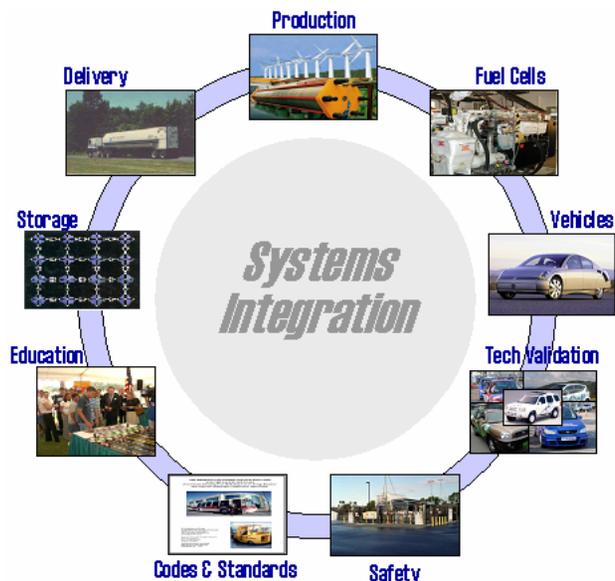


# Macro-System Model



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Project ID # AN4

This presentation does not contain any proprietary or confidential information

# Overview



## Timeline

- Start date: Feb 2005
- Completion: Sept 2010
- Percent complete: 35%

## Budget

- Total funding:
  - 100% DOE funded
- FY07 funding:
  - \$190K NREL/SIO
  - \$336K Sandia NL
  - \$80K other contracts
- FY08 funding
  - \$300K NREL/SIO
  - \$340K Sandia NL

## Barriers

- Stove-piped/Siloed analytical capability (B)
- Inconsistent data, assumptions and guidelines (C)
- Suite of Models and Tools (D)

## Partners

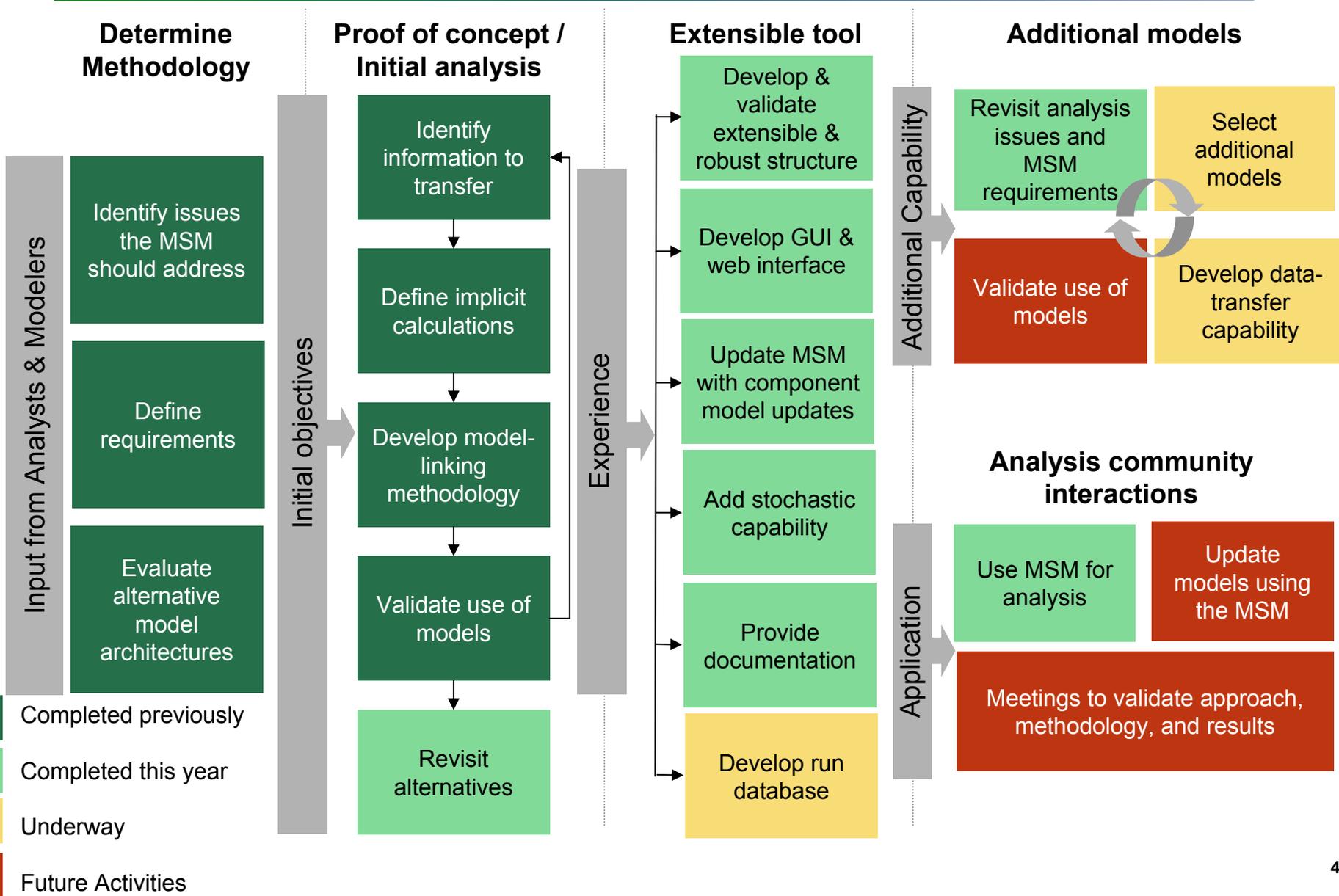
- Sandia National Laboratories (computational development)
- NREL (H2A Production, well-to-wheel analysis validation, HyDRA)
- ANL (HDSAM, GREET, well-to-wheel analysis validation)
- Sentech (Documentation)
- Directed Technologies, Inc (HyPRO)

# Project Objectives



- **Overall objectives**
  - **Develop a macro-system model (MSM) aimed at**
    - **Performing rapid cross-cutting analysis**
      - Utilizing and linking other models
      - Improving consistency of technology representation (i.e., consistency between models)
    - **Supporting decisions regarding programmatic investments and focus of funding through analyses and sensitivity runs**
    - **Supporting estimates of program outputs and outcomes**
- **2007/2008 objectives**
  - **Improve structure of the MSM and develop a GUI**
  - **Update versions of component models**
  - **Add stochastic analysis capability**
  - **Validate MSM results**
  - **Begin interaction between MSM and spatial and temporal models**

# Approach: MSM Development





**Financial**  
What effects could policy and incentives have on transition?

**Environmental**  
How / how much does a hydrogen economy affect the environment?

**R&D**

ID critical / risky links in potential hydrogen pathways?

Are the current technical targets the best ones? What interdependencies do they have?

How should components and interfaces be optimized?

**Transition**

Compare potential transition pathways.

ID stumbling blocks that could affect transition paths? Could R&D overcome them?

What impacts could competing technologies have on transition?

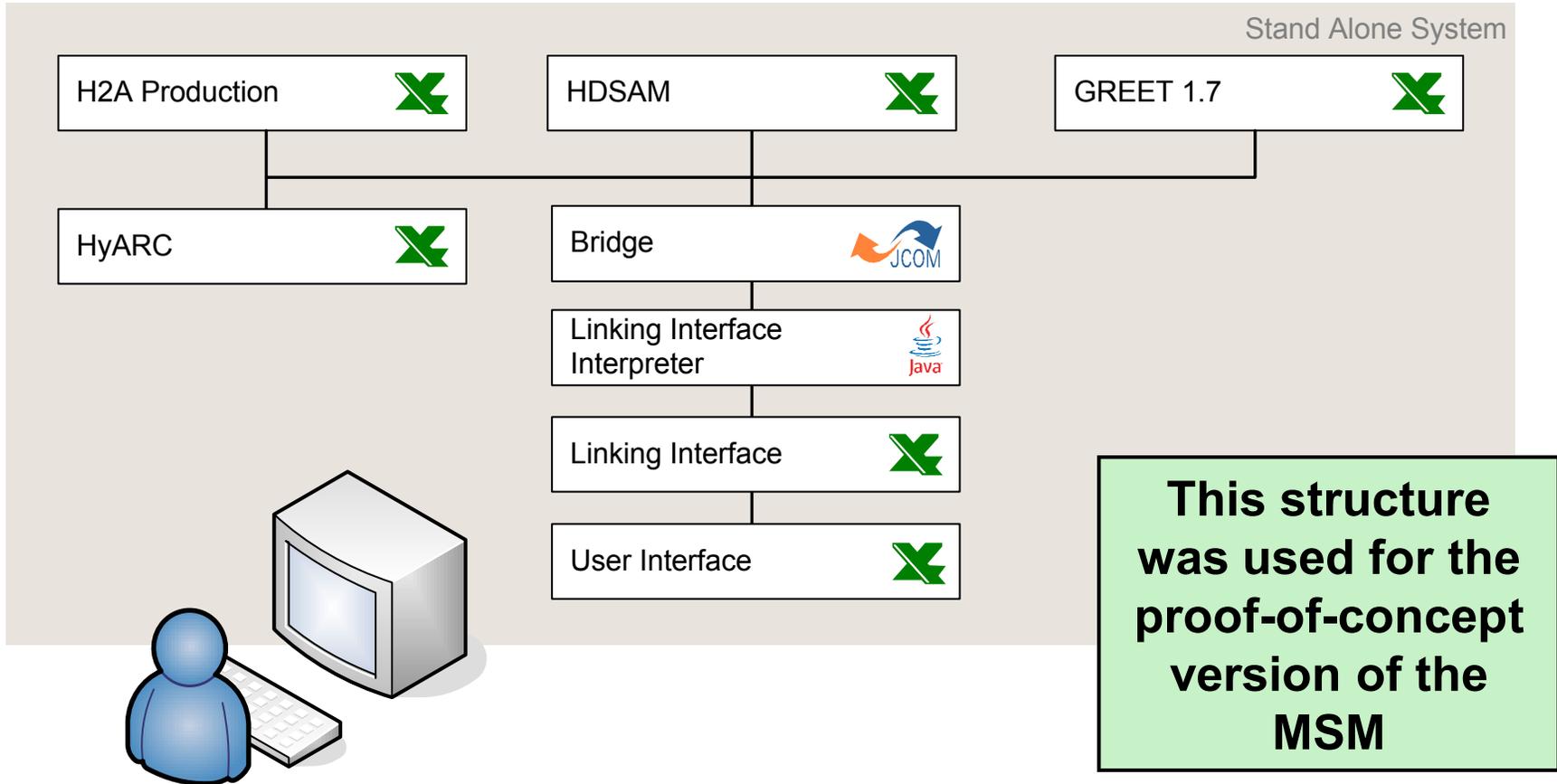
**What is the emissions profile if hydrogen is used?**

**Comparison of hydrogen costs at the pump using different hydrogen production technologies.**

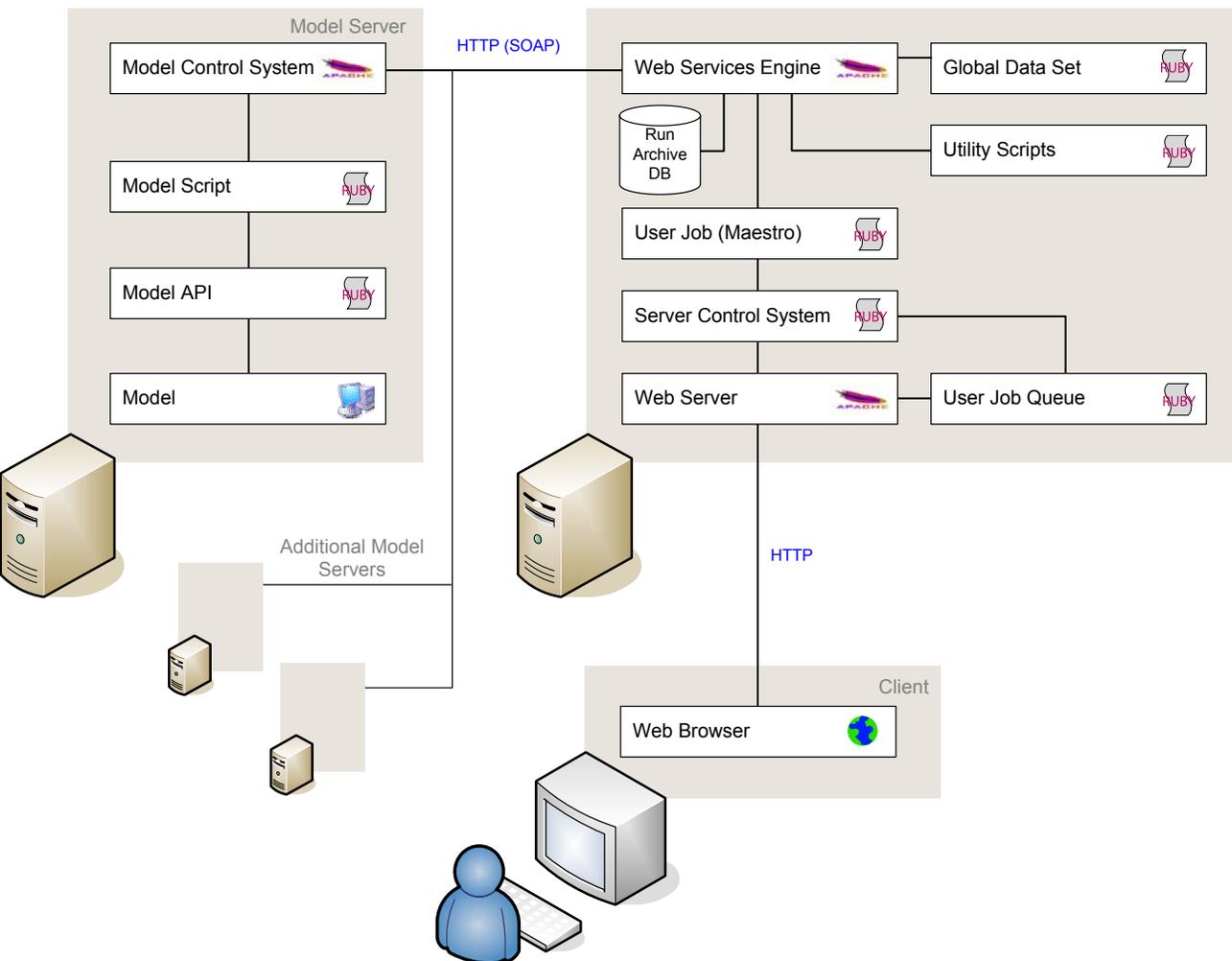
**How much hydrogen needs to be produced to supply a given city its demands?**

**What are the raw material needs to meet those demands?**

**Issues we are addressing initially**

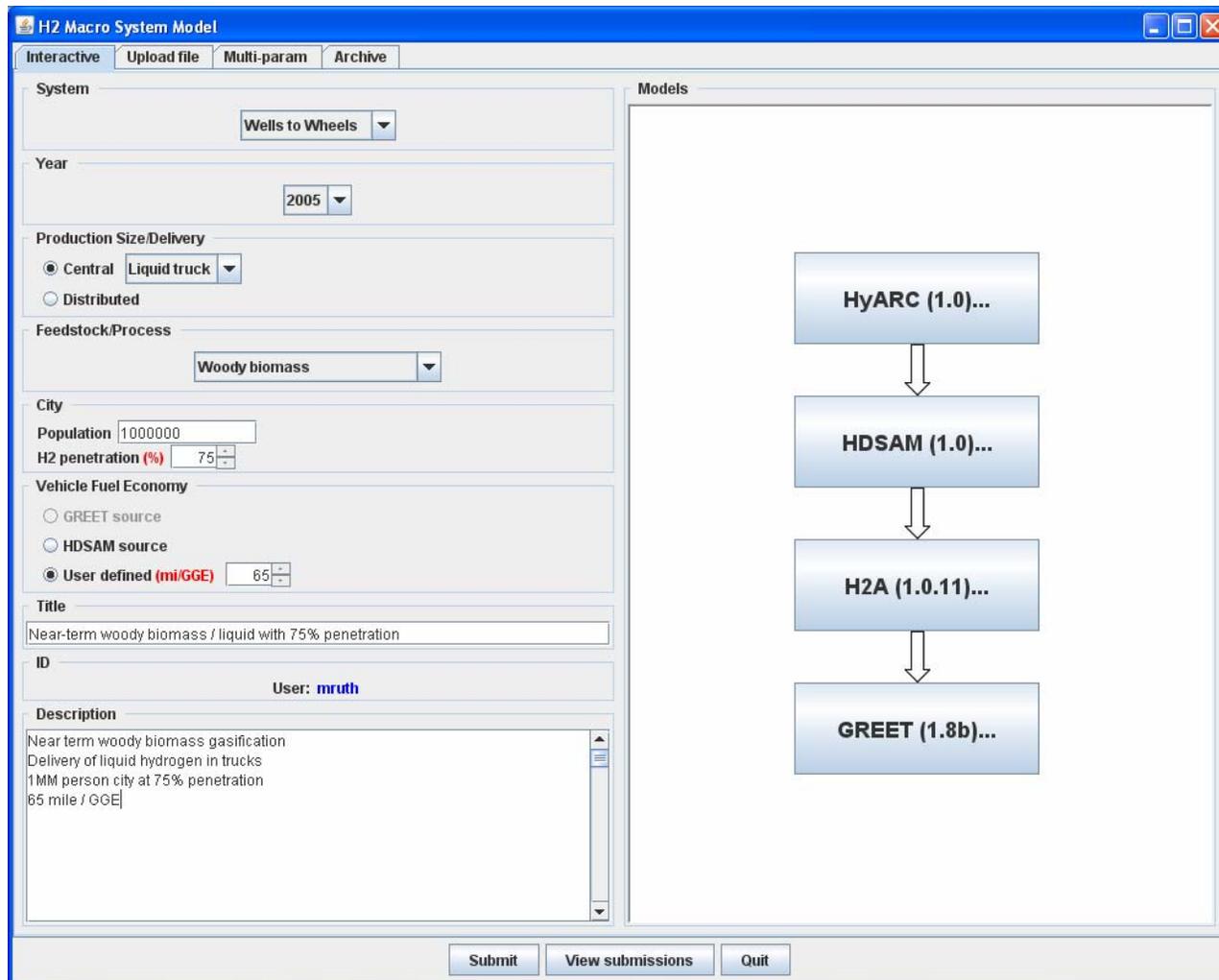


- Federated Object Model (FOM) approach was selected
- Information to be transferred between models was identified
- An Excel-based linking interface was developed with a Java/COM application to transfer data between the linking spreadsheet
- Model use was validated & initial analysis completed



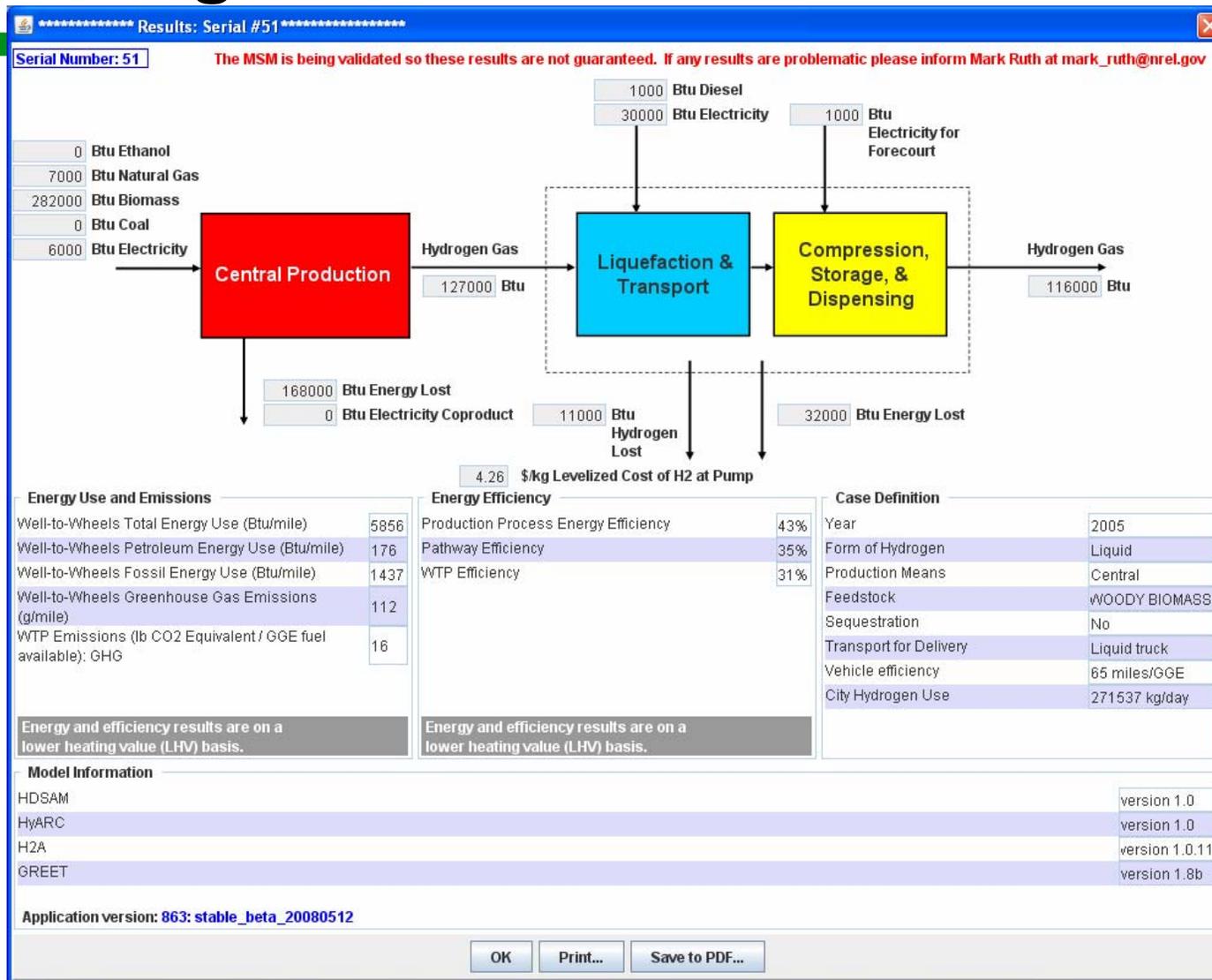
- **Converted MSM structure from Excel/Java to Ruby**
- **Ruby version is more stable and allows for additional data types**
- **Developed technique that allows models to run on different machines**
- **Developed web-browser based graphical user interface (GUI) to make the MSM available to more users**
- **Validated results against proof-of-concept MSM**

# Progress: GUI & Web Interface



GUI available to hydrogen analysts at <http://h2-msm.son.sandia.gov/>  
User defines technology, timeframe, population, and penetration.  
MSM is run and model results generated.

# Progress: GUI & Web Interface



Pathway costs, efficiencies, and well-to-wheels results are reported. Pathway results are shown and user can print them or save them to a pdf. User can also download the results in a csv file for table and figure creation.



Model	Proof-of-Concept MSM	Current MSM Version
HyARC	Heating values for hydrogen & fuels (downloaded in 2006)	Heating values for hydrogen & fuels (downloaded in 9/07)
H2A Production	Versions 1.0.9, 1.0.10, & 1.0.11 (downloaded in 2006)	Version 2.0 (Soon to be publicly available)
HDSAM	Version 1.0 (downloaded in 2006 & made a couple minor corrections)	Version 2.0 (Soon to be publicly available)
GREET	Version 1.7 (downloaded 2/21/07 & made a couple minor corrections)	Version 1.8B (downloaded 3/17/08 & made one minor correction)

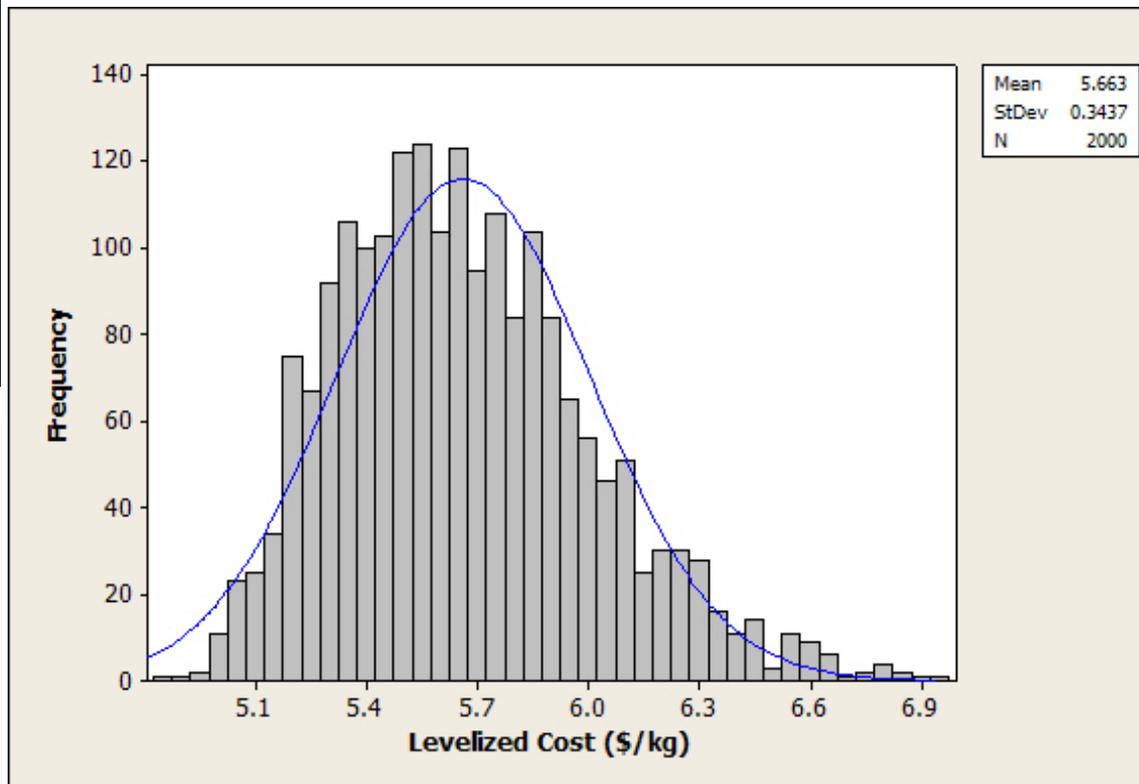
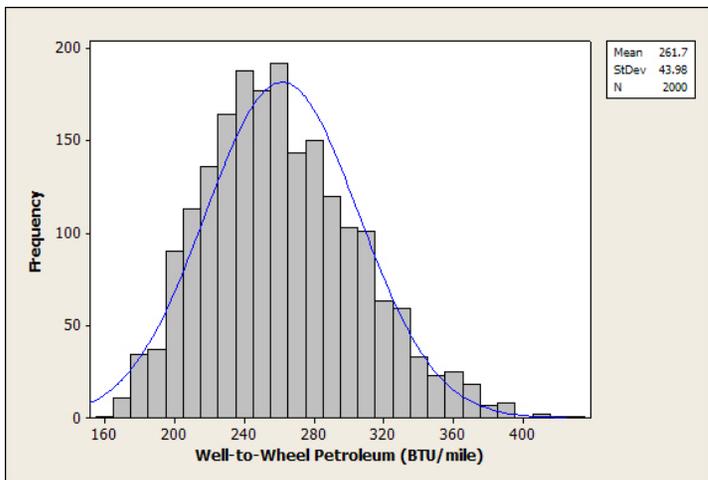
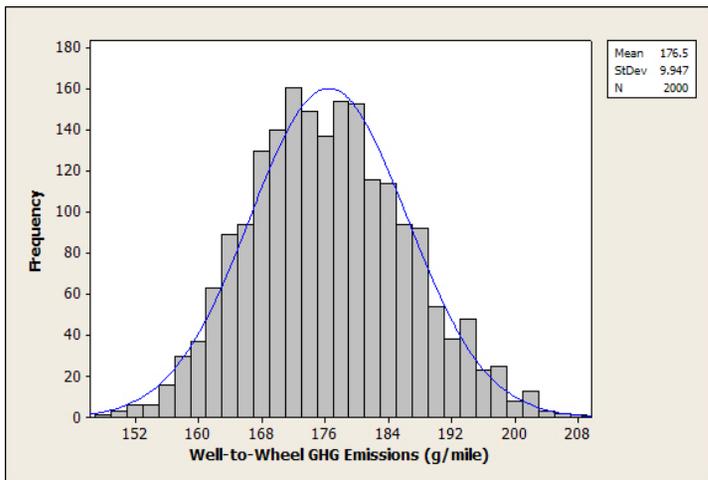
**Version updates required identification of modified input and output cells, modified model structure, and validation of results from the new model.**

Green fill indicates model versions used for results on previous slide



- **Monte Carlo simulation using DAKOTA**  
(<http://www.cs.sandia.gov/DAKOTA/>)
  - DAKOTA (Design Analysis Kit for Optimization and Terascale Applications) toolkit was developed at Sandia
  - It provides algorithms for optimization; uncertainty quantification; parameter estimation; and sensitivity/variance analysis.
- **Example Analysis**
  - Near term biomass gasification with liquid hydrogen delivery in trucks to a 250,000 person city with 50% penetration
  - # samples = 2000
  - 7 inputs, triangular distribution
    - Biomass feedstock consumption (kg/kg\_H2)
    - Biomass feedstock cost (dollar/kg)
    - Vehicle fuel efficiency (mile/GGE)
    - Production FTEs
    - Production total capital investment (dollar)
    - Production capacity factor
    - Poplar farming energy use (joule/kg)
  - 5 outputs/responses
    - Well-to-Wheel total energy consumption (Btu/mile)
    - Well-to-Wheel fossil fuels consumption (Btu/mile)
    - Well-to-Wheel GHG emissions (g/mile)
    - Well-to-Wheel petroleum energy consumption (Btu/mile)
    - Pathway levelized cost (dollar/kg)

## Example Results



Analysis run with H2A V 1.0.9, HDSAM V 1.0, and GREET 1.7

# Progress: Documentation



- **Draft user manual available**
- **Provides an overview**
  - **Goals**
  - **Scope**
  - **Component model links**
  - **Model structure**
  - **Restrictions, assumptions, constraints**
- **Provides guidance**
  - **Typical end user (using web-based GUI)**
  - **Advanced user (using Ruby and own versions of models)**
- **Is a living document that will be updated as the MSM is modified.**



## Discussions with Model Developers

- Understand the model's purpose & use
- Compile lists of inputs and results
- Recommend modifications to component models

## Understand models intimately

- Definition of terms
- Calculation methodology

## Comparison to other analyses & previous MSM runs

- Meticulous review of inputs & results
- Mapping between results from different analyses
- Many pathways were mapped to the posture plan
- Other pathways were compared in the HyWAYS / IPHE project

## Interaction with community (analysts & industry)

- Present & discuss methods & results
- Reach consensus on approach & parameters

# Key Assumptions



**Pathway assumptions are entered. Other assumptions are embedded in the models being linked but are changed in sensitivity runs**

## Pathway Assumptions

- Full-deployment scenario
- Urban demand area
- 250,000 person city
- 50% H<sub>2</sub> penetration
- 1500 kg/day stations
- Mid-size FCV –
  - Current - 57.1 mi / GGE
  - Advanced – 62.7 mi / GGE

## Financial

- 10% DCFROR
- 20 year plant life
- MACRS depreciation where appropriate

## Production

- Central Biomass
  - Current – 45% conversion eff.
  - Advanced – 51% conversion eff.
- Coal Gasification
  - Current – 72% gasifier eff. & 80% PSA eff.
  - Advanced – 72% gasifier eff. & 95% HSD eff.
- Central Natural Gas Reforming
  - Current – 82% SMR eff. & 80% PSA eff.
  - Advanced – 82% SMR eff. & 80% PSA eff.
- Distributed SMR
  - Current – 68.7% production unit efficiency
  - Advanced – 83.7% production unit efficiency
- Distributed Electrolysis
  - Current – 64% production efficiency
  - Advanced – 67% production efficiency

## HDSAM

- Fueling station capacity factor = 0.7
- 62 miles from central production to city
- Liquefier efficiency 75.5%

## GREET

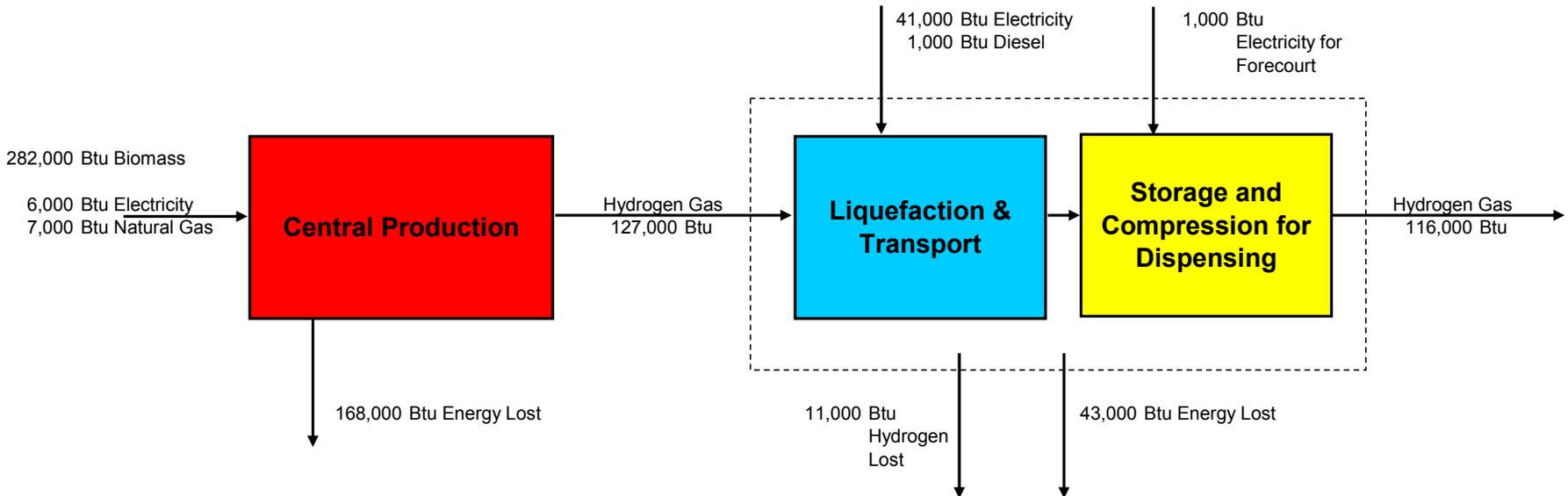
- Gasoline is RFG without oxygenate
- Current technologies use US average grid mix
- Advanced technologies use future grid mix with 85% of CO<sub>2</sub> from coal plants sequestered

# Analysis: Posture Plan Comparison



Reviewed all pathways in 2006 Hydrogen Posture Plan

Near-term biomass liquid pathway MSM results shown in black  
 Posture plan results shown in blue

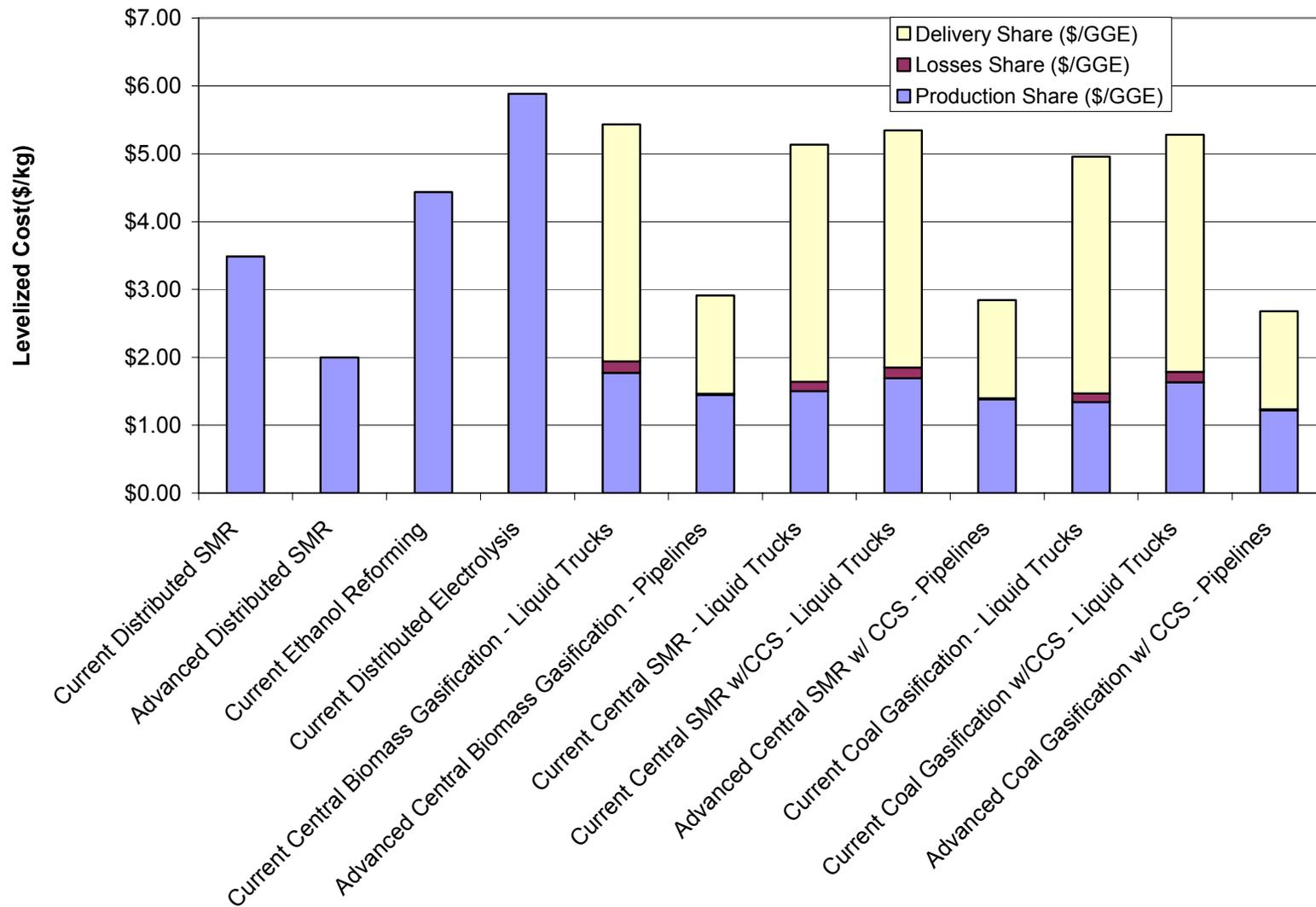


Well-to-Wheels Total Energy Use (Btu/mile)	7,426	<b>6600</b>
Well-to-Wheels Petroleum Energy Use (Btu/mile)	235	<b>200</b>
Well-to-Wheels Greenhouse Gas Emissions (g/mile)	180	<b>190</b>
Levelized Cost of H2 at Pump (\$/kg)	5.43	<b>5.10</b>

Production Process Energy Efficiency	43%	<b>45%</b>
Pathway Efficiency	34%	<b>40%</b>

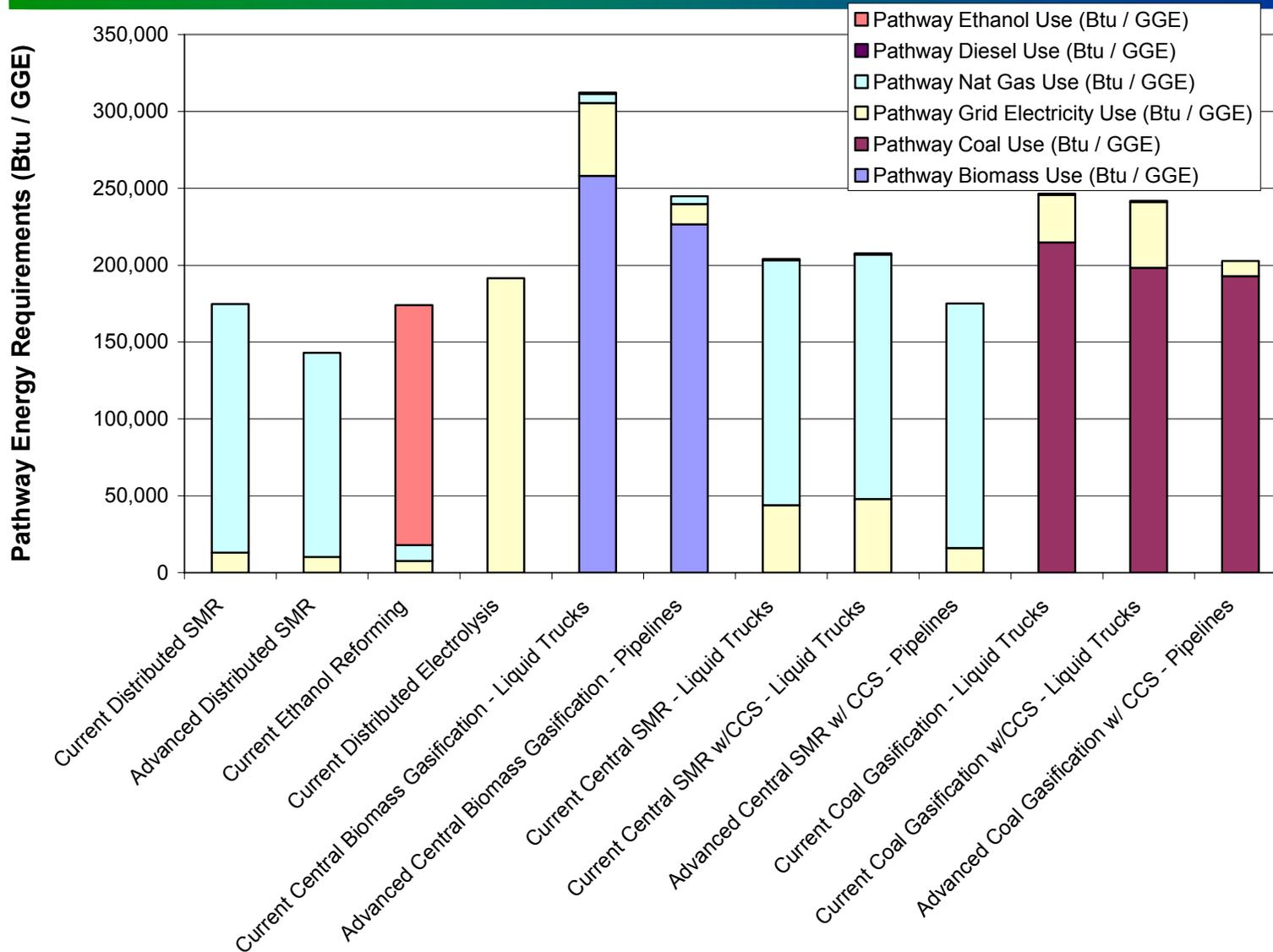
**Case Definition**  
 Year: 2005  
 Hydrogen as Liquid  
 Central Production

- Hydrogen losses were not fully incorporated in the posture plan. Incorporation of those losses drove up energy use and emissions.
- In the posture plan, GREET was set to herbaceous biomass. Setting GREET to use woody biomass reduced GHG emissions.
- The production and liquefaction efficiency were slightly different between HDSAM & GREET. Making them consistent affected results.



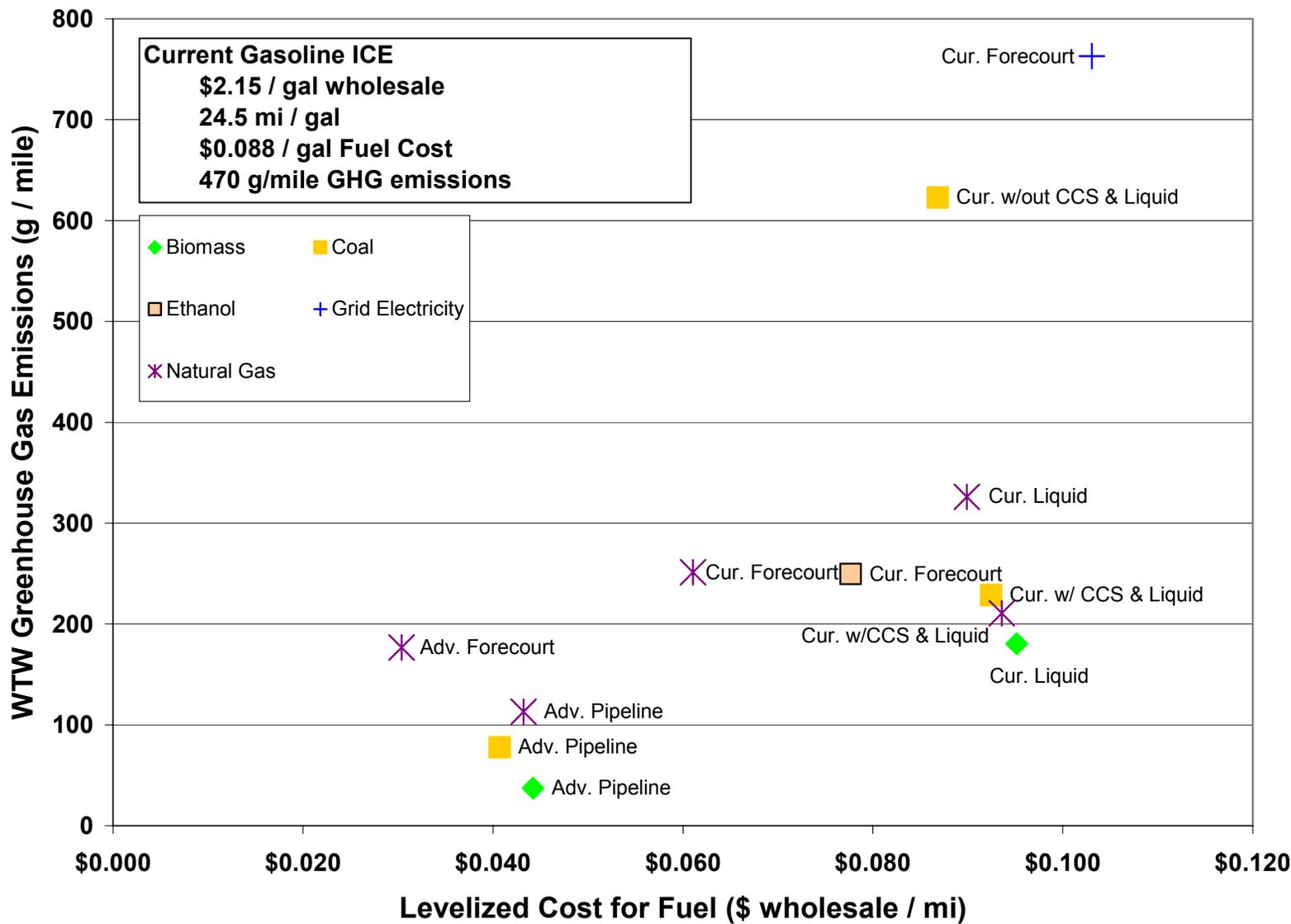
**Results from proof-of-concept version of the MSM**

# Analysis: Comparison of Energy Use



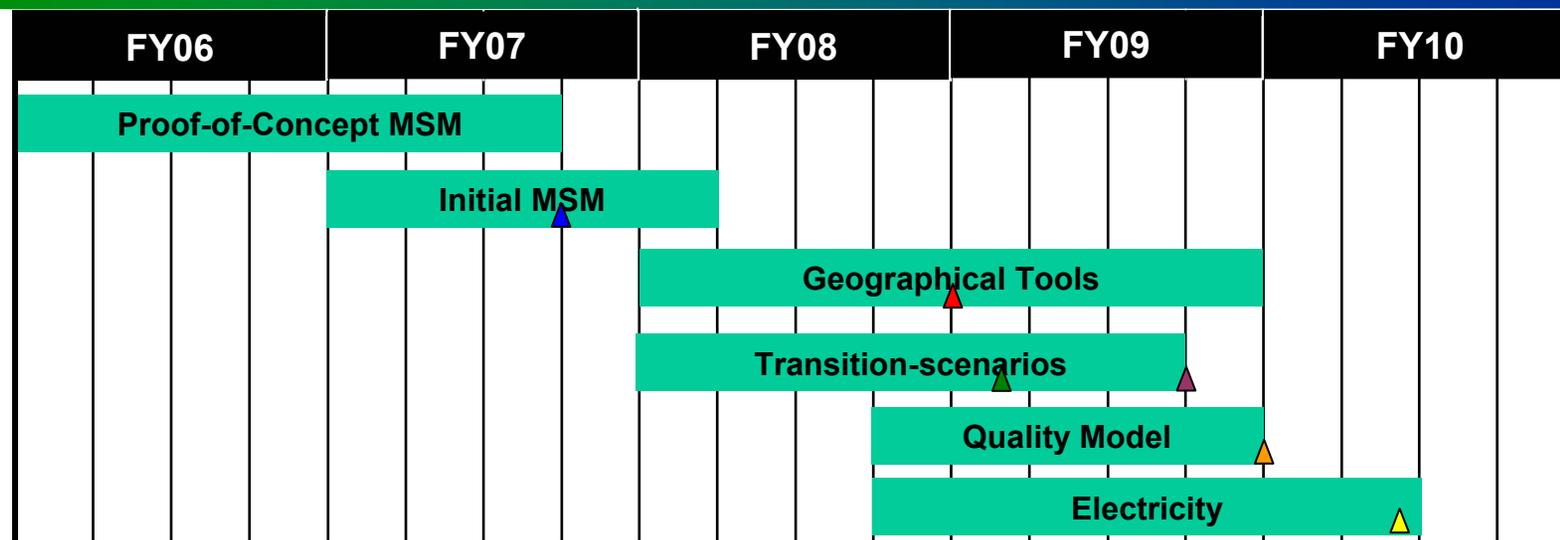
Results from proof-of-concept version of the MSM

# GHG Emissions vs Fuel Cost



Results from proof-of-concept version of the MSM

# Proposed Future Work



- **Proof-of-Concept MSM (H2A Production, HDSAM, GREET linked with Excel and Java)**
  - Peer-reviewed (September 11, 2007)
- **Initial version of an extensible MSM (H2A Prod., HDSAM, GREET linked with Ruby)**
  - Create a stable, extensible, and user-friendly MSM
  - ▲ Make MSM available on password protected internet site (September 11, 2007)
  - Develop stochastic modeling capability and decision-making tools
- **Link geographical tools to MSM**
  - ▲ Initial linkage of HyDRA to the MSM (September 30, 2008)
  - Full linkage of HyDRA to the MSM
- **Link transition-scenario models to MSM**
  - Determine next set of issues that need to be addressed
  - ▲ Link HyPRO to MSM (November 30, 2008)
  - Consider linking HyTRANS or HyDS
  - ▲ Review transition scenarios using the MSM (June 30, 2009)
- ▲ Link hydrogen quality model to MSM (September 30, 2009)
- ▲ Add stationary electrical generation and electrical infrastructure (February 28, 2010)

# Summary



- **The MSM is being built to address priority analysis issues**
- **The proof-of-concept version of the MSM includes H2A Production, HDSAM, and GREET . It was used for analysis and has been updated.**
- **A web-based MSM GUI is available to hydrogen analysts.**
- **Stochastic capability has been added to the MSM**
- **The MSM is being used for programmatic analysis.**

# Acknowledgements



- **Sandia National Laboratories**
  - Timothy Sa, Michael Goldsby, Keith Vanderveen, Pam Williams
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