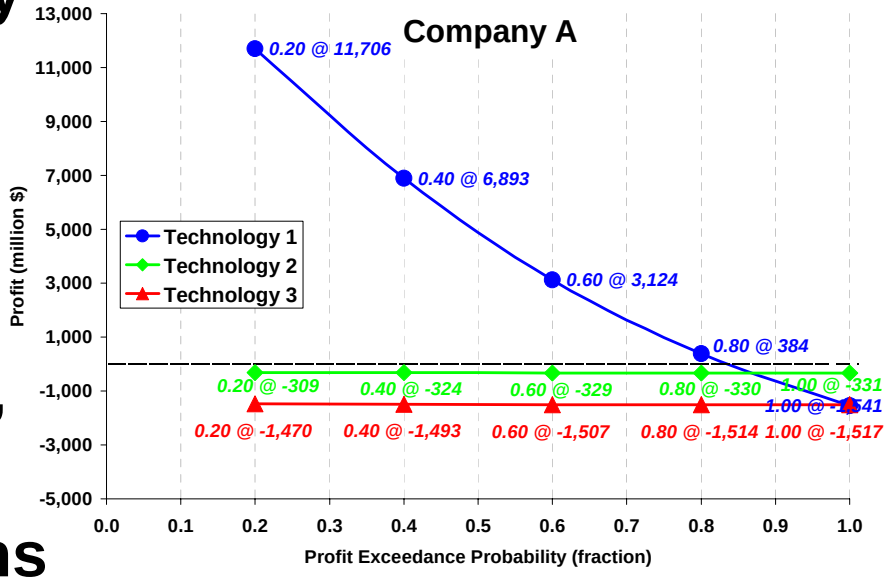
- Agents make decisions using local and public information
- Agents develop price expectations by market segment or region
- Agents develop demand scenarios by market segment/region
- Agents consider actions of competitors
- Agents consider past performance in making their decisions

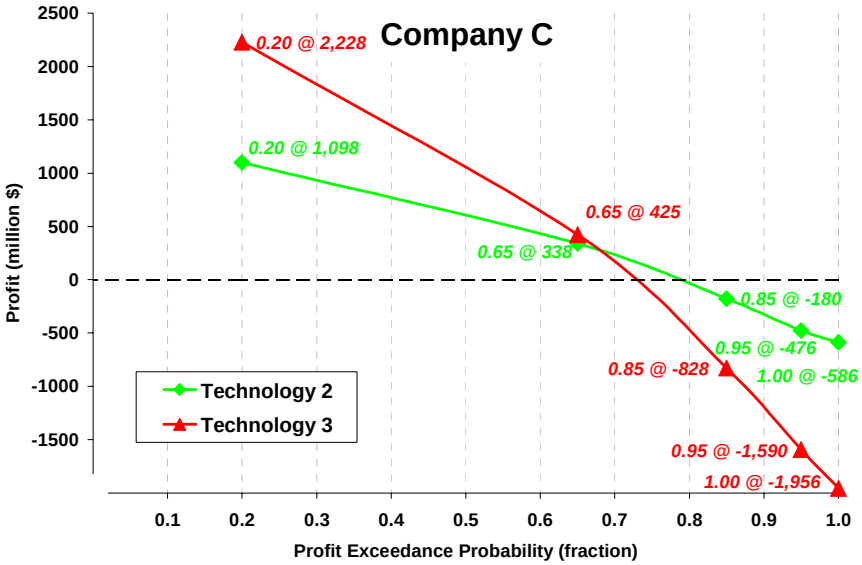




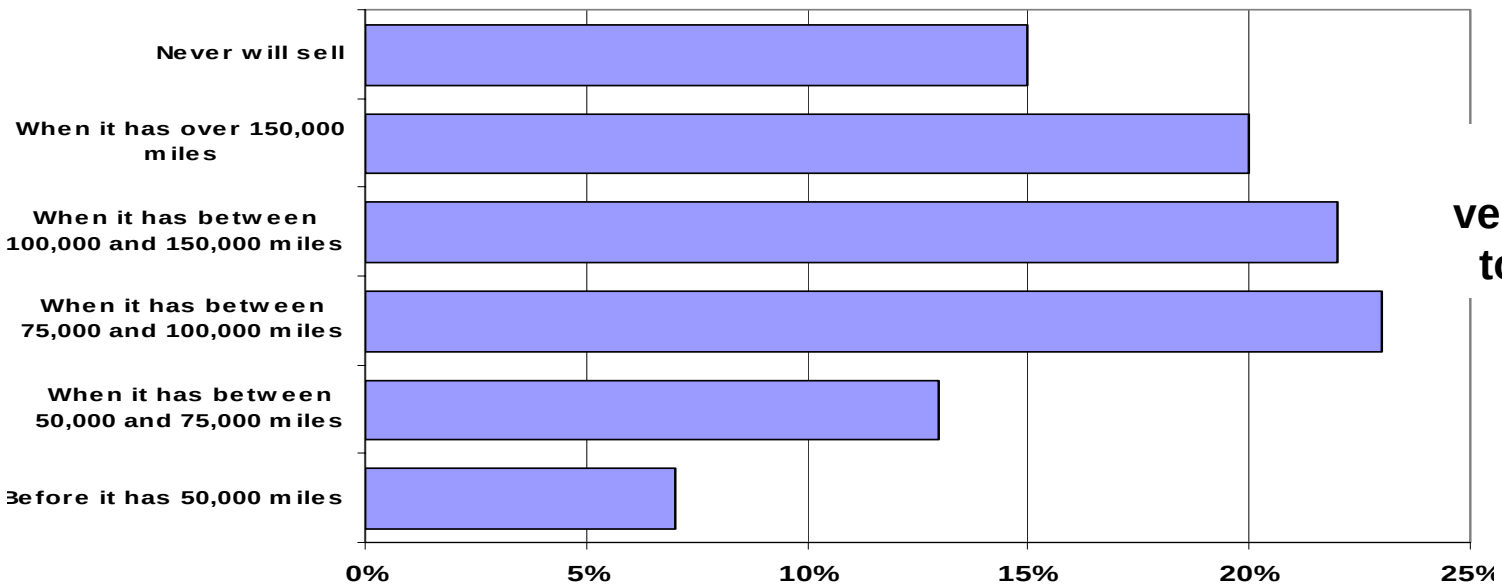
H_2/Energy Market Agents Make Market Entry/Exit Strategies in a Dynamic & Uncertain Environment

- **Agents consider technology choices**
  - Initial screening
  - Detailed evaluation using company-specific criteria (NPV, IRR, payback period, etc.) and risk profiles
- **Agents re-evaluate decisions at regular intervals or triggered by events**
- **Agents may choose to continue, delay, accelerate, or cancel at any time during project development**



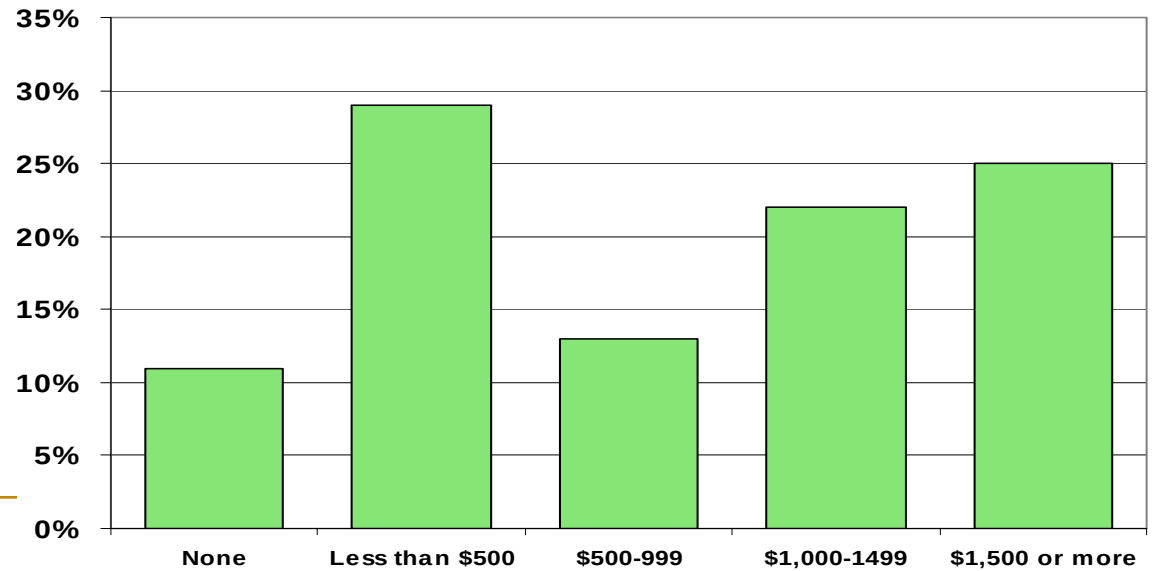


Consumers Consider Technologies, Prices and Market Conditions (Source: Opinion Research, Inc. May 2004)



When next vehicle expected to be replaced

Amount willing to pay for vehicle saving $400/yr in fuel



Summary: Agent-Based CAS Models Offer Key Advantages

- **New insights into H_2 infrastructure development issues**
  - Better represent uncertainty and volatility
  - Improved modeling of heterogeneity of market participants
  - Better understanding of transition/inflection points and their causes and drivers
- **Platform for**
  - Testing different business models/strategies, policies/market rules
  - Defining scenarios
  - Examining co-evolution of H2 demand and supply infrastructure

Where Do We Stand?

- **Substantive progress made in understanding hydrogen infrastructure requirements and their costs**
  - 2050 Study: Results available at http://www.ott.doe.gov/pdfs/final_2050_pres.pdf
  - H2A: Results to be posted by Sept. 2004

- **Agent-based CAS model is building on these results**
  - Power market model complete
  - Prototype hydrogen model designed with internal ANL funds
  - Proposal submitted to DOE for full effort (with industry, academic and NGO partners)

- **Further information: mmintz@anl.gov**

Acknowledgments

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- Argonne CAS Modeling Group