Agent-Based Modeling and Simulation (ABMS) for Hydrogen Transition Analysis

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Objectives and Scope for Phase 1

- Analyze the hydrogen infrastructure development as a complex adaptive system using an agent-based modeling and simulation (ABMS) approach.
- Develop an ABMS model to simulate the evolution of that system, spanning the entire H2 supply chain from production to consumption.
- Identify key factors that either promote or inhibit the growth of H2 infrastructure.
- Apply ABMS to get new insights into transition, particularly early transition phase:
  - Dynamic interplay between supply and demand
  - Chronological simulation of infrastructure build-up
  - Decentralized, independent decision-making
  - Agents maximize their own objectives and make decisions based on different expectations
  - Effects of uncertainties and different risk/strategy preferences
- Limited scope for FY06:
  - Early transition
  - Stylized environment
  - Demand focused on transport
Phase 1 Model Will Include Several Agent Types

- Fuel production and delivery agents
  - 3 production options
    - Decentralized (e.g., on-site reforming)
    - Medium centralized (e.g., centralized SMR)
    - Large centralized (e.g., coal or nuclear)
  - 2 delivery options
    - Low-volume, short-distance
    - High-volume long-distance
- Retailing/refueling agents selling 2 products
  - H2
  - Gasoline
- Consumers
  - Transport demand
  - Purchasing and operating decisions
- Regulator
  - Passive agent; sets the market rules (e.g., level of tax credits)
The Initial Model Version Uses a “Stylized” Environment in which the Agents Interact

- 3 metropolitan areas with interconnecting transport corridors
- Ranges in population densities provide heterogeneous market environment
  - urban, sub-urban, rural
- Larger highway grid within metro areas connected to intra-city corridors
- Local roads considered ubiquitous
- Can be scaled up and populated in Phase 2 with data for real geographical region
Consumer Agents

- Agents own and operate vehicles on road network
  - Number of agents: Low 1000s
  - Purchase car decision
    - Initially, purchase options are limited to 2 vehicle choices (conventional, H2)
    - H2 vehicles assumed to meet DOE targets in performance and cost
  - Vehicle operation and fuel purchase decision (price elastic demand)

- Randomly assigned locations (home, work)

- Have variety of attributes, such as income, income used for transportation, fuel price elasticity and lag, preferences, driving needs/patterns (randomly sampled)
  - Short/medium-distance (commute, errands)
  - Long-distance (leisure)

- Vehicle operation and purchase decisions try to maximize consumer utility with feedback on driving experience, word-of-mouth (social status), etc.
Number of agents: Low 10s
- Conventional fuel stations assumed to be universally available

Initial seed
- depending on volume/profitability, seed will either grow or decline

Retailing agents monitor sales
- Based on sales history, develop sales and profit expectations
- If expectations meet targets, new stations will be added
- If realized profits fall below threshold, station closes

Model will allow to simulate the robustness and sustainability under various initial station seeds
- Station density
- Station dispersion
Production and Delivery Agents

- Producers make investment decisions at certain intervals
  - Each agent goes through its own decision making process by forecasting prices and profits for a number of years into the future
  - Choice of several production and delivery options

- Decisions can be based on multiple objectives
  - Profits, market share

- Decisions account for uncertainties, e.g.,
  - Demand/price of H2 (based on marginal production cost plus markup)
  - Action of competitors

- Decisions for all producers are aggregated and the system is updated before simulating the next time step
  - Producers first announce intended investments
  - Other agents learn this at the start of next decision interval and take into account in their decision routine
  - After construction delay, new facility comes online
  - The process is repeated for all simulation steps

Start, $t = 1$

Producer 1 Decision Making

Producer 2 Decision Making

... Producer N Decision Making

All Investment Decisions (new announcements)

Update system for $t = t + 1$

- H2 Demand
- Existing H2 capacity
- Announcements

Exogenous Input Data

Terminate

$t$ – decision year

$T$ – last decision year
Production and Delivery Agents (cont’d)

- Number of agents: 2 – 5
- Agents have different preferences
  - Financial targets
  - Risk profiles
  - Time horizons
- Results for all decision criteria are computed for all possible combinations of scenarios over all forecast steps
  - Feeds into decision analysis that each agent uses to evaluate potential investment alternatives based on a producer’s risk preferences and trade-offs among different decision criteria
- Initially, all producer agents use the same general decision model, differentiation occurs due to
  - Differences in risk and trade-off preferences
  - Available investment alternatives
  - Learning about competitors
- Producer agents look at portfolio profits (existing and potential new production)
Current Status

- Currently developing model environment
- Team is working on agent definitions
- Team has started reviewing and compiling model inputs