National Renewable Energy Laboratory
Innovation for Our Energy Future

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

Pathway Assumptions

- Full-deployment scenario
- Urban demand area
- 1,250,000 person city
- 50% H_2 penetration
- 1500 kg/day stations
- Mid-size FCV –
  - Current - 57 mi / GGE
  - Advanced – 65 mi / GGE

Financial

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

HDSAM

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

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

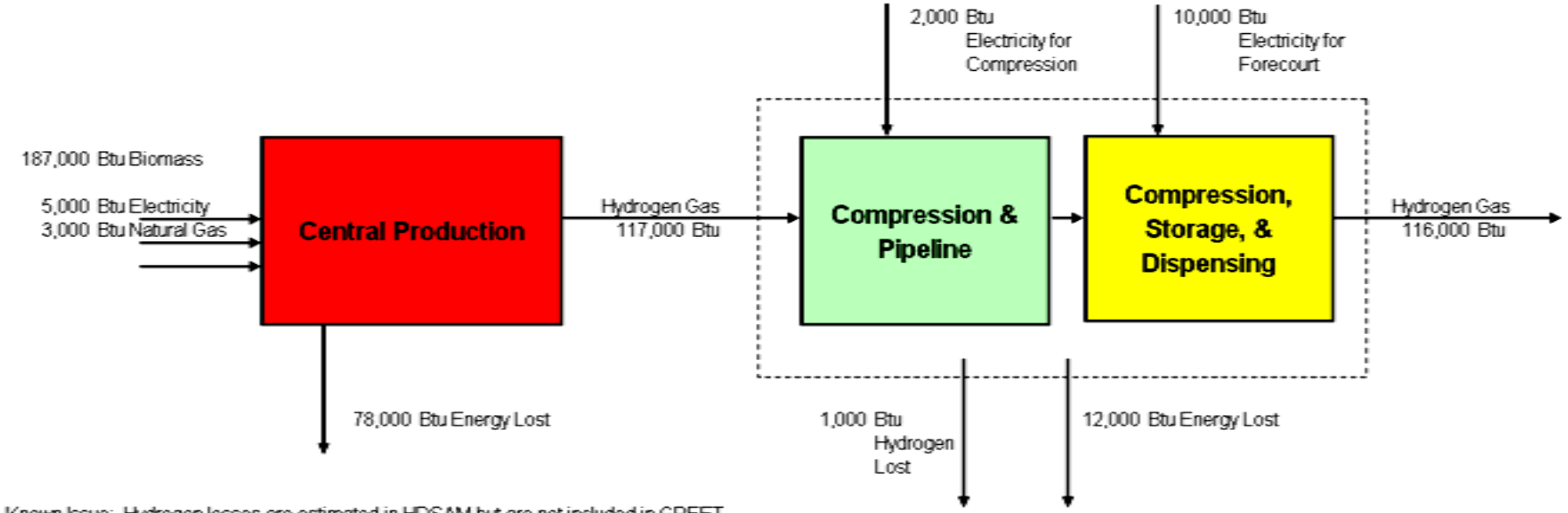
GREET

- Gasoline is RFG without oxygenate
- Current technologies use US average grid mix
- Advanced technologies use future grid mix with 85% of CO_2 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)



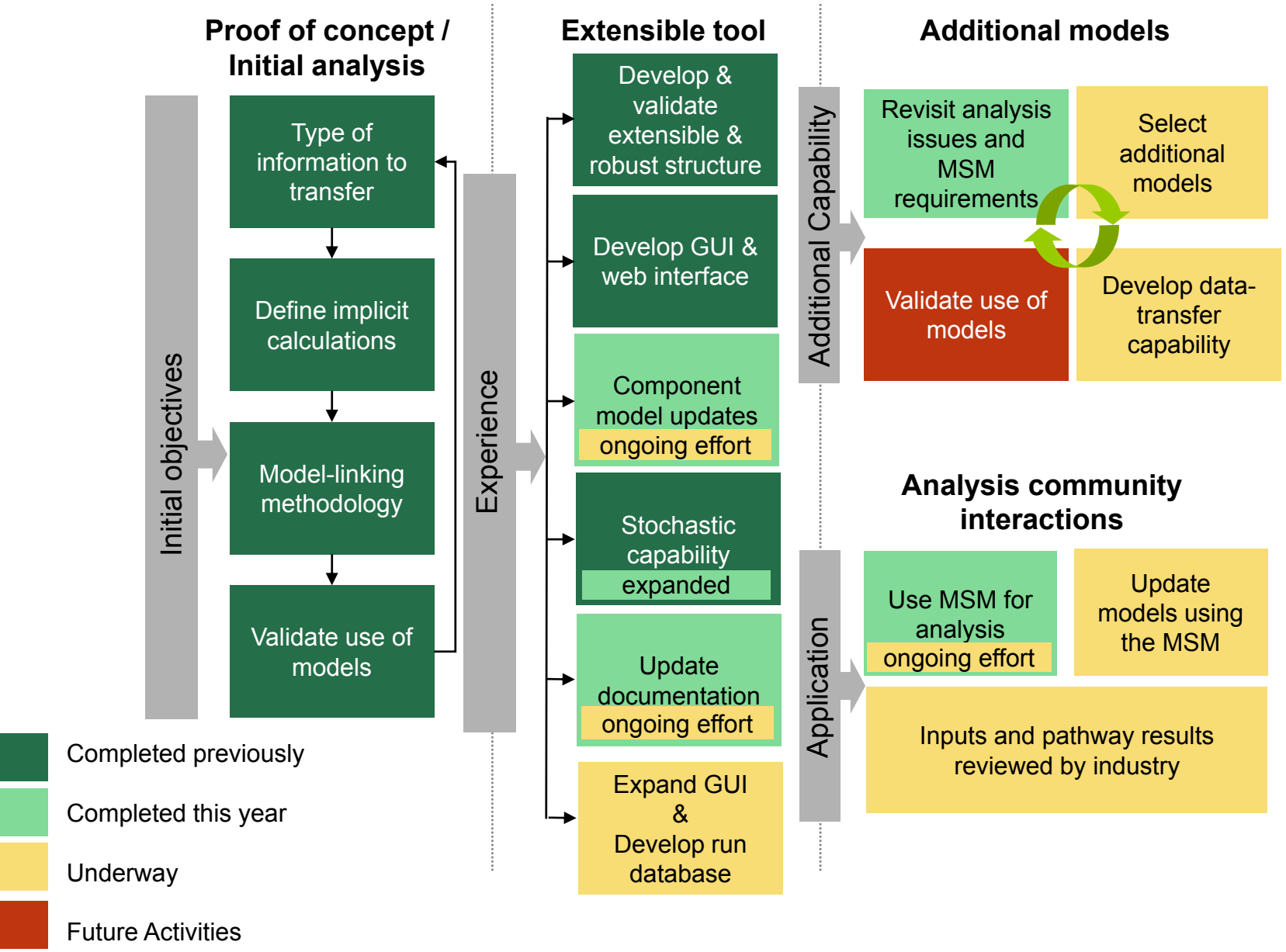
Known Issue: Hydrogen losses are estimated in HDSAM but are not included in GREET

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

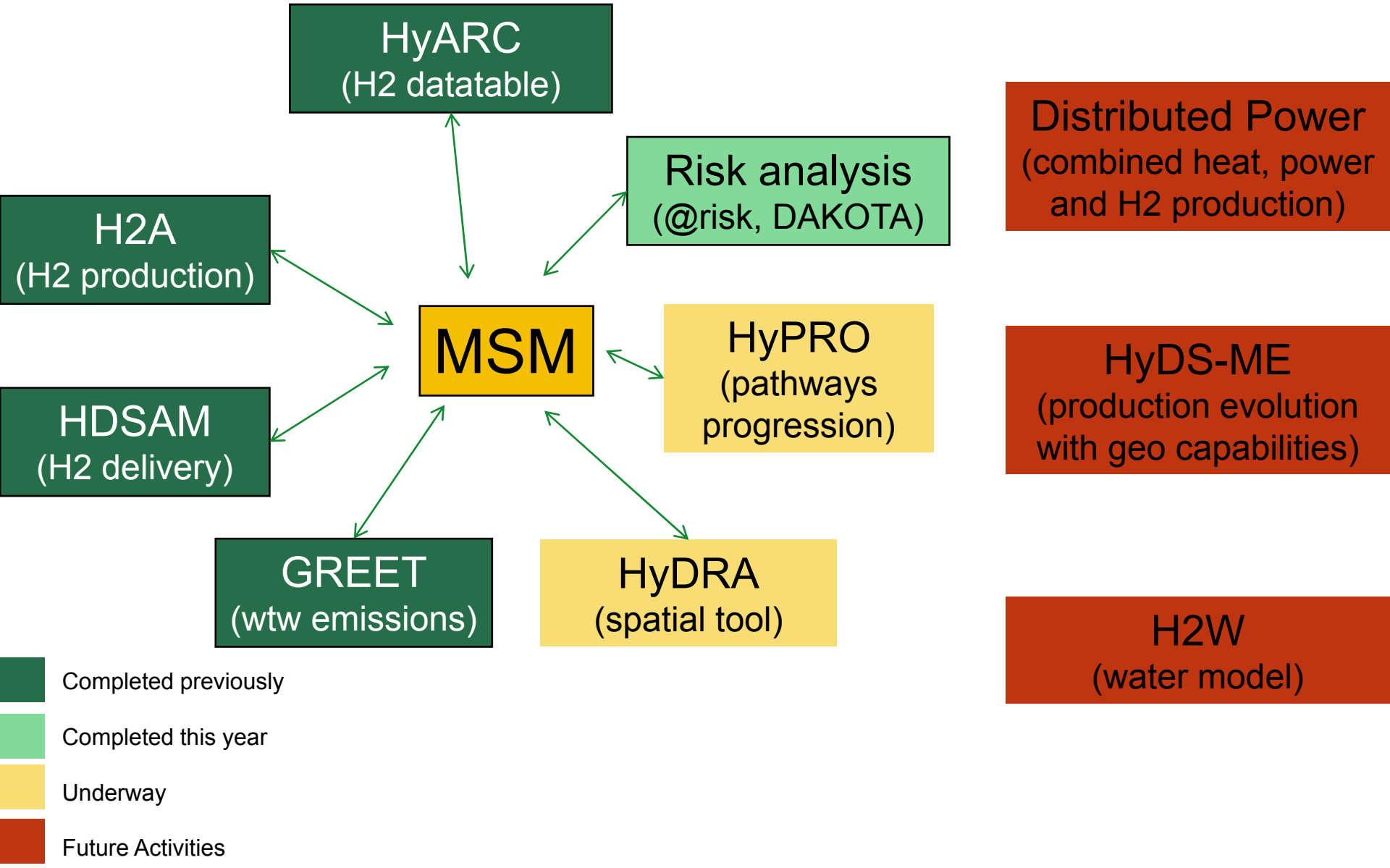
Production Process Energy Efficiency	60%
Pathway Efficiency	56%
WTP Efficiency	48%
WTP Emissions (lb CO2 Equivalent / GGE fuel available):	8

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

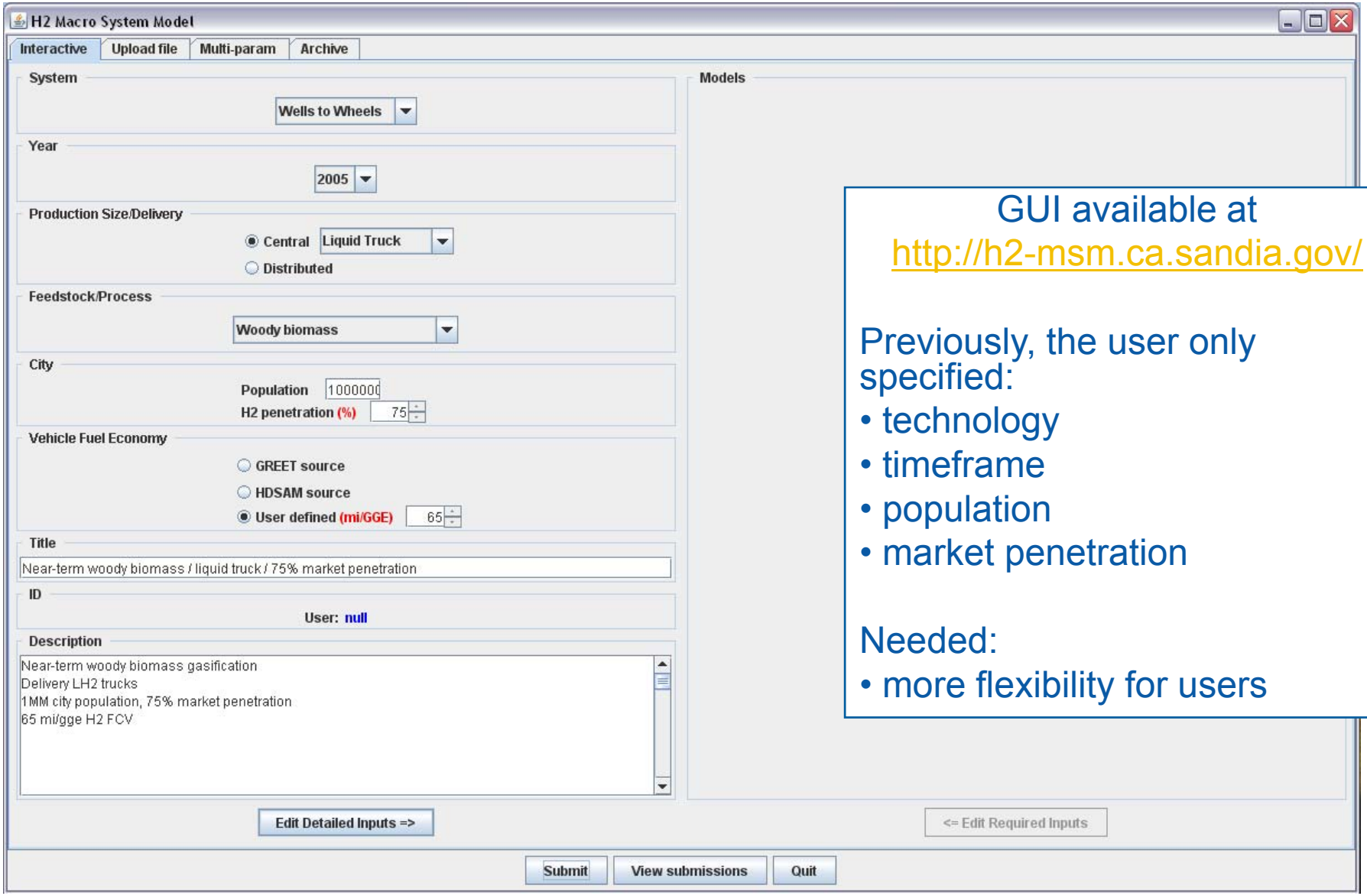
Approach: MSM development



Progress and Future Work: Overview



Accomplishment: GUI and web interface



GUI available at
http://h2-msm.ca.sandia.gov/

Previously, the user only specified:

- technology
- timeframe
- population
- market penetration

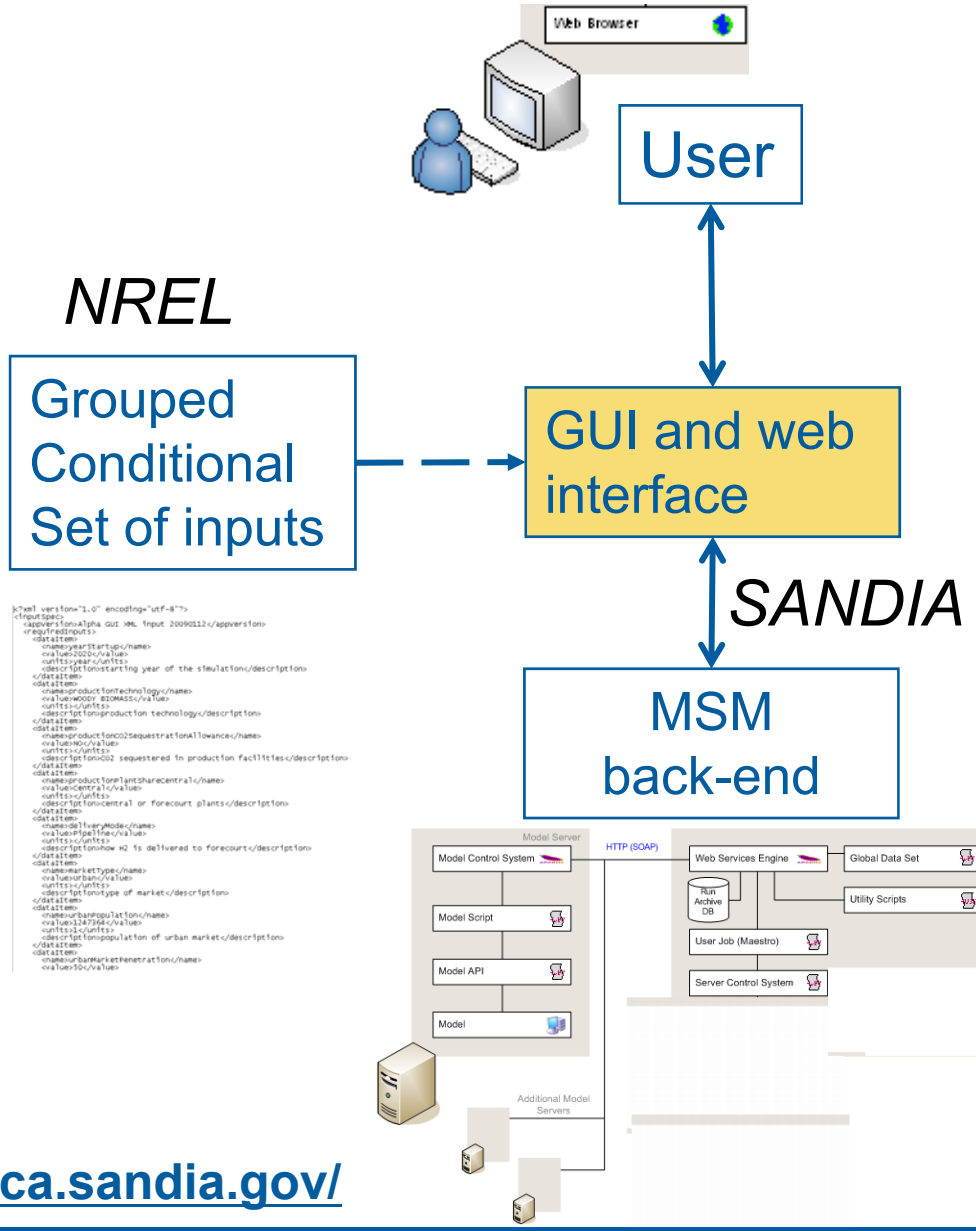
Needed:

- 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/

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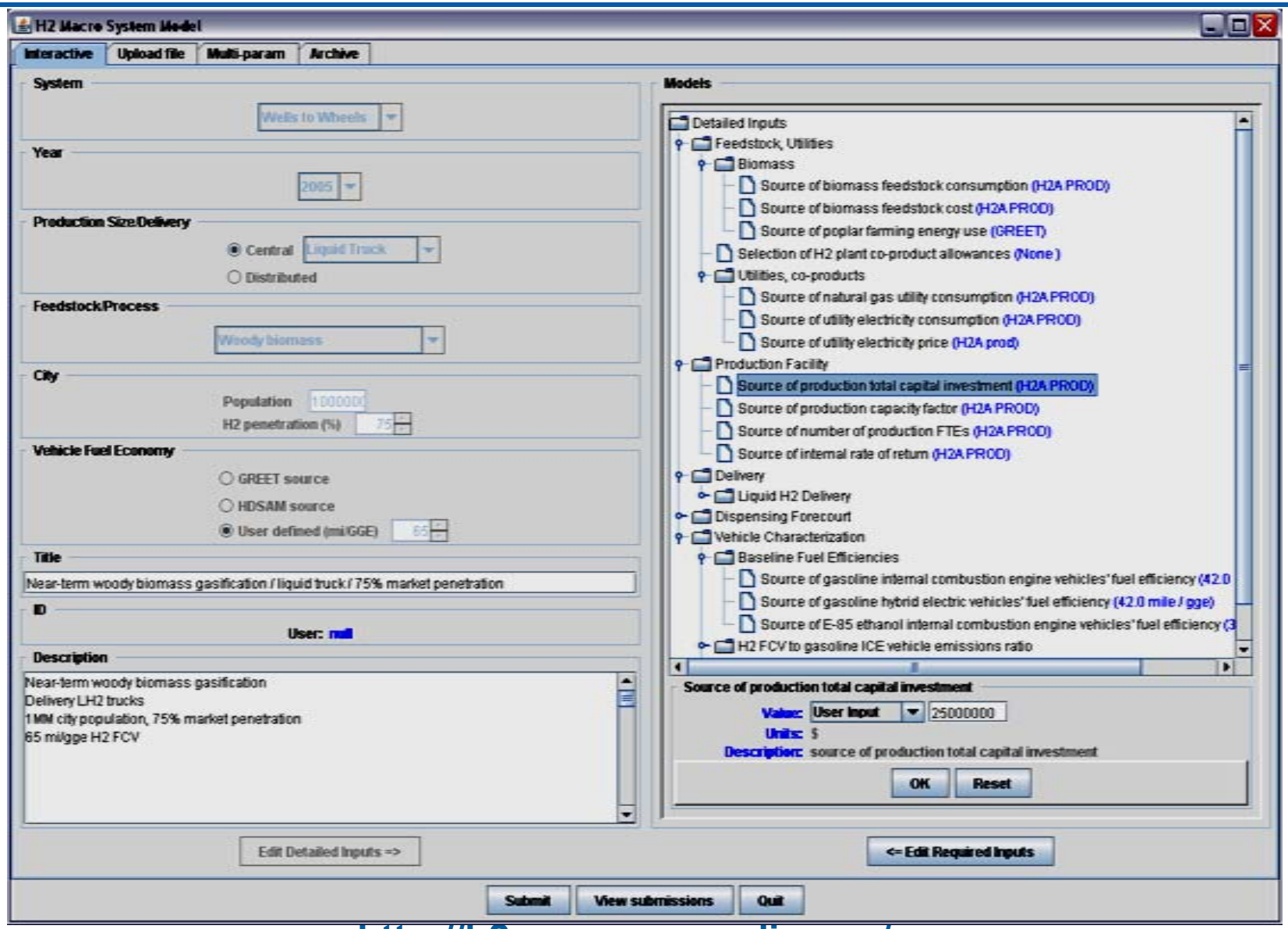


http://h2-msm.ca.sandia.gov/

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,

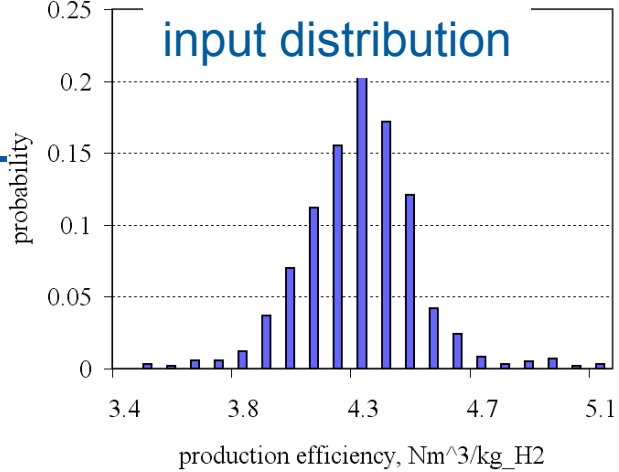
(Report NREL/MP-150-43250, May 2008)

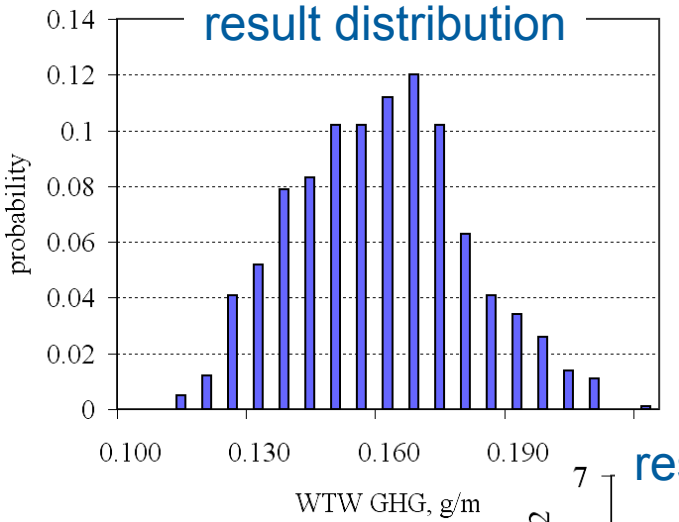
v) gasoline, NG feed cost - historic data
vi) vehicle fuel efficiency (GPRA)

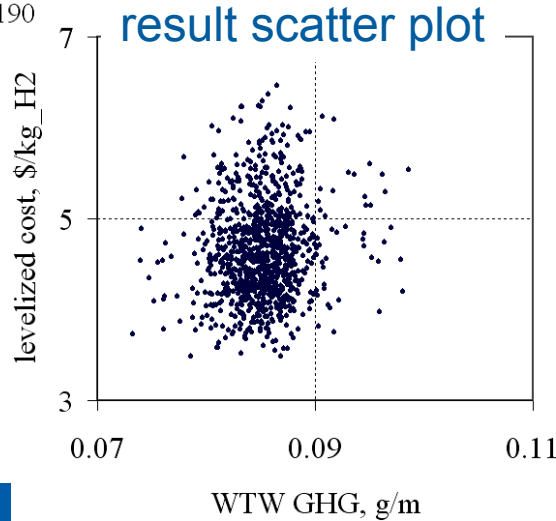
Analyzed tax on well-to-wheel (WTW) green-house gas (GHG) emissions

Compare the cost of fuel:

hydrogen vs. gasoline

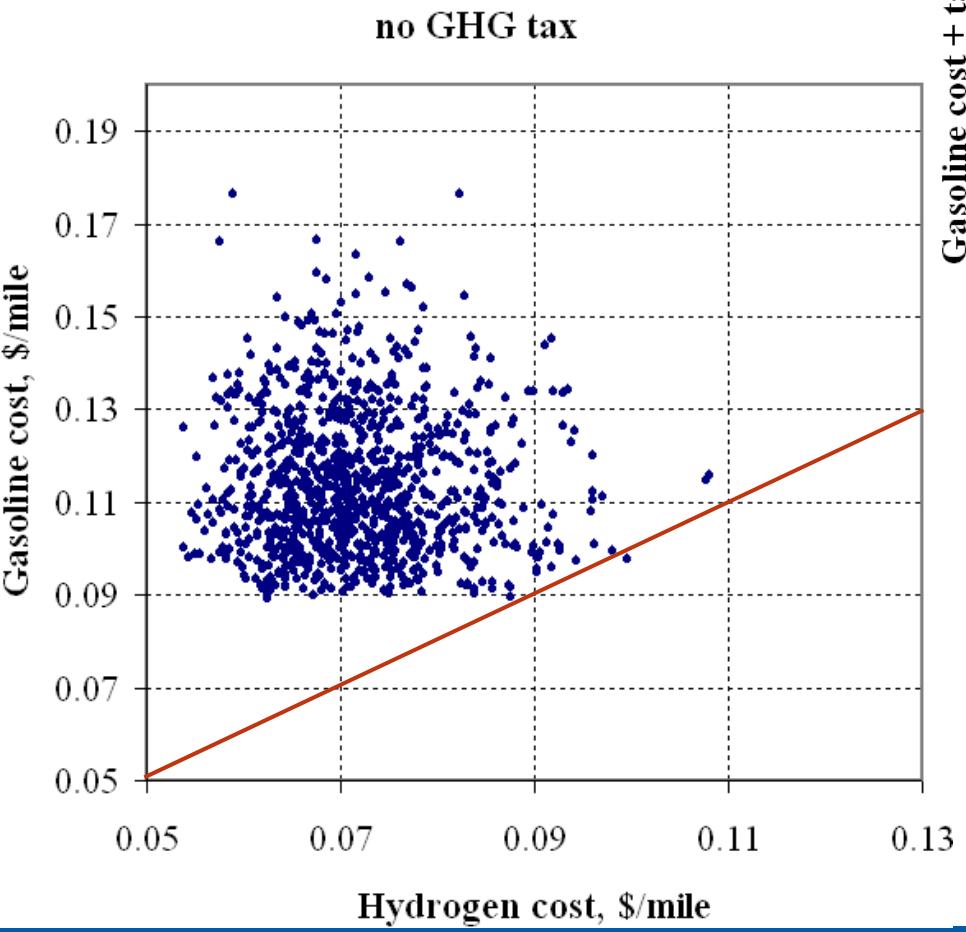


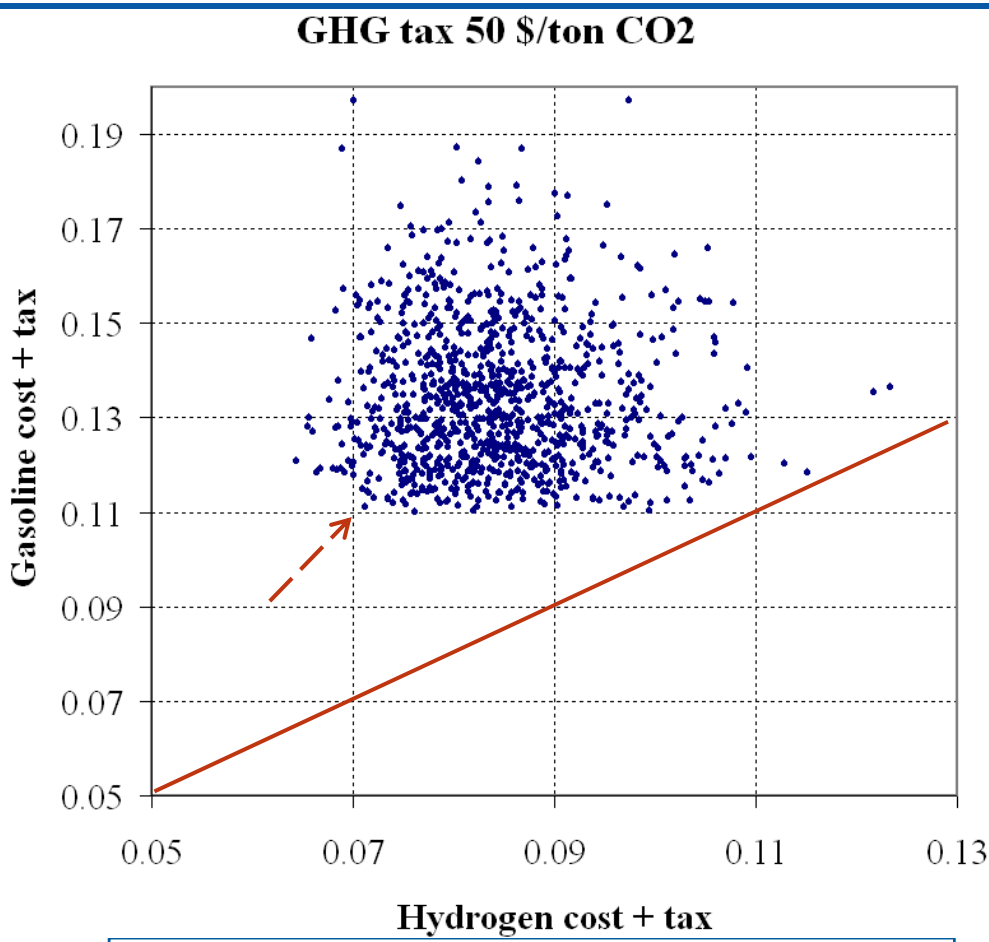




Accomplishment: WTW GHG tax risk analysis

Scatter graph points moved slightly away from the red line





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

Reviewing the methodology and primary assumptions used for the analyses

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

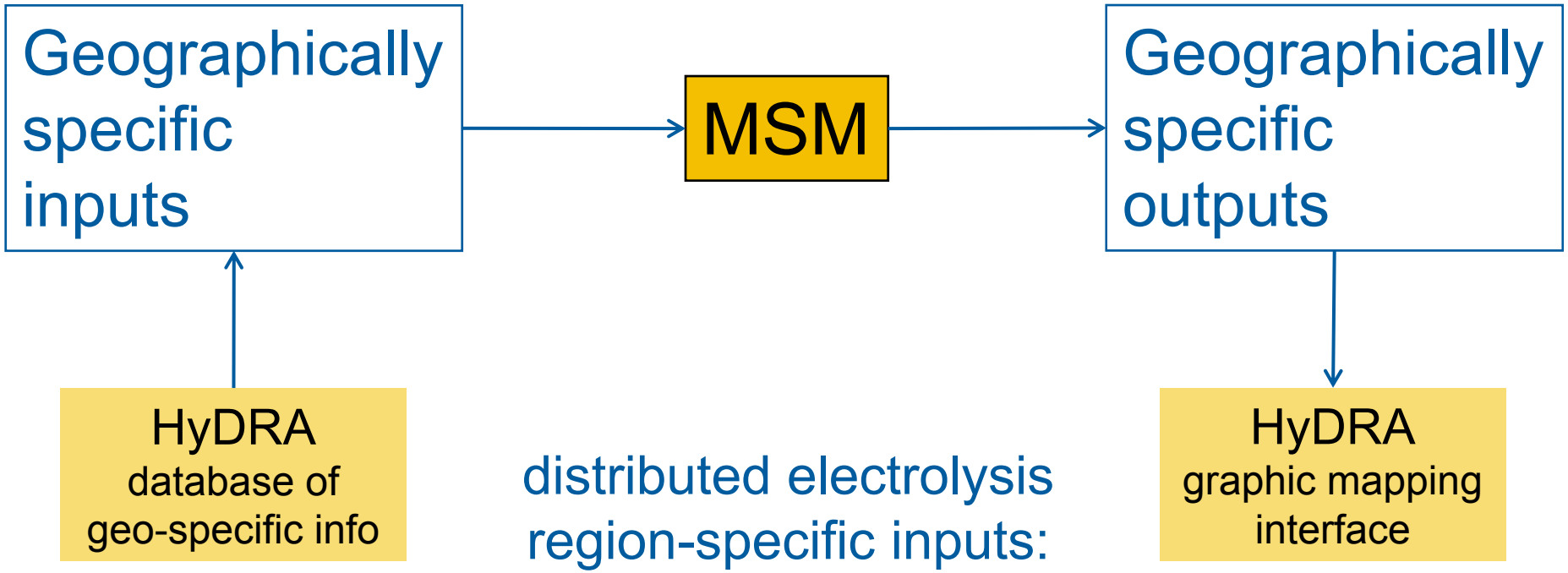
Energy company staff and other experts are validating the process and identifying gaps and issues

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



distributed electrolysis region-specific inputs:

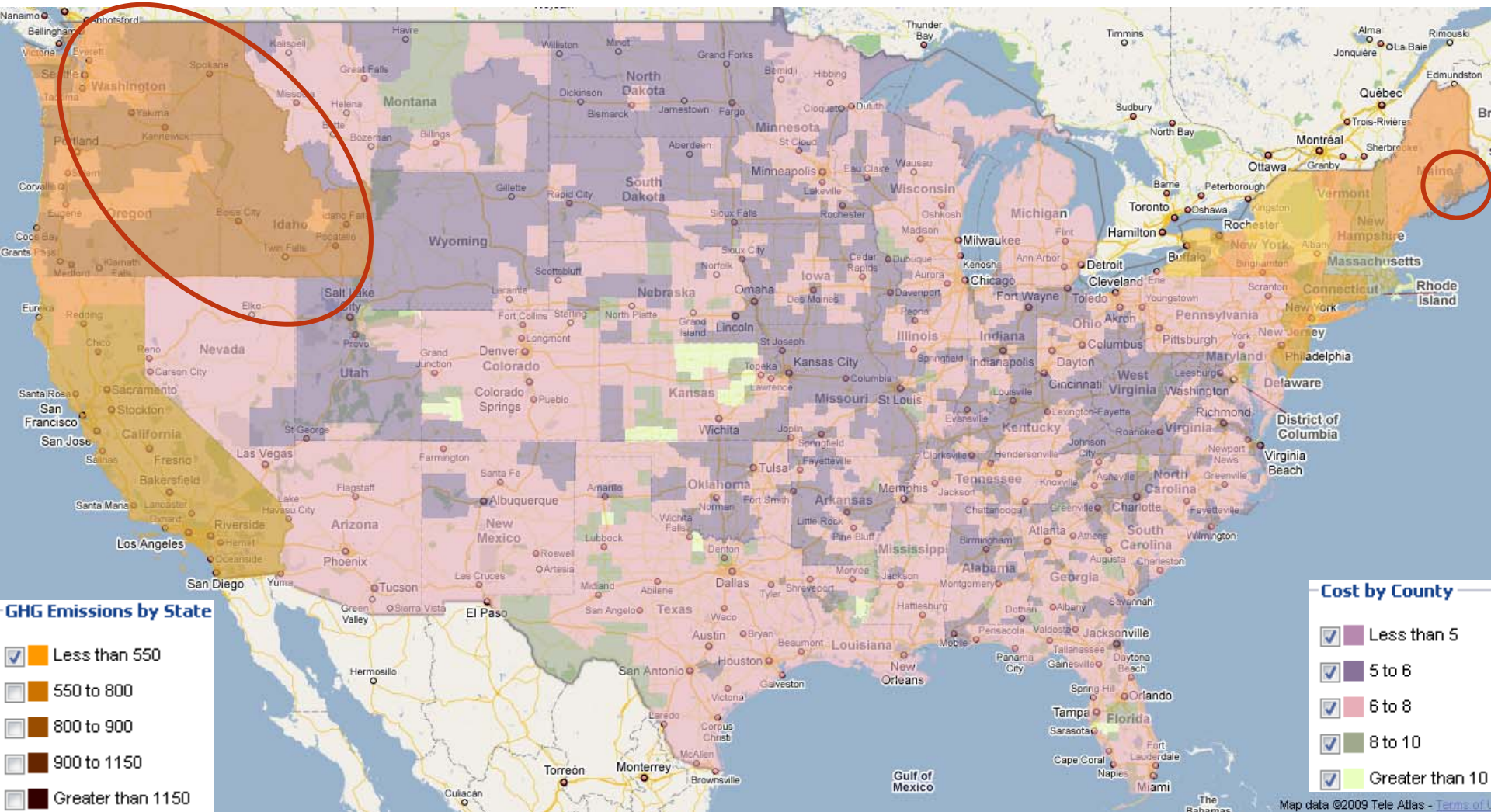
i) electricity price

ii) electricity grid mix

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;

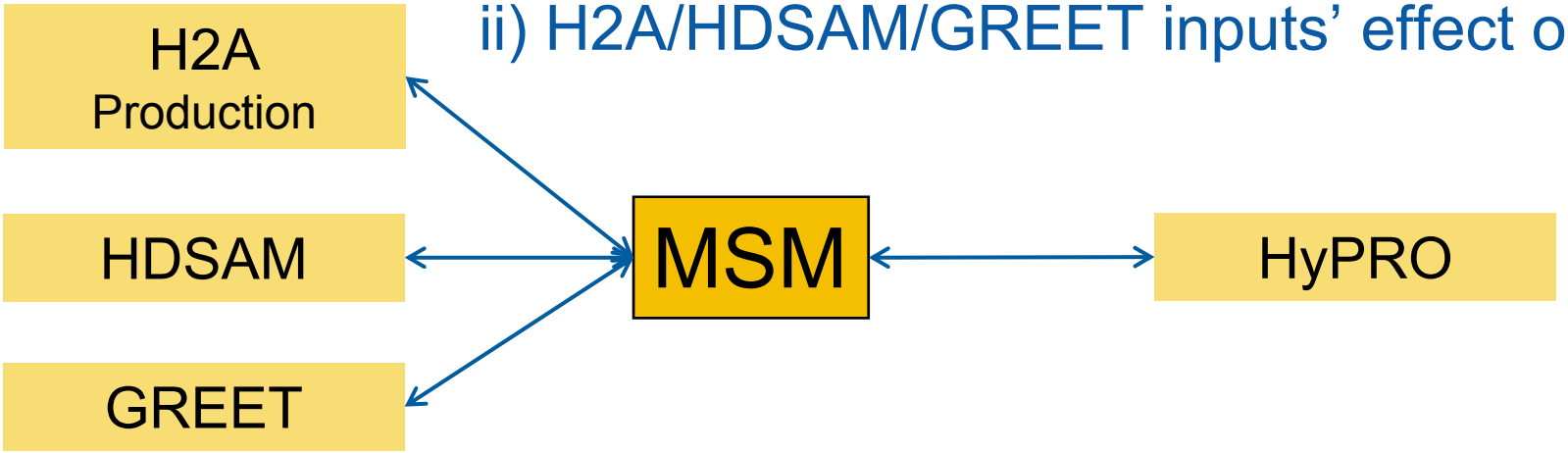
ii) H2 production options and costs (H2A)

iii) H2 delivery options/costs (HDSAM)

Advantages for linking MSM with HyPRO:

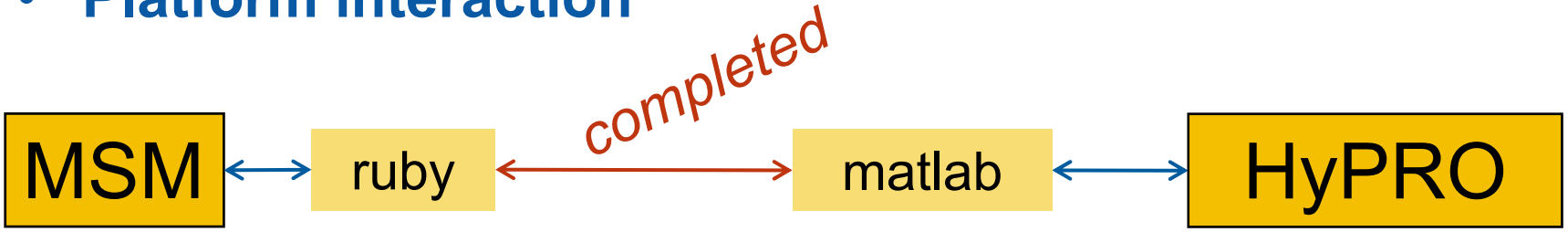
i) auto-updated links HyPRO ↔ H2A/HDSAM

ii) H2A/HDSAM/GREET inputs' effect on HyPRO

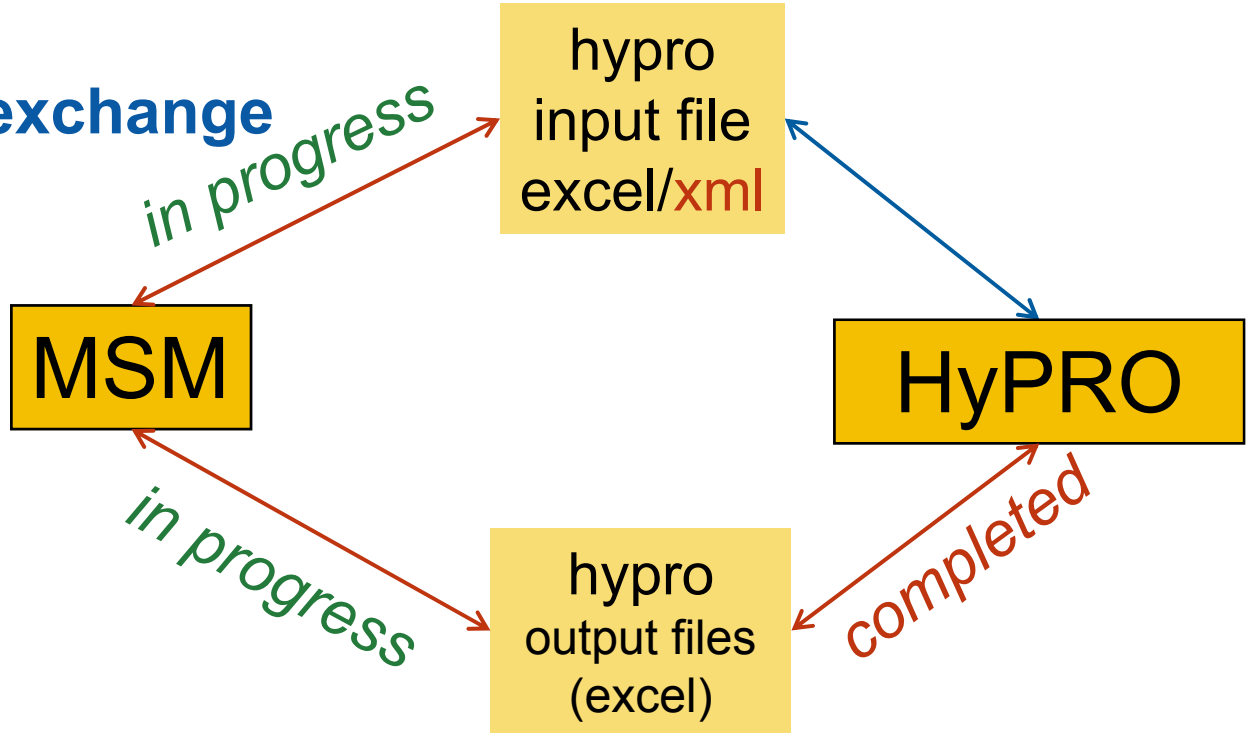


Progress & future work: linking MSM ↔ HyPRO

- **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

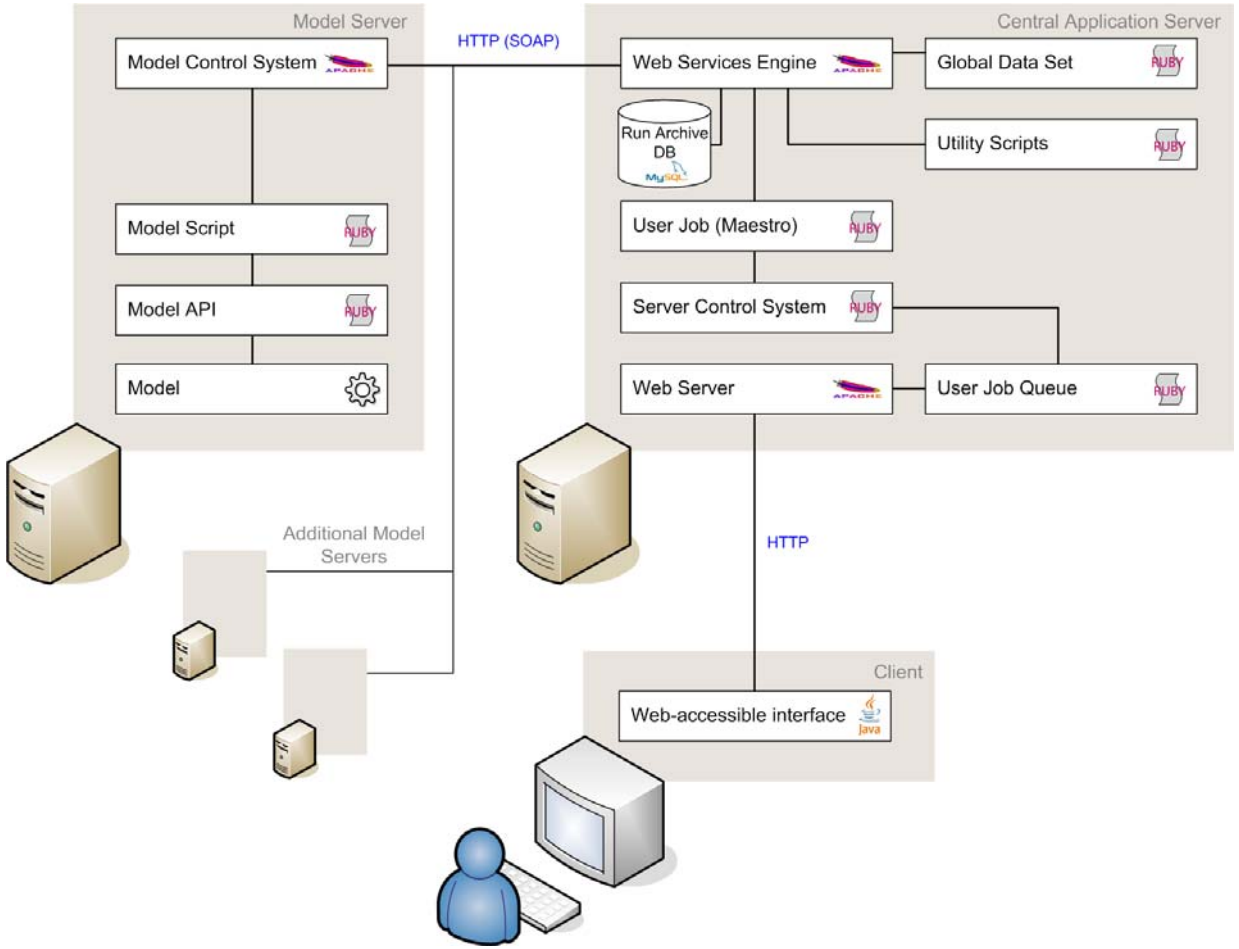
- Give users MORE flexibility
  - Significantly expand GUI capabilities
- Link to MORE models
  - H2A, HDSAM, GREET + HyPRO, HyDRA, H2Power, HyDS-ME, H2W, PowerPark, …
- Expand to MORE computers
  - Over the ‘net interactive
- Use MORE platforms
  - xl + MATLAB

Broader objectives

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

ADDITIONAL SLIDES

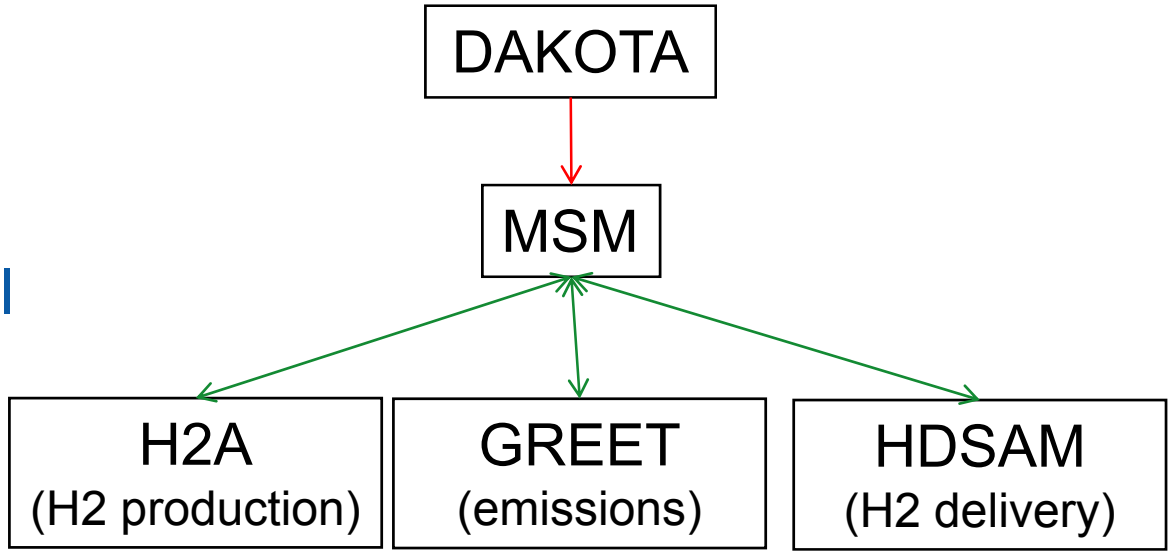
Accomplishment: extensible robust structure



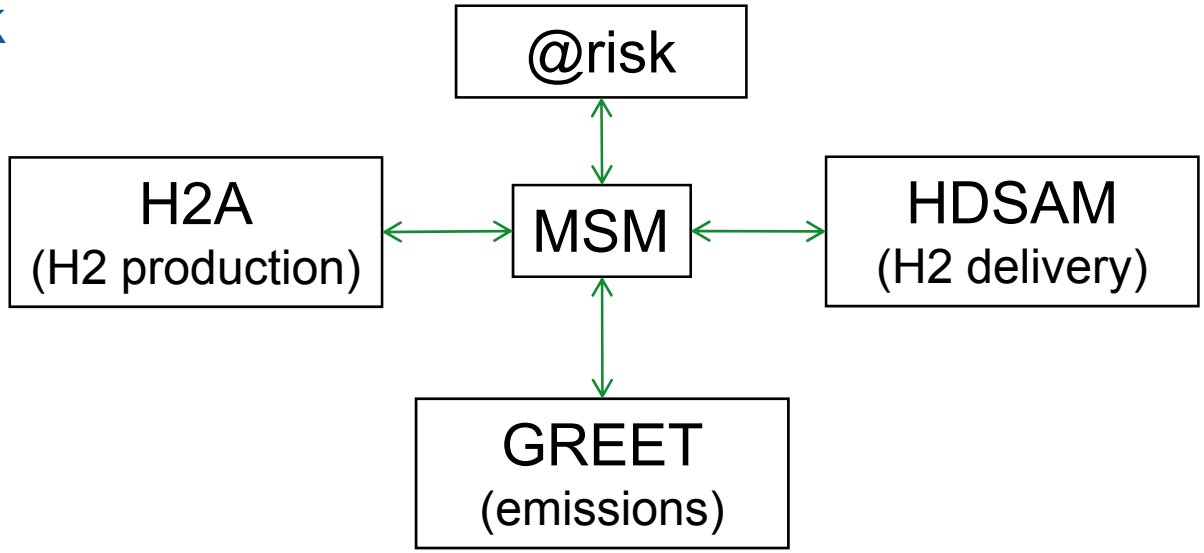
- MSM built in Ruby/Java/PHP/SQL
- Ruby version is stable and handles various data types
- Developed technique that allows models to run on different machines
- Developed web-accessible graphical user interface (GUI) to make the MSM available to more users
- Validated results against proof-of-concept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

Uncertainty analysis in MSM

1st choice: DAKOTA breaks the high-level architecture

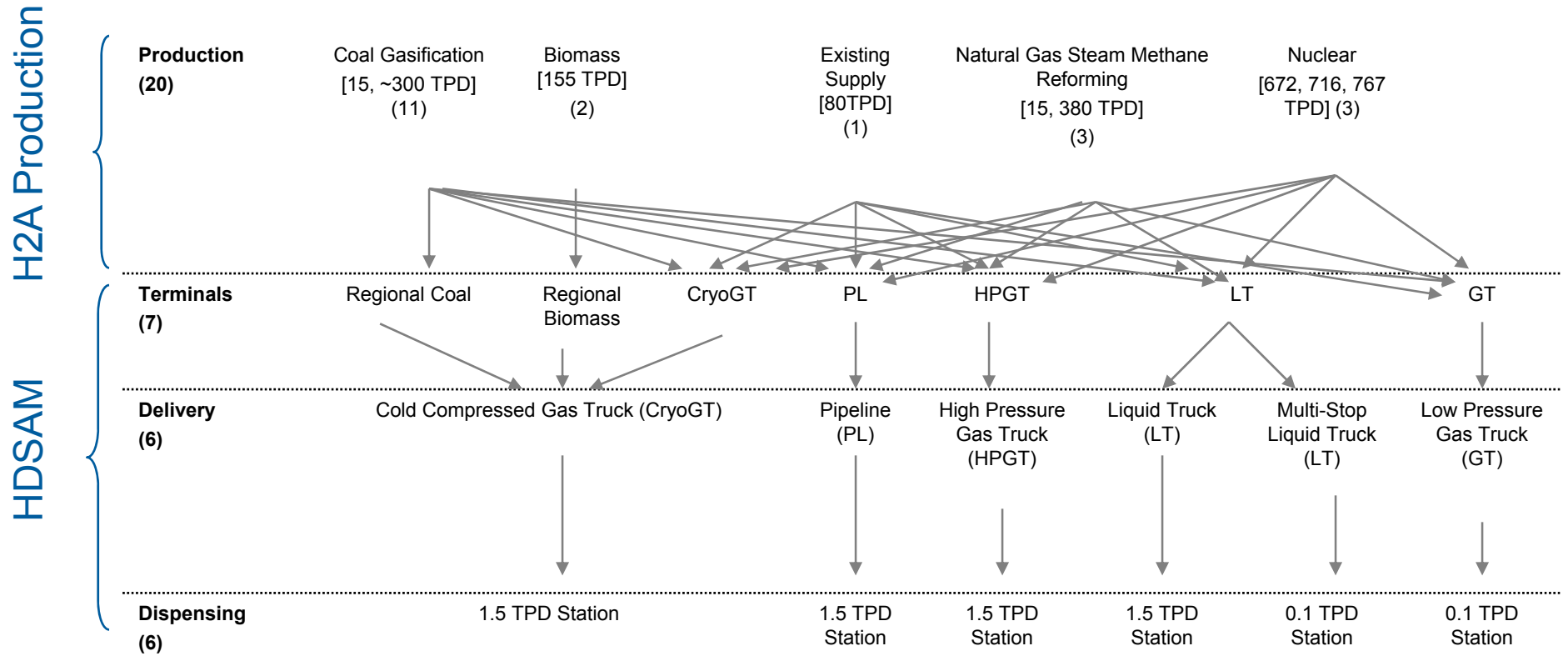


2nd choice: use @risk allows to apply risk analysis to individual models

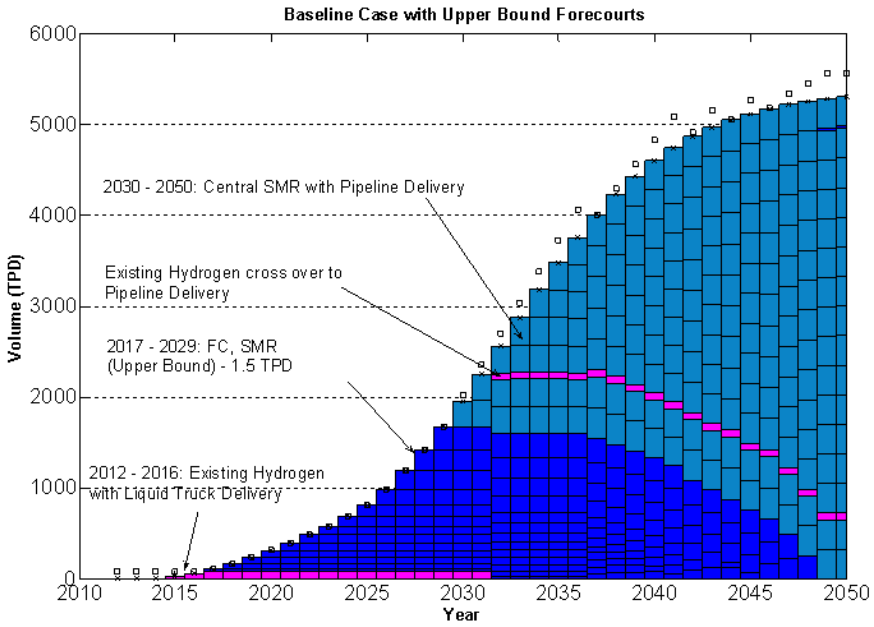


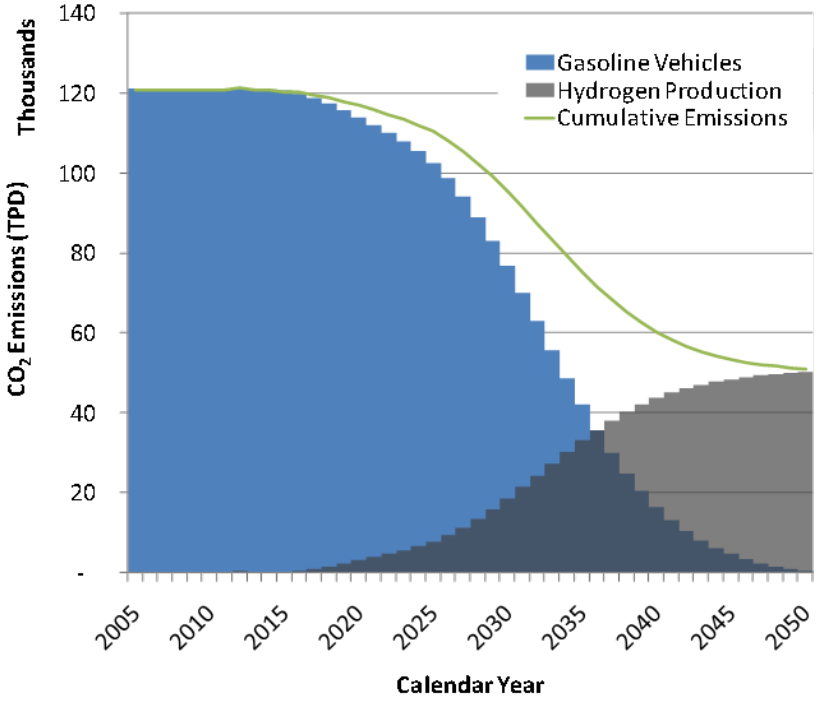
Progress: linking MSM with HyPRO

HyPro is:	– HyPro = Hydrogen Production transition model – Calculates expected H_2 cost for a variety of pathways – Uses H_2 cost to predict which H_2 pathway is built in each year – Creates a year-by-year build history of H_2 production, delivery and dispensing – Excel input spreadsheet, calculations in MatLab



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