Macro-System Model
Project # AN011

2011 Annual Merit Review

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

Overview

Timeline

Start date: Feb 2005

Status: ongoing

Percent complete: 80%

Budget

Total funding:

- 100% DOE funded

FY10 funding

- $330K NREL/SIO
- $250K Sandia NL

FY11 funding

- $250K NREL/SIO
- $250K 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, HyDRA

Argonne National Laboratory

- HDSAM, GREET

Alliance Technical Services

- Data sourcing and documentation

Directed Technologies, Inc.

- HyPRO

SENTECH

- User Guide

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

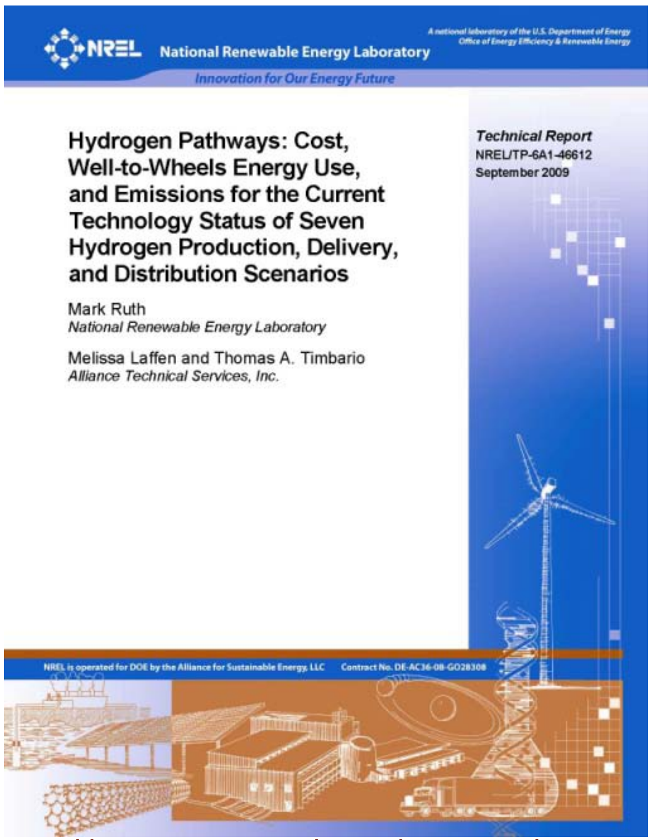
2010/2011 objectives

- Increase GUI functionality and capabilities
- Utilize the MSM to compare hydrogen production/delivery/dispensing pathways
- Follow model upgrades (GREET1.8d1, HDSAM2.2)
- Include vehicle cycle analysis from GREET2 and cost per mile tool
- Integrate the Fuel Cell Power model
- Technical breakpoints in transition scenarios analysis

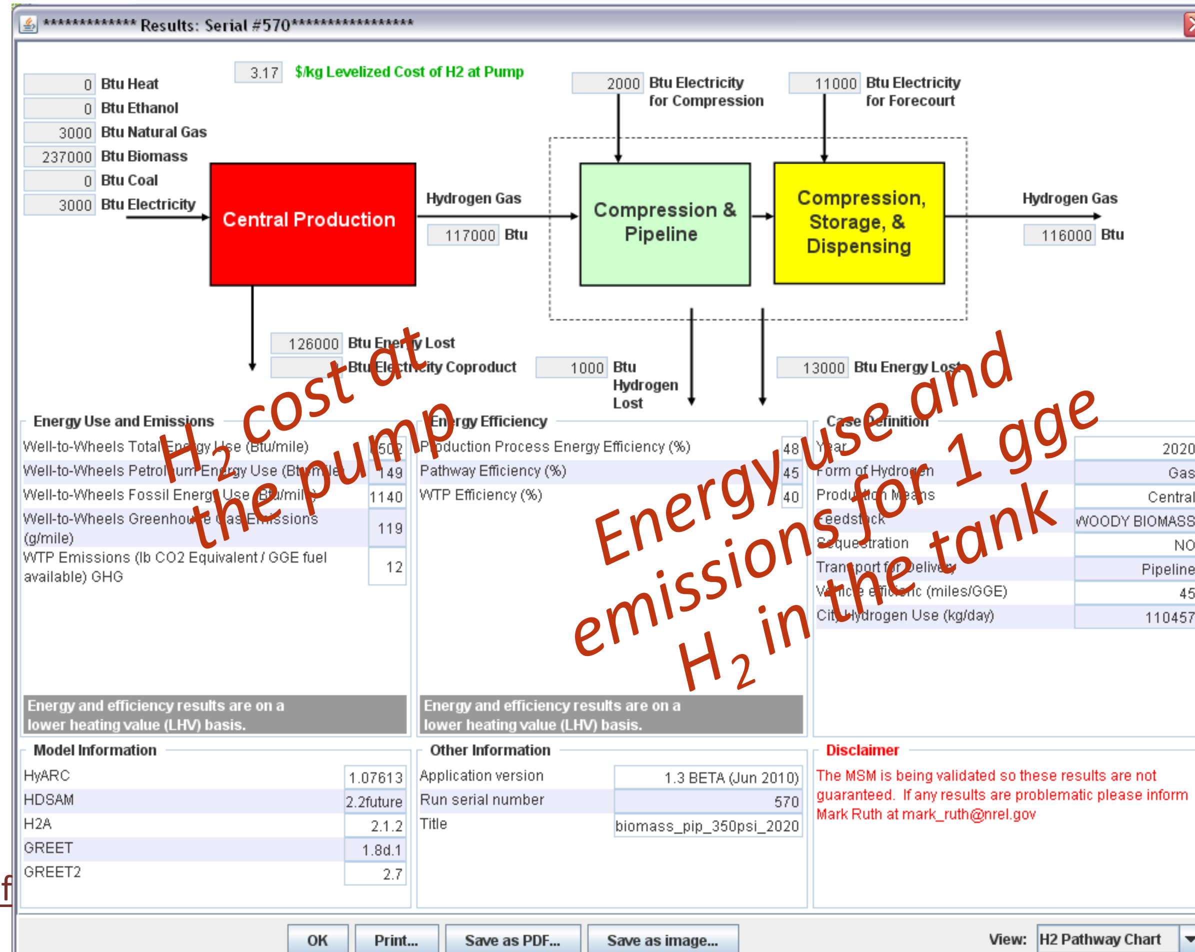
MSM available to the analysis community at **http://h2-msm.ca.sandia.gov/**

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.
- The MSM results are reported and used in setting H_2 program goals.



http://www.nrel.gov/docs/fy10osti/46612.pdf



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% H2 penetration
- 1500 kg/day stations
- Mid-size FCV –
  - Current – 45 mi / GGE
  - Advanced – 65 mi / GGE

Financial

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

Production

- Central Biomass
  - Current – 46% conversion efficiency
  - Advanced – 48% conversion efficiency
- Coal Gasification
  - Current – 56% conversion efficiency
  - Advanced – 64% conversion efficiency
- Nuclear HTE
  - Advanced – 83% conversion efficiency
- Distributed SMR
  - Current – 71% conversion efficiency
  - Advanced – 74% conversion efficiency
- Electrolysis
  - Current – 62.5% production efficiency
  - Advanced – 75% production efficiency

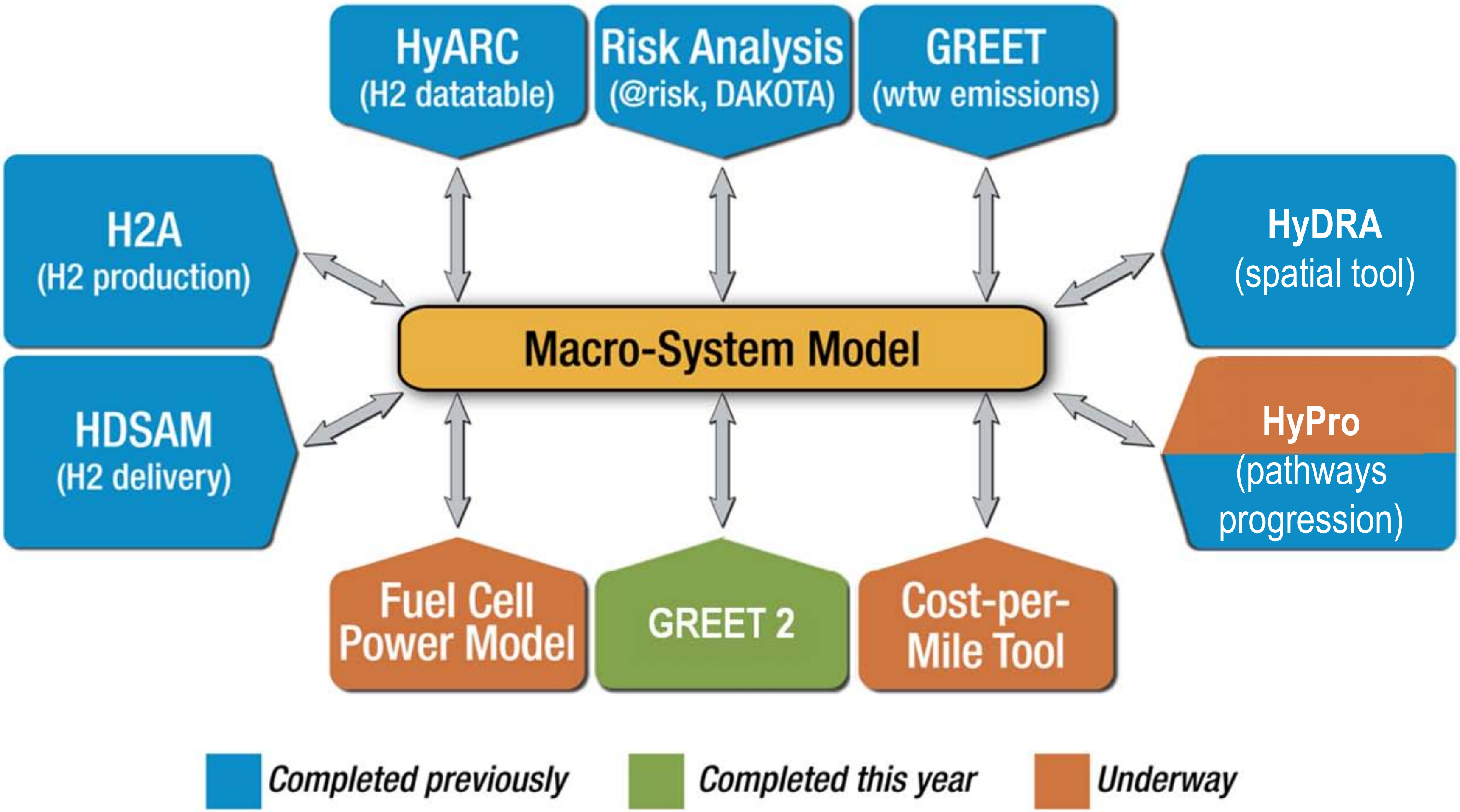
HDSAM

- Fueling station capacity factor = 0.84
- 62 miles from central production to city
- Liquefier efficiency 72%

GREET

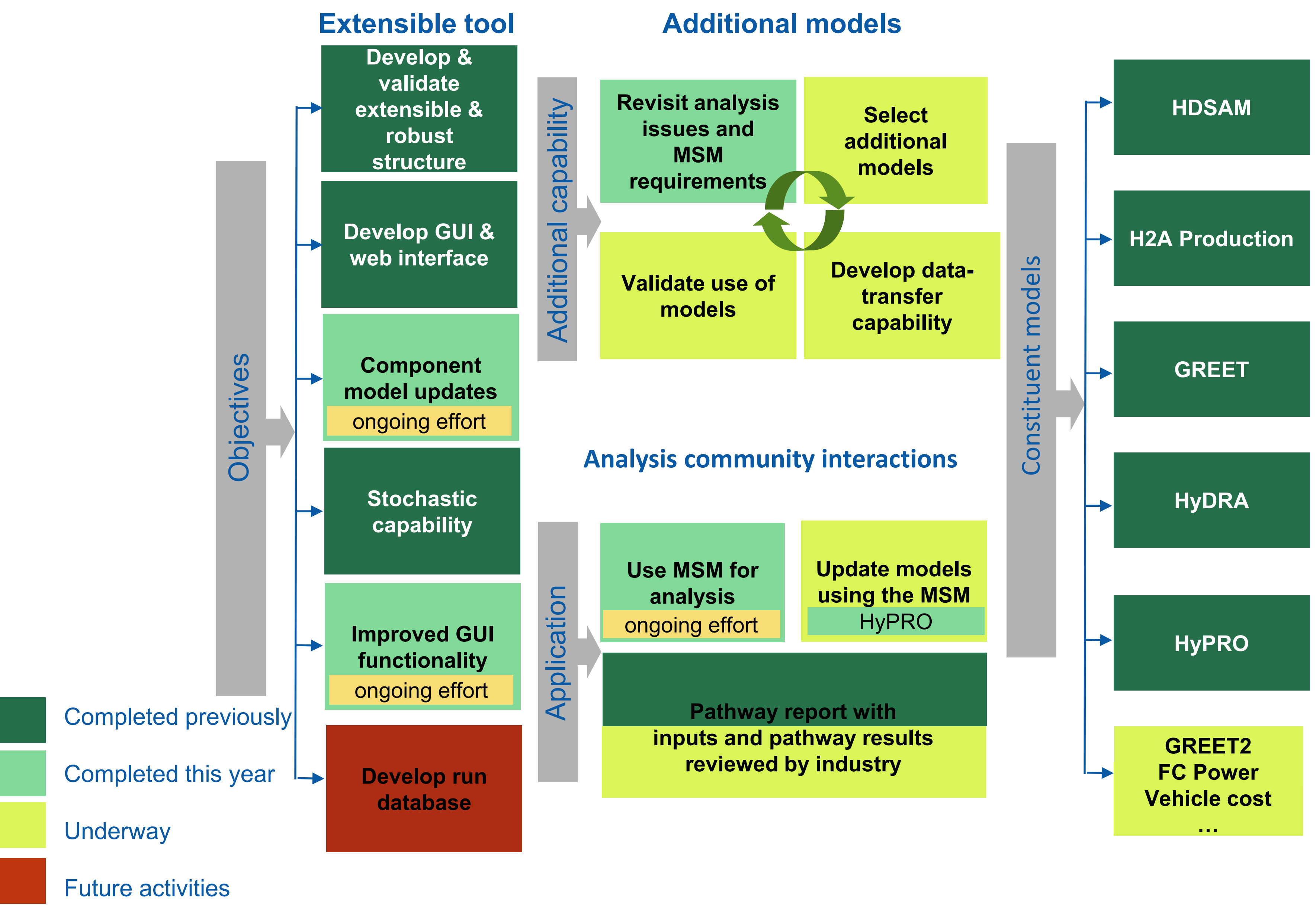
- Gasoline is RFG without oxygenate
- Current technologies use U.S. average grid mix
- Advanced technologies use future grid mix with 85% of CO2 from coal plants sequestered

Development Approach, Progress, and Future Work



The MSM provides a ***central transfer station*** to guarantee consistency in simulations that involve multiple models. A graphical user interface (GUI) allows users to easily use the models.

Approach: Process for Expanding MSM Capabilities



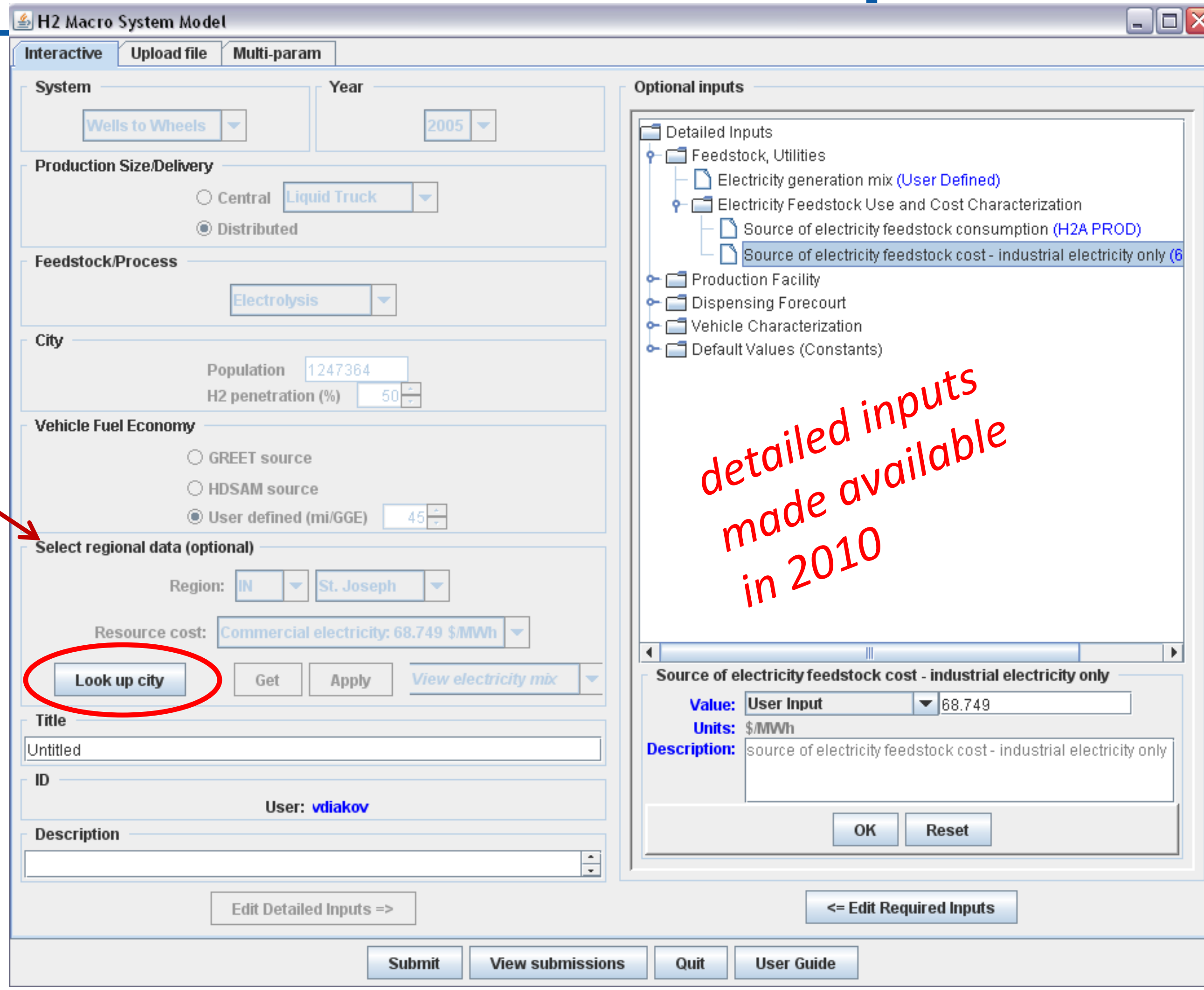
Approach: Model Validation

- Model inputs and results were reviewed by the Fuel Pathway Integration Tech Team (FPITT), others in the H_2 analysis community and industry experts
- The major MSM output – Pathway Report(s), undergo thorough reviews by FPITT
- The H2A Production models and HDSAM are built in a transparent way and undergo their own validation prior to being published; these models are reviewed by the Production Tech team and by the Delivery Tech team
- GREET is widely used and is being constantly reviewed and updated

Validating models at both integrated and component levels

Accomplishment: Enhanced GUI Inputs

Utility Costs and Grid Mix are available by county (using the link with HyDRA)

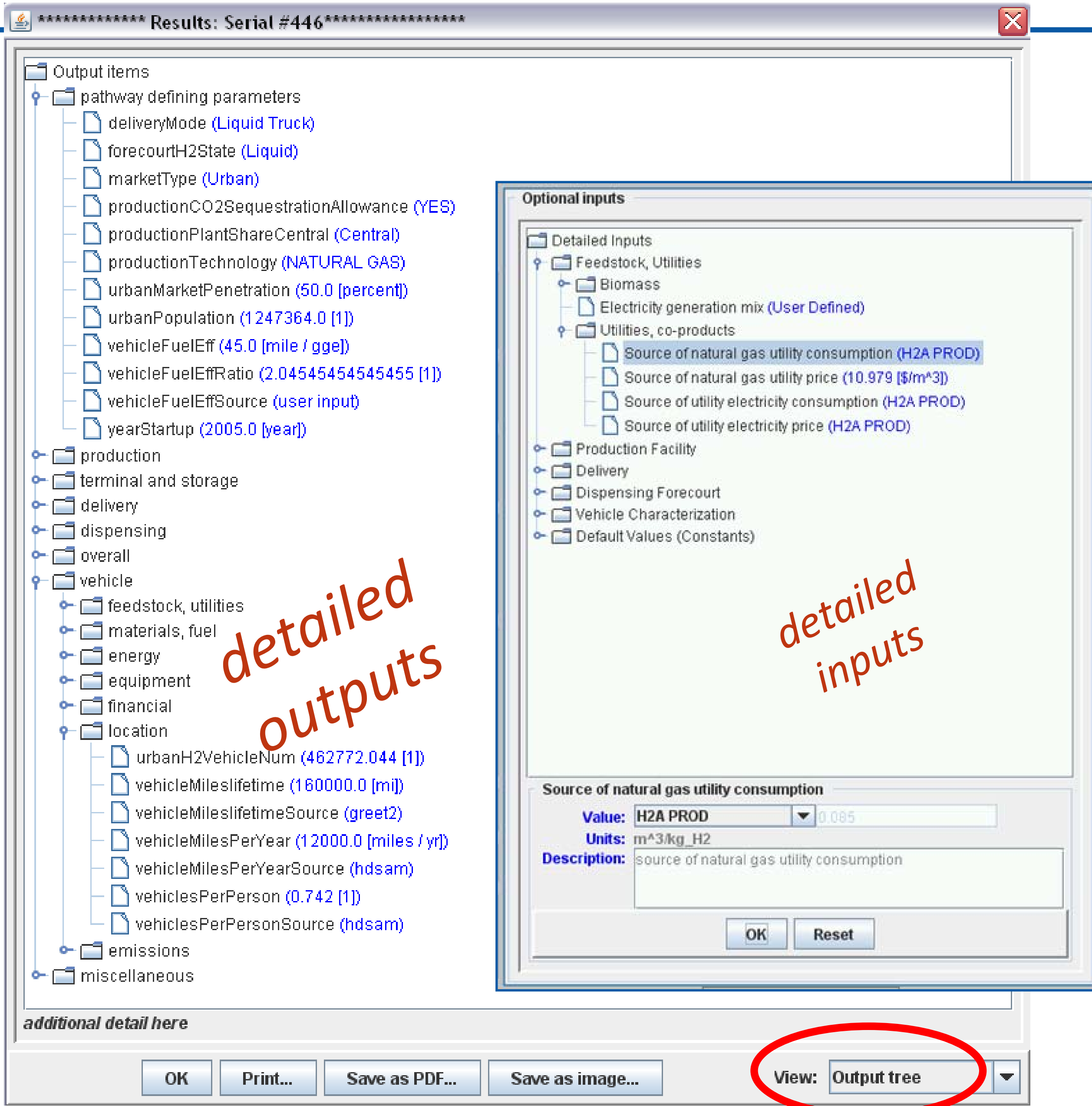


The MSM GUI now ***helps the user select a county***; HyDRA provides feedstock and energy prices and the grid mix for that county. The user can modify many technical parameters.

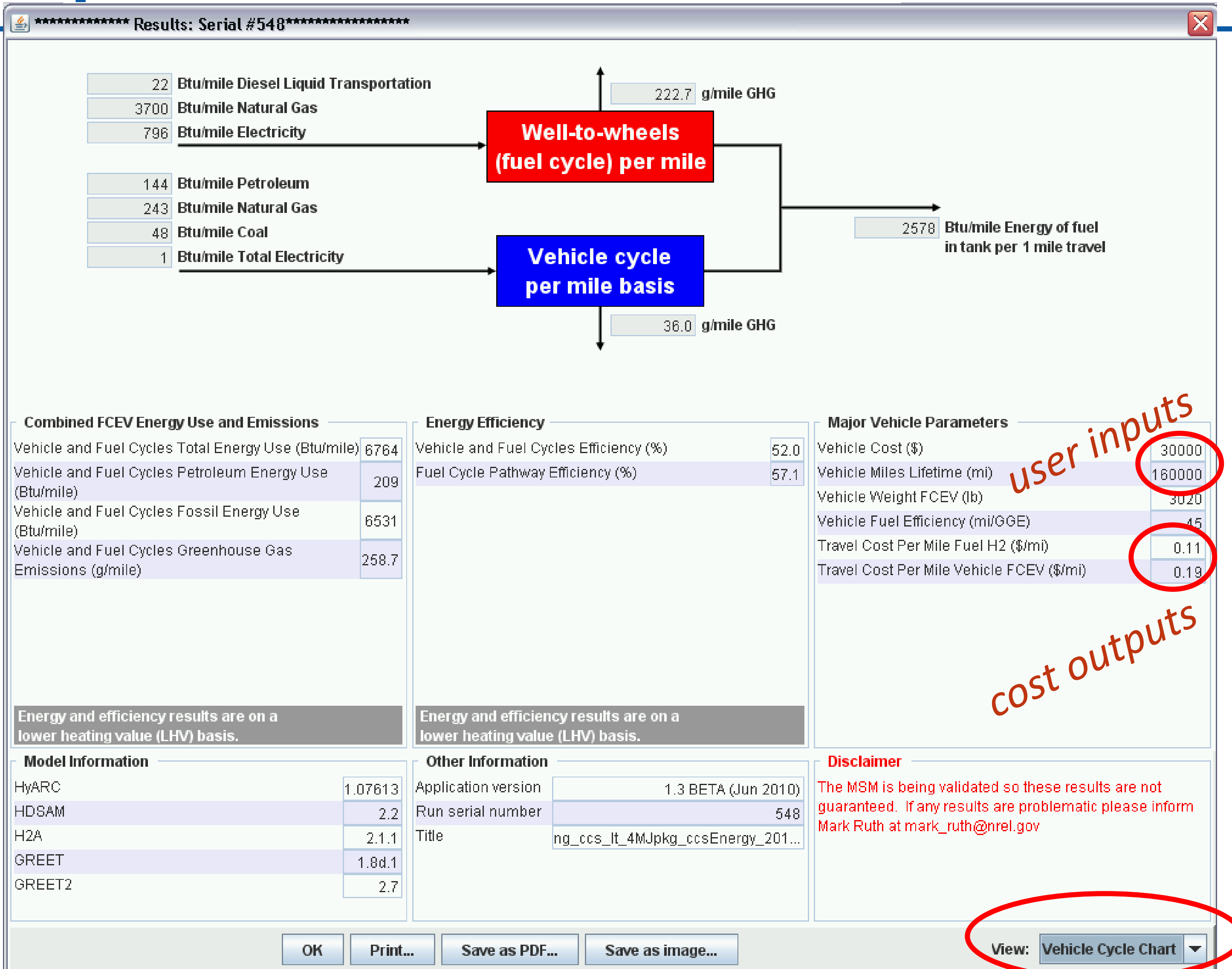
Accomplishment: Detailed outputs in the GUI

Detailed outputs capability added

- extra ~500 variable values can be viewed after each MSM run
- grouping variables into branched structures
- easily accessible groups and variables



Accomplishment: Linked GREET2 with MSM

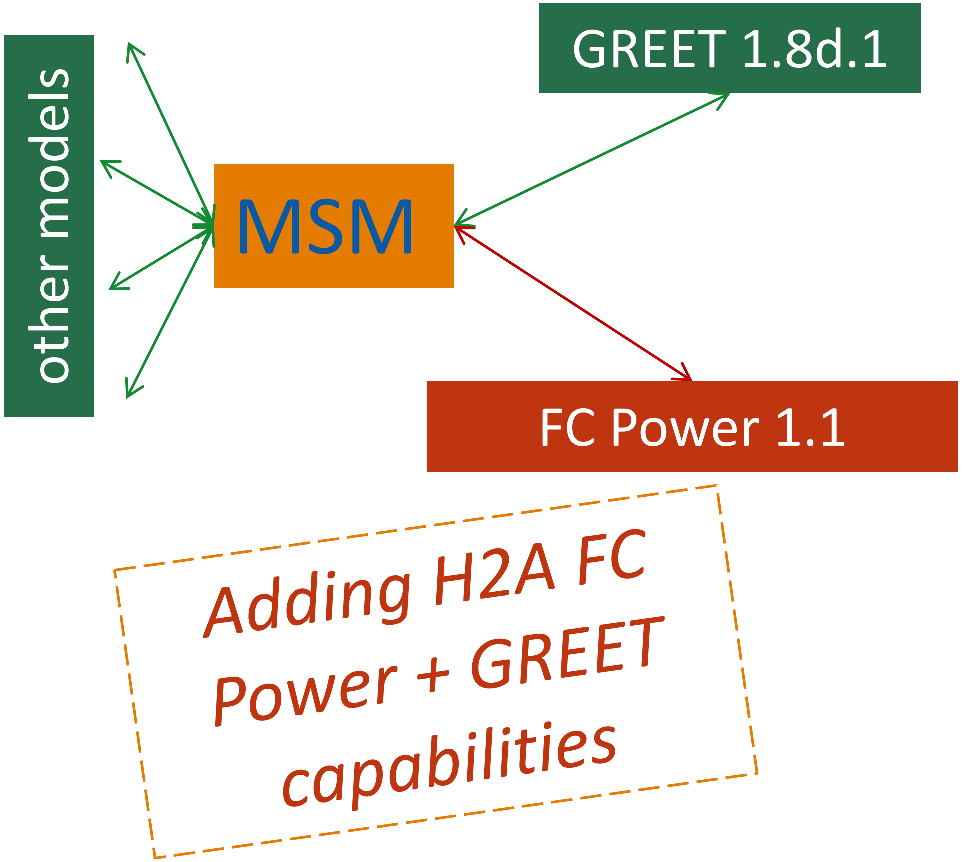


Vehicle production, non-fuel utilization, and disposal energy use and emissions can now be estimated within the MSM framework.

Approach: Including CHHP System Models

User interface items:

- H_2 FC, wind turbine, PV, etc.
- choice of power demand profile (office/hotel/mall; geographic location)
- profile location (import HyDRA data)



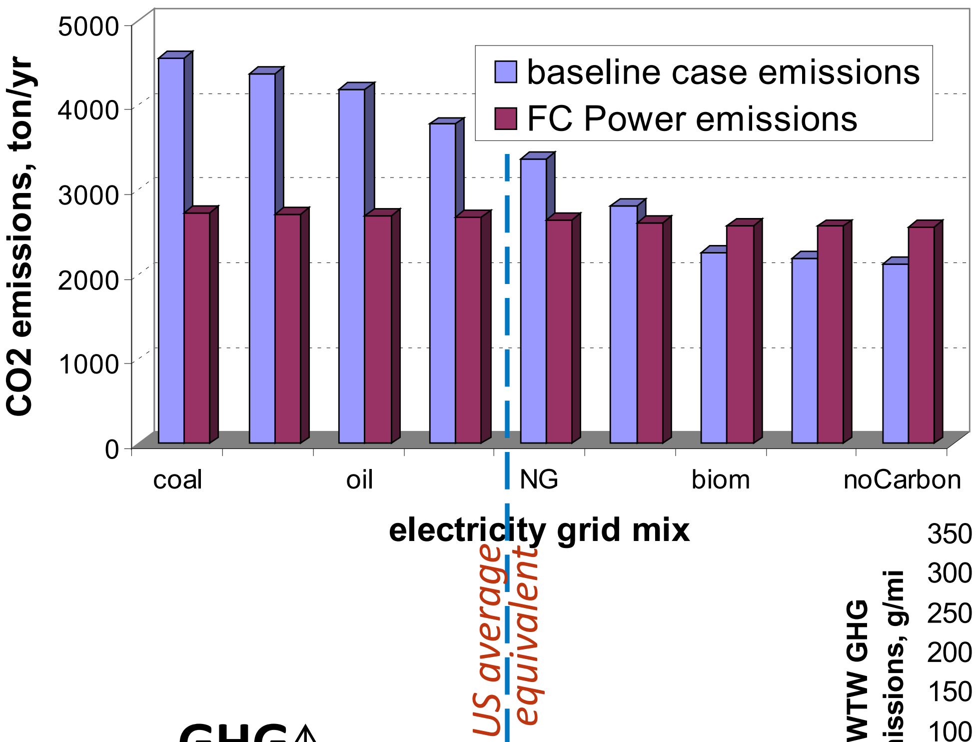
After choosing the electricity generation mix, GREET calculates:

- electricity fuel-cycle energy use & emissions / feedstock for transportation use
- NG energy use and total emissions / NG as stationary fuel

Upstream energy & emissions table, entries for NG and electricity:

- total energy
- fossil fuels
- petroleum
- CO_2, N_2O, GHG

Results: CHHP Can Reduce Emissions



for a large hotel in LA, per year

AC power produced: 1200 MWh

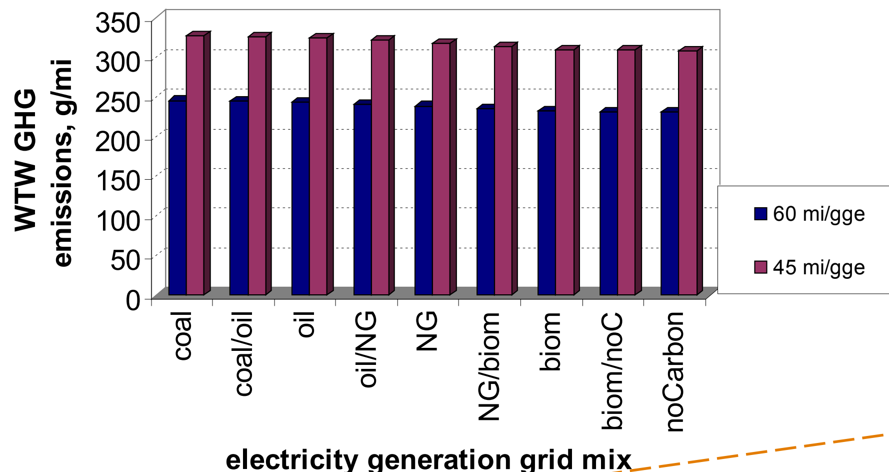
Supplemental AC: 800 MWh

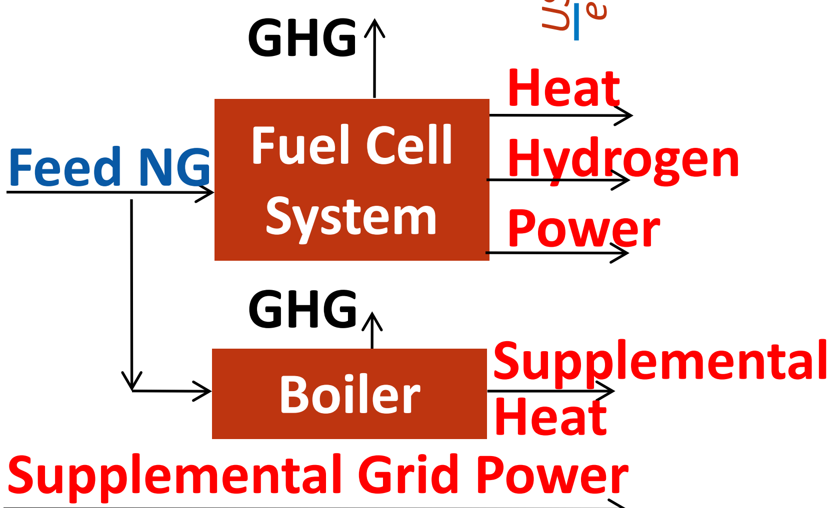
Heat produced: 800 MWh

Supplemental Heat: 1300 MWh

Hydrogen produced: 4100 MWh

= 124,000 kg H_2



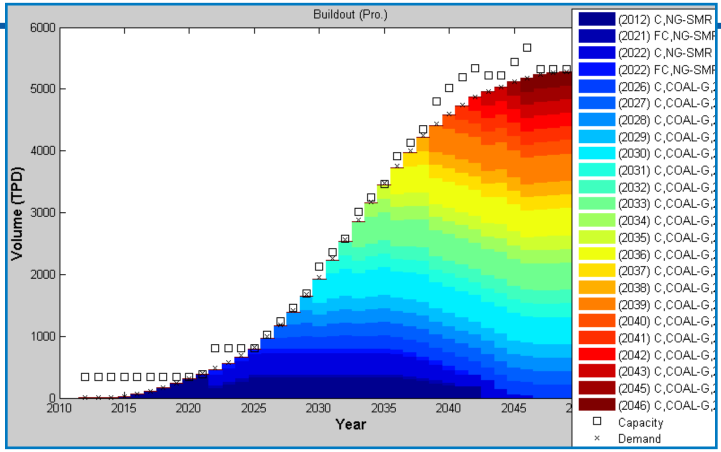


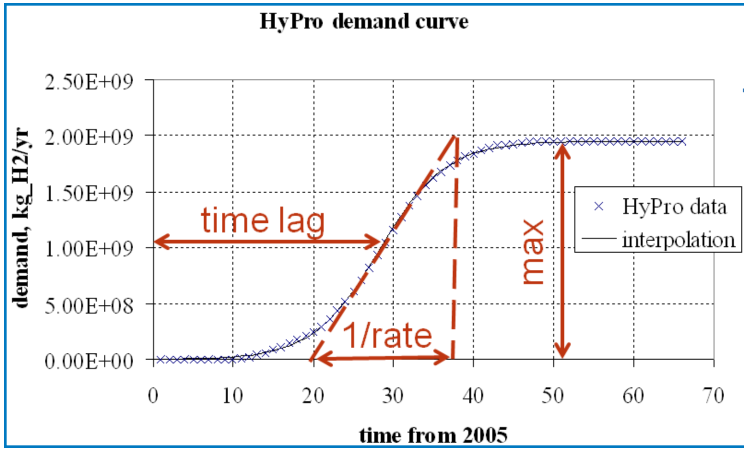
Emissions reduction depends on the grid mix

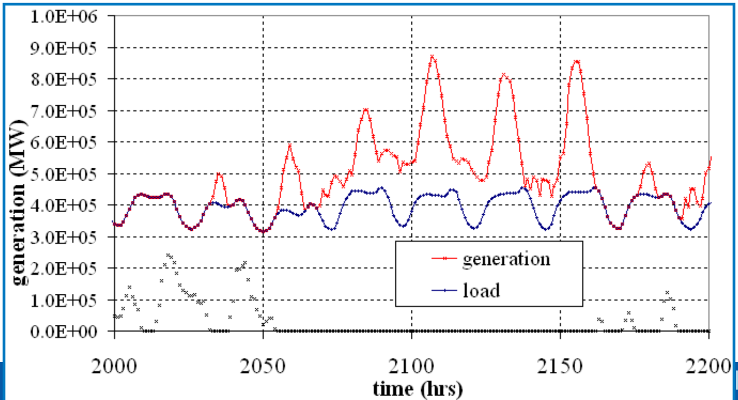
Approach: HyPro Technical Breakpoint Analysis

Characterization parameters affecting optimal hydrogen production/ delivery/ dispensing pathways evolution

1. **Base case** update HyPro:
   - latest GREET and HDSAM versions
2. **GHG tax potential effects**
   - GHG tax levels that induce changes
3. **Results sensitivity to demand curve parameters**
   - parameterize the demand curve
   - probe sensitivities to i) time lag, ii) rate iii) max level
4. **Capital costs** (electrolyzer cost reduction) and **electricity price**
   - probe critical levels, having in mind virtually free curtailed electricity







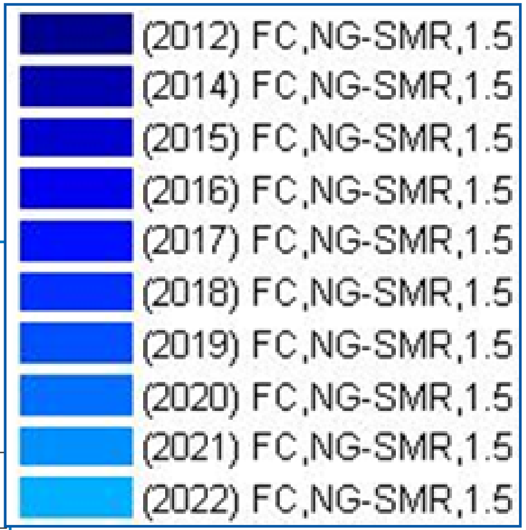
Accomplishment: Initial Growth Rate Affects Buildout

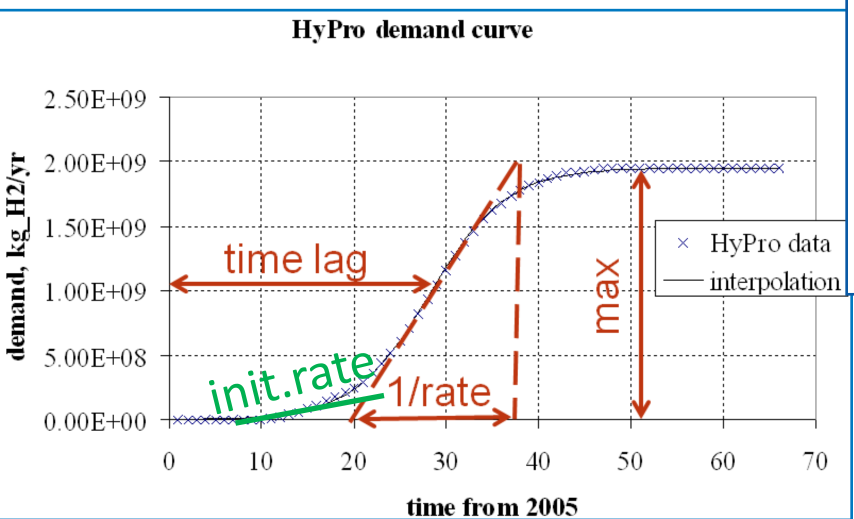
Small changes in demand curve parameters affect optimal infrastructure choices, especially at the initial deployment stages

Initial growth rate of the demand curve significantly affects optimal infrastructure

high initial rate : (1/200 yrs)

low initial rate: (1/400 yrs)





forecourt SMR → mix with central SMR with delivery

Accomplishment: User Interactions

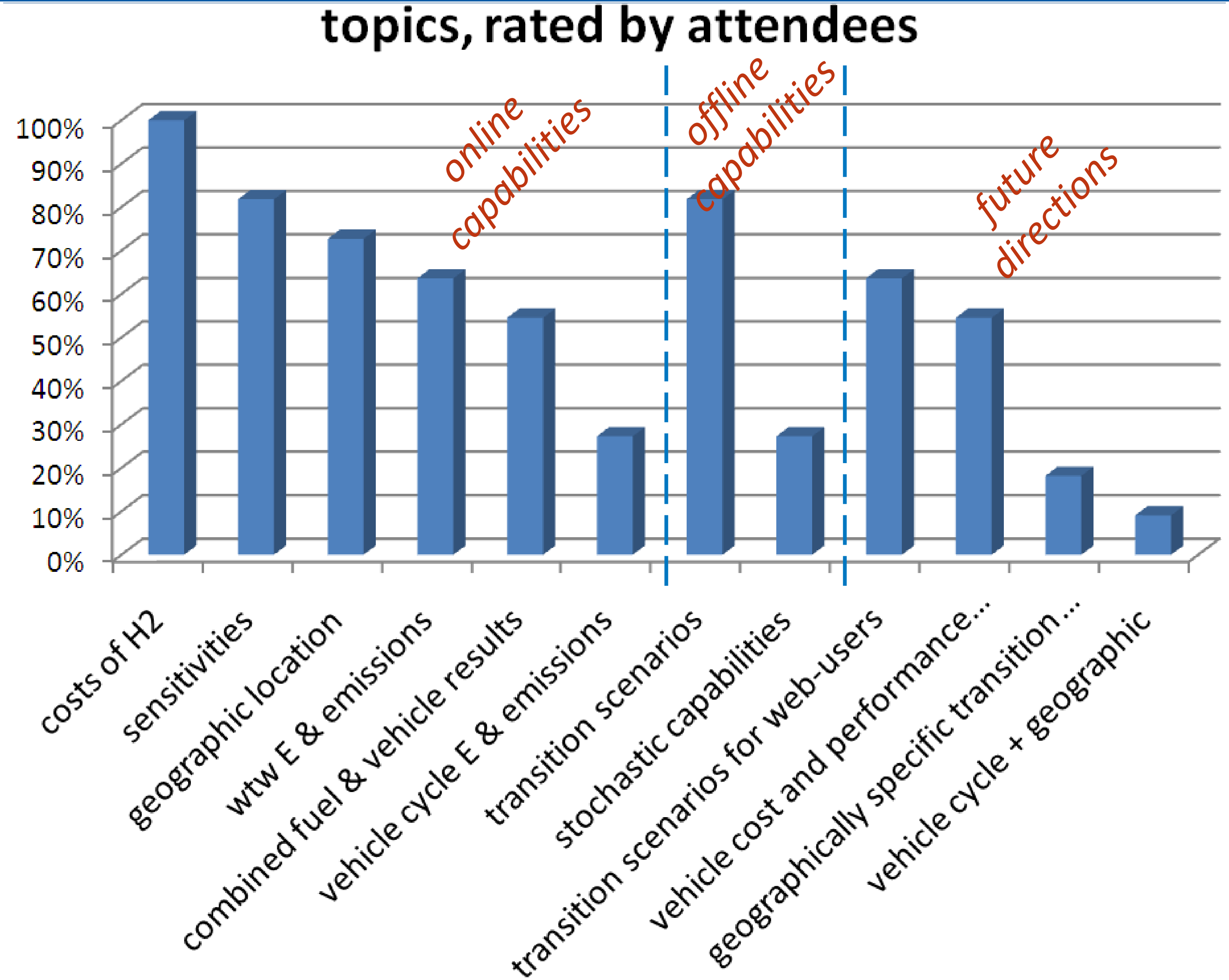
i) Department of Energy (DOE)

ii) California Air Resources Board (CARB) – ongoing, initiated by CARB

iii) MSM workshop at FCHEA conference, Feb 14 Washington, DC

- 20+ attendees
  - H_2 analysis community
  - Universities
  - Industry (Nissan, Linde, PlugPower, JPower)
- MSM demo
  - Web-based
  - Back-end
- Improving the MSM based on user feedback
  - Breaking out costs
  - Adding gas tube trailer delivery
- Potential future developments discussed
  - Adding vehicle cost and performance model
  - Geographically specific transition scenarios
  - Make available transition scenarios modeling for web-users

Accomplishment: User Feedback from Workshop



Collaborations

- **Sandia National Laboratories (computational development)**
  - Dawn Manley
  - Katherine Guzman
- **NREL**
  - Darlene Steward, Mike Penev (H2A Production, distributed power)
  - Johanna Levene, Dan Getman (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)
- **FPITT Energy Company Members (pathway analysis and report)**
  - Matt Watkins (Exxon-Mobil)
  - Jonathan Weinert (Chevron)
  - Ed Casey (ConocoPhillips)
  - CJ Guo (Shell)
- **Alliance Technical Services (pathway analysis & report)**
  - Melissa Laffen, Tom Timbario, Jr.

Proposed Future Work

Analysis Needs & MSM Plans (with planned dates)

Update the MSM as technical understanding evolves	• Link the MSM to updated component models as they are released (ongoing: H2A Production, HDSAM, GREET, H2A Power)
Identify the potential effects of not meeting targets and potential tradeoffs	• Add vehicle purchase and maintenance costs to the cost per mile calculation (Sept 2011) • Analyze potential effect of vehicle and H2 fuel costs on the demand curve and transition scenarios (Sep 2012) • Launch a 'deep-dive' global sensitivity analysis to define the possible tradeoffs (Sep 2012)
Analyze other production, delivery, and distribution options	• Add biogas conversion as a production option • Add more delivery and distribution options including cryo-compressed and tube trailer delivery (June 2011)
Compare pathways to identify strengths and potential of each	• Complete pathway report focusing on current technology status at various vehicle penetration levels (Draft Sept 2011) • Provide support to infrastructure and technical target progress analyses (Sept 2012) • Complete pathway report focusing on advanced technology status (Sept 2012)
Compare hydrogen build-out scenarios	• Complete the transition scenarios technology break-even points report (May 2011) • Make transition scenarios modeling available to the web-users (Jan 2012)

Summary

- The MSM is being developed to rapidly perform cross-cutting analysis by linking other models
- It is being used for analyses to understand and compare hydrogen production/delivery/distribution pathways
- This year
  - GUI functionality and capabilities have been improved
  - GREET2 (vehicle cycle energy use and emissions) model has been linked to add analysis capabilities to the fuel cycle models
  - H2A Power (combined heat and hydrogen) model is linked to the MSM to expand the pathway analysis options
  - Transition scenarios technical break-even points analysis is underway
- Future work involves further analysis; adding vehicle cost model, tying it to affect potential demand curve; and investigating the potential outcomes of technical progress; detailed analysis of possible trade-offs

Technical Back-Up Slides

Acronyms

AC – alternating current

ANL – Argonne National Laboratory

CARB – California Air Resources Board

CHHP – combined production of heat, hydrogen, and power

DOE – US Department of Energy

FC – fuel cell

FCHEA – Fuel Cell and Hydrogen Energy Association

FPITT – fuel pathways integration tech team

GGE – gallon gasoline equivalent (by energy)

GHG – green-house gases

GREET – emissions in transportation model

GUI – online graphical user interface

HDSAM – H_2 delivery analysis model

HTE – high temperature electrolysis

HyDRA – online geospatial tool

HyPro – H_2 pathway succession analysis tool

IRR – internal rate of return

MSM – macro-system model

NG – natural gas

NREL – National Renewable Energy Laboratory

RFG – reformulated gasoline

SIO – Systems Integration Office at NREL

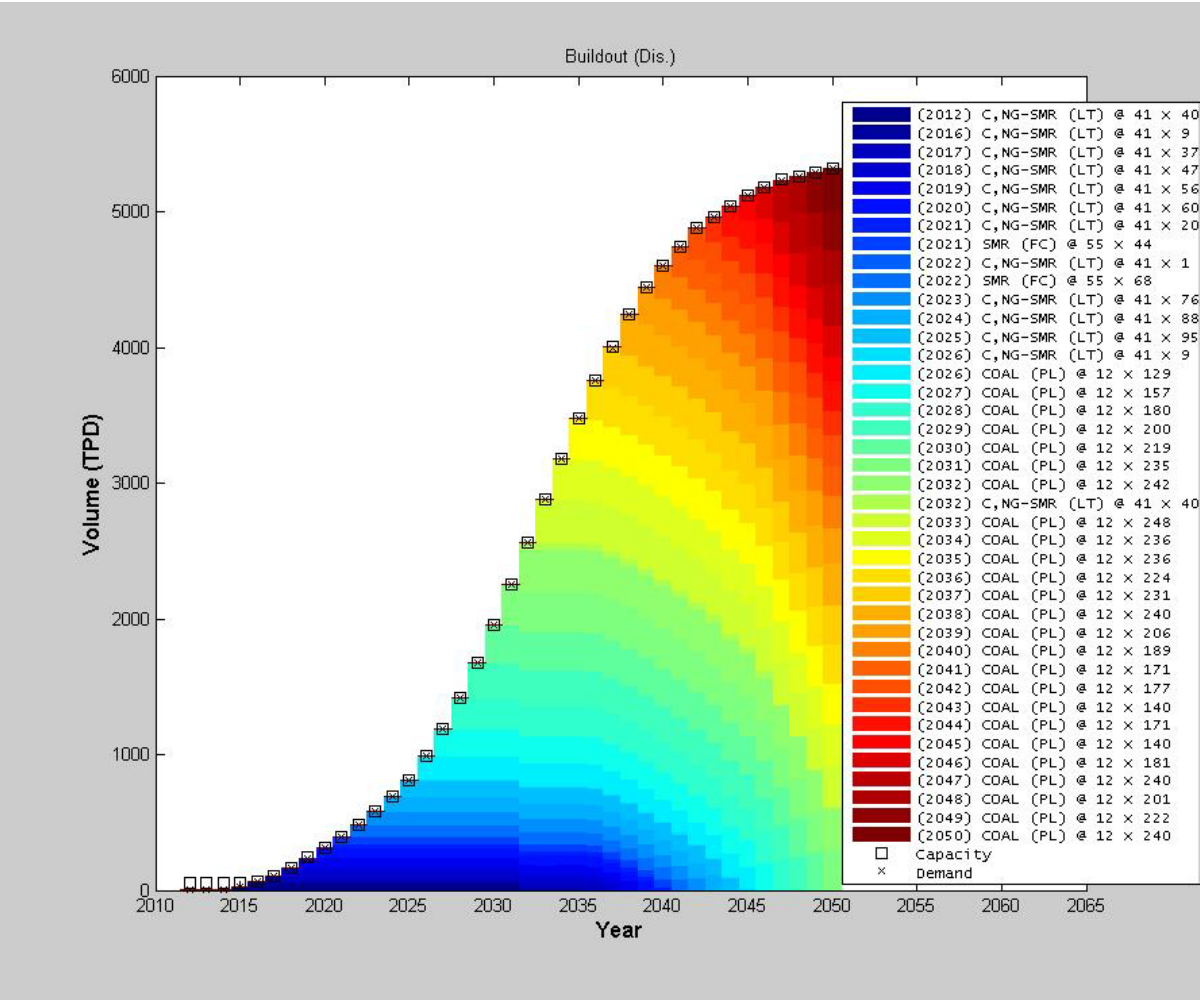
SMR – steam-methane reforming

SNL – Sandia National Laboratories

WTW – well-to-wheels

Accomplishment: HyPRO Results

Baseline dispensing buildout



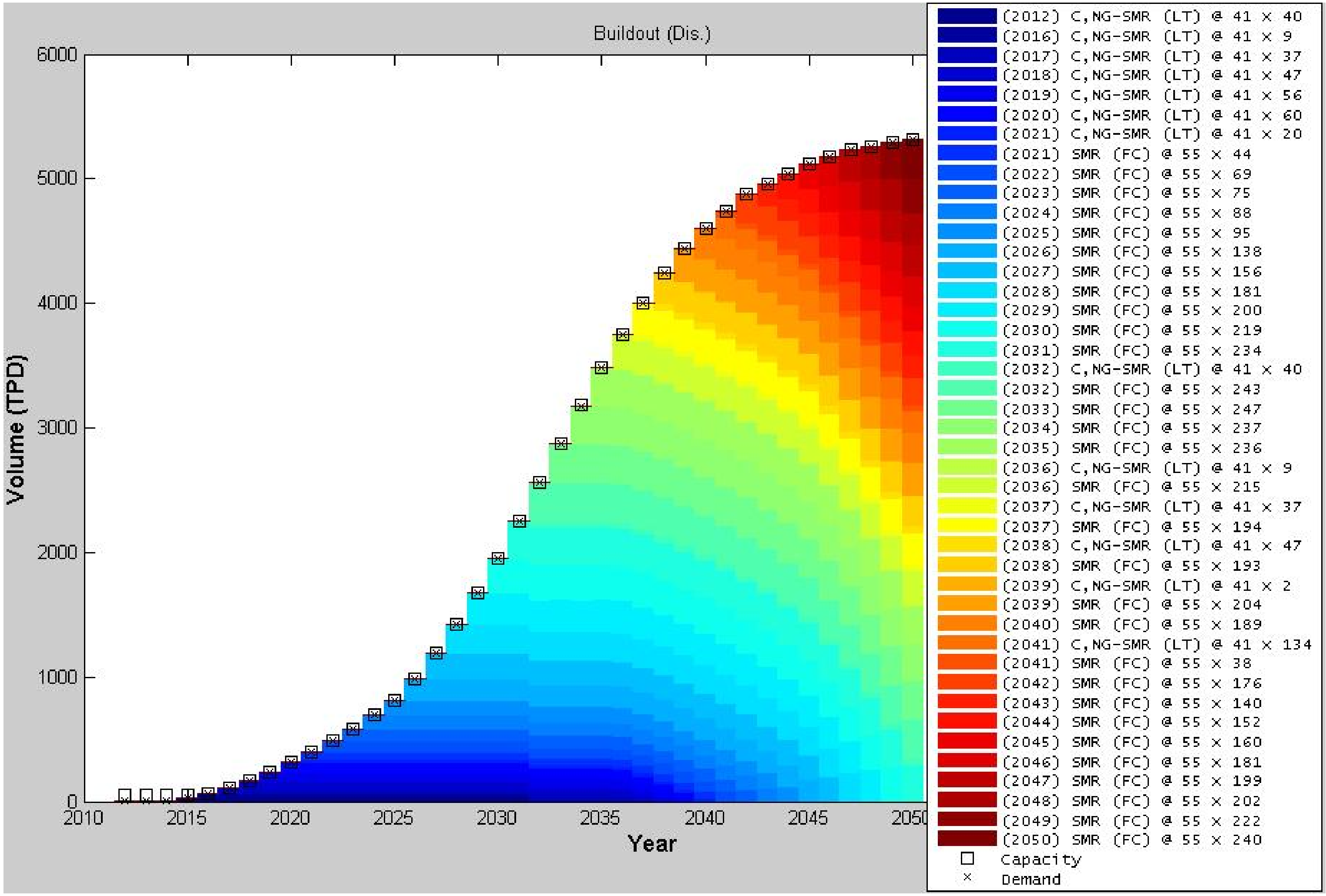
Scenario Assumptions

- **1,125,000 FCVs in 2050**
- **Average fuel economy: 45 miles / gge**
- **Average FCV use: 20 mile / day**
- **City land-area: 1662 square miles**
- **1500 kg/day stations**

Feedstock is natural gas initially and moves to coal with higher demand

Accomplishment: HyPRO Results

Dispensing buildout with $40/tonne cost of carbon



Feedstock is natural gas throughout buildout