

# Macro-System Model

(project #AN\_04\_Diakov)



**2009 DOE Hydrogen  
Program Review**

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Arlington, VA**

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**Sandia  
National  
Laboratories**

# Overview

## Timeline

Start date: Feb 2005

Completion: Sept 2010

Percent complete: 65%

## Budget

Total funding:

- 100% DOE funded

FY08 funding

- \$300K NREL/SIO
- \$340K Sandia NL

FY09 funding

- \$525K NREL/SIO
- \$370K 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)

# Relevance: 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 through analyses and sensitivity runs
  - Supporting estimates of program outputs and outcomes

## 2008/2009 objectives

- Improve structure of the MSM and expand GUI capabilities
- Update versions of component models
- Expand stochastic analysis capability
- Build interaction between MSM and spatial and temporal models

# Key assumptions

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

## Production

- Central Biomass
  - Current – 46% conversion eff.
  - Advanced – 48% conversion eff.
- Coal Gasification
  - Current – 55% conversion eff.
  - Advanced – 55% conversion eff.
- Nuclear HTE
  - Advanced – 83% conversion eff.
- Distributed SMR
  - Current – 71% conversion efficiency
  - Advanced – 74% conversion efficiency
- Electrolysis
  - Current – 62.5% production efficiency
  - Advanced – 75% production efficiency

## Financial

- 10% IRR
- 20 year plant life
- MACRS depreciation where appropriate
- 1.9% inflation

## Pathway Assumptions

- Full-deployment scenario
- Urban demand area
- 1,250,000 person city
- 50% H<sub>2</sub> penetration
- 1500 kg/day stations
- Mid-size FCV –
  - Current - 57 mi / GGE
  - Advanced – 65 mi / GGE

## HDSAM

- Fueling station capacity factor = 0.7
- 76 miles from central production to city
- Liquefier efficiency 77%

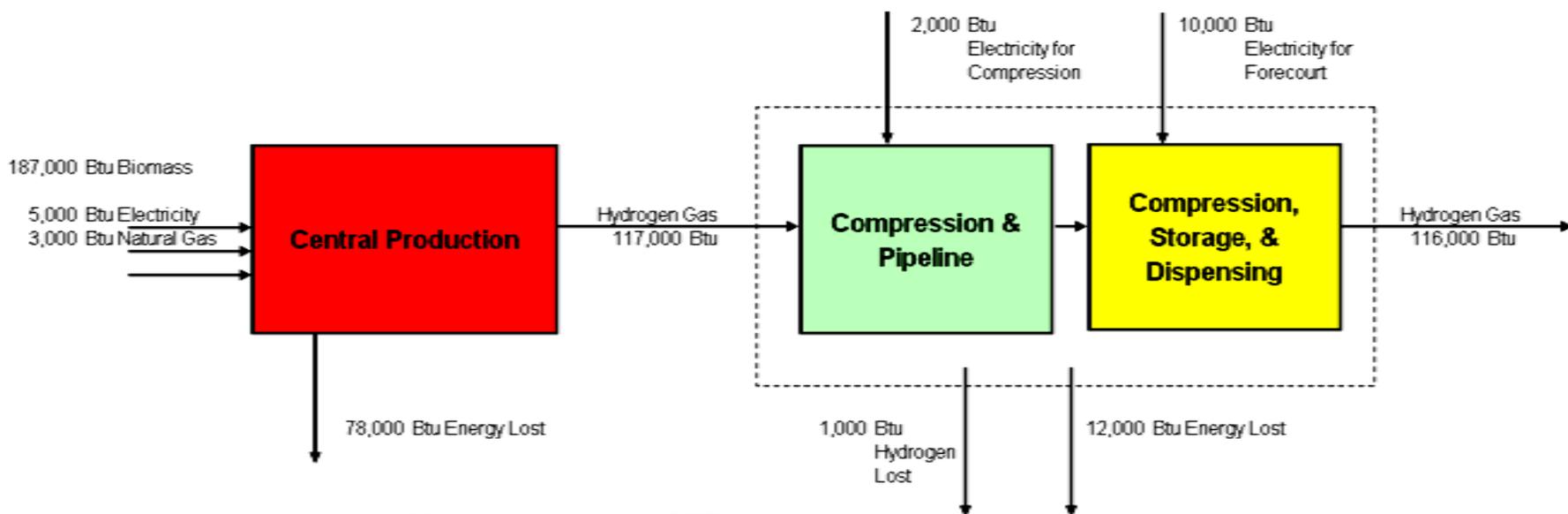
## GREET

- 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

# Relevance: supporting program goal setting

The MSM is a tool for cross-cutting H2 production pathways analysis – both economics and emissions, which makes it instrumental in assessing technology potential for **Posture Plan** updates

## Hydrogen Produced In Central Plant and Transported as Gas via Pipeline (R090213E)



Known Issue: Hydrogen losses are estimated in HDSAM but are not included in GREET

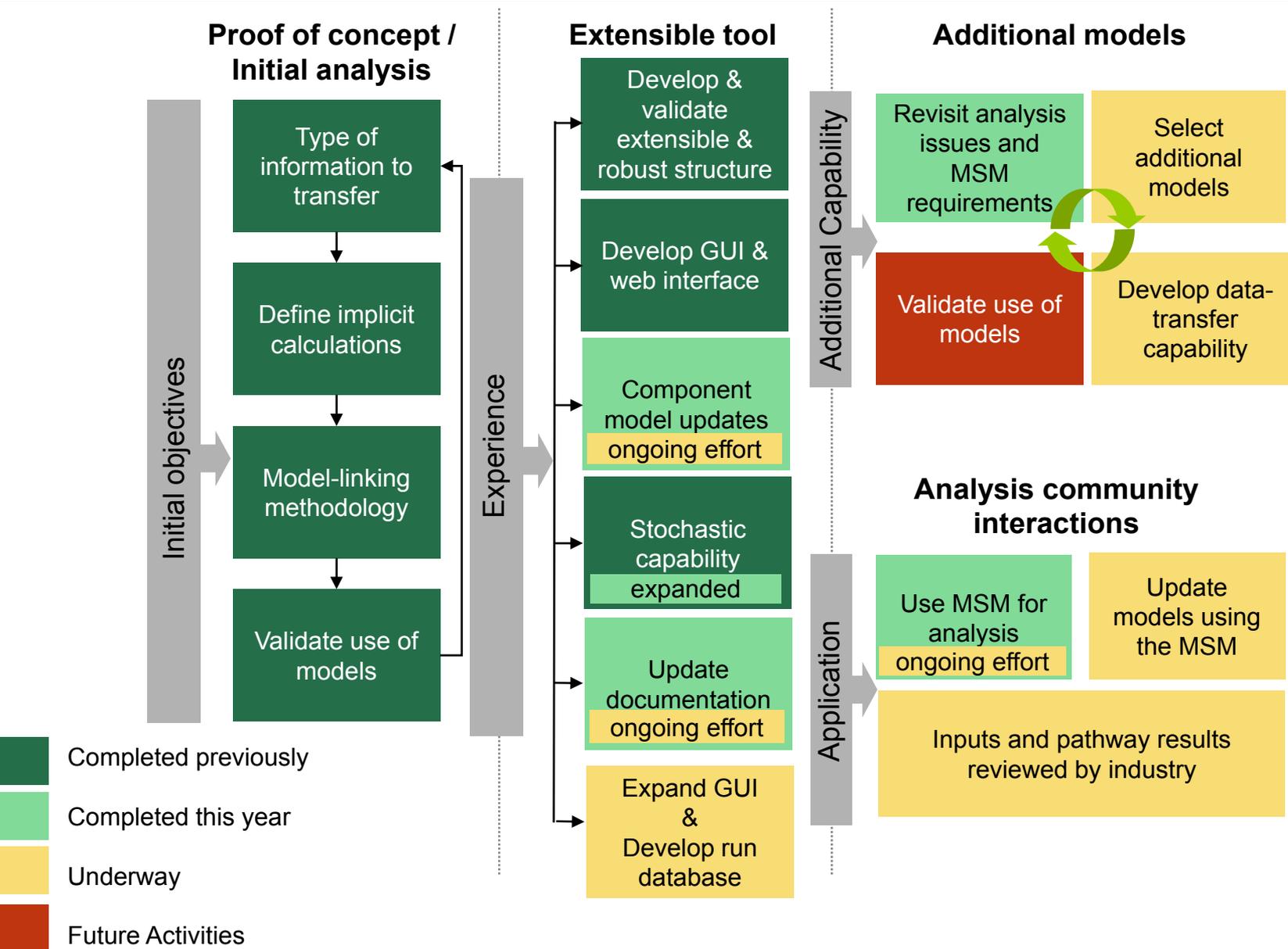
Well-to-Wheels Total Energy Use (Btu/mile)	3,707
Well-to-Wheels Petroleum Energy Use (Btu/mile)	96
Well-to-Wheels Greenhouse Gas Emissions (g/mile)	53
Levelized Cost of H2 at Pump (\$/kg)	3.26

Production Process Energy Efficiency	60%
Pathway Efficiency	56%
WTP Efficiency	48%
WTP Emissions (lb CO2 Equivalent / GGE fuel available):	8

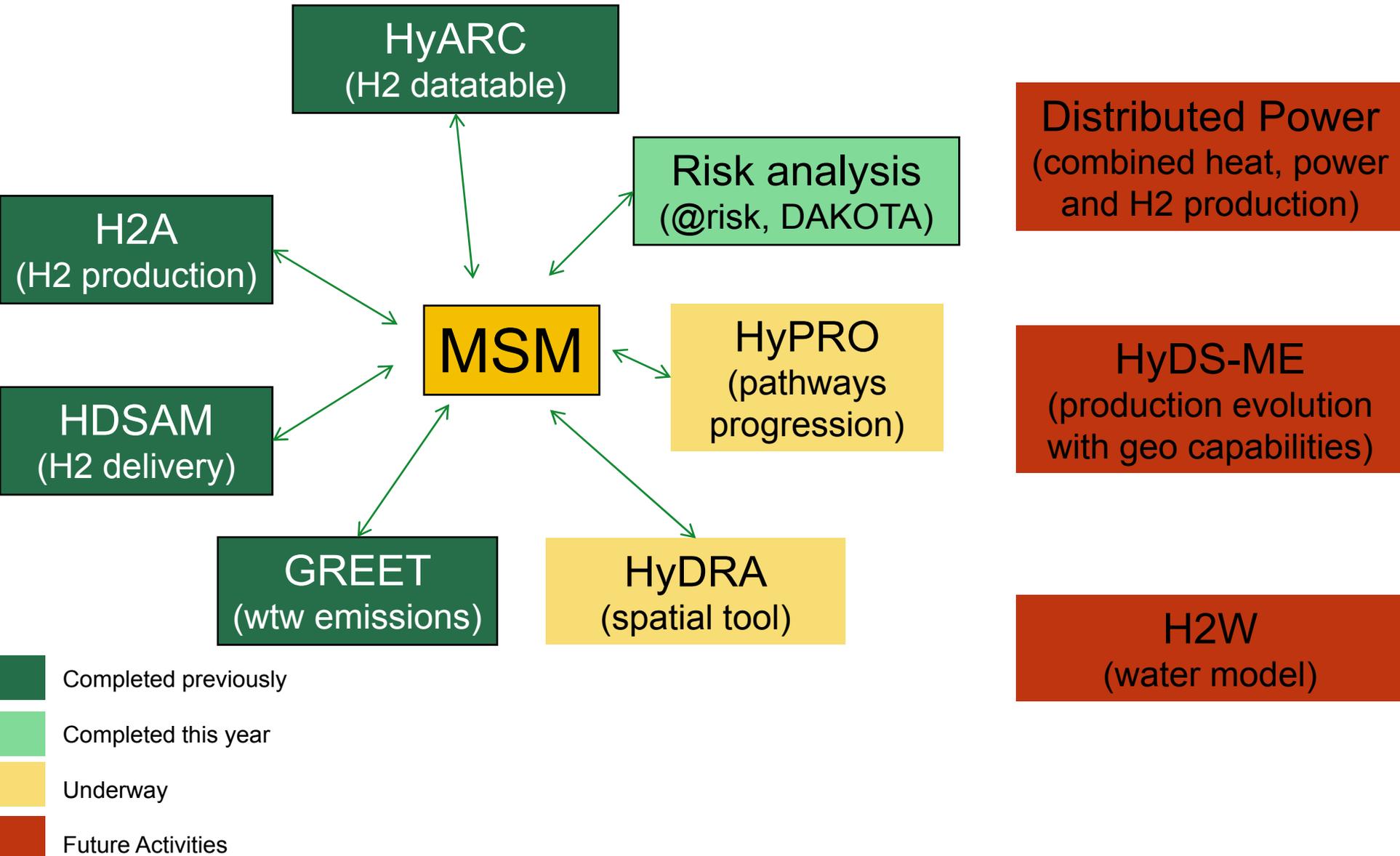
### Case Definition

Year: 2020  
 Hydrogen as Gas  
 Central Production  
 Woody Biomass Feedstock  
 Sequestration: No  
 Transport for Delivery: Pipeline  
 Vehicle Efficiency: 65.0 mile / GGE  
 City Hydrogen Use: 238466 kg/day

# Approach: MSM development



# Progress and Future Work: Overview



# Accomplishment: GUI and web interface

The screenshot shows the 'H2 Macro System Model' web interface. It features a top navigation bar with 'Interactive', 'Upload file', 'Multi-param', and 'Archive' tabs. The main content area is divided into two columns: 'System' on the left and 'Models' on the right. The 'System' column contains several sections with input fields and controls:

- System:** A dropdown menu set to 'Wells to Wheels'.
- Year:** A dropdown menu set to '2005'.
- Production Size/Delivery:** Radio buttons for 'Central' (selected) and 'Distributed'. A dropdown menu next to 'Central' is set to 'Liquid Truck'.
- Feedstock/Process:** A dropdown menu set to 'Woody biomass'.
- City:** A 'Population' input field with '1000000', and an 'H2 penetration (%)' input field with '75'.
- Vehicle Fuel Economy:** Radio buttons for 'GREET source', 'HDSAM source', and 'User defined (mi/GGE)' (selected). A corresponding input field contains '65'.
- Title:** A text input field containing 'Near-term woody biomass / liquid truck / 75% market penetration'.
- ID:** A text input field containing 'User: null'.
- Description:** A text area containing 'Near-term woody biomass gasification', 'Delivery LH2 trucks', '1MM city population, 75% market penetration', and '65 mi/gge H2 FCV'.

At the bottom of the 'System' column is a button labeled 'Edit Detailed Inputs =>'. The 'Models' column is currently empty. At the bottom of the interface are three buttons: 'Submit', 'View submissions', and 'Quit'. A button labeled '<= Edit Required Inputs' is located at the bottom right of the main content area.

GUI available at

<http://h2-msm.ca.sandia.gov/>

Previously, the user only specified:

- technology
- timeframe
- population
- market penetration

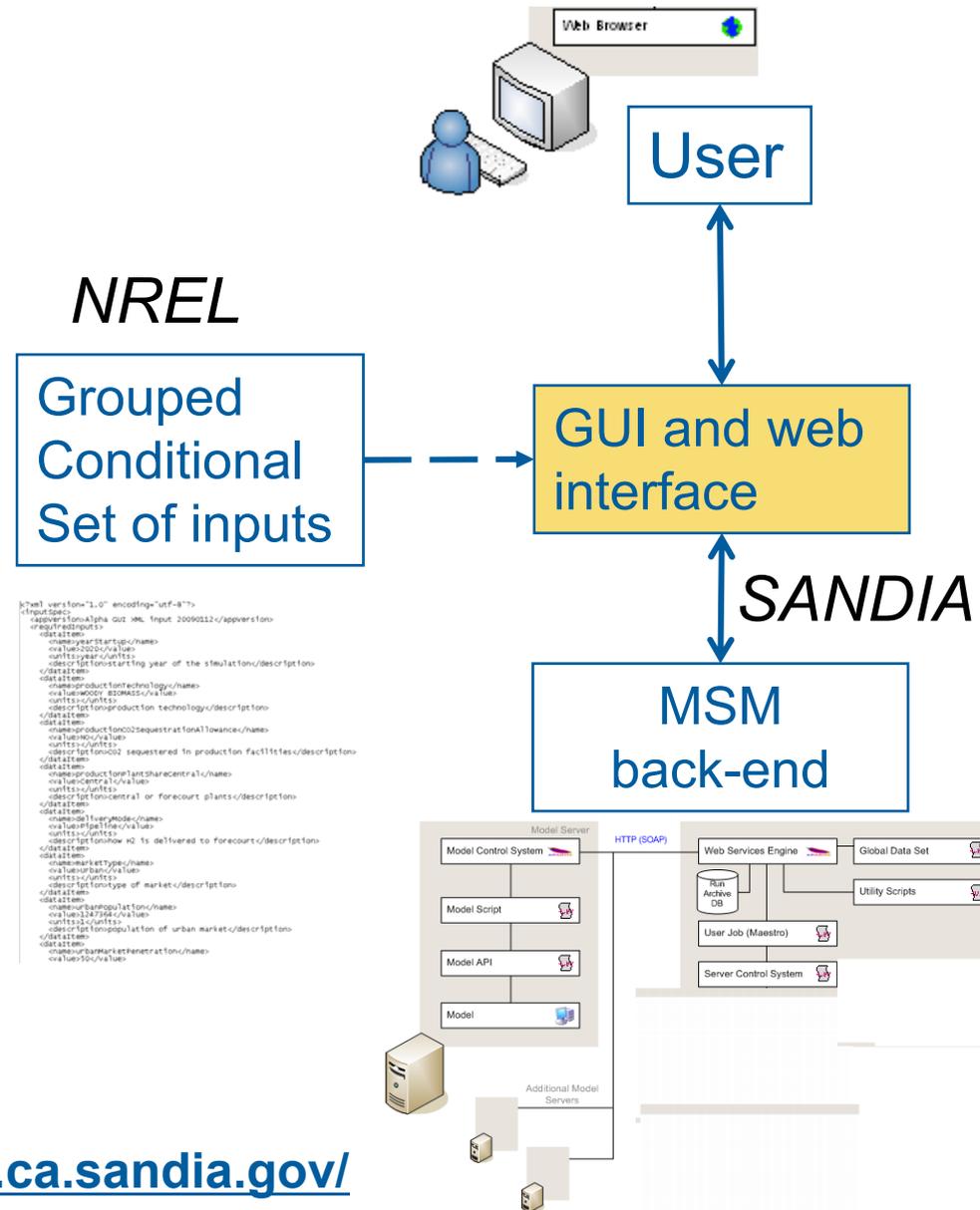
Needed:

- more flexibility for users

# Accomplishment: user interface upgrade

## Detailed inputs capability added

- extra ~200 variable values can be specified for each MSM run
- grouping the variables into branched structures
- conditionally accessible groups and variables
- flexible structure



<http://h2-msm.ca.sandia.gov/>

# Accomplishment: GUI and web interface

The screenshot displays the H2 Macro System Model interface. The main window is titled "H2 Macro System Model" and features a menu bar with "Interactive", "Upload file", "Multi-param", and "Archive". The left pane contains system configuration sections: "System" (Well to Wheels), "Year" (2005), "Production Size/Delivery" (Central, Liquid Truck), "Feedstock/Process" (Woody biomass), "City" (Population: 1000000, H2 penetration: 75%), "Vehicle Fuel Economy" (User defined, 65 mi/GGE), "Title" (Near-term woody biomass gasification / liquid truck / 75% market penetration), "ID" (User: null), and "Description" (Near-term woody biomass gasification, Delivery LH2 trucks, 1MM city population, 75% market penetration, 65 mi/gge H2 FCV). The right pane shows a tree view of "Models" including Detailed Inputs, Feedstock/Utilities, Biomass, Production Facility, Delivery, Dispensing Forecourt, and Vehicle Characterization. A dialog box is open for "Source of production total capital investment", showing a value of 25000000, units of \$, and a description: "source of production total capital investment". Buttons for "OK" and "Reset" are visible. At the bottom of the main window are "Submit", "View submissions", and "Quit" buttons. A button at the bottom right says "<- Edit Required Inputs".

<http://h2-msm.ca.sandia.gov/>

# Accomplishment: risk analysis capabilities

**Assumptions:** distributed SMR advanced technology case; fuel efficiency 28 mpg GV, 50-70 mi/kg\_H2; year 2020

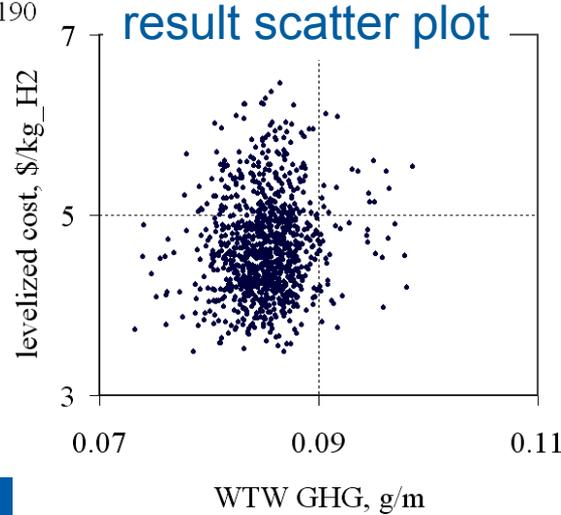
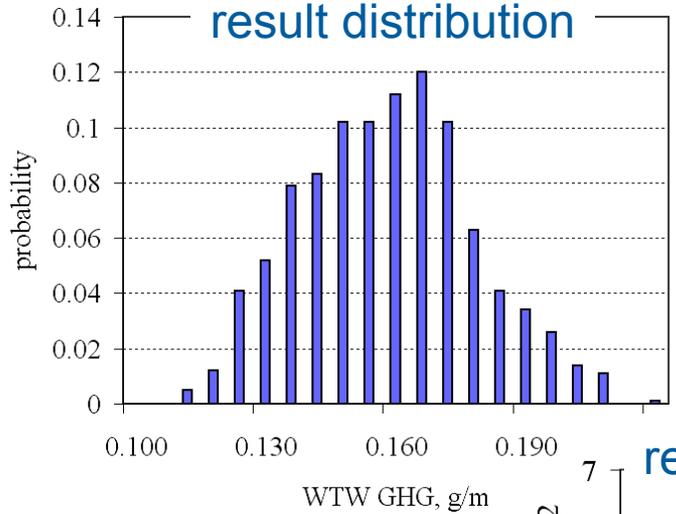
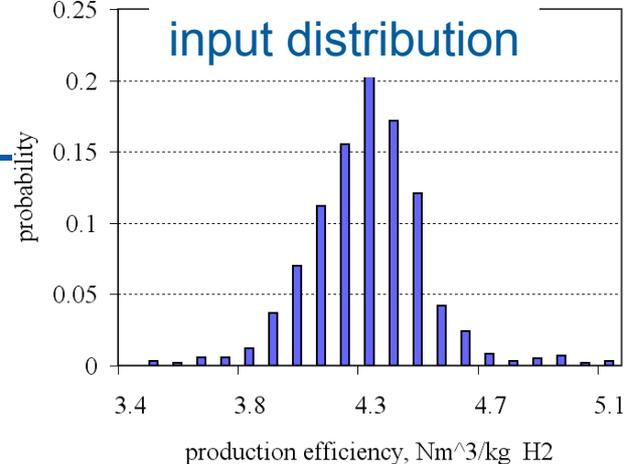
**Inputs:** risk analysis expert opinions summarized in distribution functions for

- i) capital investment,
  - ii) O&M,
  - iii) capacity factor,
  - iv) production unit efficiency,
- (Report NREL/MP-150-43250, May 2008)

- v) gasoline, NG feed cost - historic data
- vi) vehicle fuel efficiency (GPRA)

**Analyzed** tax on well-to-wheel (WTW) green-house gas (GHG) emissions

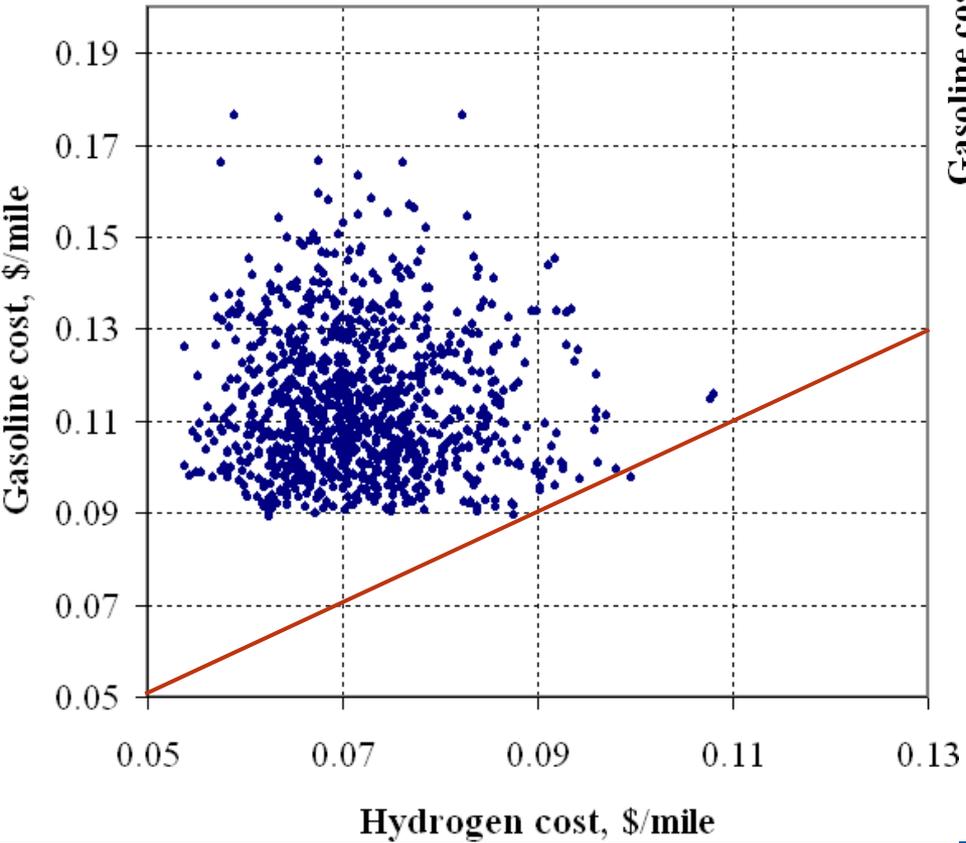
**Compare** the cost of fuel:  
hydrogen vs. gasoline



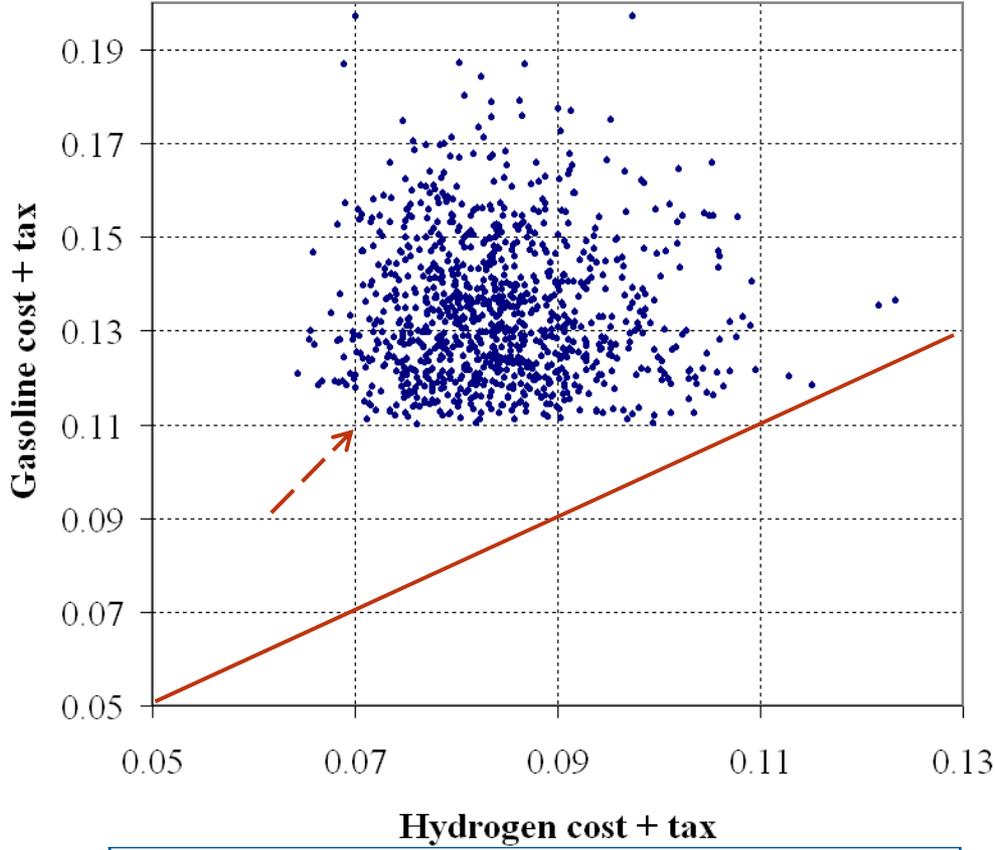
# Accomplishment: WTW GHG tax risk analysis

*Scatter graph points moved slightly away from the red line*

no GHG tax



GHG tax 50 \$/ton CO2



**SMR: GHG tax expected to have marginal effect on stimulating hydrogen use in transportation**

# Progress: Milestone in MYRD&D Plan

The MSM is being used to complete the 2009 MYRD&D Plan milestone on hydrogen pathways and scenarios.

**Developing presentation techniques that include all three results & breaking each down by system to identify primary drivers**

**Presenting pathway levelized cost and well-to-wheels energy use and emissions**

**Analyzing hydrogen production / delivery / distribution pathways using H2A Production, HDSAM, and GREET**

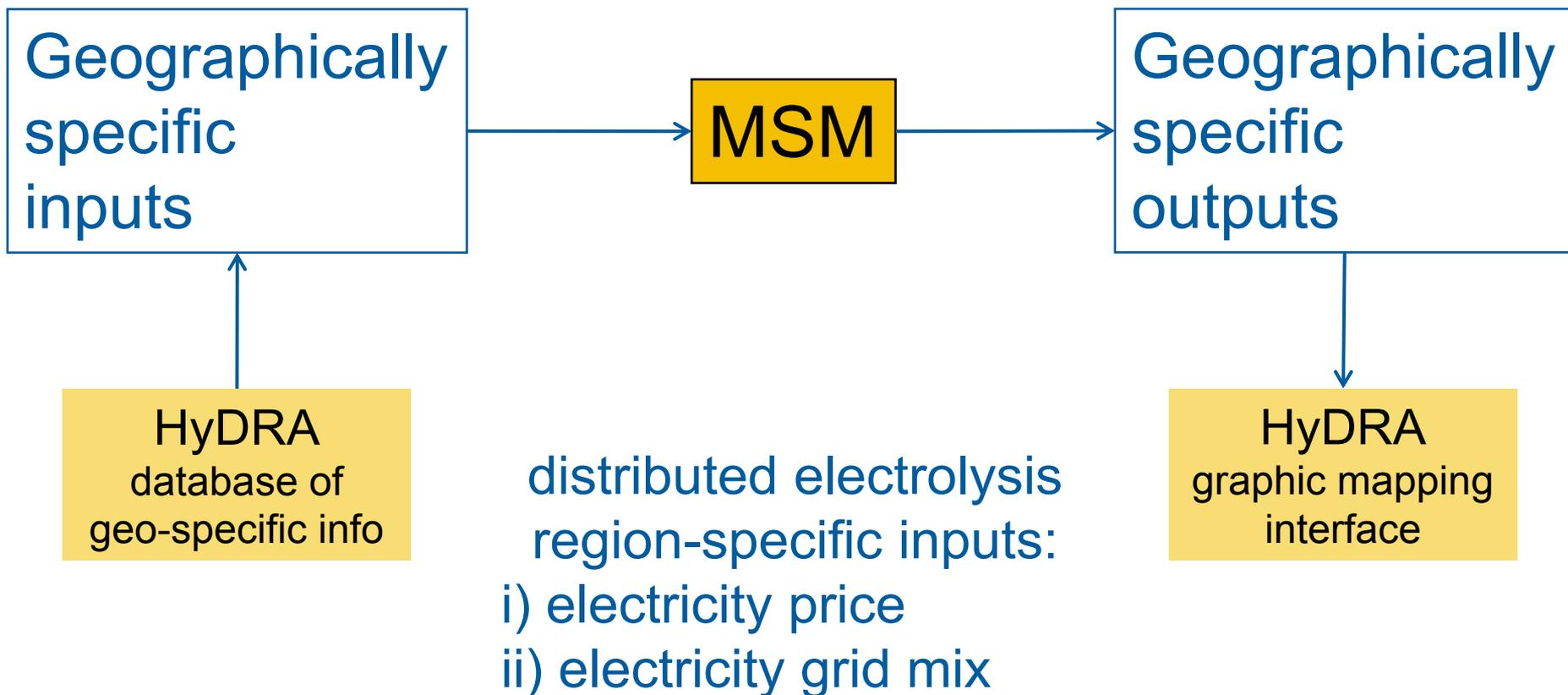
**Reviewing the methodology and primary assumptions used for the analyses**

**Energy company staff and other experts are validating the process and identifying gaps and issues**

# Approach: linking with HyDRA

HyDRA: <http://rpm.nrel.gov>

Goal: to bring spatial dimension into the MSM



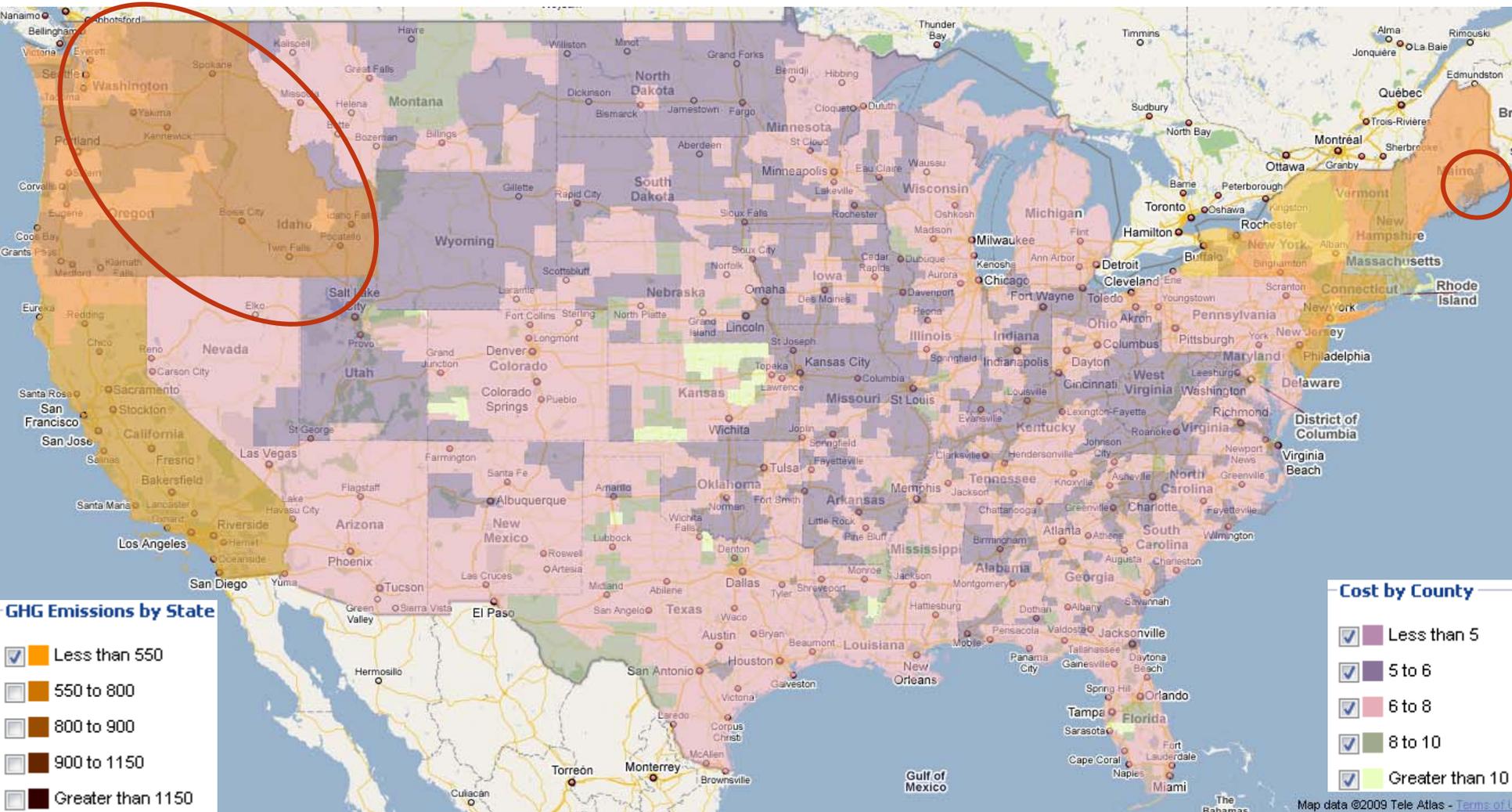
# Accomplishment: linking with HyDRA

input:

electricity price, \$/MWh  
electricity grid mix by state

output:

electrolysis H2 cost (< 5 \$/kg)  
GHG emissions < 550 g/mile



# Approach: linking with HyPRO

HyPRO: Directed Technologies, Inc.

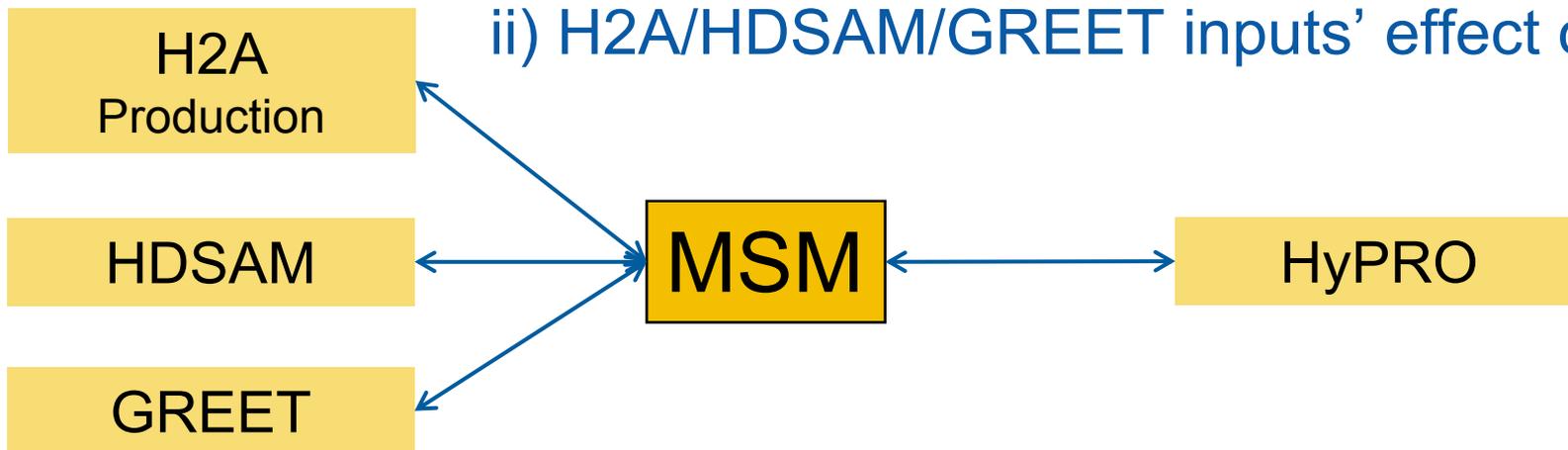
**Goal:** to analyze technology/pathway evolution

Starting point:

- i) H2 demand curve projection;
- ii) H2 production options and costs (H2A)
- iii) H2 delivery options/costs (HDSAM)

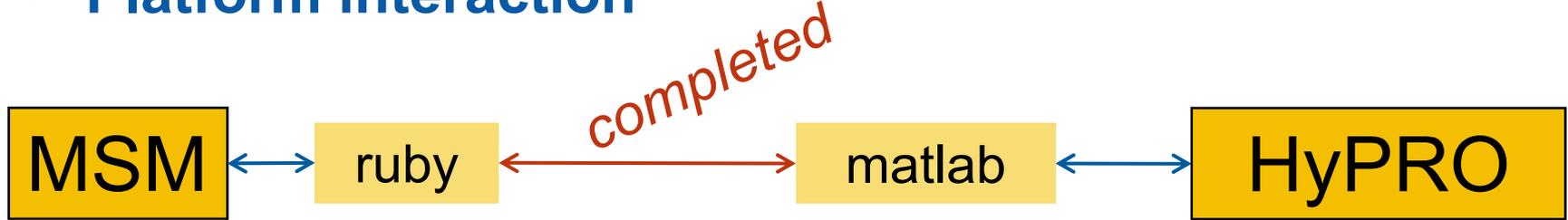
**Advantages** for linking MSM with HyPRO:

- i) auto-updated links HyPRO ↔ H2A/HDSAM
- ii) H2A/HDSAM/GREET inputs' effect on HyPRO

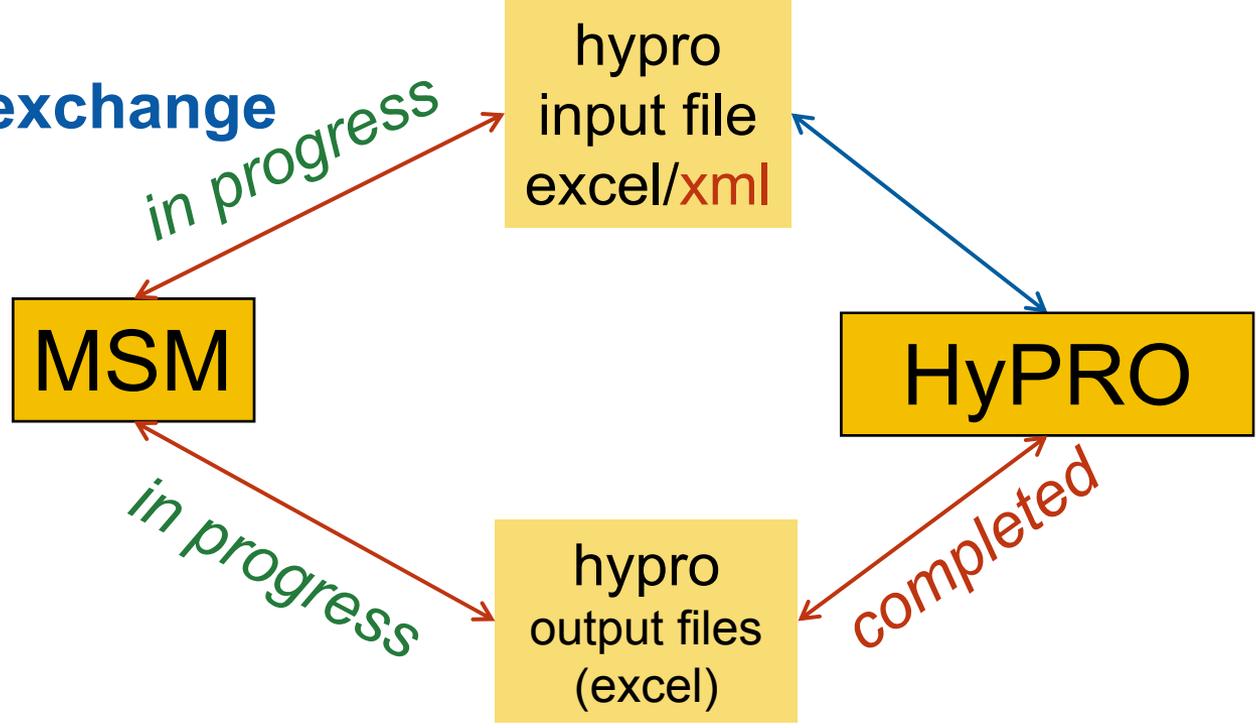


# Progress & future work: linking MSM ↔ HyPRO

- Platform interaction



- Data exchange



# Collaborations

- **Sandia National Laboratories (computational development)**
  - Andy Lutz (manager, matlab expertise)
  - Mike Goldsby (MSM architecture)
  - Tim Sa (web server, GUI)
- **NREL**
  - Darlene Steward, Mike Penev (H2A Production, distributed power)
  - Johanna Levene, Chris Helms, Witt Sparks (HyDRA)
- **ANL**
  - Amgad Elgowainy, Michael Wang (HDSAM, GREET)
- **Sentech**
  - Elvin Yuzugullu (Documentation)
- **Directed Technologies, Inc.**
  - Brian James, Julie Perez, Andrew Spisak (HyPRO)
- **Indiana University, Kelly School of Business**
  - Ion Diakov (@Risk)
- **Energy Companies (MYRD&D Plan Milestone)**
  - Matt Watkins (Exxon-Mobil)
  - Jonathan Weinert, Bhaskar Balasubramanian (Chevron)
  - Ed Casey (ConocoPhillips)
  - CJ Guo, Karel Kapoun (Shell)
- **Alliance Technical Services (MYRD&D Plan Milestone)**
  - Melissa Laffen, Tom Timbario, Jr.

# Future work summary

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## Ongoing effort:

- update MSM to new versions of linked models
- support programmatic decisions through analyses

## FY'09 goals:

- expand GUI capabilities and develop run-database (60% completed)
- link with HyDRA (50% completed), HyPRO (50%), H2A combined heat and power (start linking upon official model release)

## Looking ahead:

- H2W (water model); HyDS-ME (transient and geospatial H2); PowerPark (details of underlying physical properties)

# Summary: MSM structure and future goals

## Enhanced structure

- Give users MORE flexibility
  - Significantly expand GUI capabilities
- Link to MORE models
  - H2A, HDSAM, GREET + HyPRO, HyDRA, H2Power, HyDS-ME, H2W, PowerPark, ...
- Expand to MORE computers
  - Over the 'net interactive
- Use MORE platforms
  - xl + MATLAB

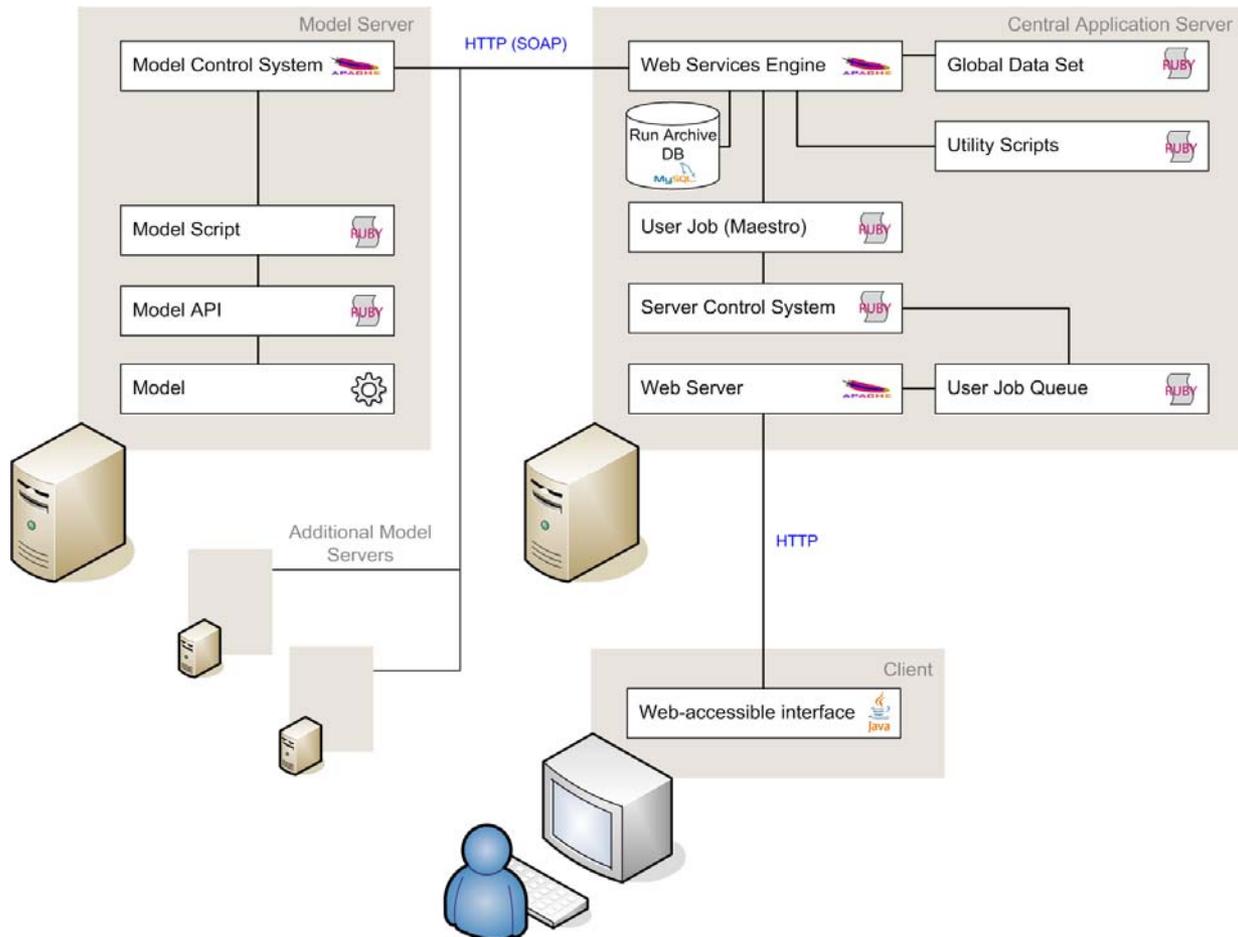
## Broader objectives

- Wider cross-cutting analysis capabilities
  - Expanded links to models
- Expanded range of problems to analyze
  - Include spatial and transient analysis

# ADDITIONAL SLIDES

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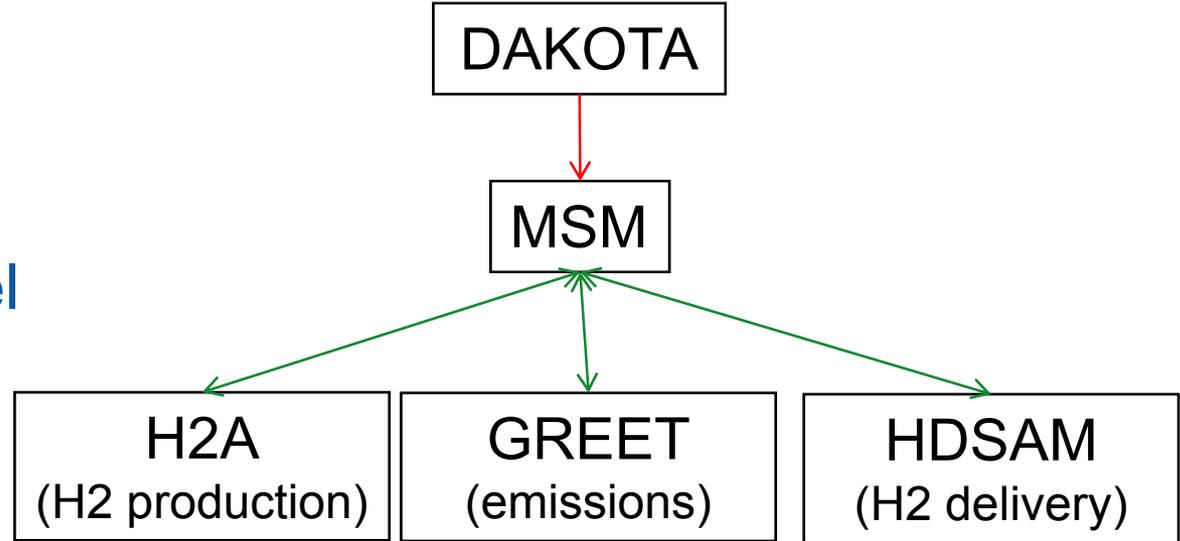
# Accomplishment: extensible robust structure



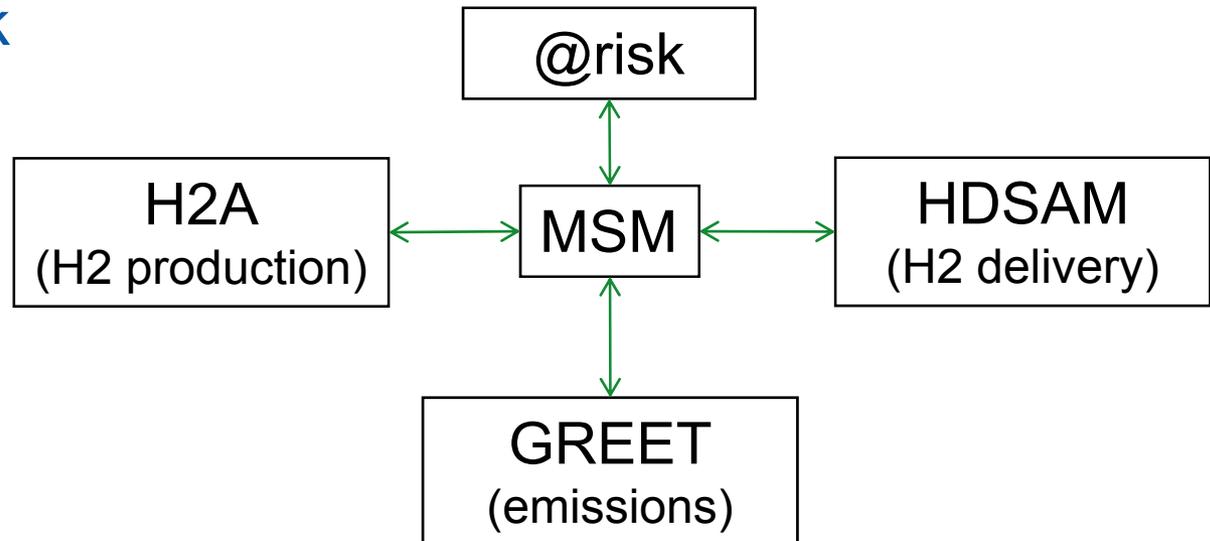
- MSM built in Ruby/Java/PHP/SQL
- Ruby version is stable and handles various data types
- Developed technique that allows models to run on different machines
- Developed web-accessible graphical user interface (GUI) to make the MSM available to more users
- Validated results against proof-of-concept MSM

# Uncertainty analysis in MSM

1<sup>st</sup> choice: DAKOTA  
breaks the high-level  
architecture



2<sup>nd</sup> choice: use @risk  
allows to apply  
risk analysis to  
individual models



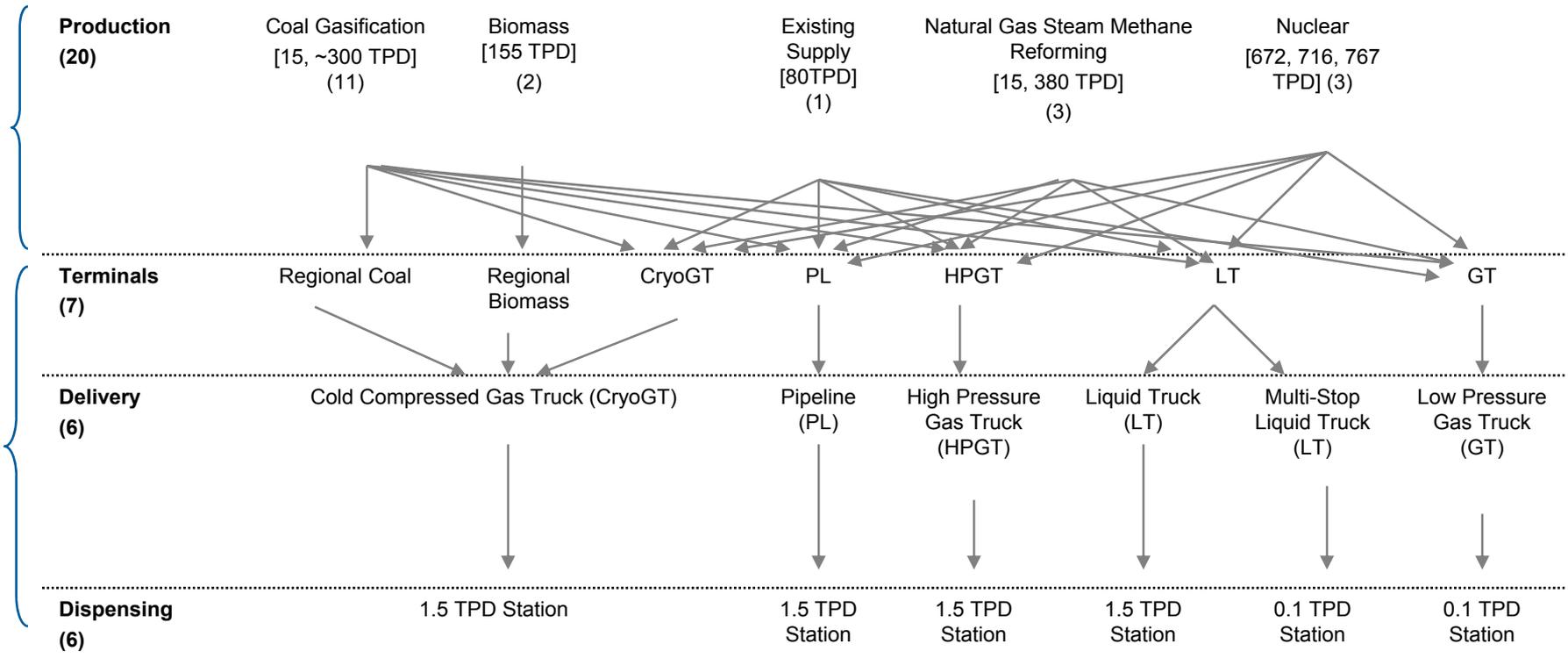
# Progress: linking MSM with HyPRO

HyPro is:

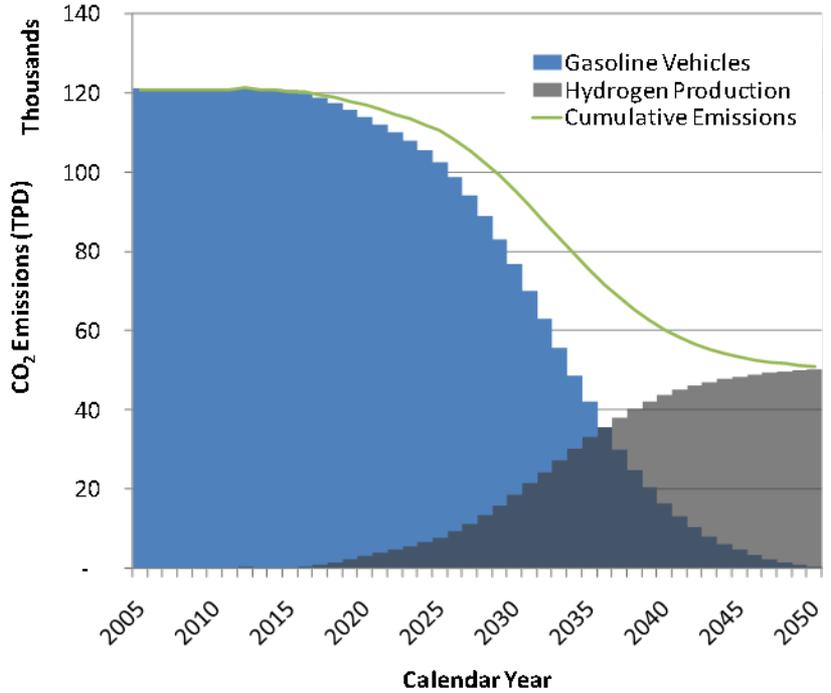
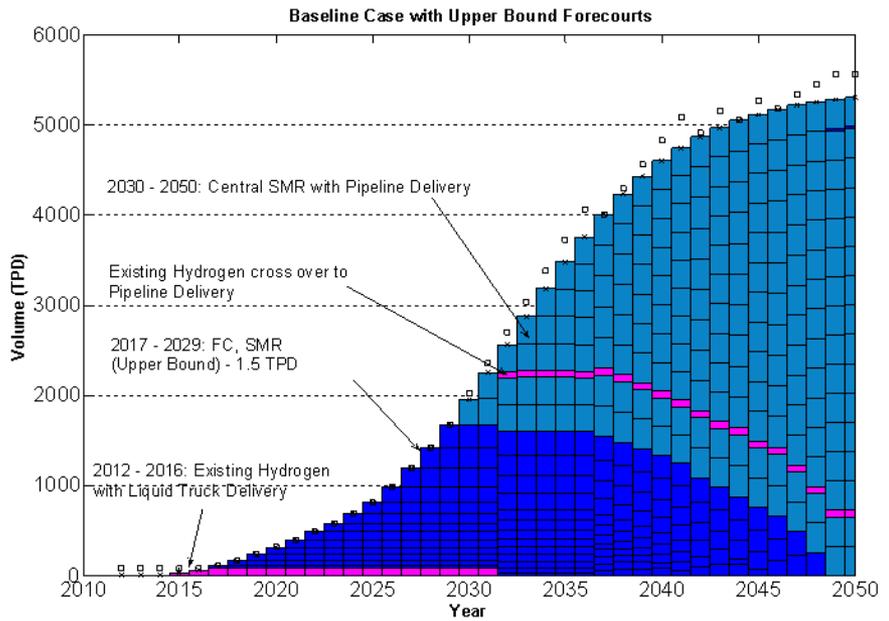
- HyPro = Hydrogen Production transition model
- Calculates expected H<sub>2</sub> cost for a variety of pathways
- Uses H<sub>2</sub> cost to predict which H<sub>2</sub> pathway is built in each year
- Creates a year-by-year build history of H<sub>2</sub> production, delivery and dispensing
- Excel input spreadsheet, calculations in MatLab

H2A Production

HDSAM



# Future work: transient emissions with HyPRO



Using MSM links with GREET, we will keep transient GHG updated

DTI has also shown the effect of emissions taxation on the succession of H2 production technologies built