SAND2008-5992P

Analysis Of Energy Infrastructures And Potential Impacts From An Emergent Hydrogen Fueling Infrastructure

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Project ID # ANP4

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Sandia is a multiprogram laboratory operated by Sandia Corporation, a Lockheed Martin Company, for the United States Department of Energy's National Nuclear Security Administration under contract DE-AC04-94AL85000.

Overview

Timeline

- Start – Dec. 2007
- Finish – Sep. 2015
- 2% complete

Budget

- Total project funding
  - DOE $200K
- Funding received in FY07
  - $0K
- Funding for FY08
  - $150K

Barriers

- A. Future Market Behavior
- B. Stove-piped/Siloed Analytical Capability
- E. Unplanned Studies and Analysis

Targets

- Analyze issues and long term impacts related to infrastructure evolution, hydrogen fuel, and vehicles (Task 1)

Partners

- Looking to partner with UC-Davis and UC-Berkeley as program grows

Objectives

- **Use dynamic models of interdependent infrastructure systems (natural gas, coal, electricity, petroleum, water, etc.) to analyze the impacts of widespread deployment of a hydrogen fueling infrastructure**
- **Identify potential system-wide deficiencies that would otherwise hinder infrastructure evolution, as well as mitigation strategies and unintended collateral effects on supporting systems**

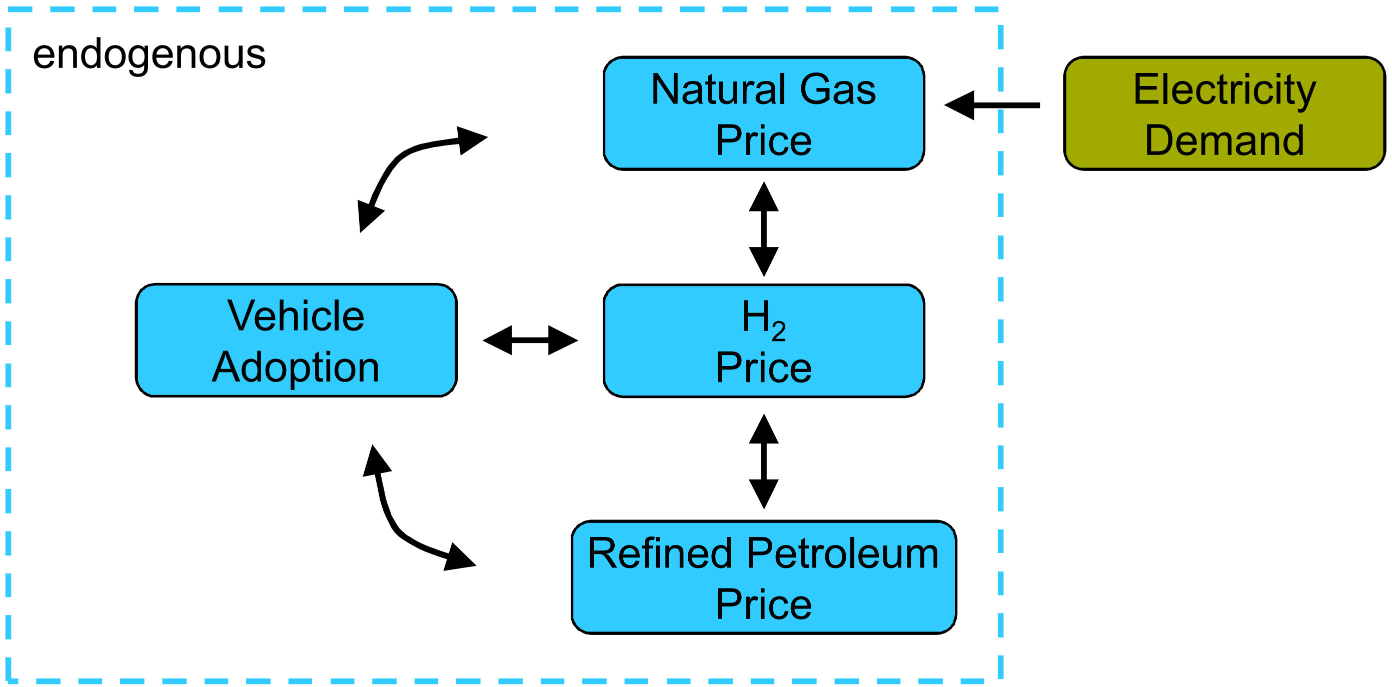
Milestones

MM / YYYY	Milestone
Apr / 2008	Build a SD model of the CA natural gas distribution system coupled to refined petroleum and electricity generation systems in order to execute a regional analysis of the impacts of SMR-derived hydrogen fuel on the natural gas infrastructure.
Sep / 2008	Extend the SD model to include refined details of the electricity generation sector in order to resolve key interdependencies and complex behaviors that may result from non-linear feedback effects. Complete the analysis for CA.

Approach

- **Analysis-driven approach defined by programmatic needs**
  - Provide analysis and insight into the dynamic behavior of complex systems
- **System dynamics: Methodology**
  - Pose detailed questions
    - Will the demand for SMR-derived H_2 negatively impact NG distribution and short circuit vehicle roll-out?
    - Is there a potential for infrastructure interdependency issues to become problematic?
    - Are there means to mitigate negative or amplify positive consequences?
- **System dynamics: Analysis**
  - Formulate SD models of infrastructure components and interrelations to a sufficient level of detail
  - Use Vensim software to quickly and efficiently generate code
    - Dedicate resources to analysis not model formulation

Model California Energy Infrastructures



- **Natural Gas and Refined Petroleum distribution dynamics**
  - Governed by supply/demand market theory
- **Vehicle adoption dynamics**
  - Bass technology diffusion model
- **Electricity distribution dynamic not yet coupled**

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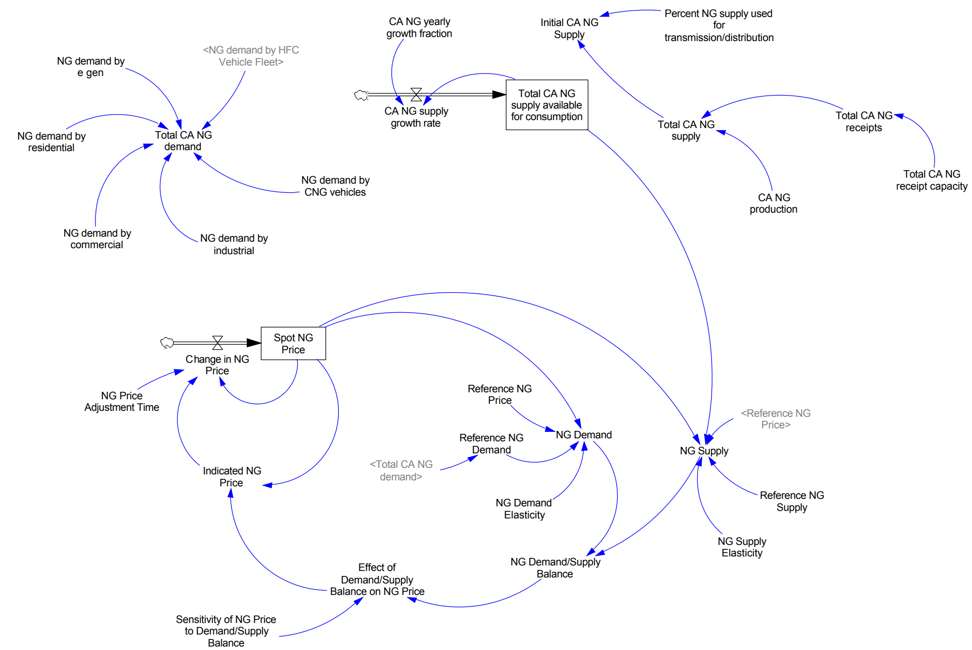
CA Aggregate Natural Gas Distribution Model

California — Natural Gas 2006

*California Energy Commission Report

	Million Cu. Feet	Percent of National Total		Million Cu. Feet	Percent of National Total
Total Net Movements:	1,987,018	—	Industrial:	732,054	11.27
Dry Production:	301,153	1.63	Vehicle Fuel:	10,247	41.12
Deliveries to Consumers:					
Residential:	491,777	11.26	Electric Power:	770,836	12.39
Commercial:	244,432	8.62	Total Delivered:	2,249,347	11.28



- **Supply side dynamic accounts for:**
  - NG receipts, in-state production
- **Demand side dynamic accounts for:**
  - Electric power, industrial, commercial, residential, and CNG vehicle fleet (currently static variables)
  - H_2 fuel via steam methane reforming (dynamic variable)
- **NG spot price determined by:**
  - Market latency and elasticity (both supply and demand)
  - Power law relationship between the demand and supply balance
- **H_2 fuel price a function of NG price, market forces, conversion efficiency, and distribution margins (consistent with H2A)**

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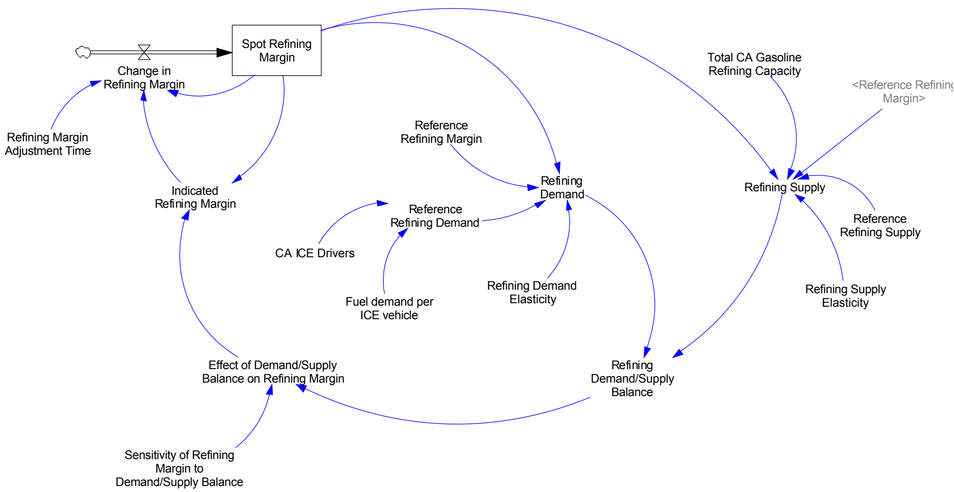
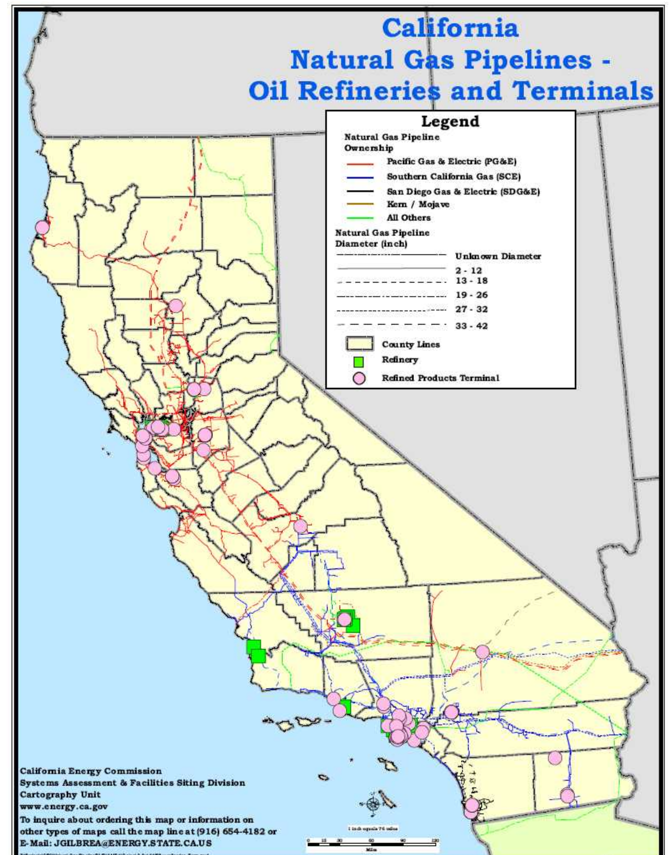
CA Aggregate Refined Petroleum Distribution Model





- **Supply side dynamic accounts for:**
  - Refining capacity (fixed variable)
  - Spot refining margins (dynamic variable)
- **Demand side dynamic accounts for:**
  - Gasoline demand by ICE drivers
- **Gasoline price determined by:**
  - Market latency and elasticity (both supply and demand)
  - Price of oil on world market

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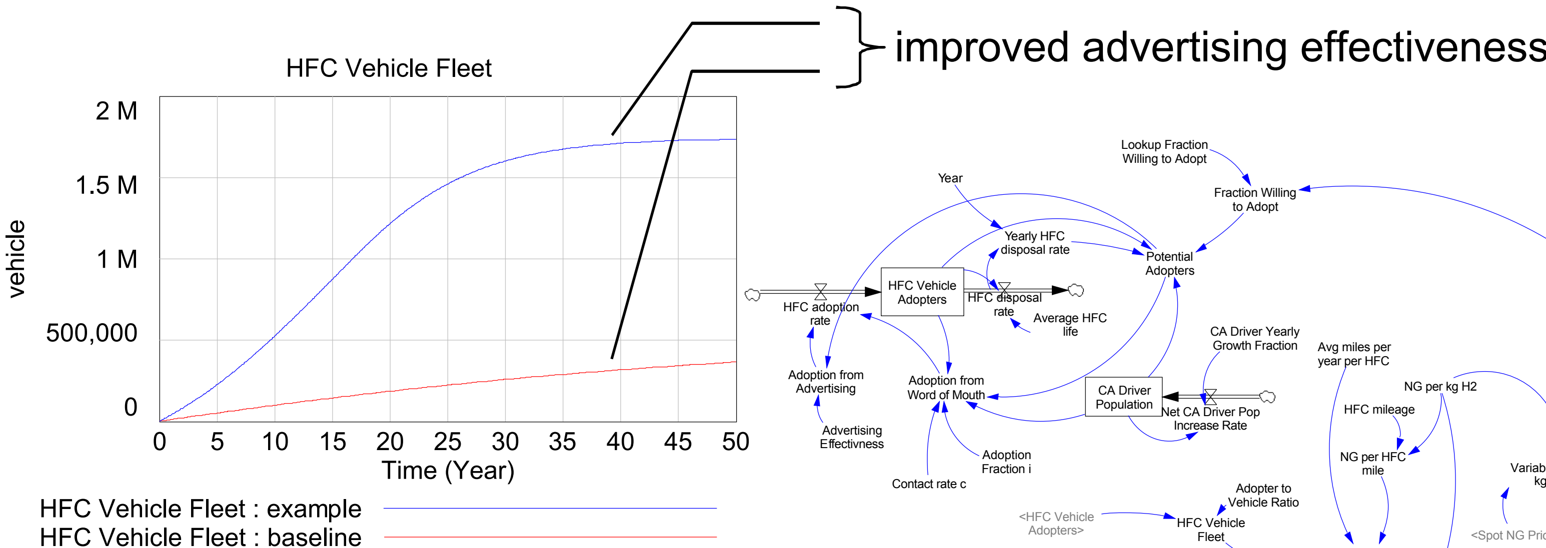
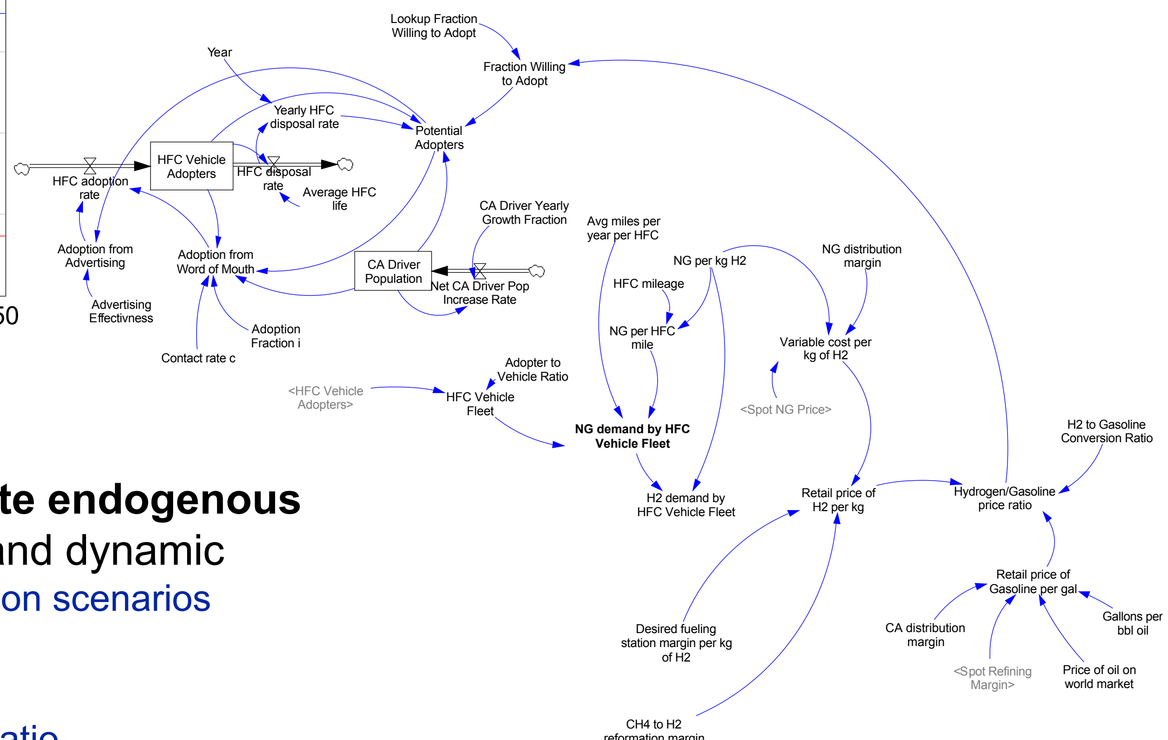
Bass Technology Adoption Model





- **H_2 fueled vehicle adoption rate endogenous**
  - Capture complex fuel demand dynamic
    - No *a priori* imposed adoption scenarios
  - Sensitive to:
    - Advertising effectiveness
    - H_2 Price / Gasoline Price ratio
- **Easily modified to incorporate NREL Discrete Choice Analysis Dynamic**

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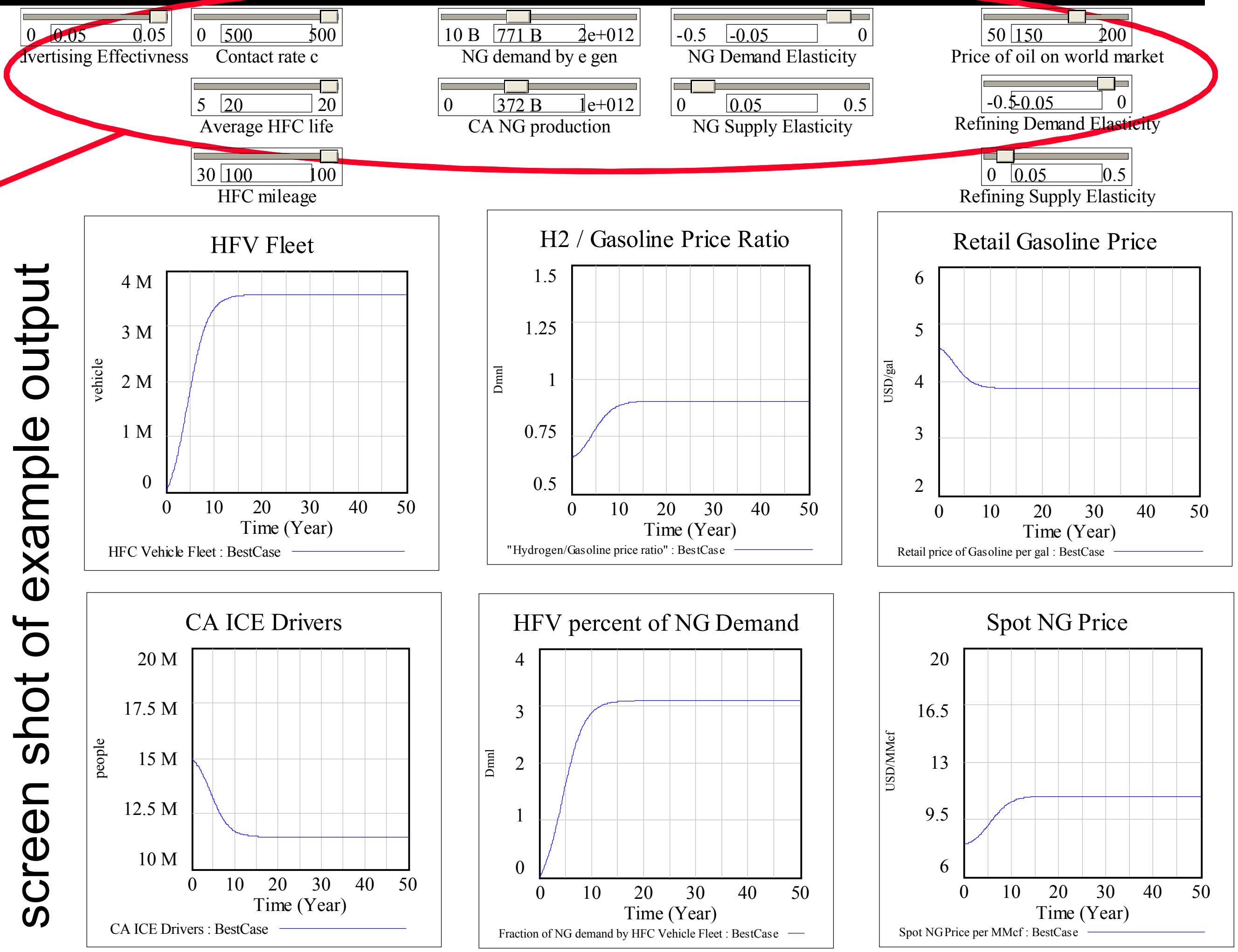
Model Assumptions

- **Endogenous variables**
  - Rate of vehicle adoption
  - Price and demand (NG, H_2, and gasoline)
- **Analysis constrained by fixed or exogenous variables (an incomplete list)**
  - NG demand other than H_2, market elasticity factors, crude oil price, CA population or economic growth, NG or electricity import constraints, +others...
  - Sensitivity analysis can be used to capture the range of dynamic behavior for each of these and infer critical behavior
- **Model does not resolve geospatial features of the infrastructure but can be addressed if necessary**

Impact Of Large H_2 Fueled Vehicle Market Penetration

sliders used to dynamically adjust parameters

screen shot of example output



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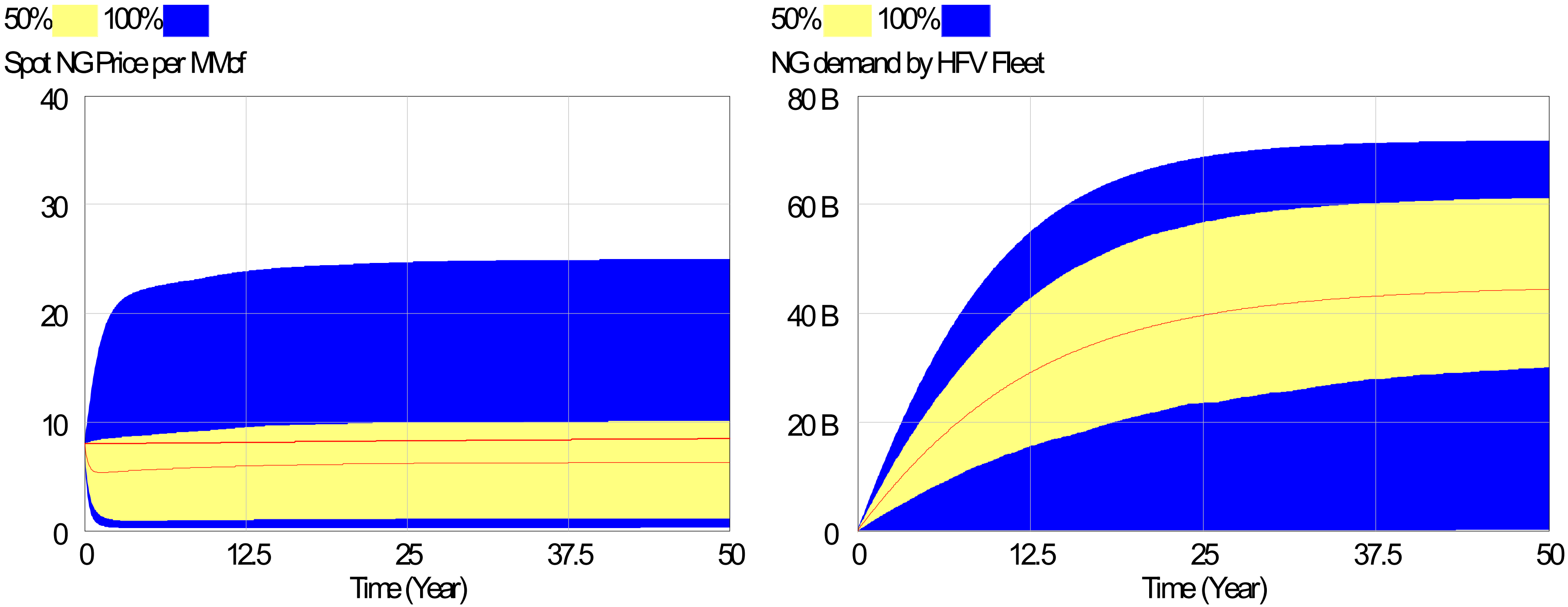
Example Sensitivity Analysis



- **Model runs quickly and efficiently on PC**
- **1000's of scenarios used to execute sensitivity analysis (stochastic sampling of variables)**

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Preliminary Findings

- **A successful H_2 fueled vehicle rollout in CA represents a small amount of new demand**
  - 3.5MM vehicles total about 3% of current NG demand
  - NG infrastructure may have time to adapt over a long time period
    - Increase import capacity

HOWEVER

  - 3.5MM vehicles added tomorrow would be a different matter
    - If NG import capacity does not grow then HFV would stress an already stressed system
    - NG and electrical generation in CA today is at capacity

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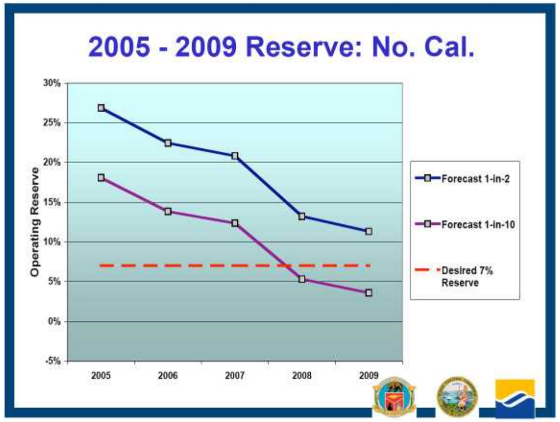
Preliminary Findings

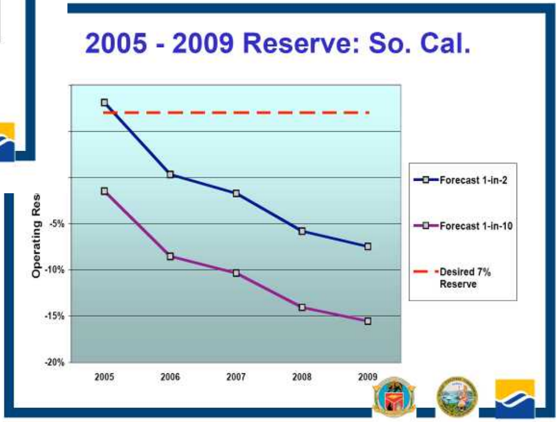
- **Gasoline prices would likely drop as H_2 fueled vehicles penetrate market**
  - Refining capacity in CA is at its limit; decreasing gasoline demand would free up capacity thereby decreasing refinery margins
  - Falling gasoline prices would make HFV less attractive relative to liquid hydrocarbon ICE vehicles
- **The prospect of increasing NG prices and falling gasoline prices due to the H_2 vehicle rollout poses an original question: could HFV become a victim of their own success?**

Future Work

2006 gross system power (GWhr)

Fuel Type	In-State	NW	SW	GSP	GSP %
Coal	17,573	5,467	23,195	**46,235**	**15.7%**
Large Hydro	43,088	10,608	2,343	**56,039**	**19.0%**
Natural Gas	106,968	2,051	13,207	**122,226**	**41.5%**
Nuclear	31,959	556	5,635	**38,150**	**12.9%**
Renewables	30,514	1,122	579	**32,215**	**10.9%**
Biomass	5,735	430	120	**6,285**	**2.1%**
Geothermal	13,448	0	260	**13,708**	**4.7%**
Small Hydro	5,788	448	0	**6,236**	**2.1%**
Solar	616	0	0	**616**	**0.2%**
Wind	4,927	244	199	**5,370**	**1.8%**
Total	230,102	19,804	44,959	**294,865**	**100.0%**





- **Imperative to include the dynamic behavior of CA electricity generation**
  - Relies heavily on the NG infrastructure
  - System already operates at capacity with projected peak power deficits by end of decade

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Future Work

- **Complete analysis for questions posed against CA infrastructures**
  - Integrate electricity and water distribution dynamic
  - Resolve key dynamical behaviors resulting from infrastructure interdependencies
    - Identify system vulnerabilities that may hinder HFV rollout
    - Use a resource utilization metric to quantify system perturbations induced by H_2 fuel demand
- **Assess and analyze other US regions**
  - Investigate issues stemming from coal-to-hydrogen in regions dependent on coal-derived electrical power

Summary

- **System dynamics approach used to analyzing CA energy infrastructures**
  - Developed SD model that describes the complex market behavior of interconnected infrastructures
    - Natural gas, refined petroleum, electricity
  - HFV market adoption endogenous to SD model
    - Bass technology diffusion approach
- **Vensim software used for code development**
  - Fast and flexible model development
    - Dedicate resources to analysis not model building
- **Preliminary results suggests that a successful rollout of HFVs in CA does not dramatically increase demand for natural gas, however...**
  - Natural gas and electricity systems running at capacity in CA
    - Small perturbations in supply/demand dynamics could have significant consequences

Responses to Previous Year Reviewers' Comments

- **This project was not reviewed in FY07**

Publications And Presentations

- None

Critical Assumptions and Issues

- **SD model not sufficiently refined or developed to capture important behavioral patterns**
- **Values assigned to model parameters or variables may be inaccurate or induce unrealistic behavior**

- **To avoid questionable model behavior:**
  - Utilize best available information for deriving pertinent model parameters
    - Databases, reports, public and controlled information
  - Execute detailed sensitivity analysis to identify critical parameters and model variables
    - Focus validation efforts on most critical elements of the model
    - Bound predictive behavior in order to assess trends and model uncertainty

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