



NREL National Renewable Energy Laboratory
Innovation for Our Energy Future

Macro-System Model (project #AN_04_Diakov)



**2009 DOE Hydrogen
Program Review**

**May 19, 2009
Arlington, VA**

**Victor Diakov (NREL),
Mark Ruth (NREL),
Mike Goldsby (SNL),
Tim Sa (SNL)**



**Sandia
National
Laboratories**

This presentation does not contain any proprietary, confidential, or otherwise restricted information

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% H₂ 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%

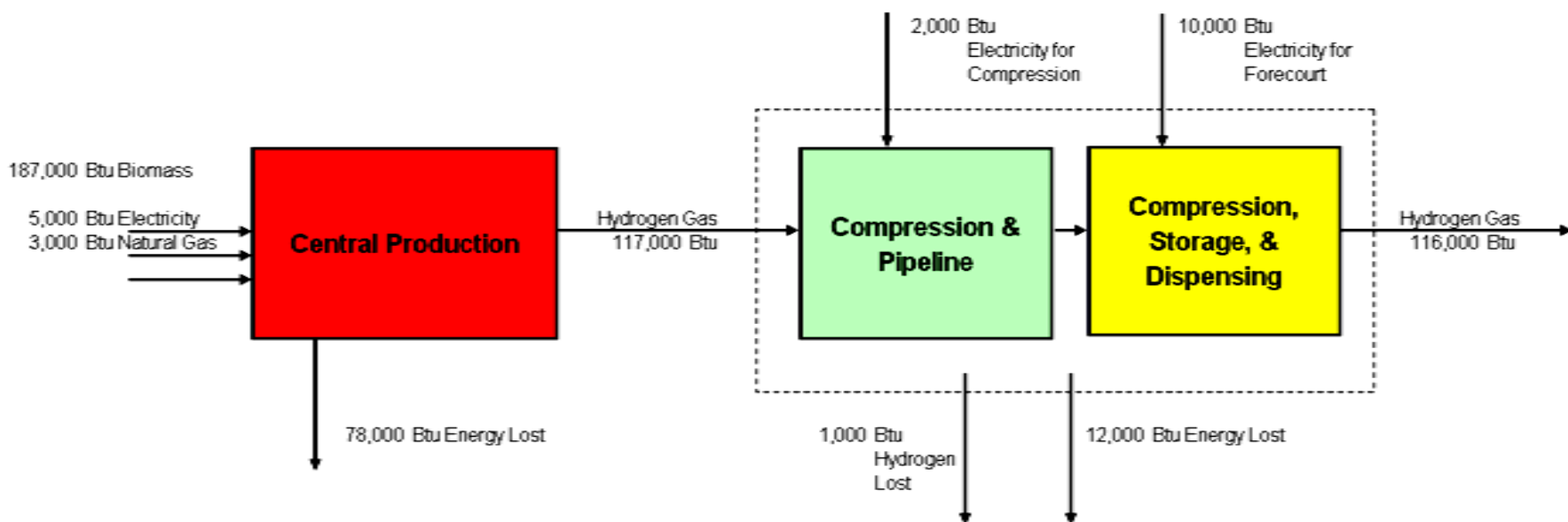
GREET

- Gasoline is RFG without oxygenate
- Current technologies use US average grid mix
- Advanced technologies use future grid mix with 85% of CO₂ 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

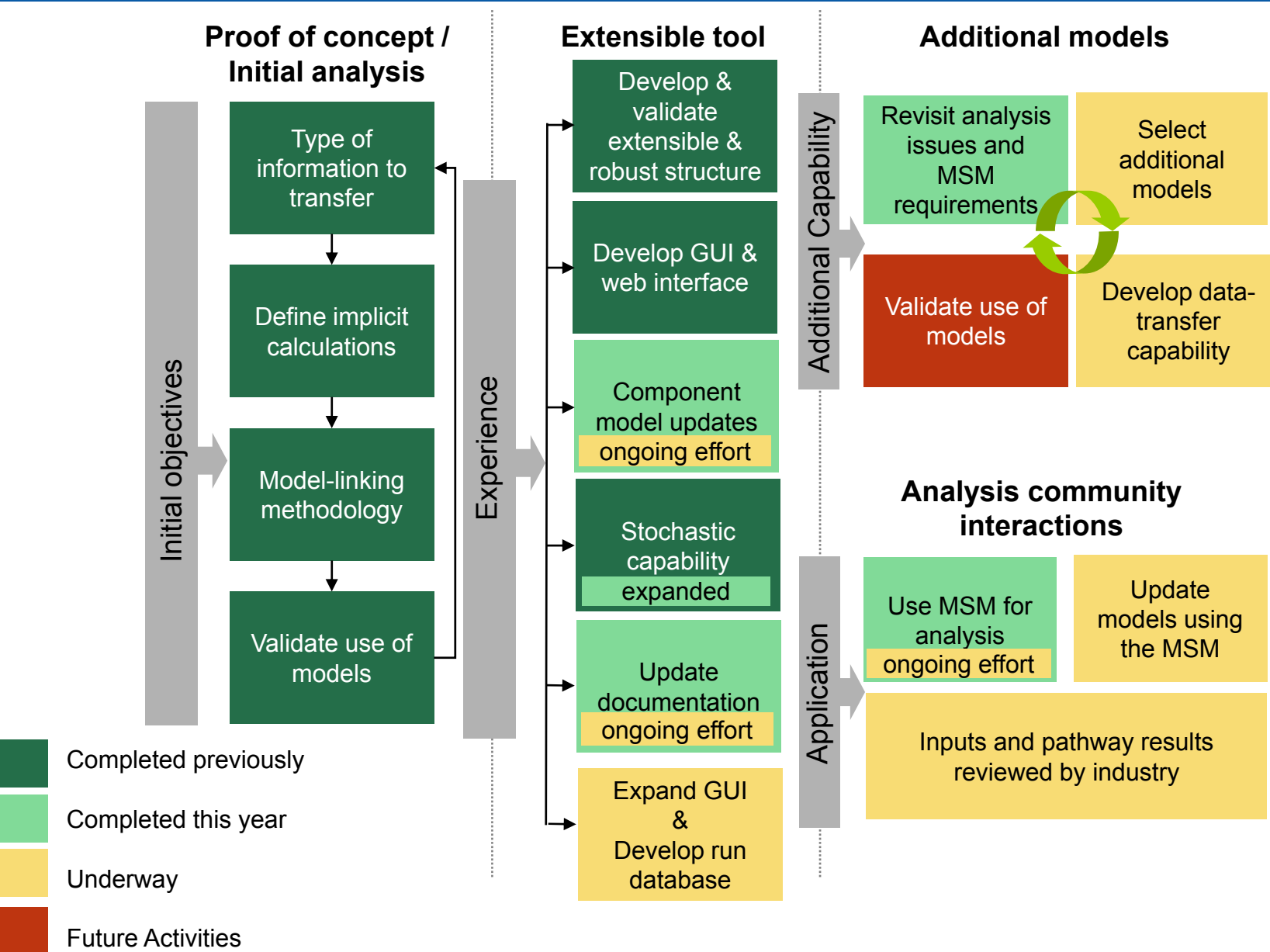
Well-to-Wheels Total Energy Use (Btu/mile)	3,707
Well-to-Wheels Petroleum Energy Use (Btu/mile)	96
Well-to-Wheels Greenhouse Gas Emissions (g/mile)	53
Levelized Cost of H2 at Pump (\$/kg)	3.26

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

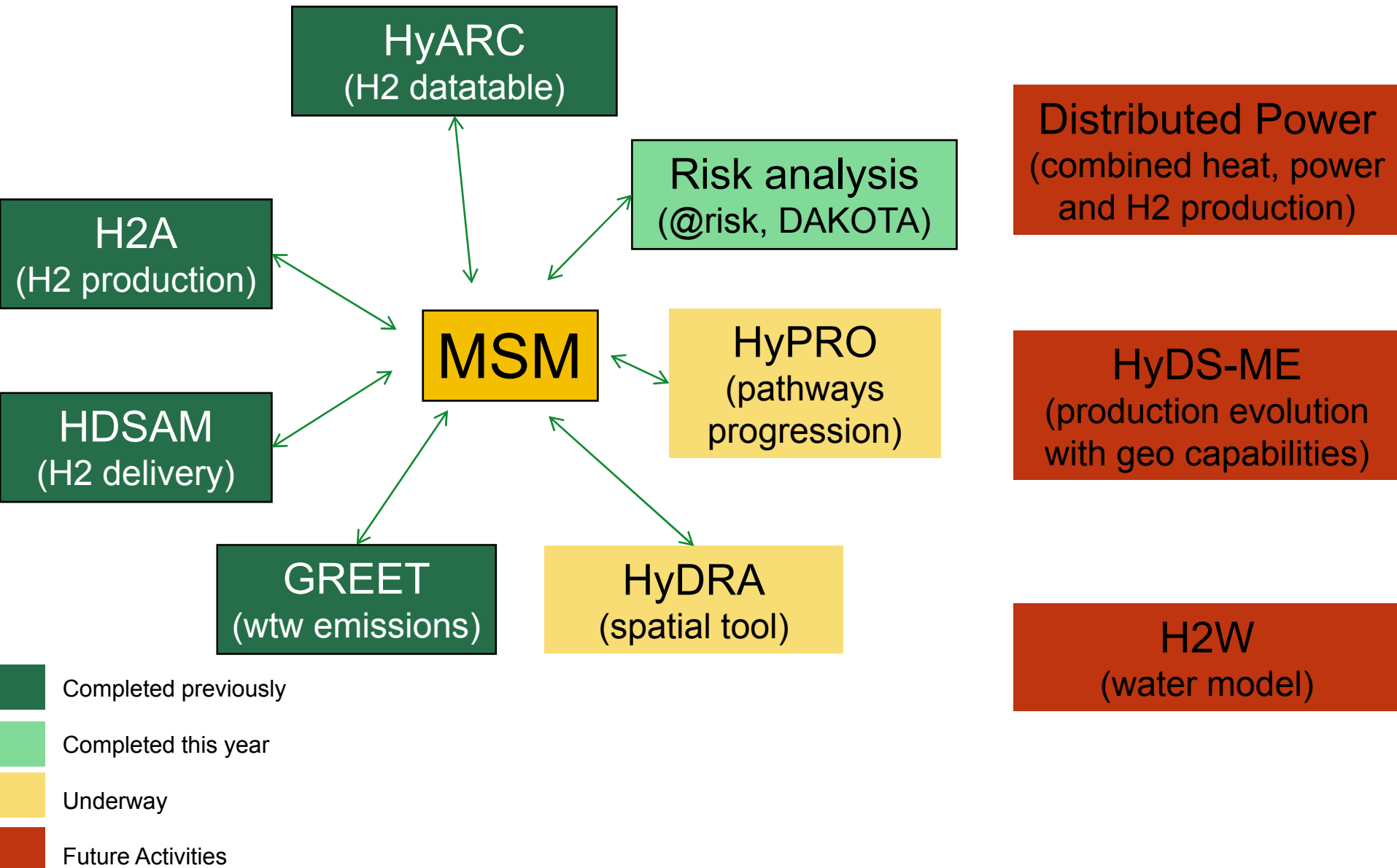
Case Definition

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 secondary 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

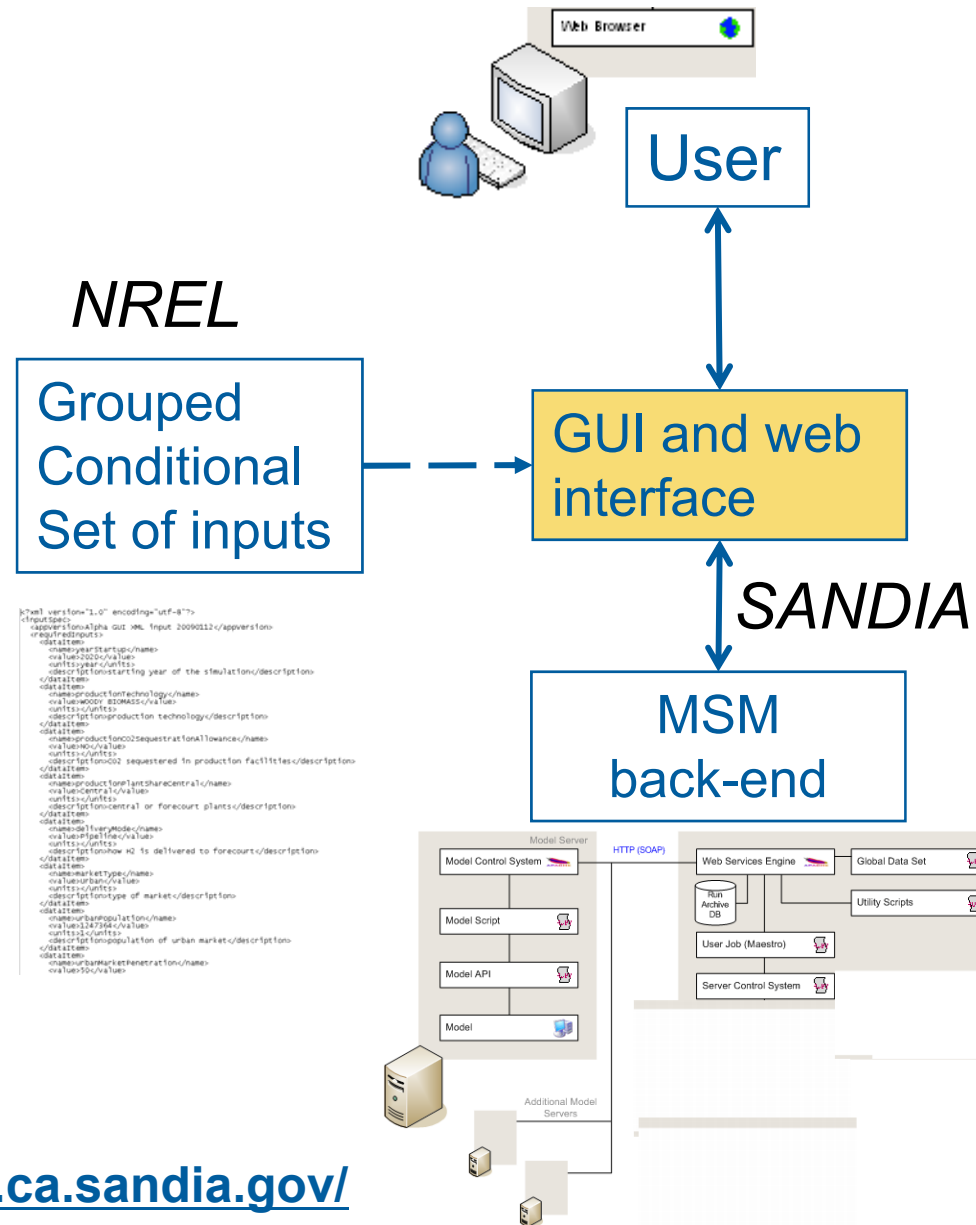
Needed:

- 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' software interface. The main window is divided into several sections:

- System:** Includes a dropdown menu for 'Wells to Wheels'.
- Year:** A dropdown menu set to '2005'.
- Production Size/Delivery:** Radio buttons for 'Central' (selected) and 'Distributed', with a dropdown for 'Liquid Truck'.
- Feedstock/Process:** A dropdown menu set to 'Woody biomass'.
- City:** Input fields for 'Population' (1000000) and 'H2 penetration (%)' (75).
- Vehicle Fuel Economy:** Radio buttons for 'GREET source', 'HDSAM source', and 'User defined (mi/GGE)' (selected), with a dropdown for '65'.
- Title:** A text field containing 'Near-term woody biomass gasification / liquid truck / 75% market penetration'.
- ID:** A text field with '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'.

On the right side, there is a 'Models' panel with a tree view of input categories:

- Detailed Inputs
 - Feedstock, Utilities
 - Biomass
 - Source of biomass feedstock consumption (H2A PROD)
 - Source of biomass feedstock cost (H2A PROD)
 - Source of poplar farming energy use (GREET)
 - Selection of H2 plant co-product allowances (None)
 - Utilities, co-products
 - Source of natural gas utility consumption (H2A PROD)
 - Source of utility electricity consumption (H2A PROD)
 - Source of utility electricity price (H2A prod)
 - Production Facility
 - Source of production total capital investment (H2A PROD)
 - Source of production capacity factor (H2A PROD)
 - Source of number of production FTEs (H2A PROD)
 - Source of internal rate of return (H2A PROD)
 - Delivery
 - Liquid H2 Delivery
 - Dispensing Forecourt
 - Vehicle Characterization
 - Baseline Fuel Efficiencies
 - Source of gasoline internal combustion engine vehicles' fuel efficiency (42.0)
 - Source of gasoline hybrid electric vehicles' fuel efficiency (42.0 mile / gge)
 - Source of E-85 ethanol internal combustion engine vehicles' fuel efficiency (3)
 - H2 FCV to gasoline ICE vehicle emissions ratio

Below the tree view, a specific input is highlighted: 'Source of production total capital investment'. It shows a 'Value' of '25000000', 'Units' of '\$', and a 'Description' of 'source of production total capital investment'. 'OK' and 'Reset' buttons are present.

At the bottom of the main window, there are buttons for 'Submit', 'View submissions', 'Quit', 'Edit Detailed Inputs ->', and '<- 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

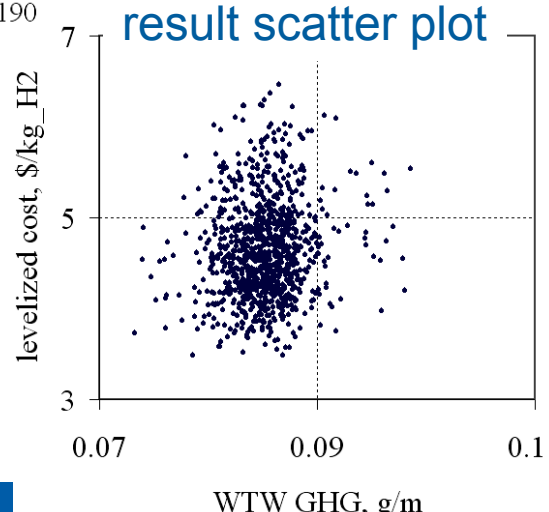
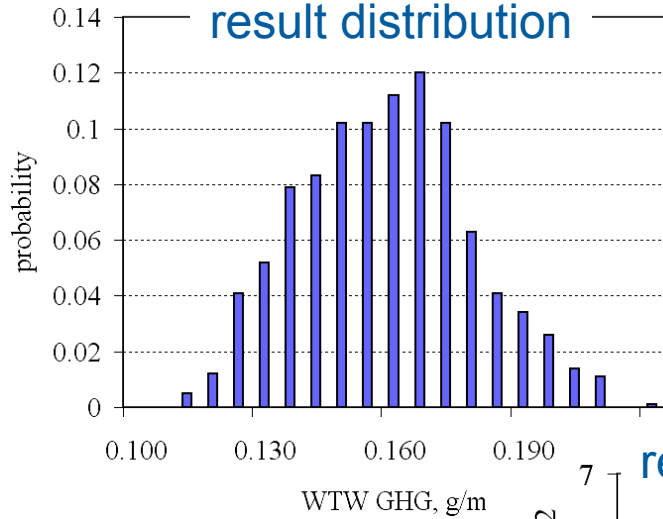
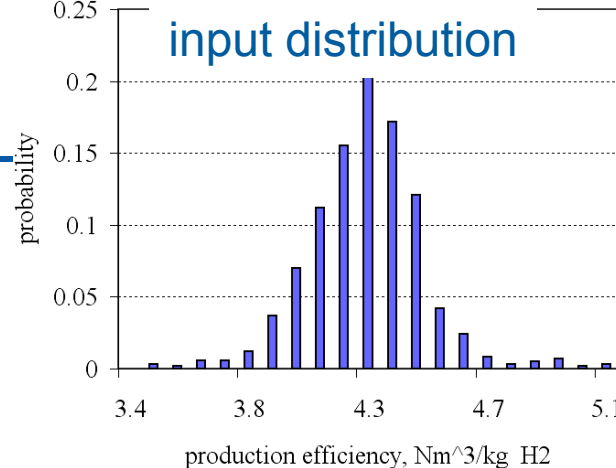
Inputs: risk analysis expert opinions summarized in distribution functions for

- 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

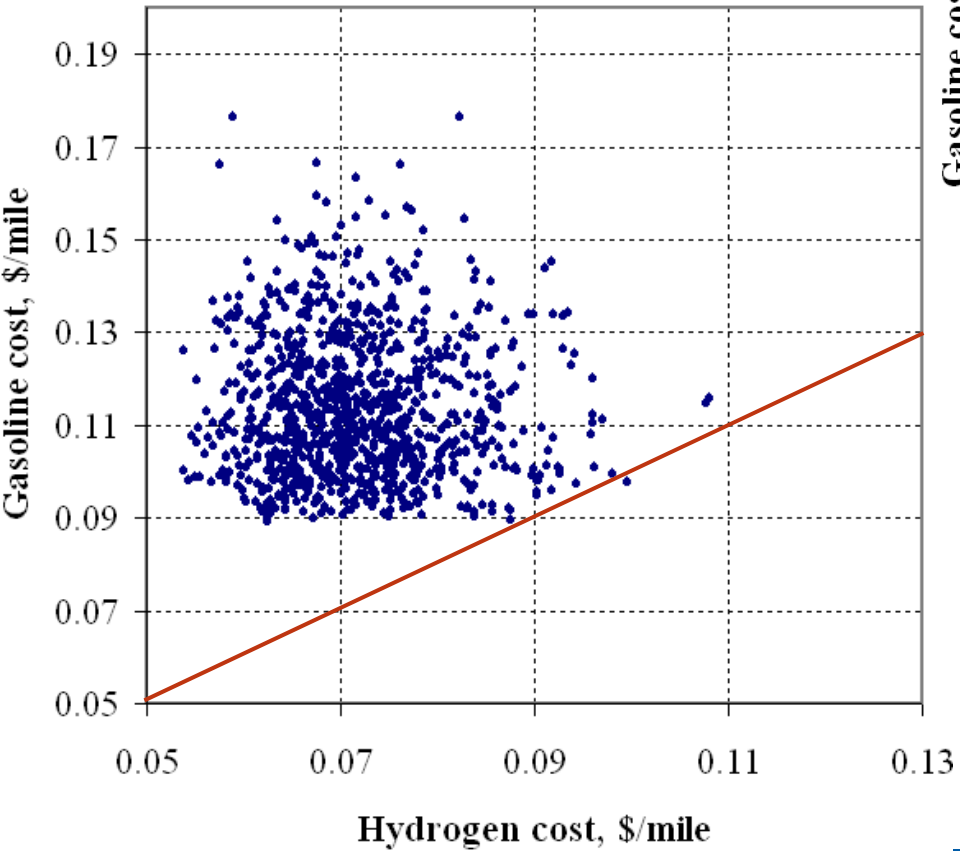
Compare the cost of fuel:
hydrogen vs. gasoline



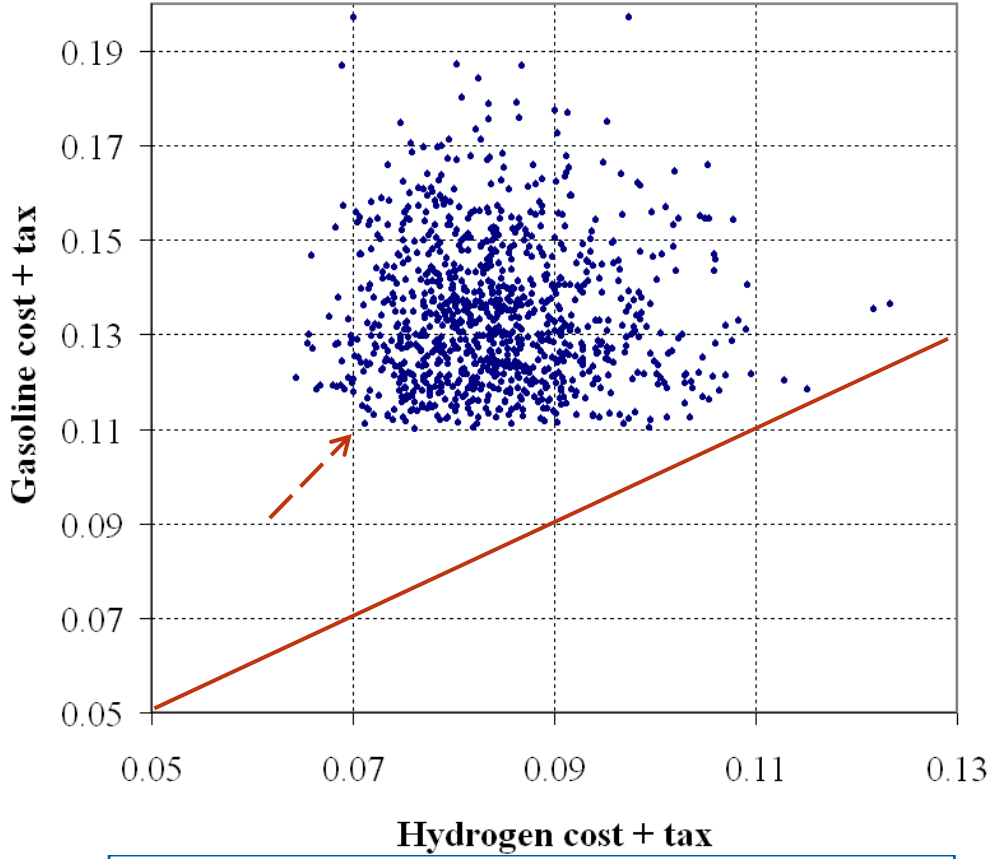
Accomplishment: WTW GHG tax risk analysis

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

Reviewing the methodology and primary assumptions used for the analyses

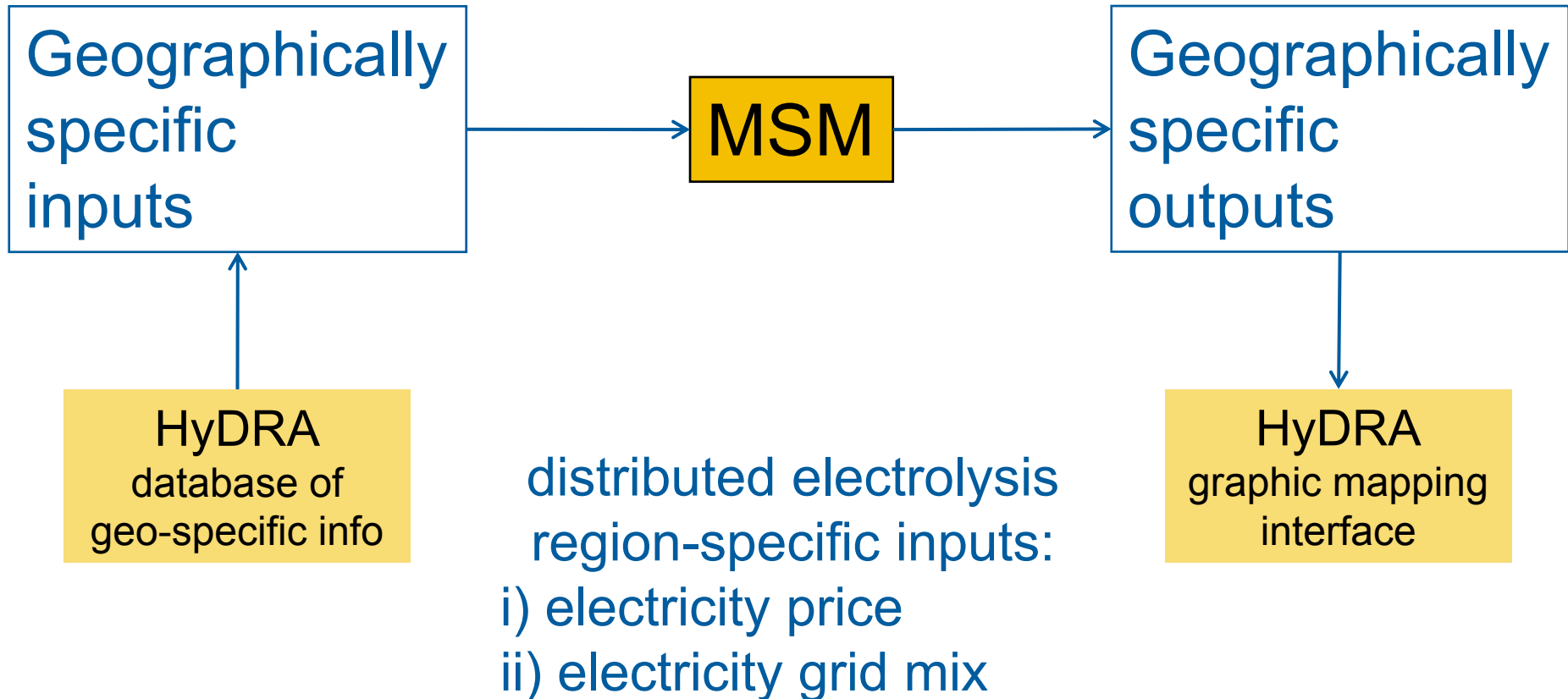
Energy company staff and other experts are validating the process and identifying gaps and issues

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

Approach: linking with HyDRA

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

Goal: to bring spatial dimension into the MSM



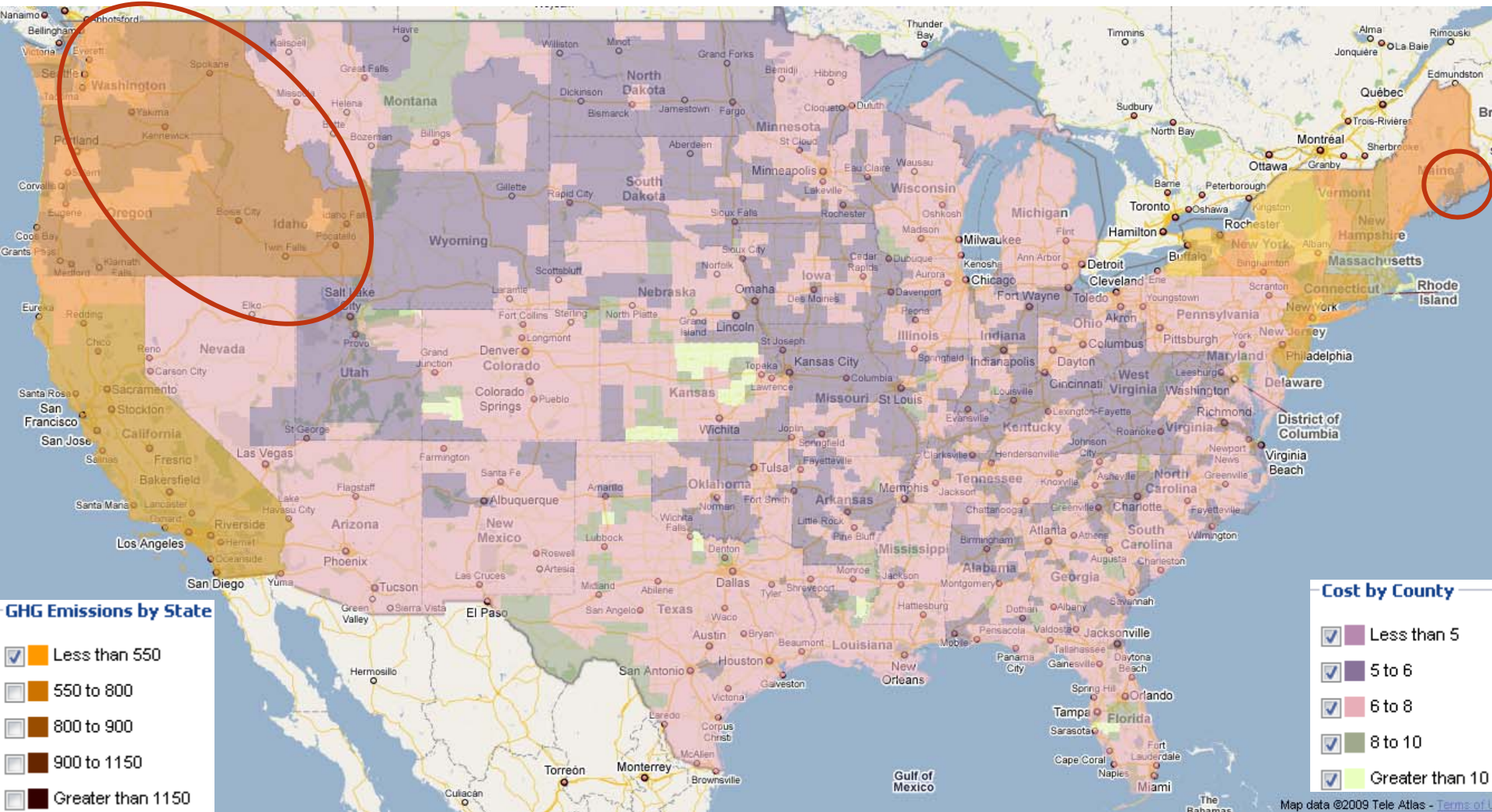
Accomplishment: linking with HyDRA

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.

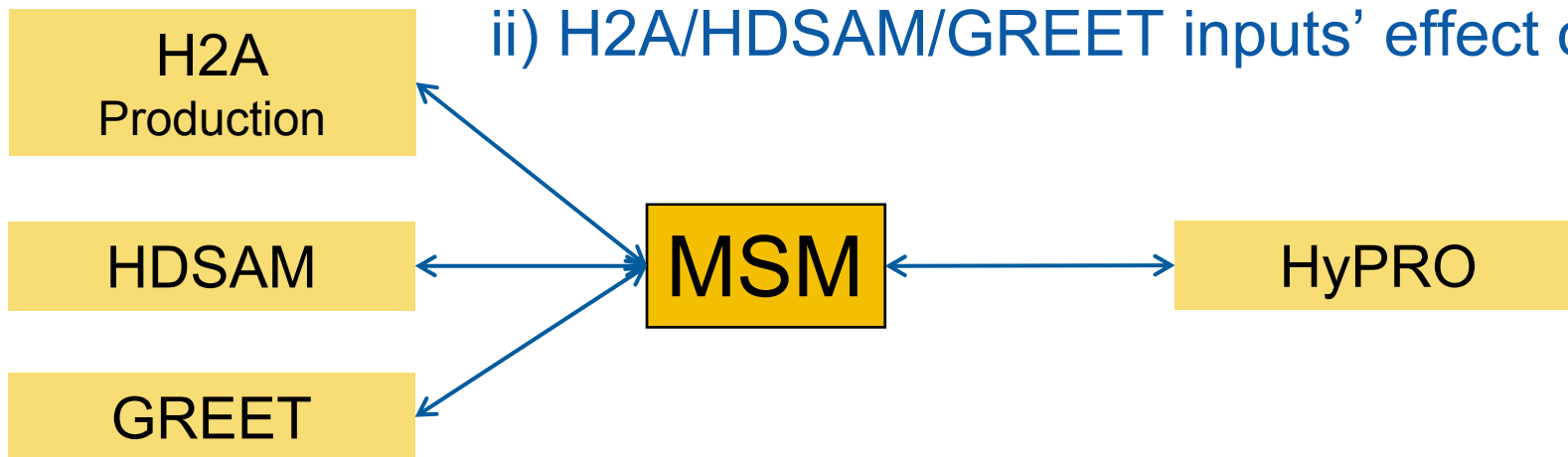
Goal: to analyze technology/pathway evolution

Starting point:

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

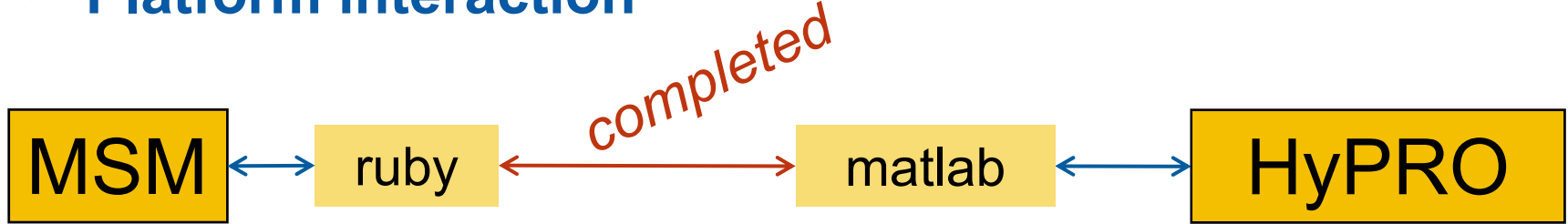
Advantages for linking MSM with HyPRO:

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

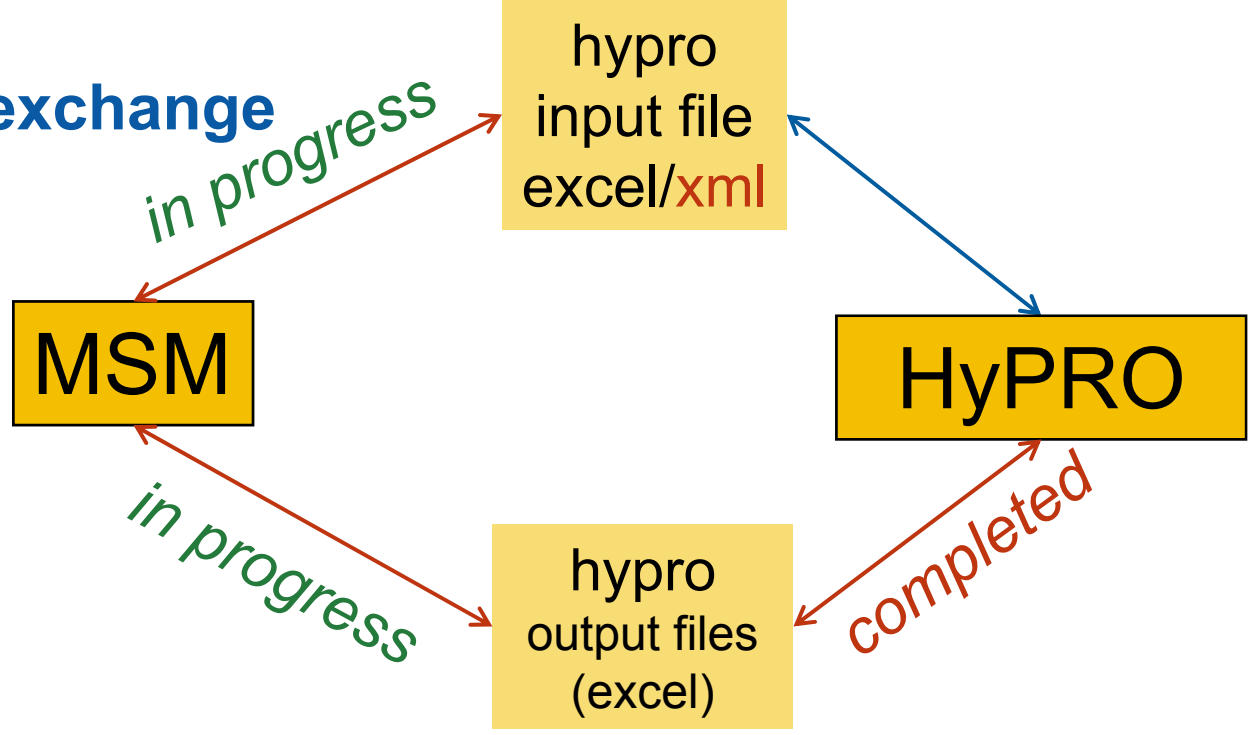


Progress & future work: linking MSM ↔ HyPRO

- 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

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

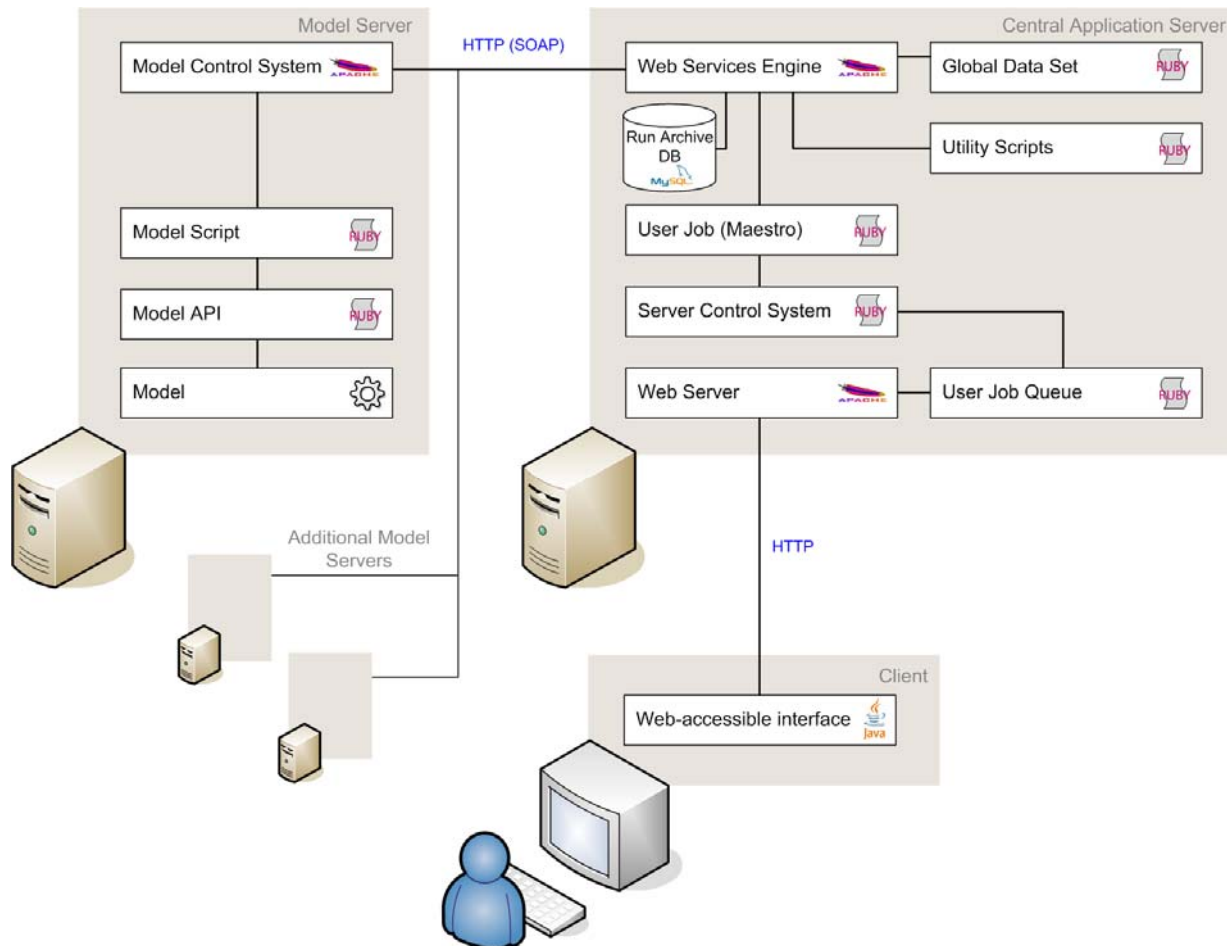
- Give users MORE flexibility
 - Significantly expand GUI capabilities
- Link to MORE models
 - H2A, HDSAM, GREET + HyPRO, HyDRA, H2Power, HyDS-ME, H2W, PowerPark, ...
- Expand to MORE computers
 - Over the 'net interactive
- Use MORE platforms
 - xl + MATLAB

Broader objectives

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

ADDITIONAL SLIDES

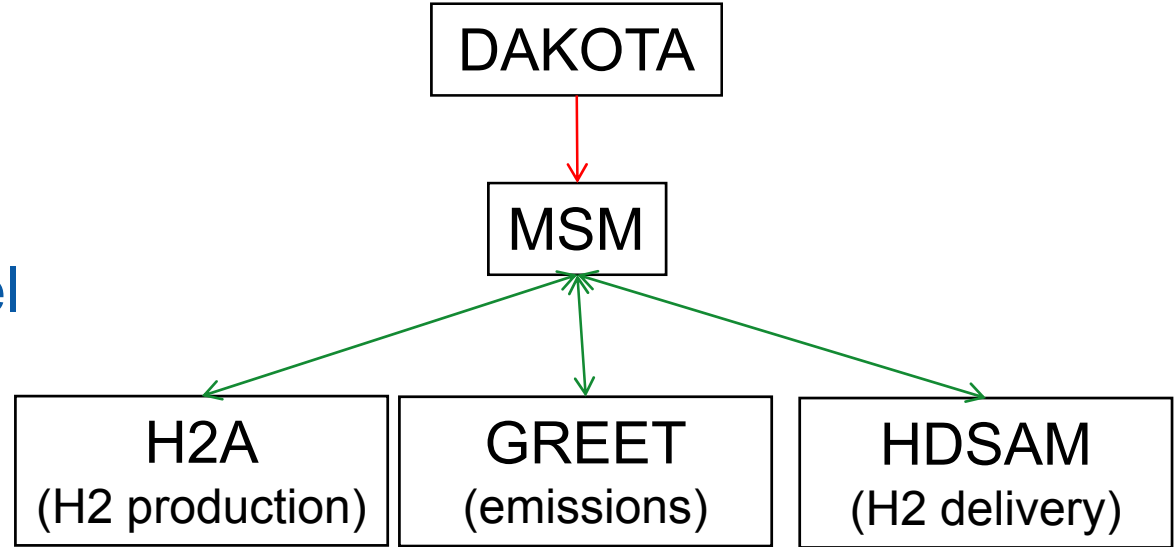
Accomplishment: extensible robust structure



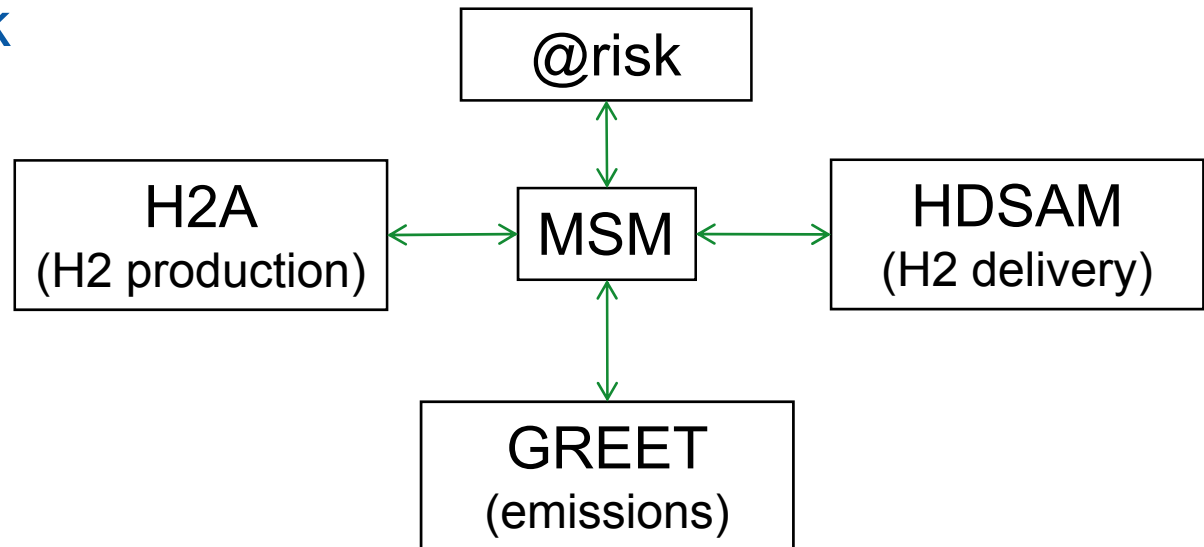
- MSM built in Ruby/Java/PHP/SQL
- Ruby version is stable and handles various data types
- Developed technique that allows models to run on different machines
- Developed web-accessible graphical user interface (GUI) to make the MSM available to more users
- Validated results against proof-of-concept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

Uncertainty analysis in MSM

1st choice: DAKOTA
breaks the high-level
architecture



2nd choice: use @risk
allows to apply
risk analysis to
individual models



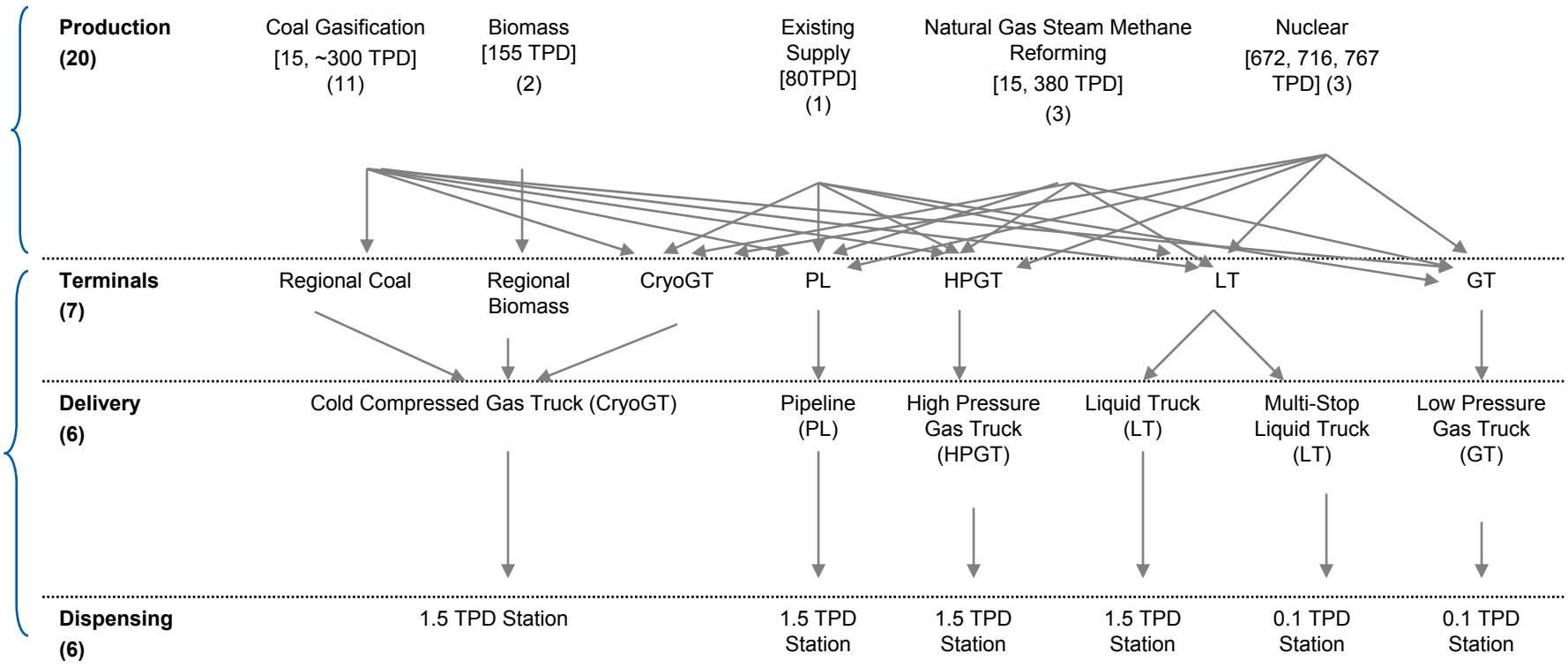
Progress: linking MSM with HyPRO

HyPro is:

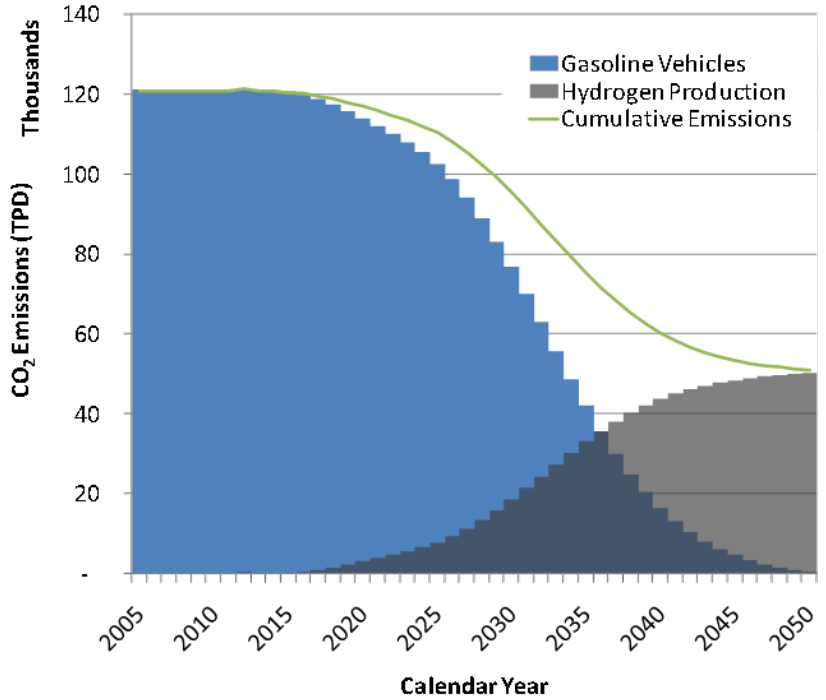
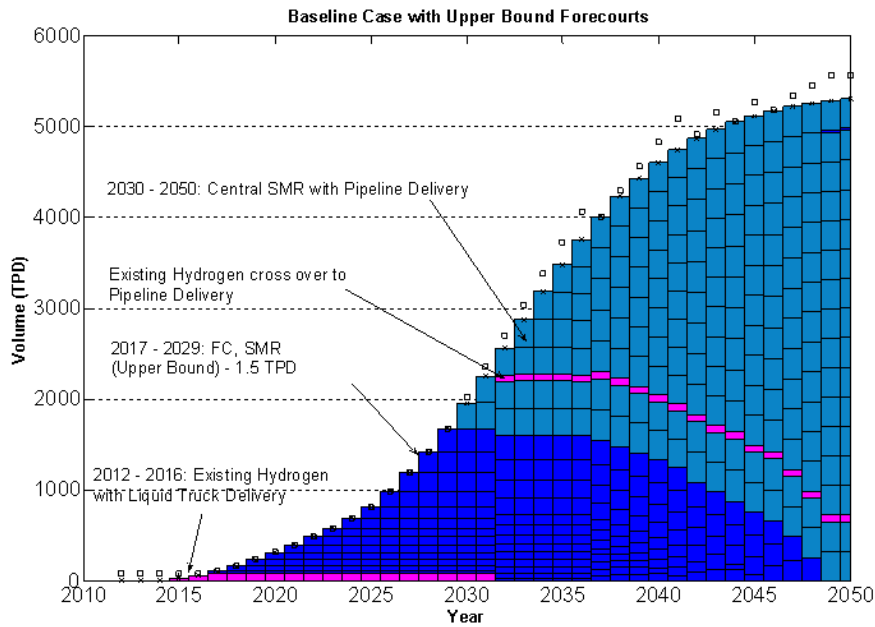
- HyPro = Hydrogen Production transition model
- Calculates expected H₂ cost for a variety of pathways
- Uses H₂ cost to predict which H₂ pathway is built in each year
- Creates a year-by-year build history of H₂ production, delivery and dispensing
- Excel input spreadsheet, calculations in MatLab

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