National Renewable Energy Laboratory
Innovation for Our Energy Future

Macro-System Model

2011 FC&HE conference

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

Outline

- Intro
  - What is MSM
  - What and how does it integrate
- How does it operate
  - Web-based interface
  - Pathway defining inputs
  - Region-specific inputs
  - Detailed inputs
  - Run
  - Results: fuel cycle chart
  - Results: vehicle cycle chart
  - Detailed outputs
- Sensitivities, stochastic analysis
- Pathway evolution analysis

Focus: Initial Analysis Issues

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

Focus: Communication and Consistency

Communication

Simplifies data and information updates between models (i.e., models dependent upon others for information can be updated more easily and sensitivities are easier to run)

Consistency

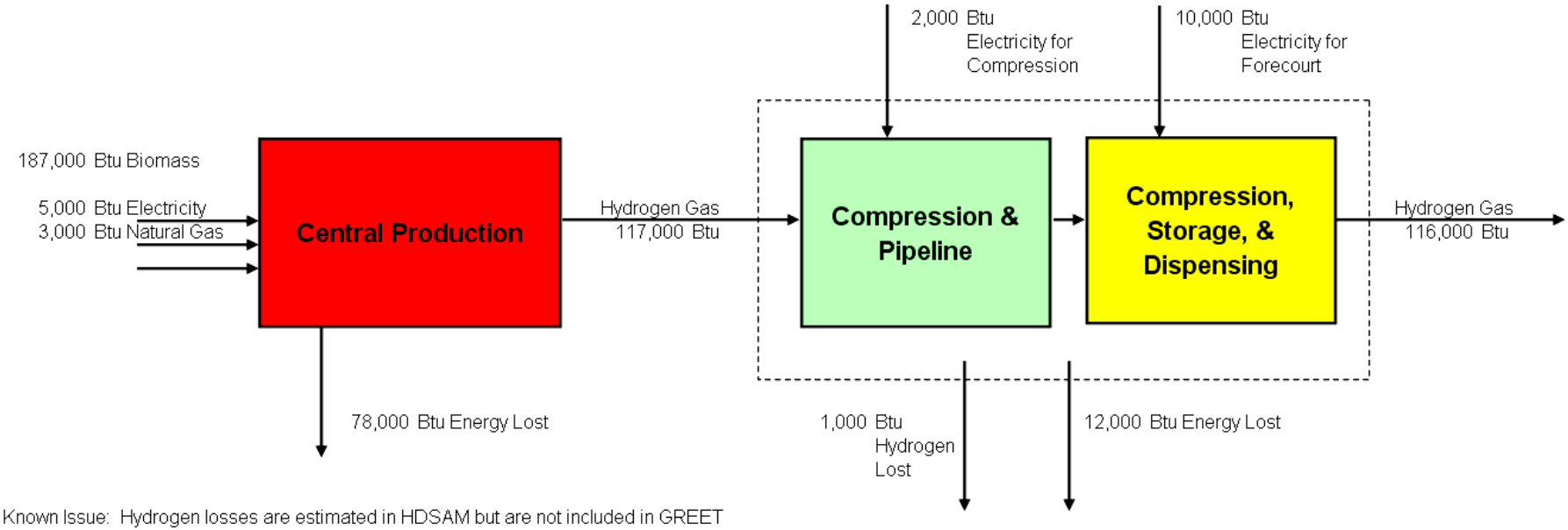
Improvements in understanding requires updates to models. With MSM as the conduit of information, updates can be pushed out to other models. Thus the user knows results across models are based on the same input parameters.

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

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

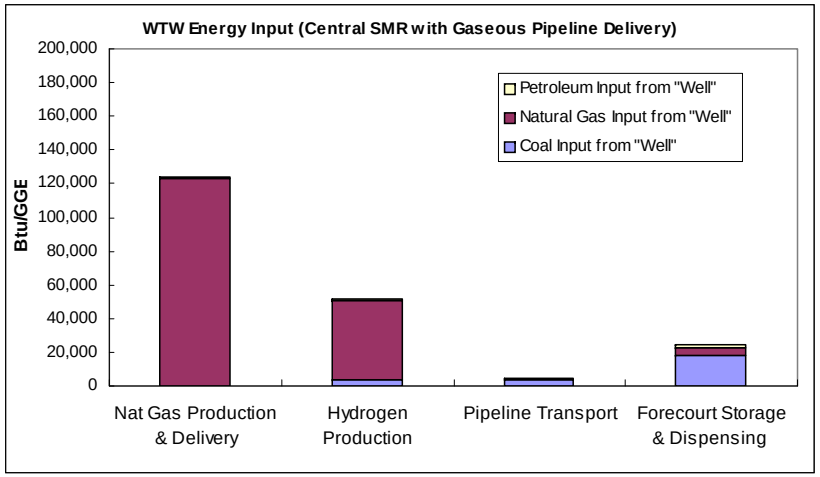
Production Process Energy Efficiency	60%
Pathway Efficiency	56%
WTP Efficiency	48%
WTP Emissions (lb CO2 Equivalent / GGE fuel available):	8

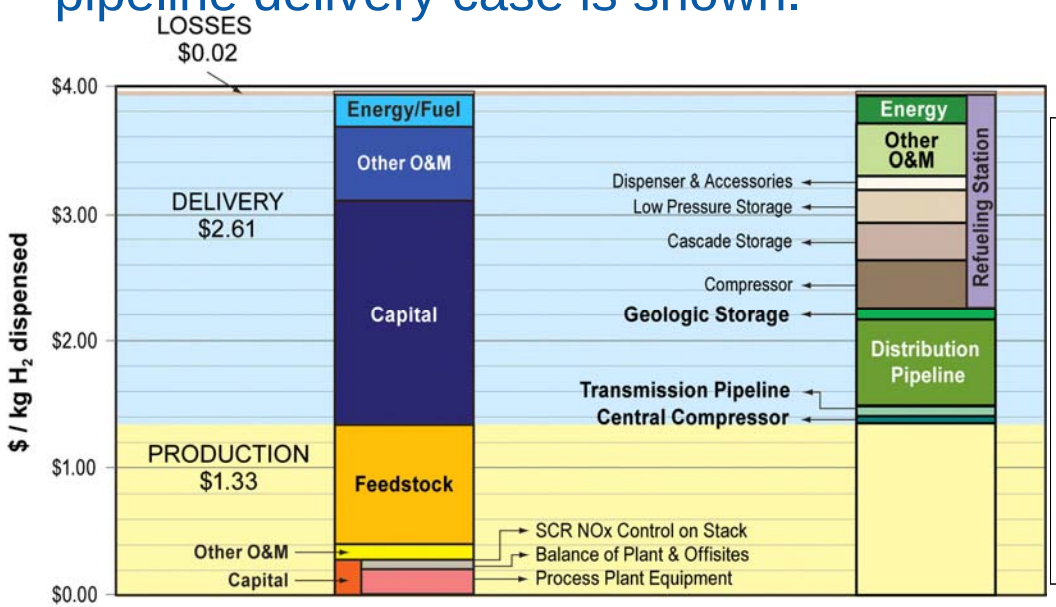
Case Definition
Year: 2020
Hydrogen as Gas
Central Production
Woody Biomass Feedstock
Sequestration: No
Transport for Delivery: Pipeline
Vehicle Efficiency: 65.0 mile / GGE
City Hydrogen Use: 238466 kg/day

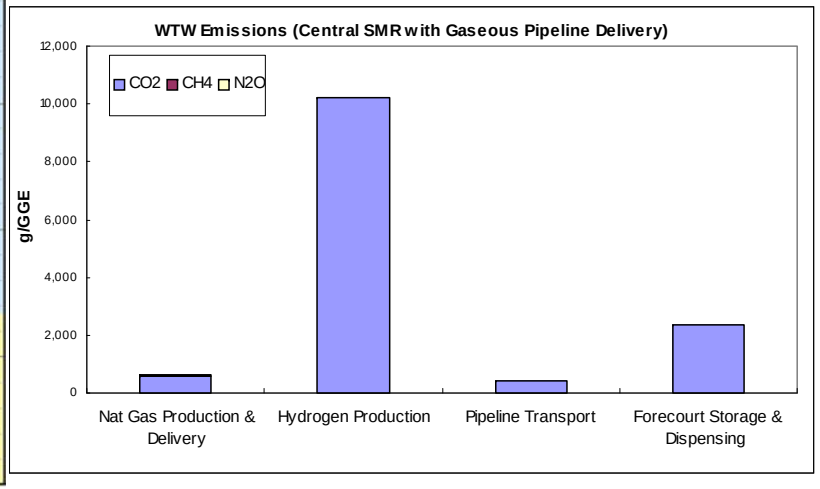
Supply Chain Costs Analysis

A report on hydrogen production and delivery pathways was published in September 2009. It shows results from the MSM and additional disaggregated results. It is available at http://www.nrel.gov/docs/fy10osti/46612.pdf

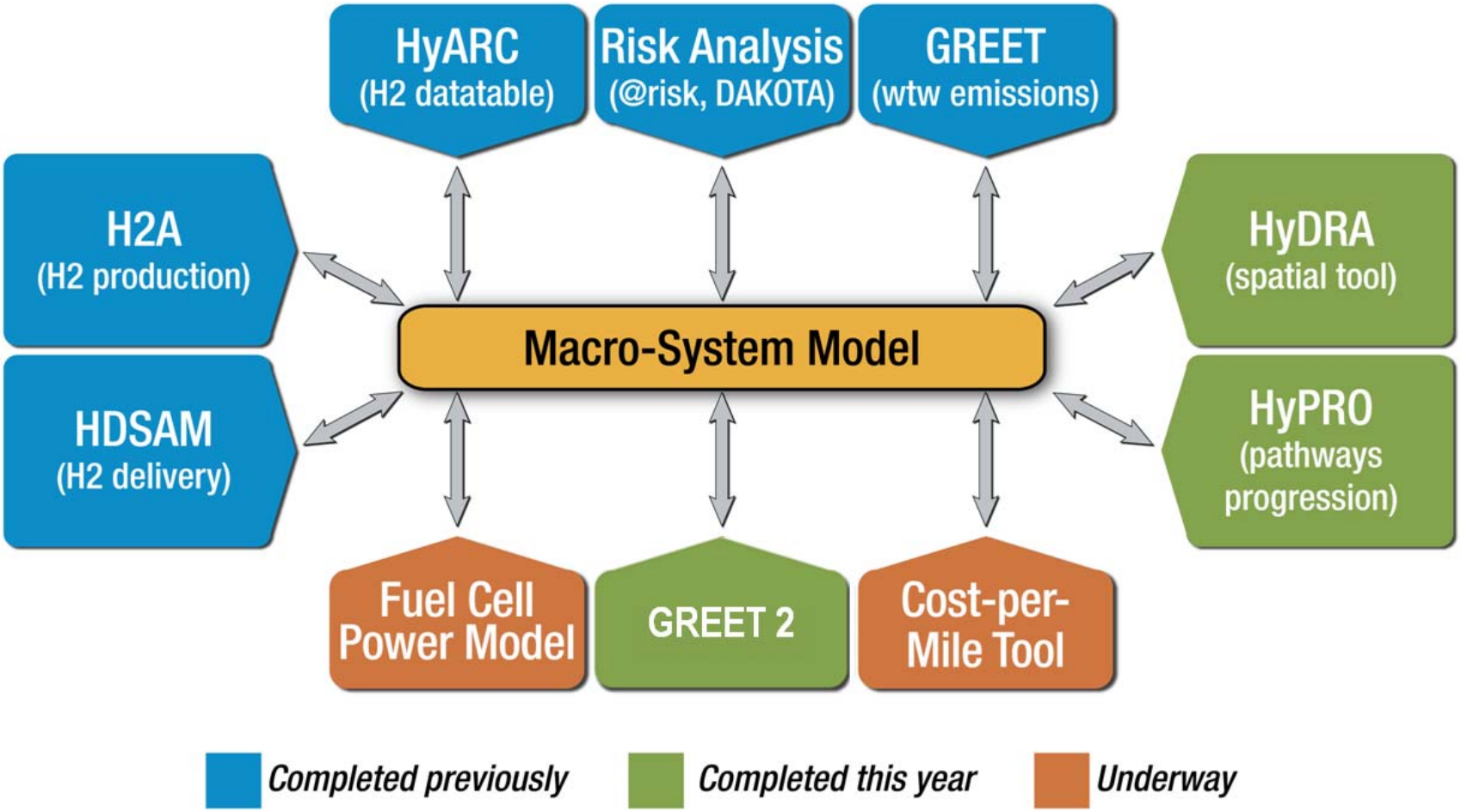
A summary of the central SMR with pipeline delivery case is shown.





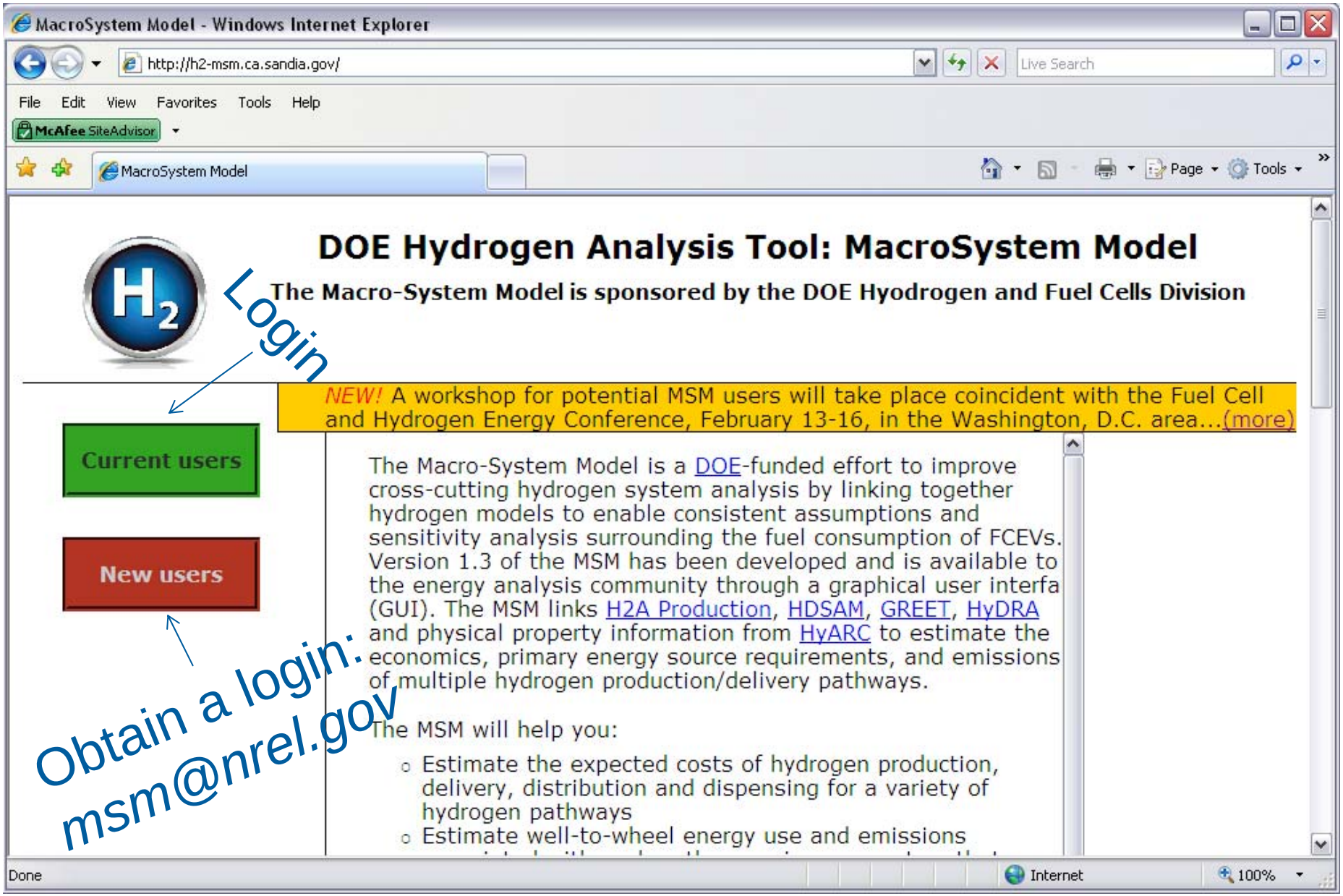


Approach: how does the MSM operate



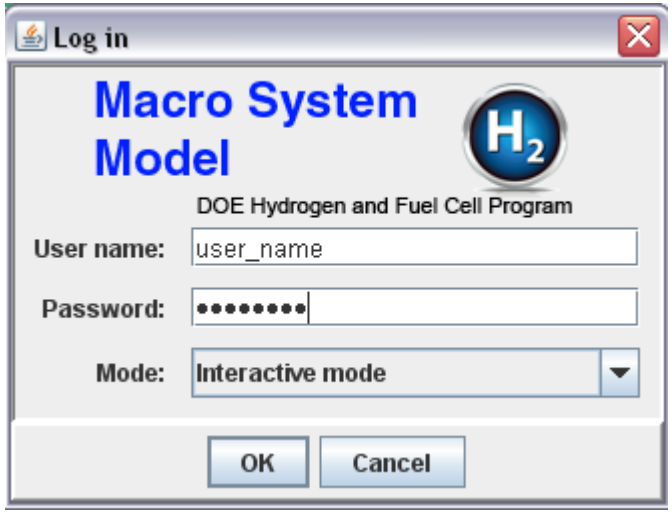
The MSM provides a central transfer station to guarantee consistency in simulations that involve multiple models. A graphical user interface (GUI) allows users with minimal understanding of the models to use them.

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

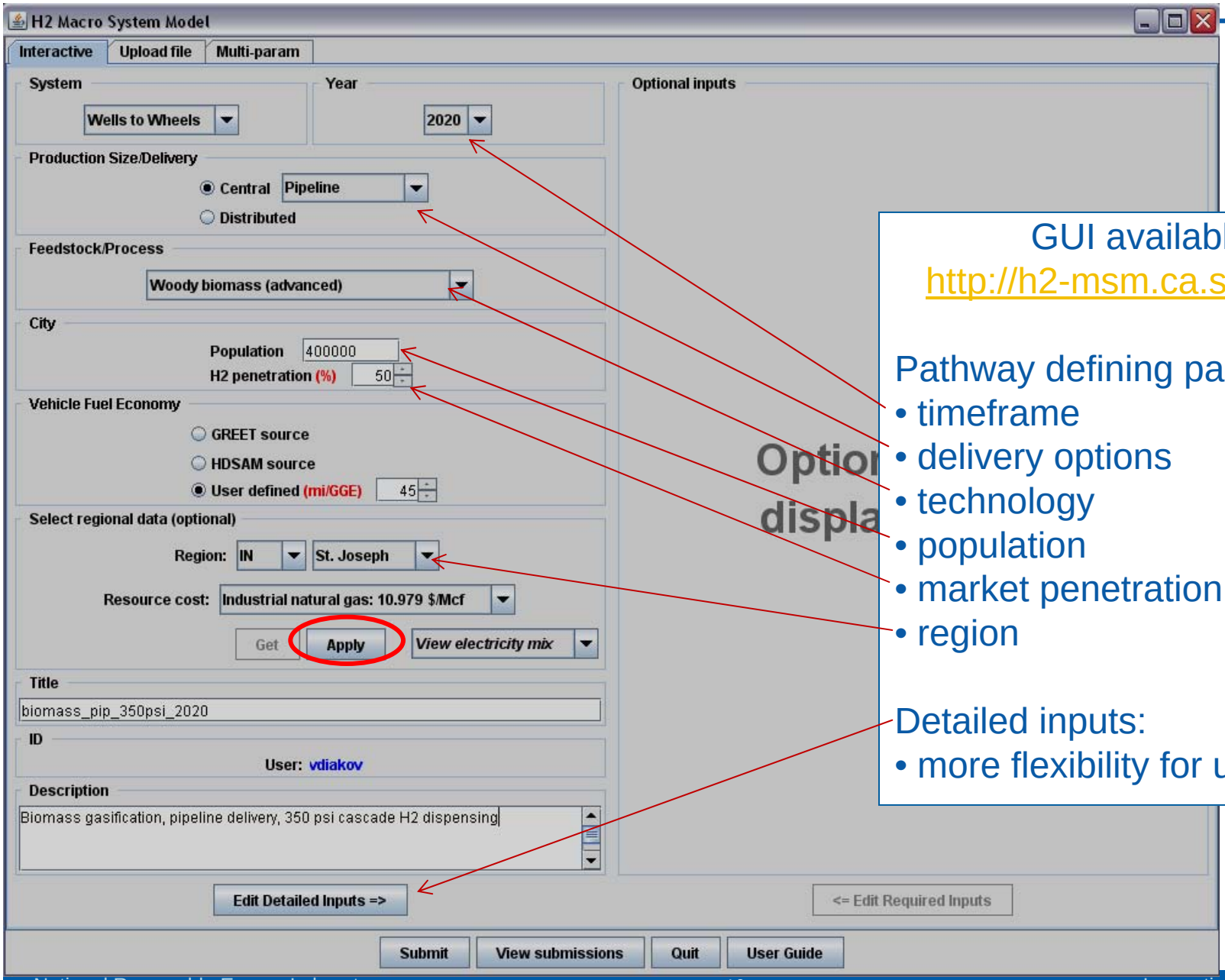


http://h2-msm.ca.sandia.gov: *login*

The login info for a new user can be obtained at msm@nrel.gov



GUI and web interface

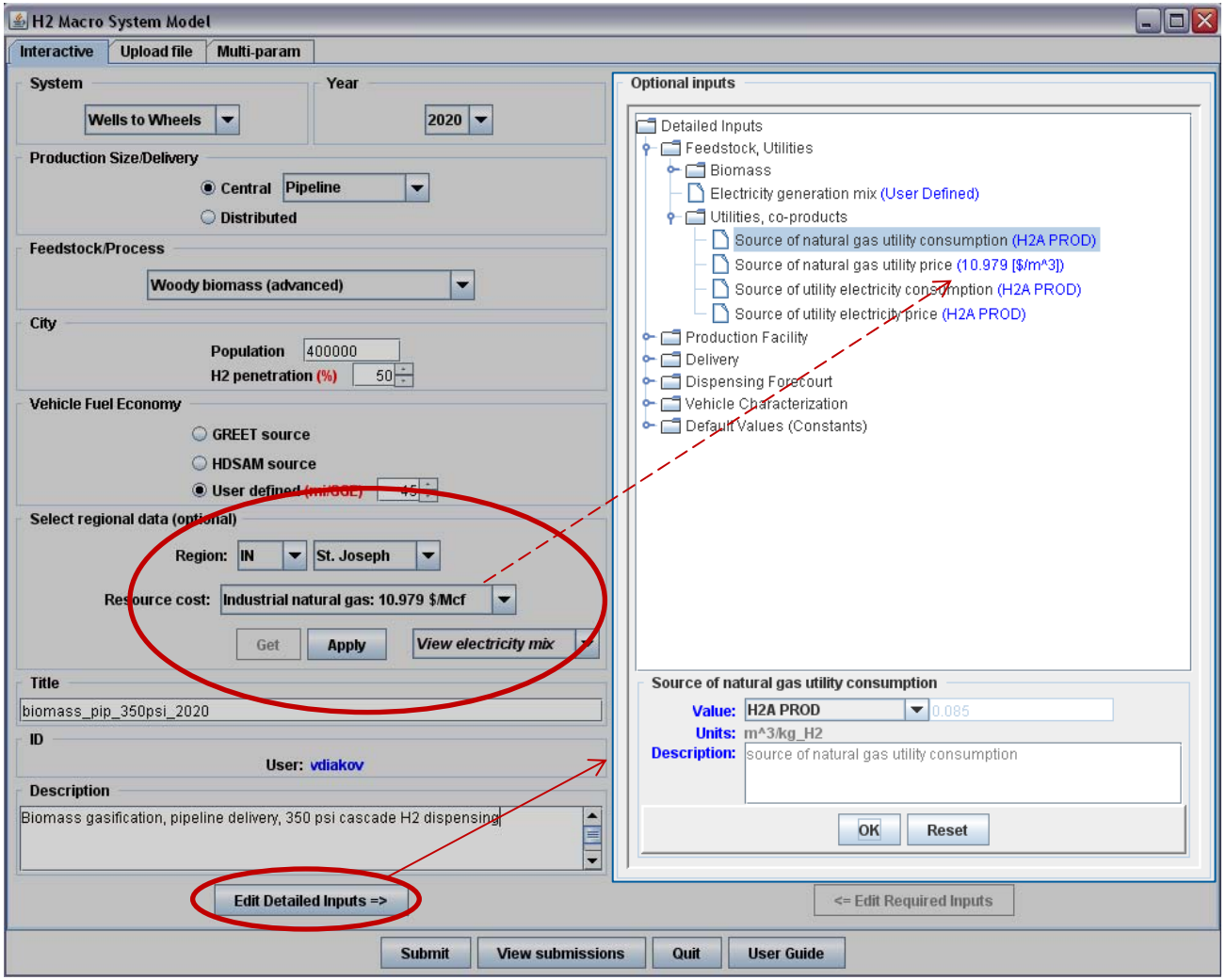


GUI available at
http://h2-msm.ca.sandia.gov/

Pathway defining parameters:
- timeframe
- delivery options
- technology
- population
- market penetration
- region

Detailed inputs:
- more flexibility for users

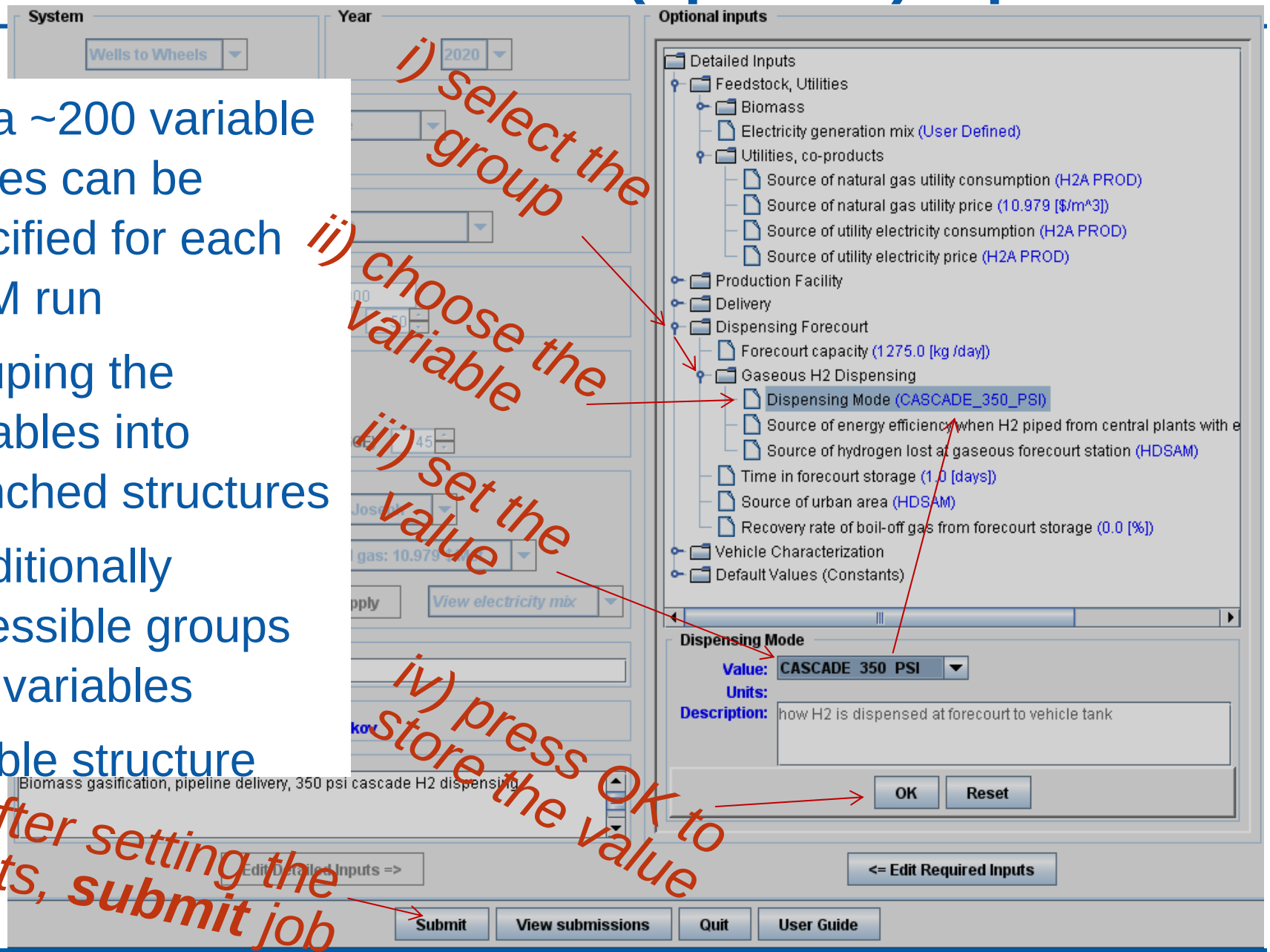
Geographic location: HyDRA over the ‘net



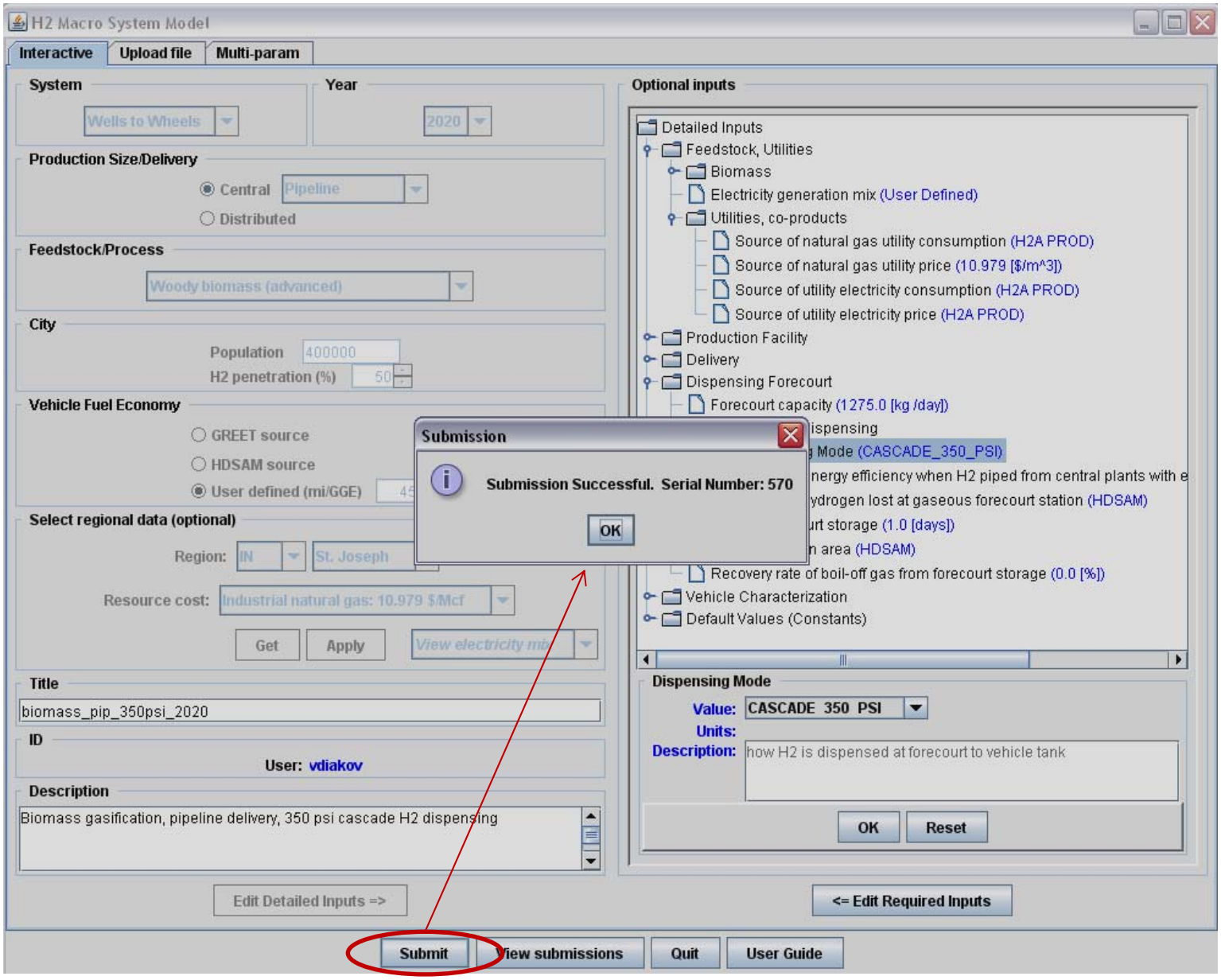
The MSM GUI user selects a county; HyDRA provides feedstock and energy prices and the grid mix for that county. The user can modify many technical parameters.

User interface: detailed (optional) inputs

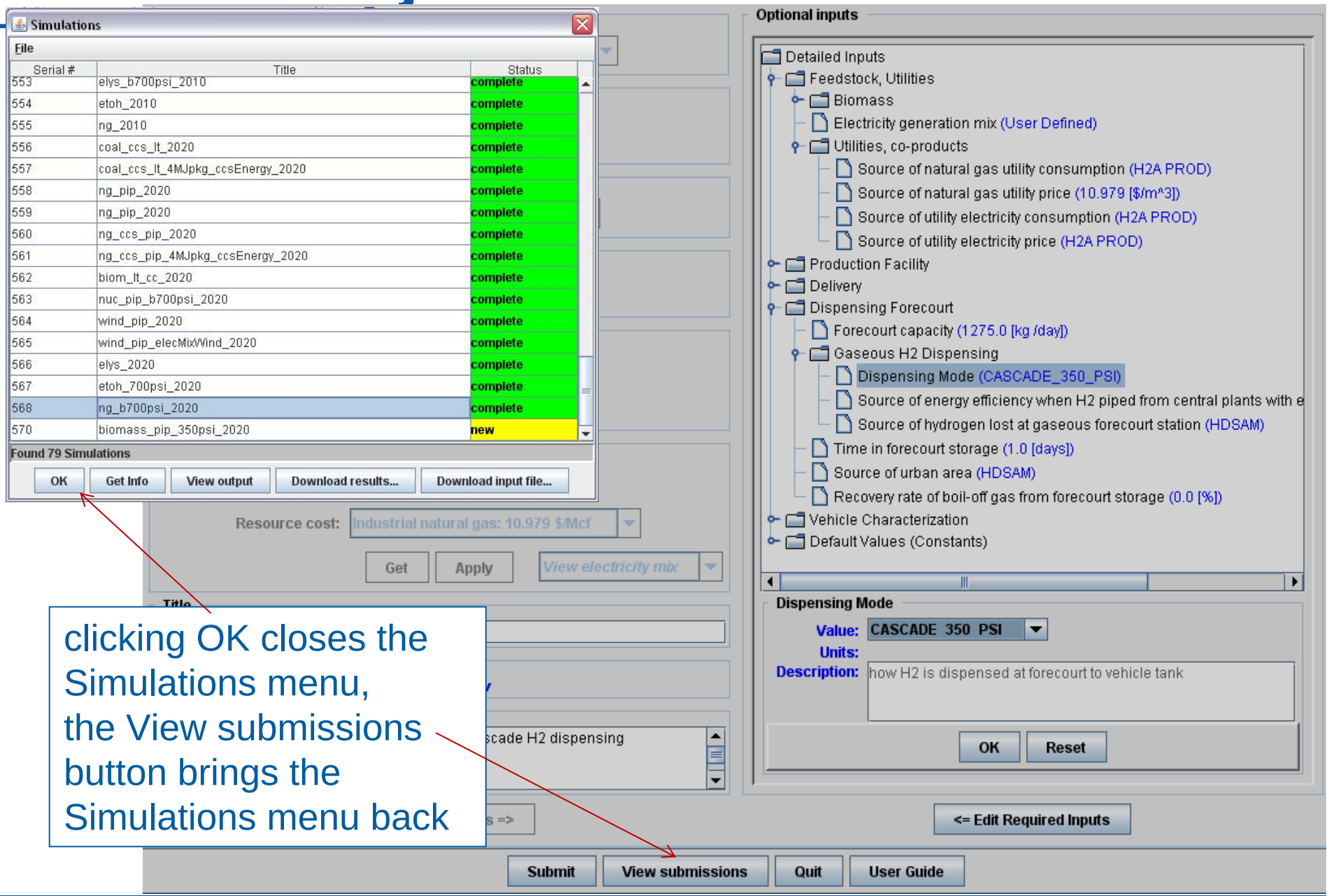
- extra ~200 variable values can be specified for each MSM run
- grouping the variables into branched structures
- conditionally accessible groups and variables
- flexible structure



MSM job submission



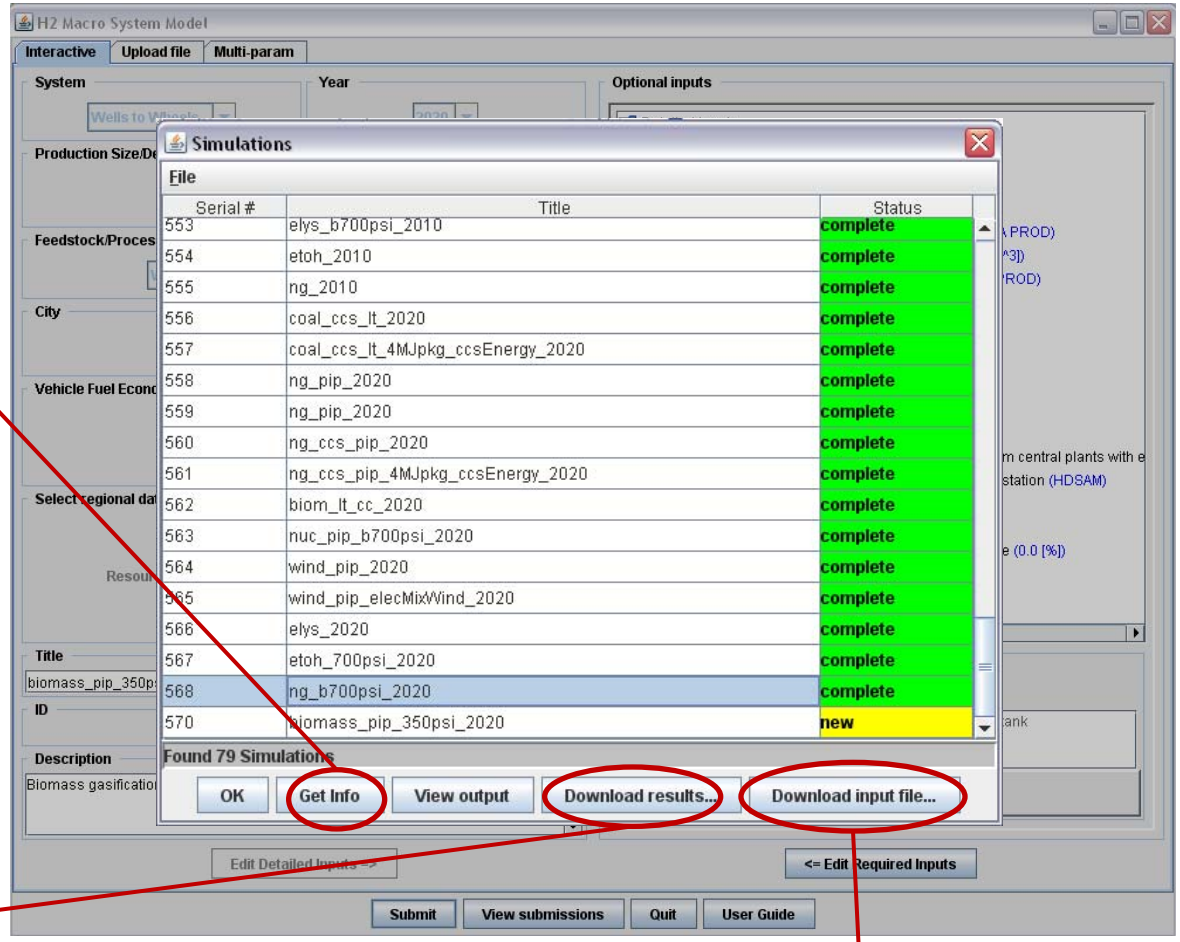
Submitted jobs menu



clicking OK closes the Simulations menu, the View submissions button brings the Simulations menu back

Simulations menu: select a completed run

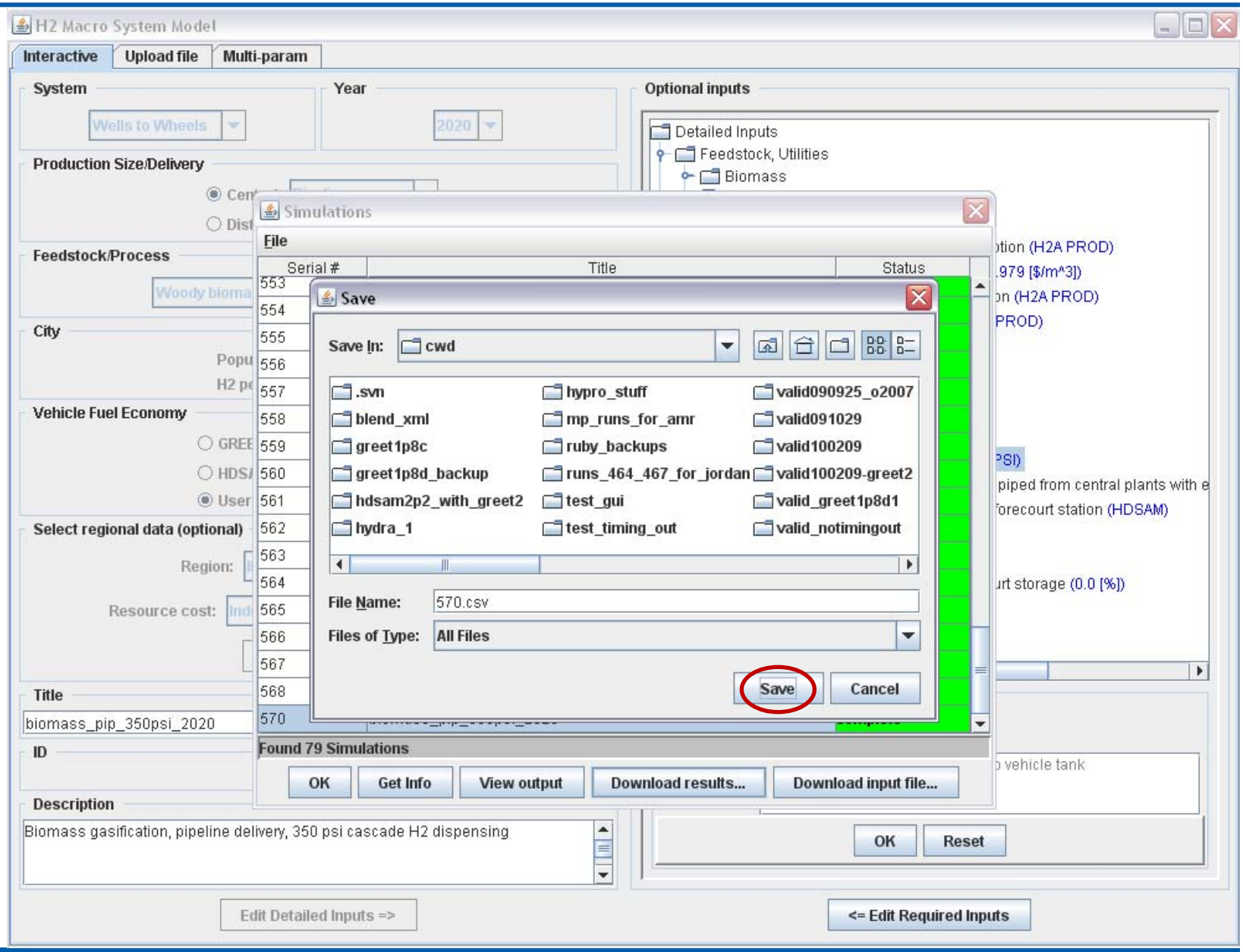
GUI users can easily see the detailed information entered when the simulation was defined.



GUI users can download results files (in CSV form, all the variables listed in alphabetical order) to develop their own figures and tables.

GUI users can download input files for record-keeping or to set up additional runs.

Download MSM run results



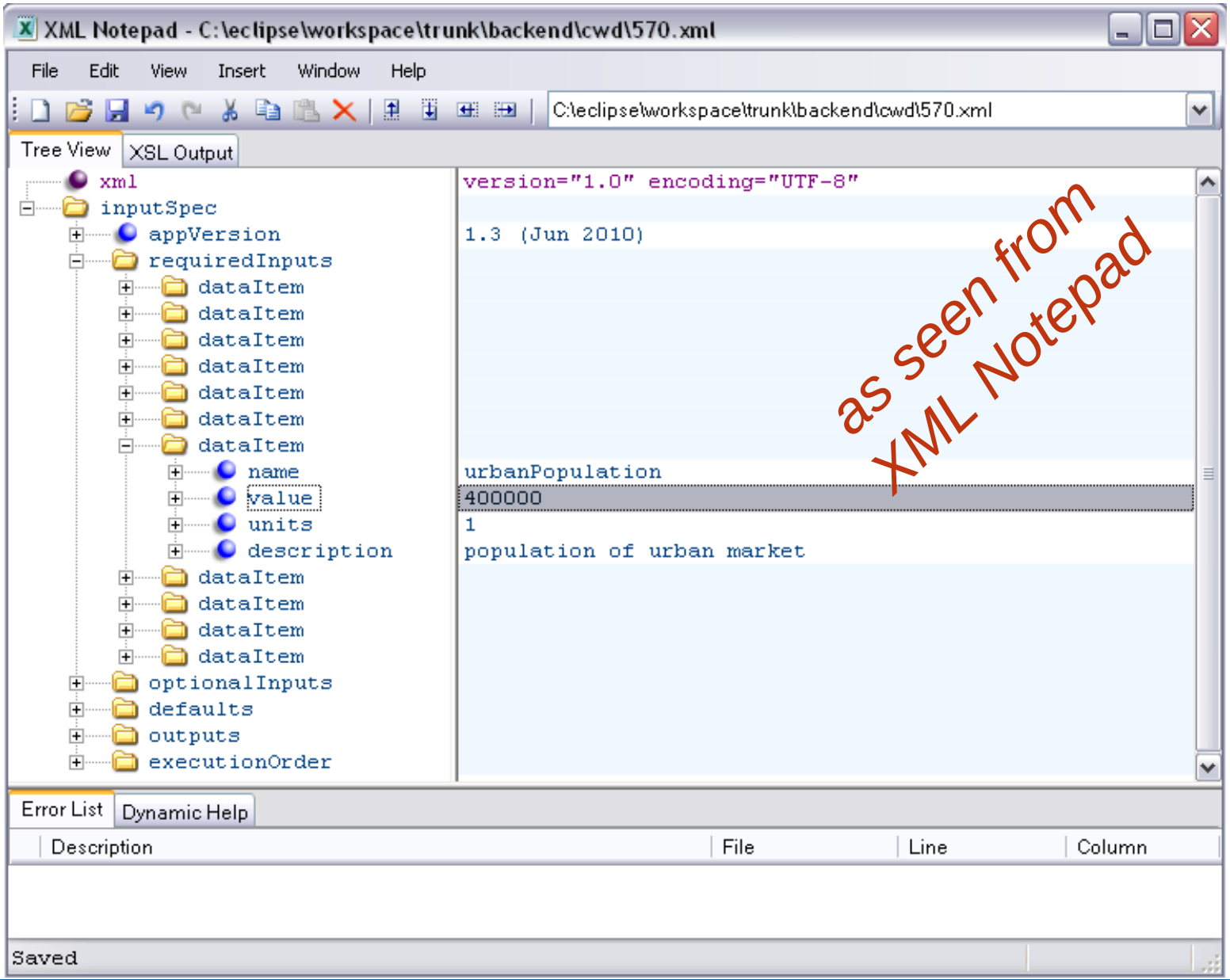
Downloaded output file (csv format)

570.csv

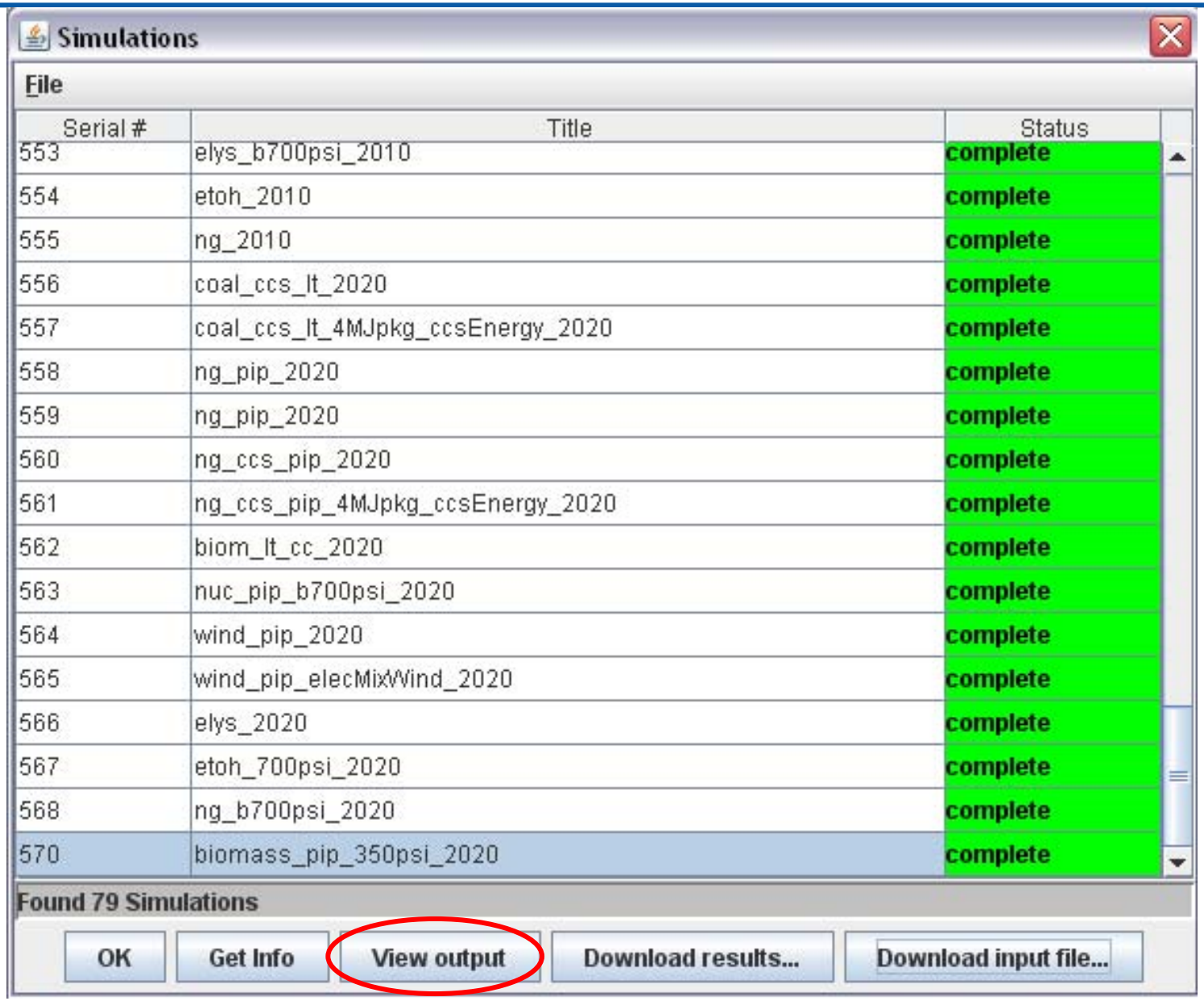
	A (parameter name)	B (value)	C (units)	D (description)	E	F (source)	G
2	cityH2ProductionRequirement	40836280	kg/yr	City H2 pr	kilogram /	GDS script	
3	cityH2Use	40344524	kilogram /	City hydrc	kilogram /	HDSAM	
4	deliveryDieselUseTotal	0	m^3/yr	diesel use	meter^3 /	GDS script	
5	deliveryDieselUseTotalMass	0	J/kg_H2	diesel use	joule / kg_	GDS script	
6	deliveryElectricityUseForCompression	8.28E+13	J/yr	electricity	joule / ye	GDS script	
7	deliveryElectricityUseForCompressionMass	2051563	J/kg_h2	electricity	joule / kg_	GDS script	
8	deliveryElectricityUseForForecourt	4.69E+14	J/yr	electricity	joule / ye	GDS script	
9	deliveryElectricityUseForForecourtMass	11626402	J/kg_H2	electricity	joule / kg_	GDS script	
10	deliveryElectricityUseForLiquefaction	0	J/yr	electricity	joule / ye	GDS script	
11	deliveryElectricityUseForLiquefactionMass	0	J/kg_H2	electricity	joule / kg_	GDS script	
12	deliveryElectricityUseTotal	5.52E+14	J/yr	total elect	joule / ye	GDS script	
13	deliveryElectricityUseTotalMass	13677964	J/kg_H2	total elect	joule / kg_	GDS script	
14	deliveryMode	Pipeline		how H2 is delivered		User Input	
15	deliveryTotalCapitalCostLevelized	0.9827	dollar / kil	Total Deli	dollar / kil	HDSAM	
16	deliveryTotalFuelCostLevelized	0.2905	dollar / kil	Total Deli	dollar / kil	HDSAM	
17	deliveryTotalLevelizedCost	1.682754	dollar / kil	Total Deli	dollar / kil	HDSAM	
18	deliveryTotalOmCostLevelized	0.4095	dollar / kil	Total Deli	dollar / kil	HDSAM	
19	depreciableCapital	1.45E+08	dollar	depreciab	dollar	H2A	
20	depreciationLength	20	year	depreciati	year	H2A	

Ready

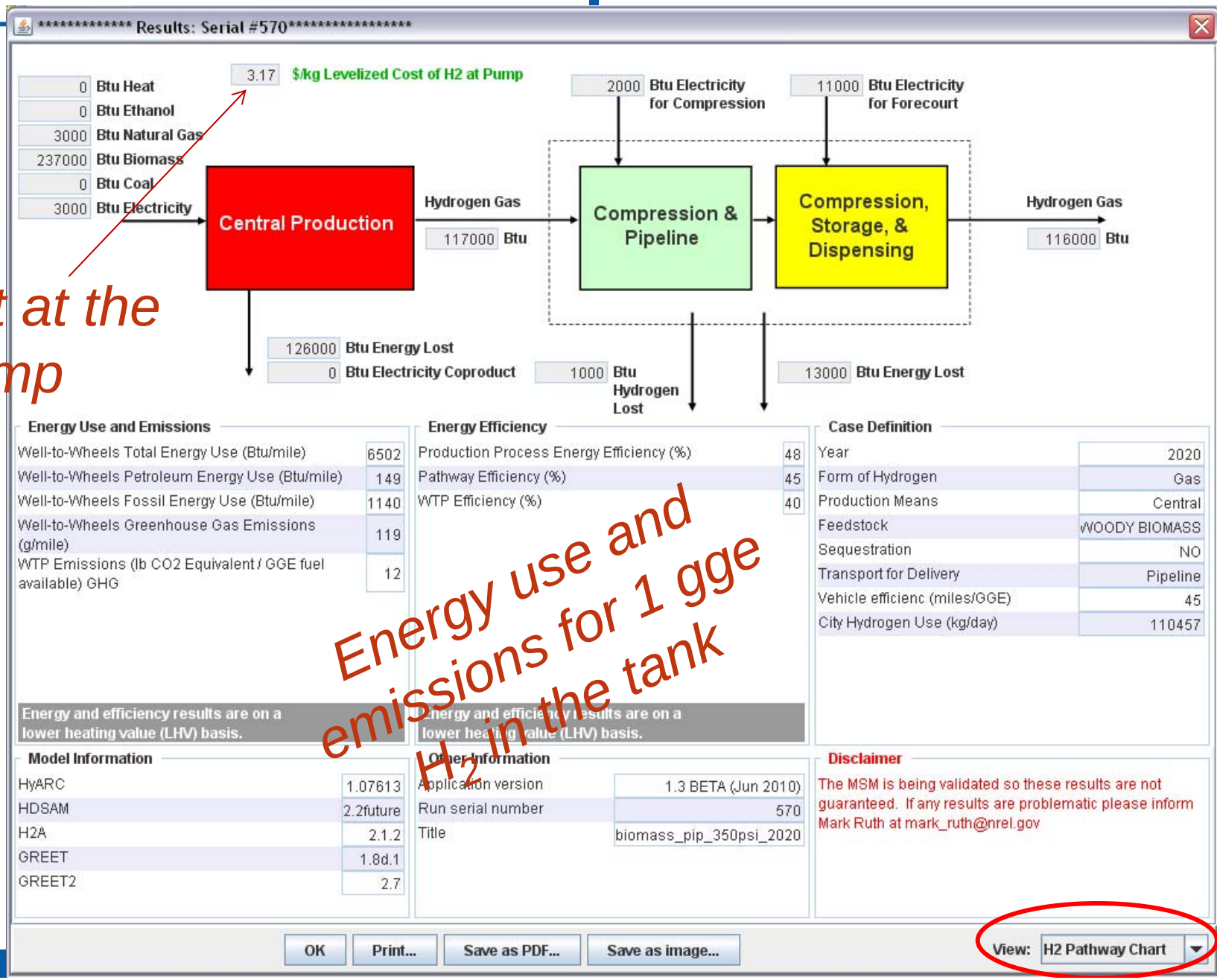
Downloaded input file (xml format)



simulations menu: view output



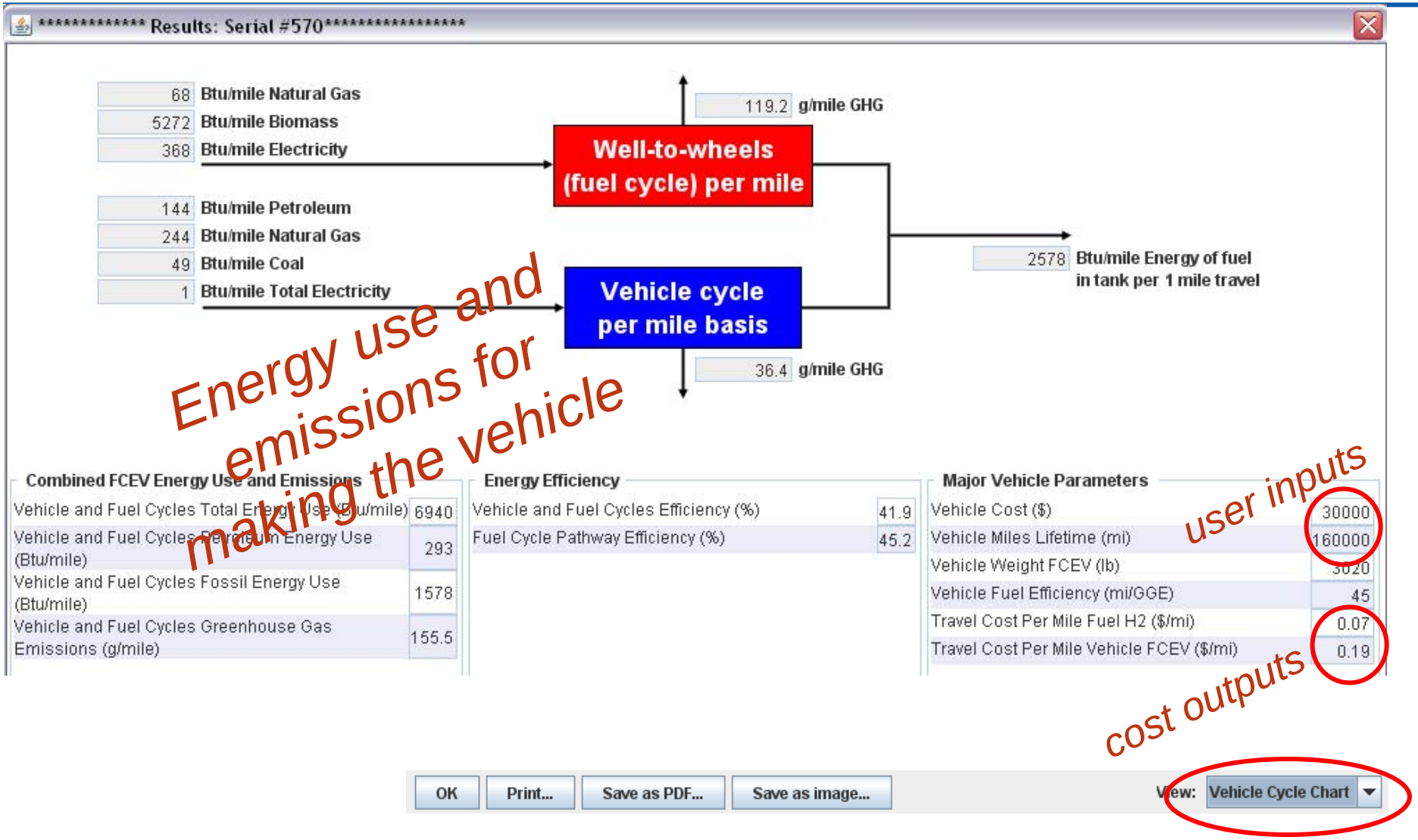
Run results: view output



H_2 cost at the pump

Energy use and emissions for 1 gge H_2 in the tank

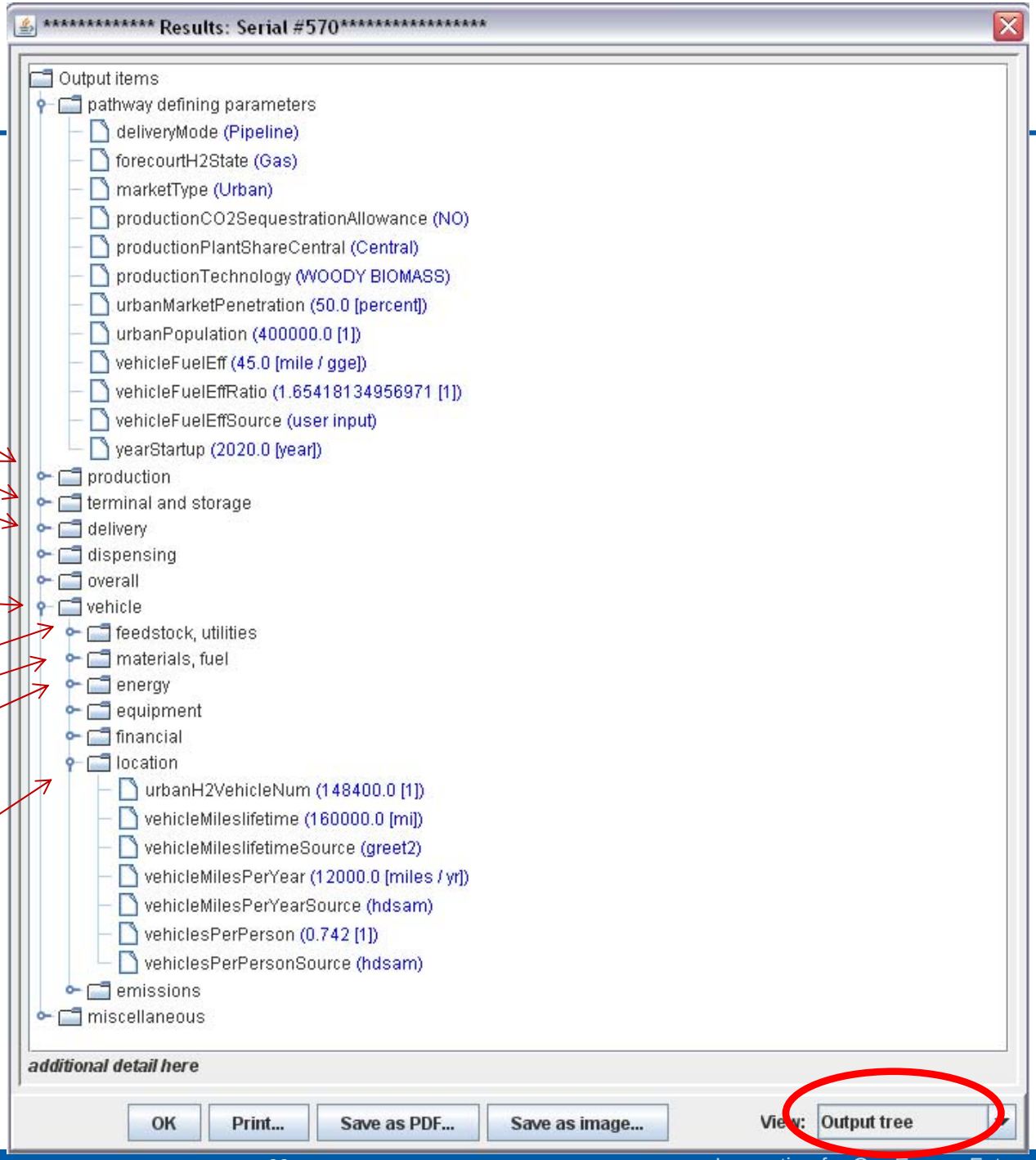
Results: view vehicle cycle chart



GUI:output tree

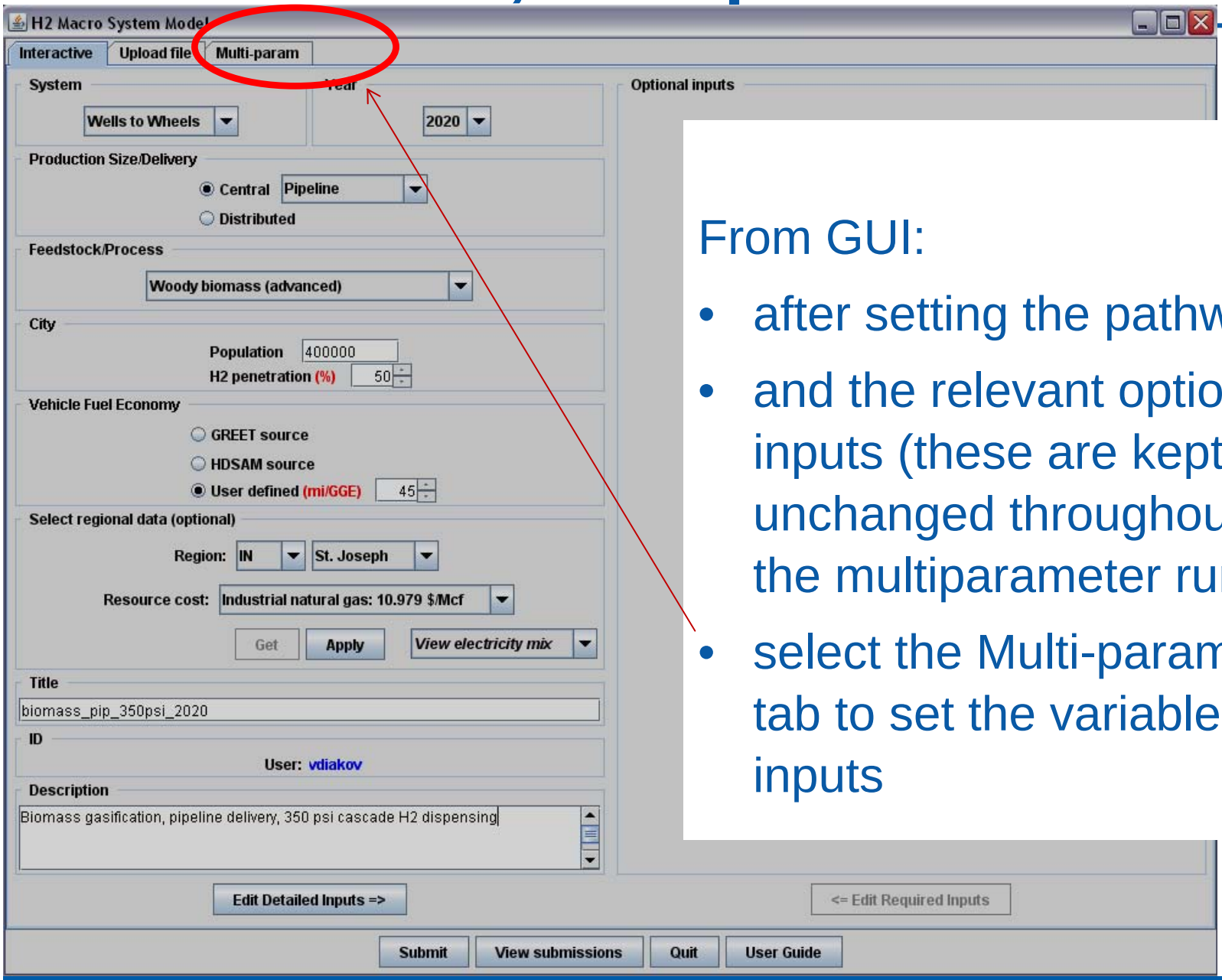
Two-level groups:

- Higher level
  - production
  - terminal
  - delivery
  - dispensing
  - overall (pathway)
  - vehicle
- Lower level
  - feedstock
  - fuel
  - energy
  - equipment
  - financial
  - location
  - emissions



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

Sensitivities, multiparameter runs

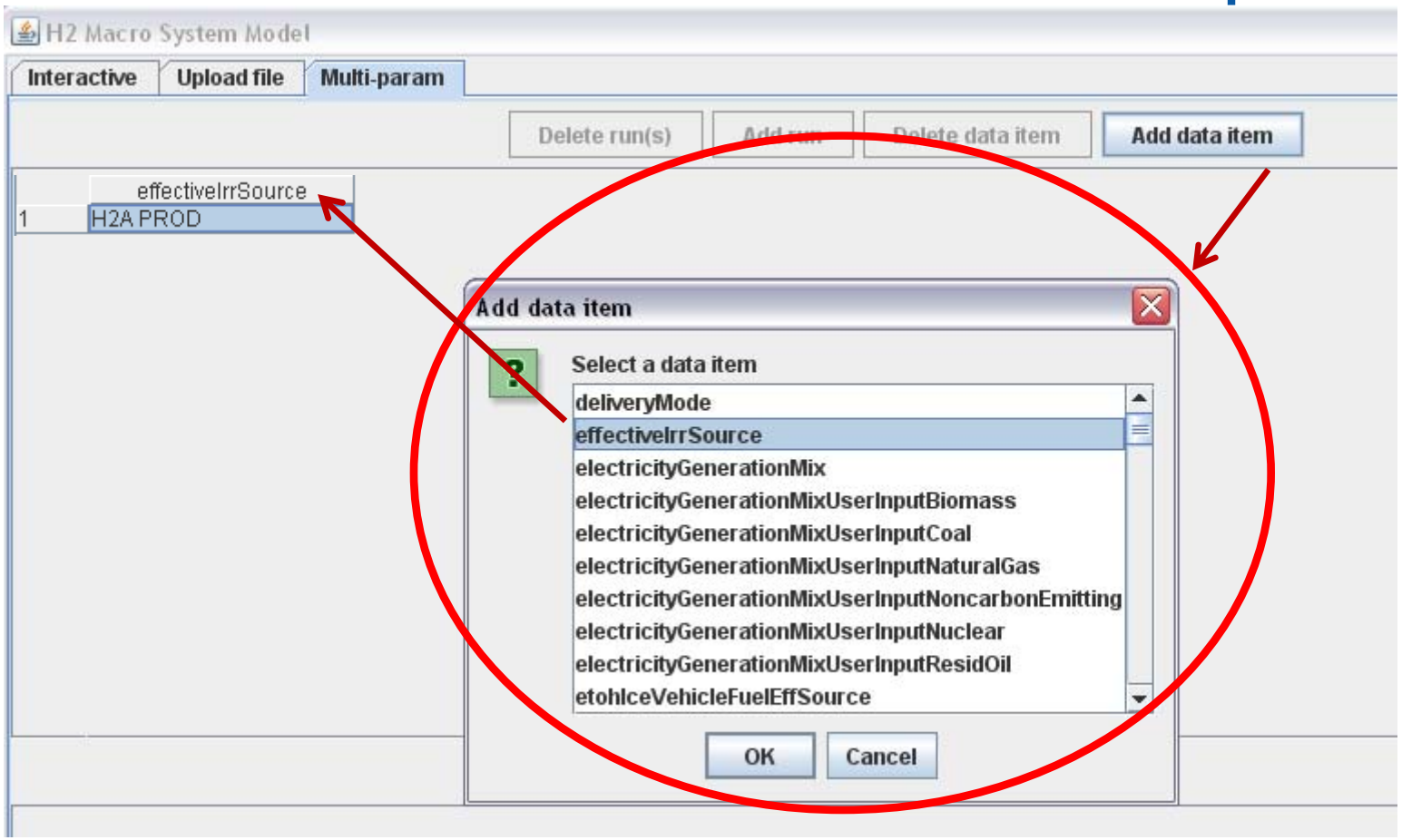


From GUI:

- after setting the pathway
- and the relevant optional inputs (these are kept unchanged throughout the multiparameter run)
- select the Multi-param tab to set the variable inputs

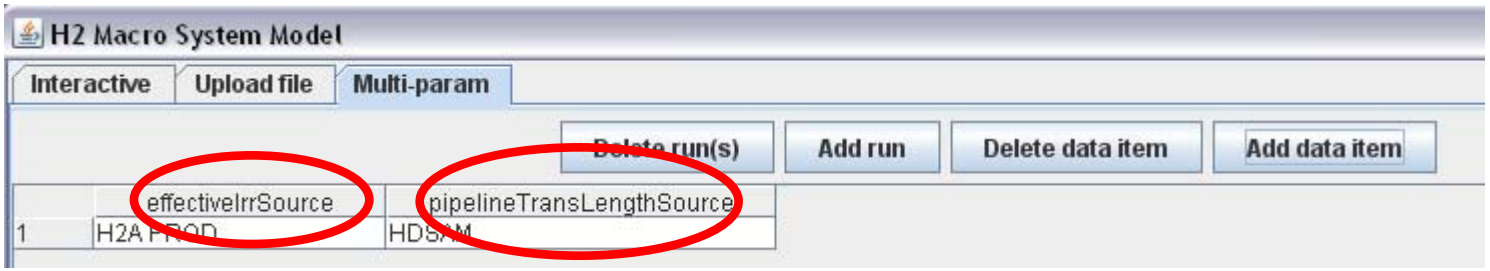
Multiparameter run:

to probe sensitivities, set variable inputs

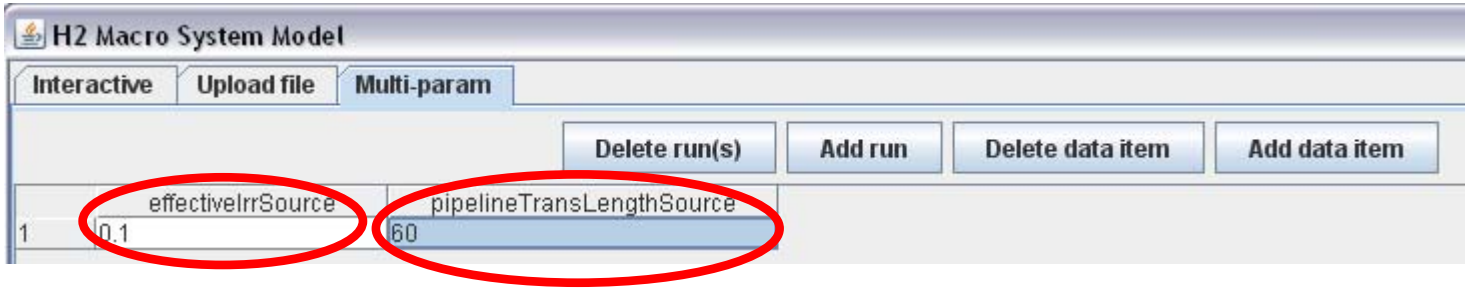


Multiparameter run: set variable inputs

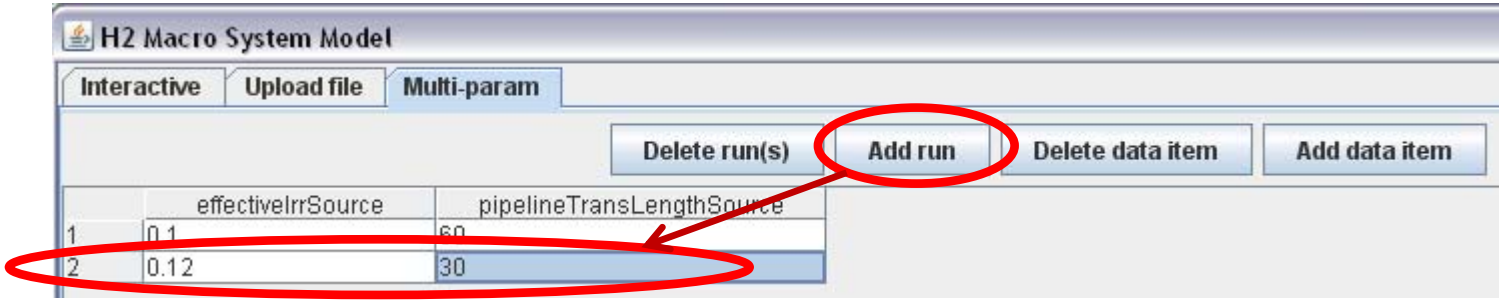
Add the variable input parameters:



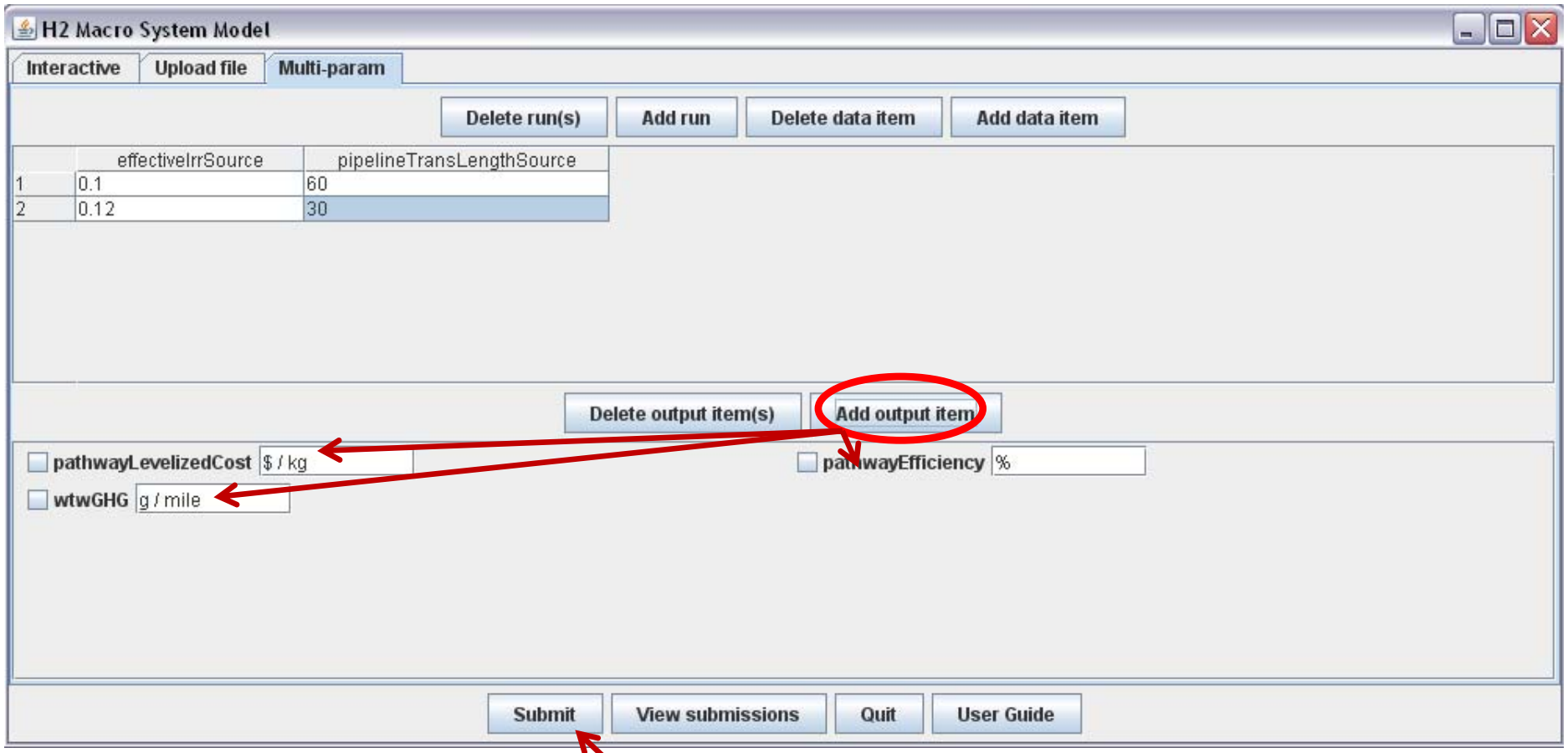
Set values:



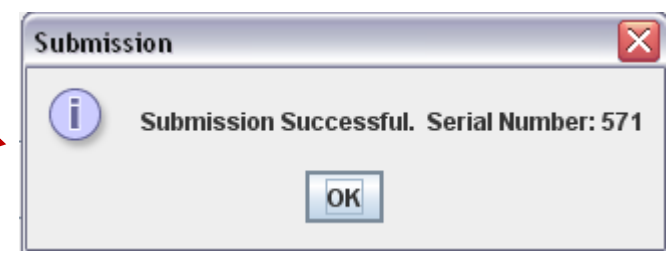
Add runs (other set of values):



Multiparameter run: select outputs



After selecting the variable inputs and the outputs of interest, submit the job to the MSM server



Multiparameter run results

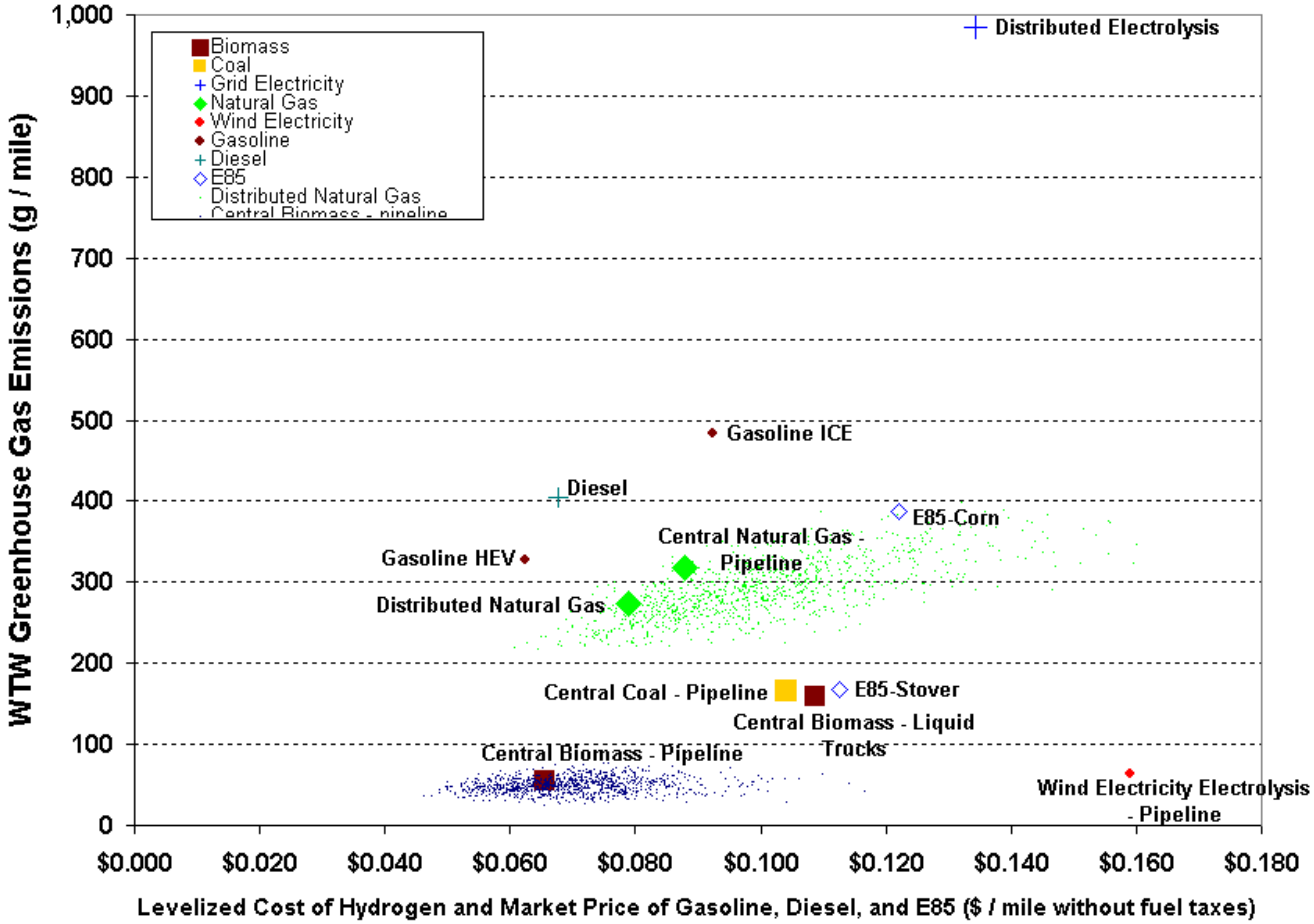
View submissions → [select run] → download results

571.csv

	A	B	C	D	E	F	G	H	I
4		effectivel	effectiveIrr	pipelineTi	pipelineTransLength	pathwayLevelizedCost	pathwayEfficiency	wtwGHG	
5		none	1	none	mi	$ / kg	%	g / mile	
6	run1	User Input	0.1	User Input	60	3.166271134	45.16455712	119.1497	
7	run2	User Input	0.12	User Input	30	3.378843973	45.18960176	119.1196	
8									
9									
10									

Example: stochastic capability

*MSM allows to compare **results across pathways** and between hydrogen pathways and competing technologies.*

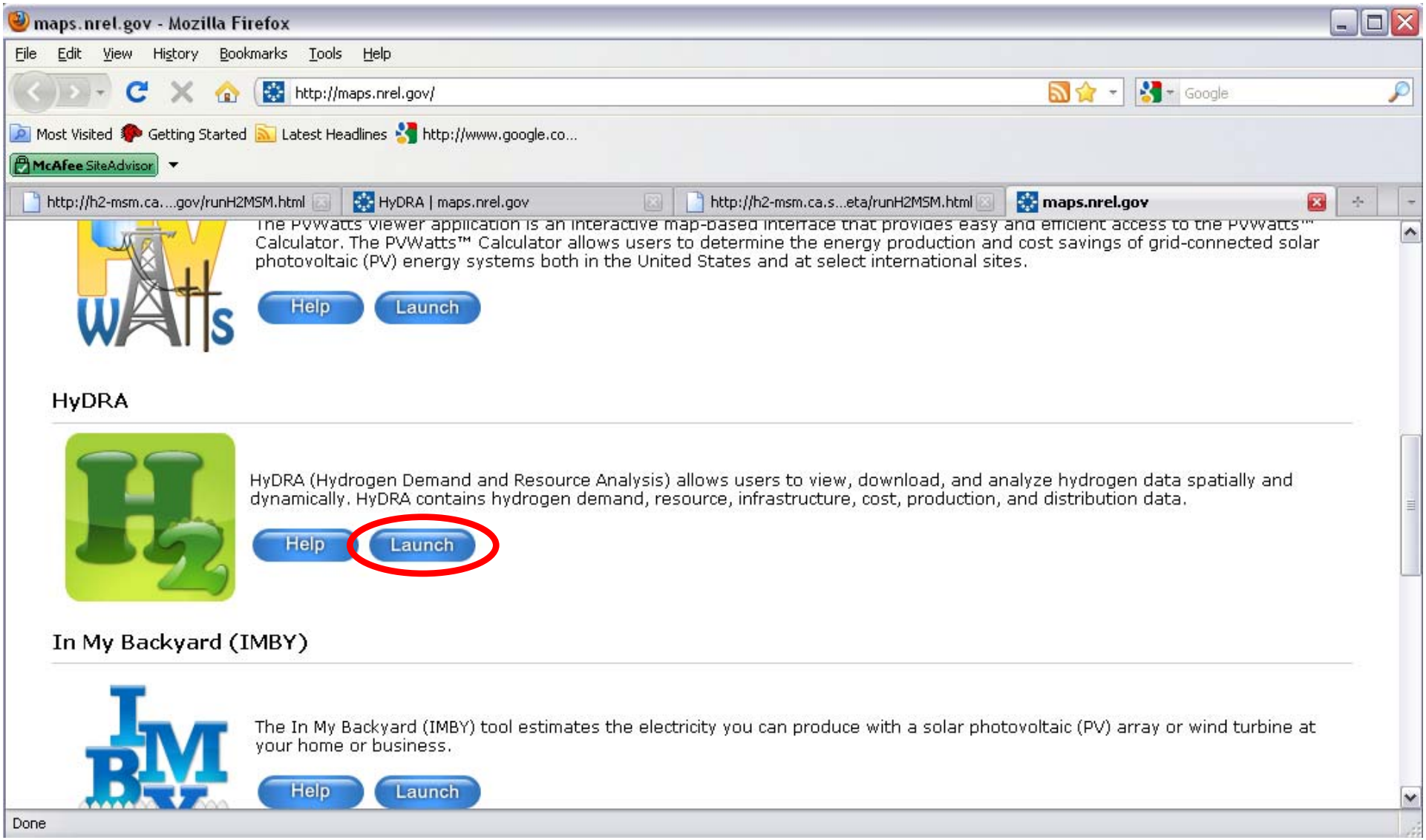


Monte Carlo results for distributed SMR and central biomass – pipeline cases are shown here but are not in the report.

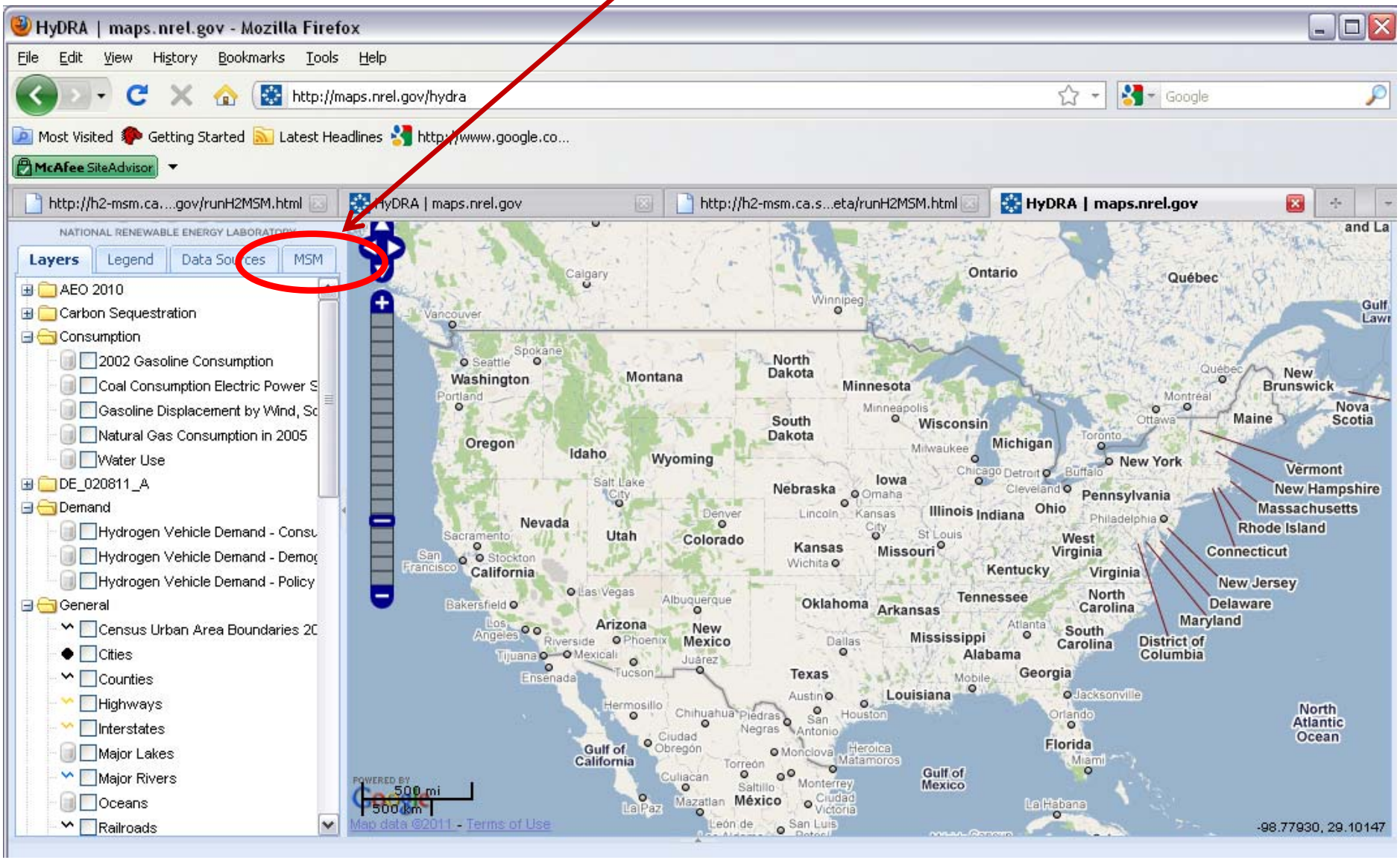
Hydrogen results in the figure are based on current technology status scaled to full utilization of production capacity, as represented in H2A and HDSAM.

Gasoline and diesel prices are from AEO 2007 high projections for 2009 and do not include fuel taxes.

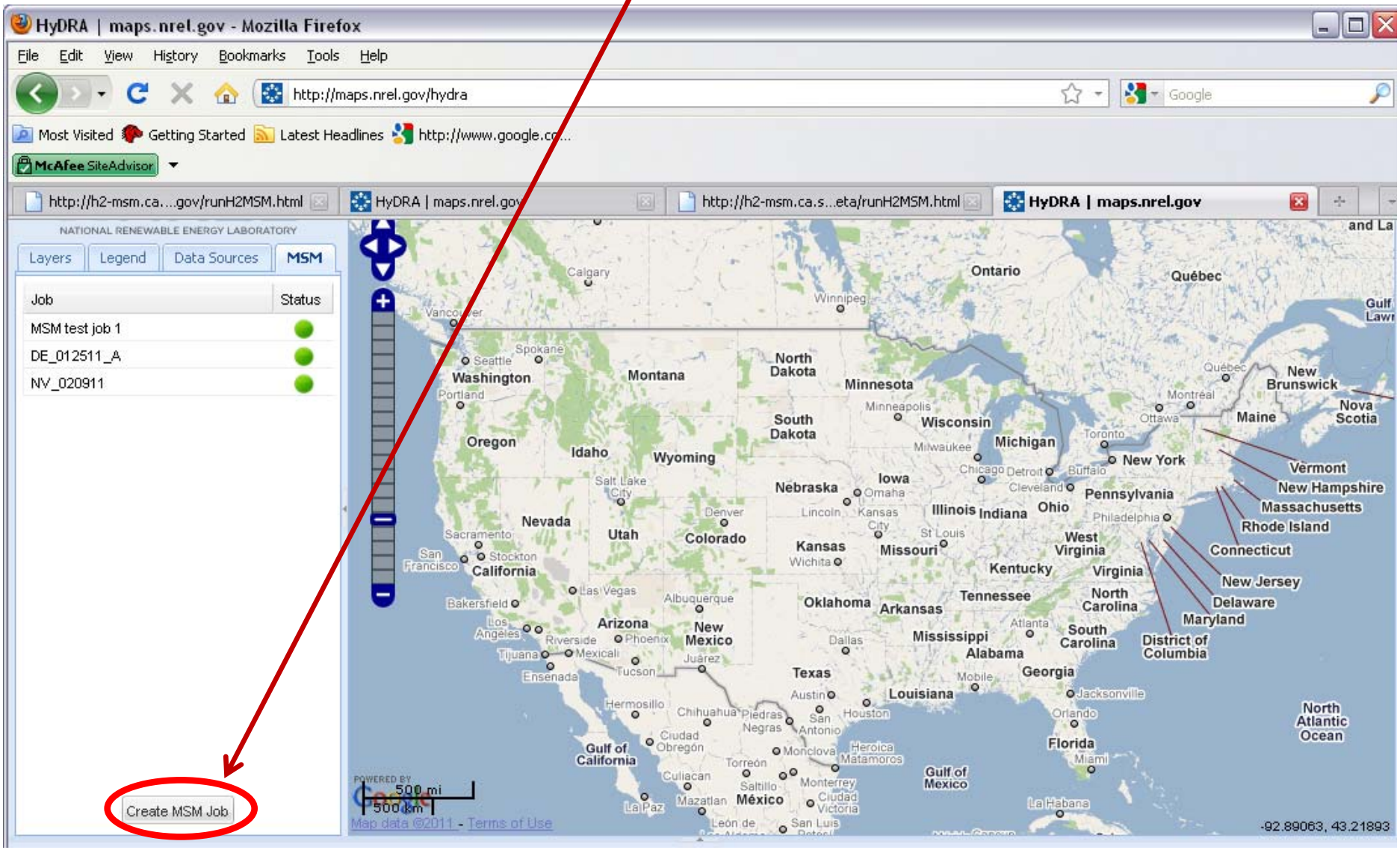
HyDRA: http://maps.nrel.gov



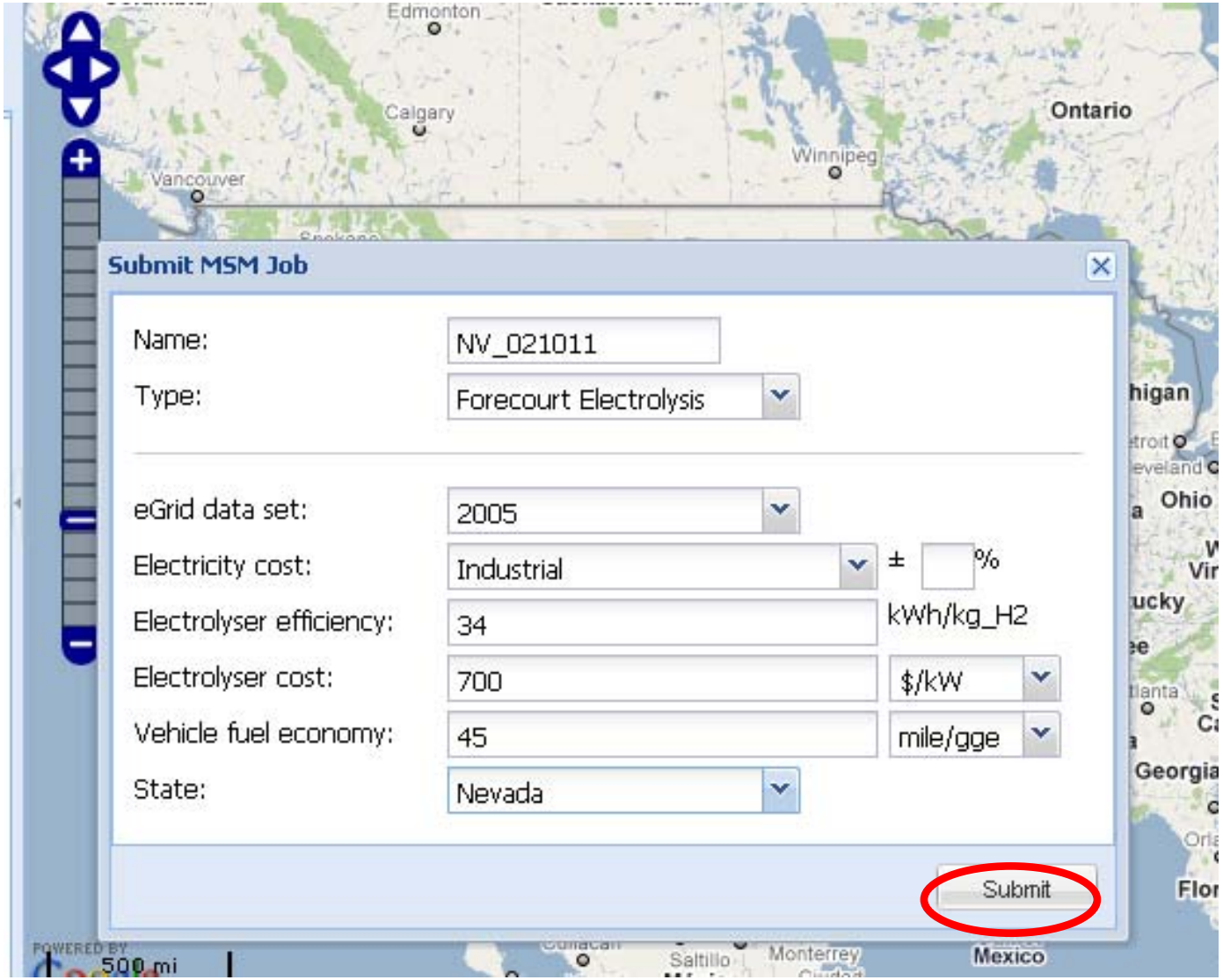
HyDRA: select MSM link (after login)



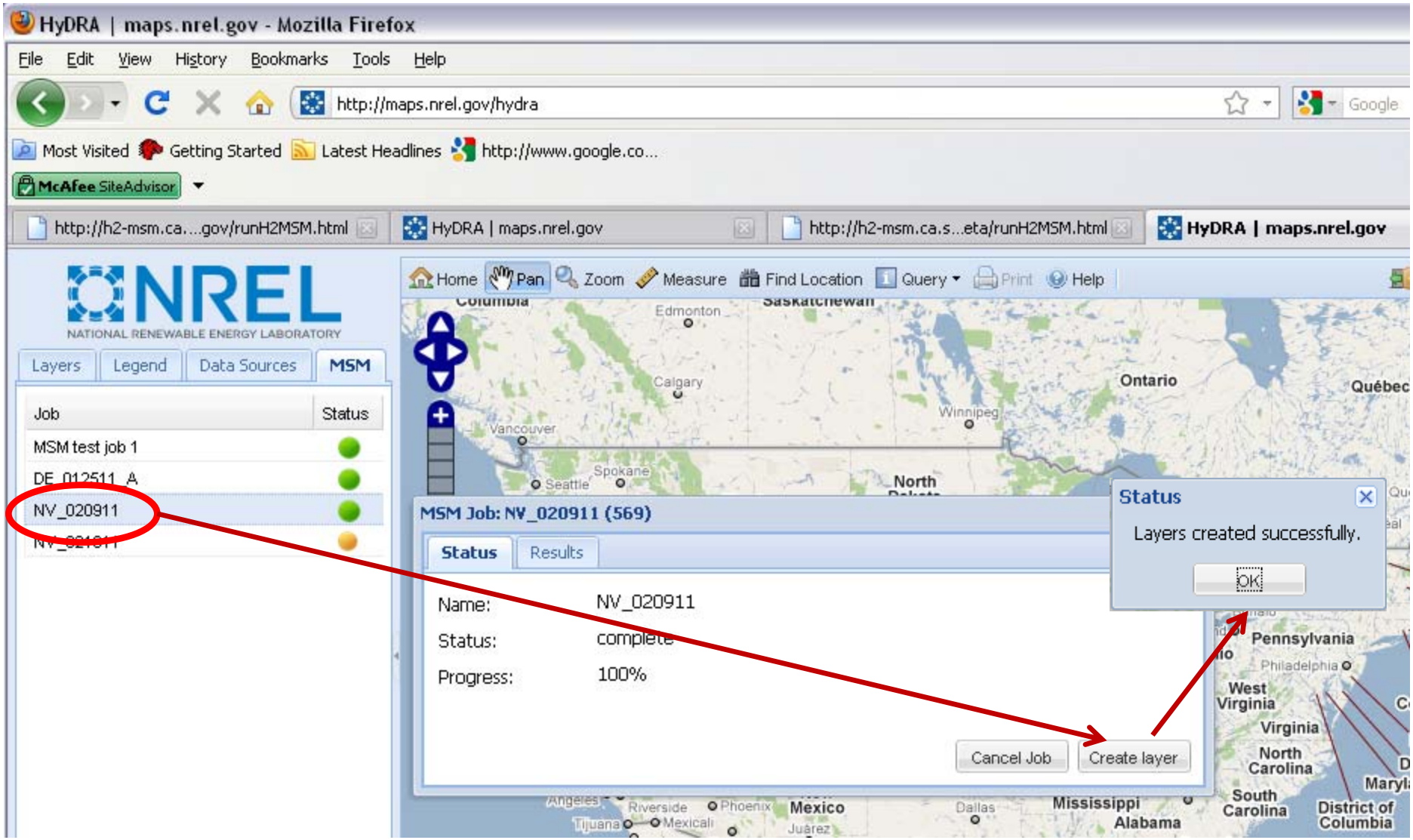
HyDRA: create MSM job



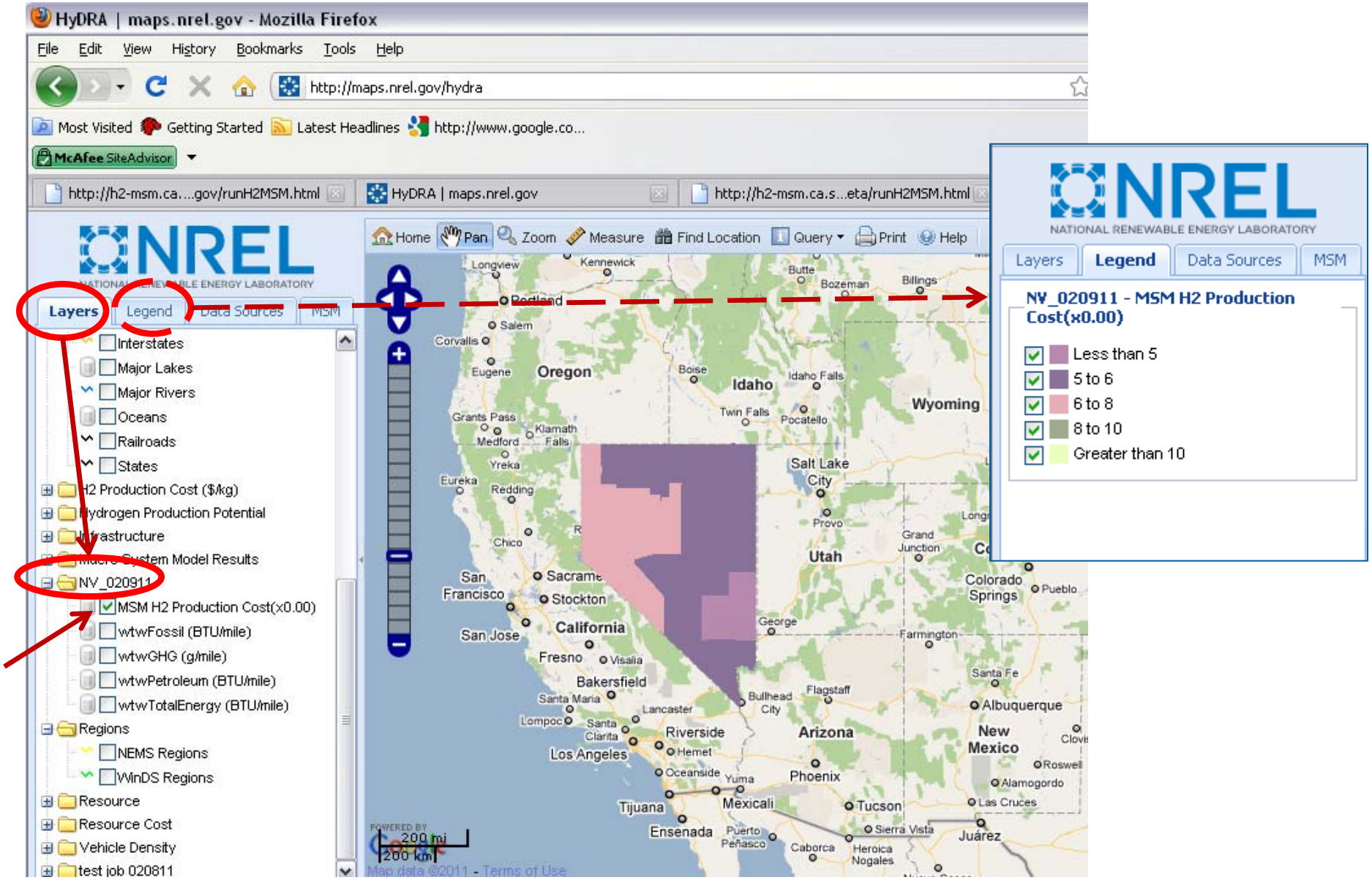
HyDRA: submit MSM job



HyDRA: retrieve MSM job results



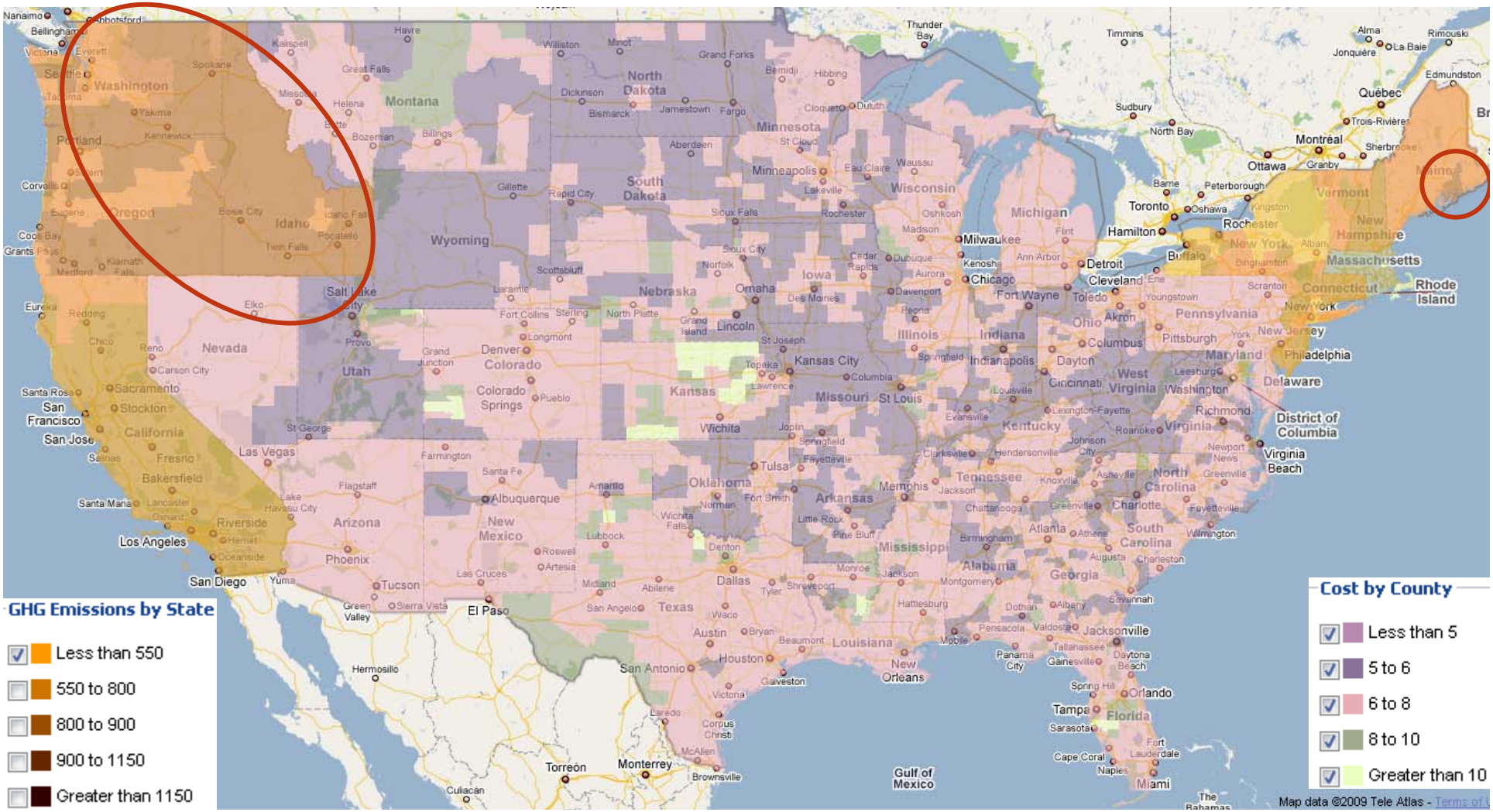
HyDRA: mapping MSM results



Example: linking with HyDRA

input:
electricity price, $/MWh
electricity grid mix by state

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



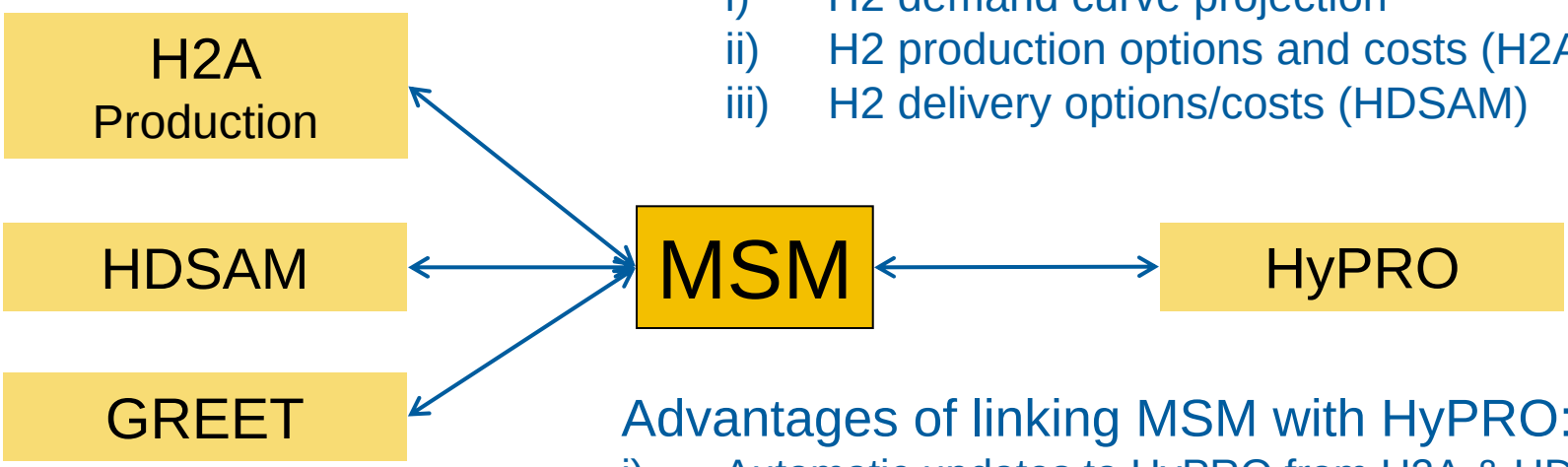
MSM + HyPRO

HyPRO

- MATLAB-based computer model developed by Directed Technologies Inc. (DTI)
- Calculates the expected levelized "pump price" of hydrogen for a variety of production/delivery/dispensing pathways over a span of years in an area with uniform demand density
- Calculates the ideal infrastructure build-out over time

Inputs to HyPRO:

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

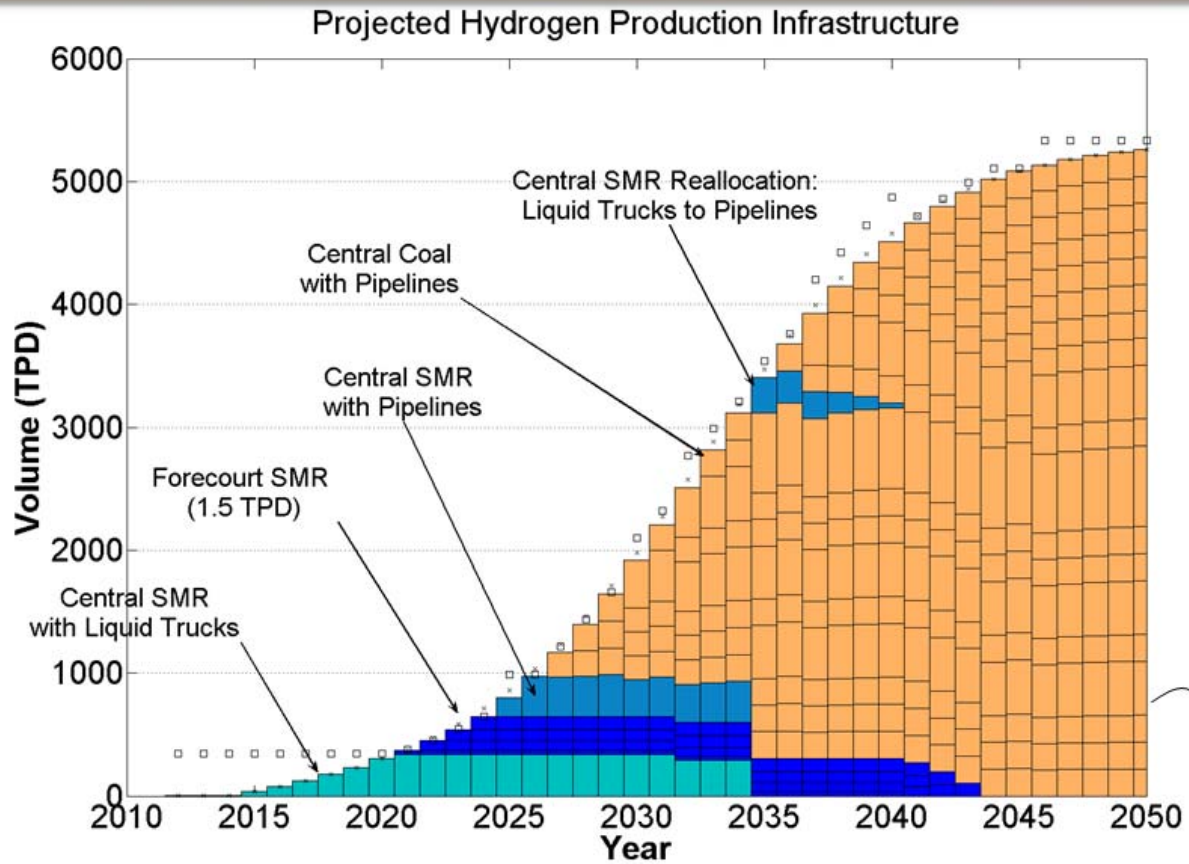


Advantages of linking MSM with HyPRO:

i) Automatic updates to HyPRO from H2A & HDSAM
ii) H2A/HDSAM/GREET inputs' effect on HyPRO can be studied

HyPRO Results – base case

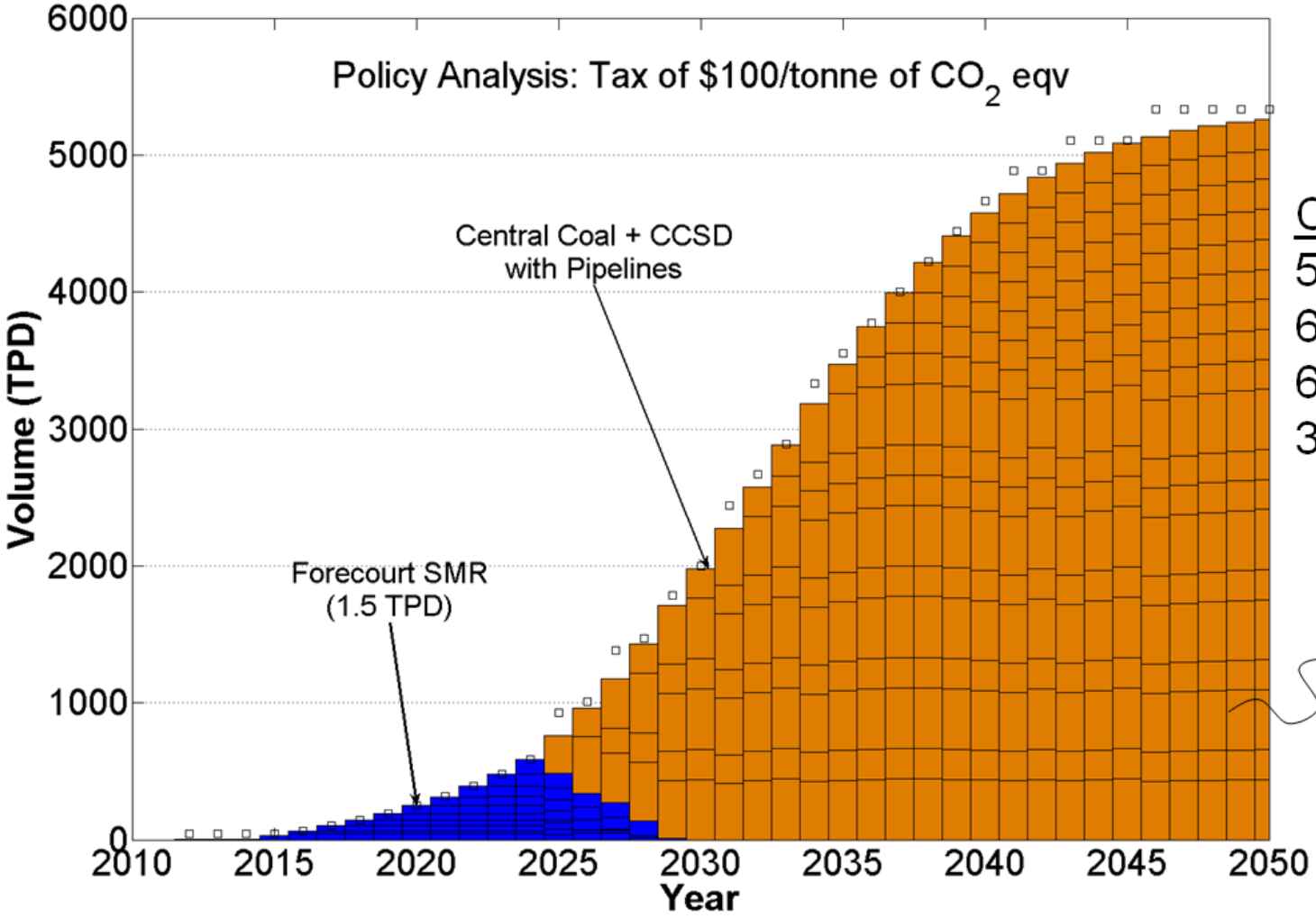
Scenario: Los Angeles Area, Single Forecourt SMR option, Central Coal Available, Regional Feedstock Prices Used



Cost Split:
48% Production
7% Terminals
6% Delivery
38% Dispensing

$26.2B

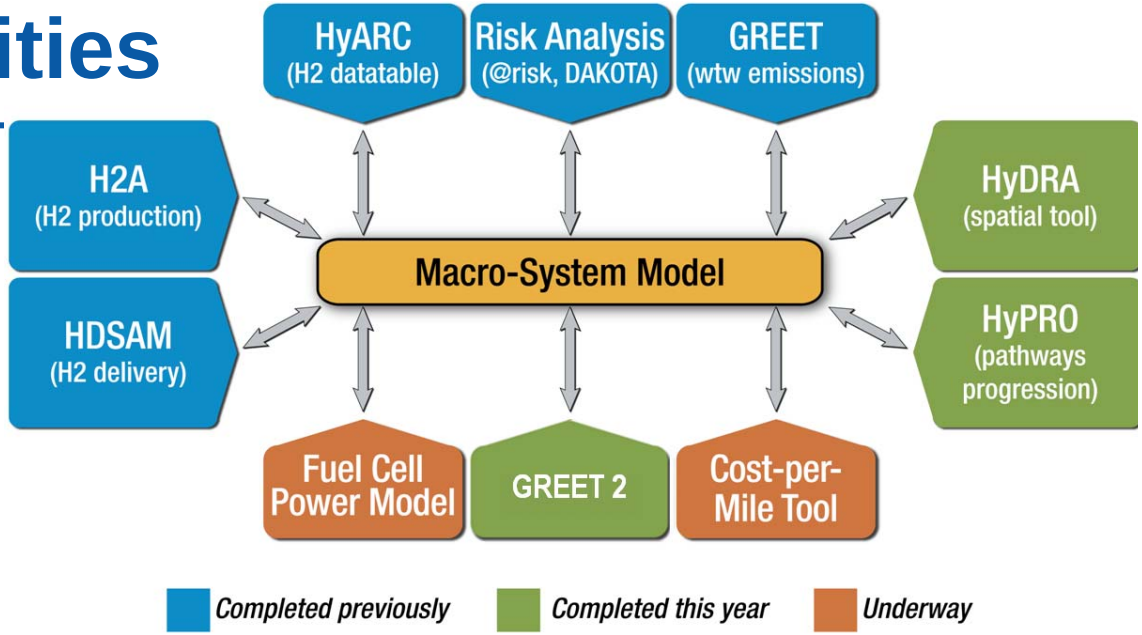
HyPro results: $100/ton GHG case



Cost Split:
57% Production
6% Terminals
6% Delivery
31% Dispensing

$29.5B

Expanding capabilities



- Adding a vehicle cost model
- Completing links to H2A Power
- Add a model that simulates vehicle fleet development and costs / energy use / GHGs
- Analyzing energy storage options
- Adding geographic specificity
- Adding other transition analysis tools
- Linking HyDRA & GREET2 - ‘What if the car is built there?’
- Linking HyDRA & HyPRO - ‘How the deployment scenario changes with location?’

Acknowledgements

- **Sandia National Laboratories (computational development)**
  - Mike Goldsby (MSM architecture), Tim Sa (web server, GUI), Dawn Manley, Katherine Guzman
- **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.

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, H2APower, …
- Expand to MORE computers
  - Over the ‘net interactive

Broader objectives

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