National Renewable Energy Laboratory
Innovation for Our Energy Future

Pathway and Resource Overview

Delivering Renewable Hydrogen Workshop – A Focus on Near-Term Applications

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NREL is a national laboratory of the U.S. Department of Energy, Office of Energy Efficiency and Renewable Energy, operated by the Alliance for Sustainable Energy, LLC.

Definition and Presentation Outline

Hydrogen pathway analysis is analysis of the total levelized cost (including return on investment), well-to-wheels (WTW) energy use, and WTW emissions for hydrogen production, delivery, and distribution pathways.

<u>This presentation focuses on</u>

- Pathway analyses using the Macro-System Model (MSM)
- Resource and pathway analysis using the Hydrogen Demand and Resource Analysis Tool (HyDRA)
- Status of water-electrolysis technology

MSM: Hydrogen Macro-System Model

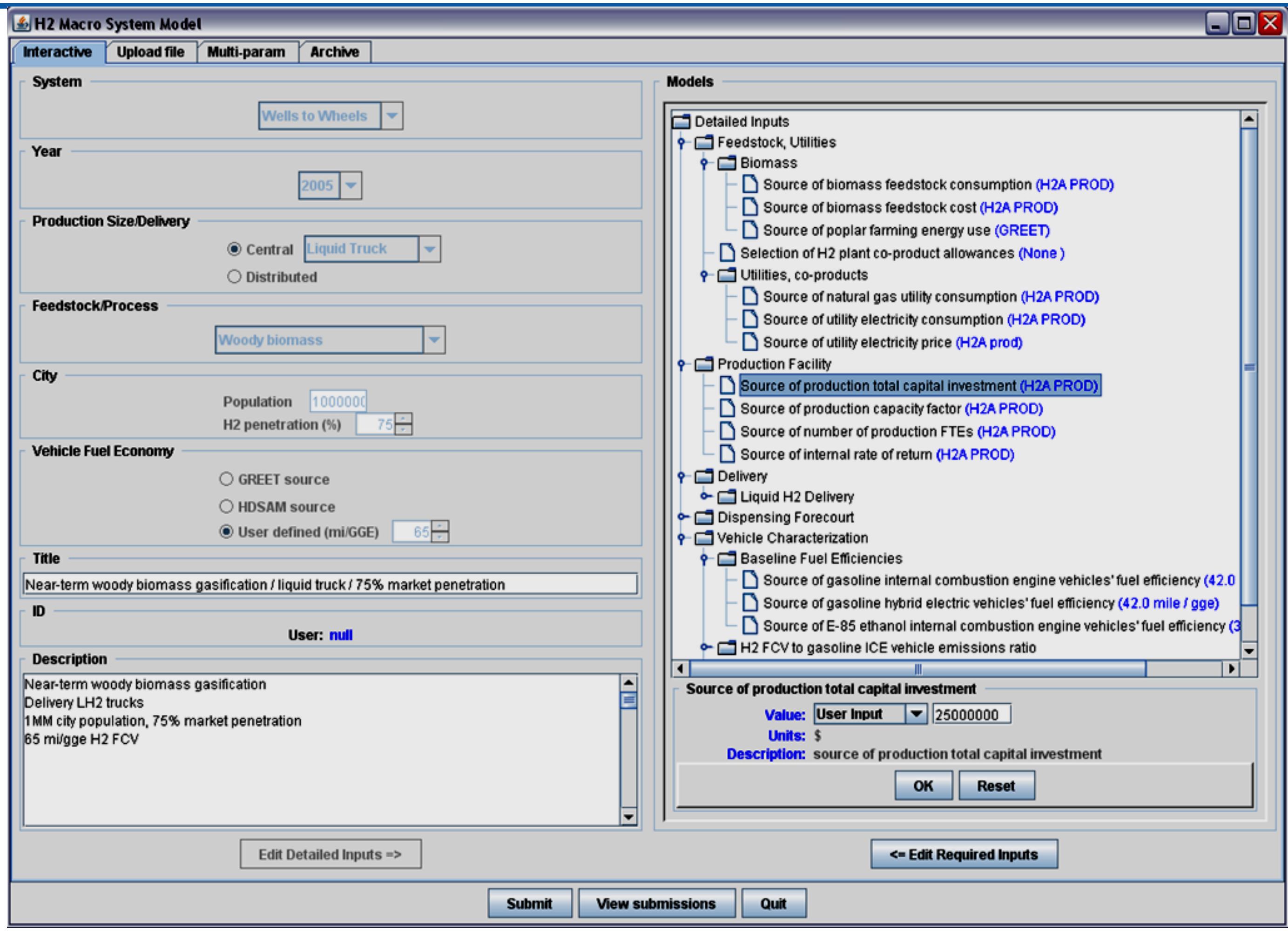
Modeling tool that supports DOE Hydrogen Program and stakeholder decision-making by performing rapid cross-cutting analysis while providing consistency, data assurance, and an easy-to-use tool for sensitivity analysis

- Consistency provided by utilizing and linking other models
  - Current version performs pathway analyses
  - It links H2A Production, the Hydrogen Delivery Scenario Analysis Model (HDSAM), and ANL's Greenhouse Gas, Regulated Emissions, and Energy Use for Transportation (GREET) model
  - Models estimate "nth plant" costs so the assumption is that the extra expenses for process integration, permitting, and process guarantees for first-of-a-kind plants have been eliminated.
- Data assurance provided by documentation of data in each of the foundational models and data validation with industrial partners
  - Pathway report at http://www.nrel.gov/docs/fy10osti/46612.pdf presents results of the current status for seven hydrogen pathways and shows many sensitivities around those results.
- Ease-of-use provided by web-based graphical user interface (GUI)
  - Available at http://h2-msm.ca.sandia.gov/

GUI Allows All Users To Perform Pathway Analyses

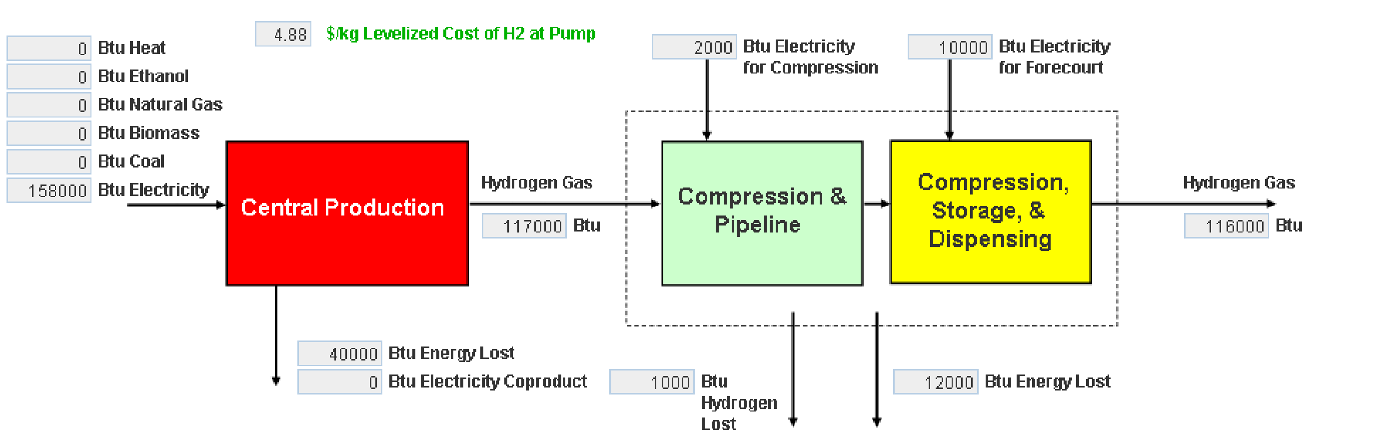
Initial input
- Technology
  - Production
  - Delivery
- City size
- Fuel Economy

Defaults
- Model defaults
- National averages
- Users can modify as desired



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

GUI Results – Central Electrolysis / Wind Power



Energy Use and Emissions

Well-to-Wheels Total Energy Use (Btu/mile)	2920
Well-to-Wheels Petroleum Energy Use (Btu/mile)	21
Well-to-Wheels Fossil Energy Use (Btu/mile)	438
Well-to-Wheels Greenhouse Gas Emissions (g/mile)	43
WTP Emissions (lb CO2 Equivalent / GGE fuel available): GHG	6

Energy and efficiency results are on a lower heating value (LHV) basis.

Energy Efficiency

Production Process Energy Efficiency	75%
Pathway Efficiency	68%
WTP Efficiency	61%

Energy and efficiency results are on a lower heating value (LHV) basis.

Case Definition

Year	2020
Form of Hydrogen	Gas
Production Means	Central
Feedstock	WIND
Sequestration	NO
Transport for Delivery	Pipeline
Vehicle efficiency	65 miles/GGE
City Hydrogen Use	238466 kg/day

Model Information

HDSAM	version 2.0
HyARC	version 1.0
H2A	version 2-01
GREET	version 1.8b

Other Information

Application version	1.1 (May 2009)
Run serial number	252

Disclaimer

The MSM is being validated so these results are not guaranteed. If any results are problematic please inform Mark Ruth at mark_ruth@nrel.gov

Single-value results for central hydrogen production via electrolysis from wind-electricity and delivered via pipeline are shown. Many other results are available but not shown by the GUI

Comparative Fuel Cost and GHG Emissions

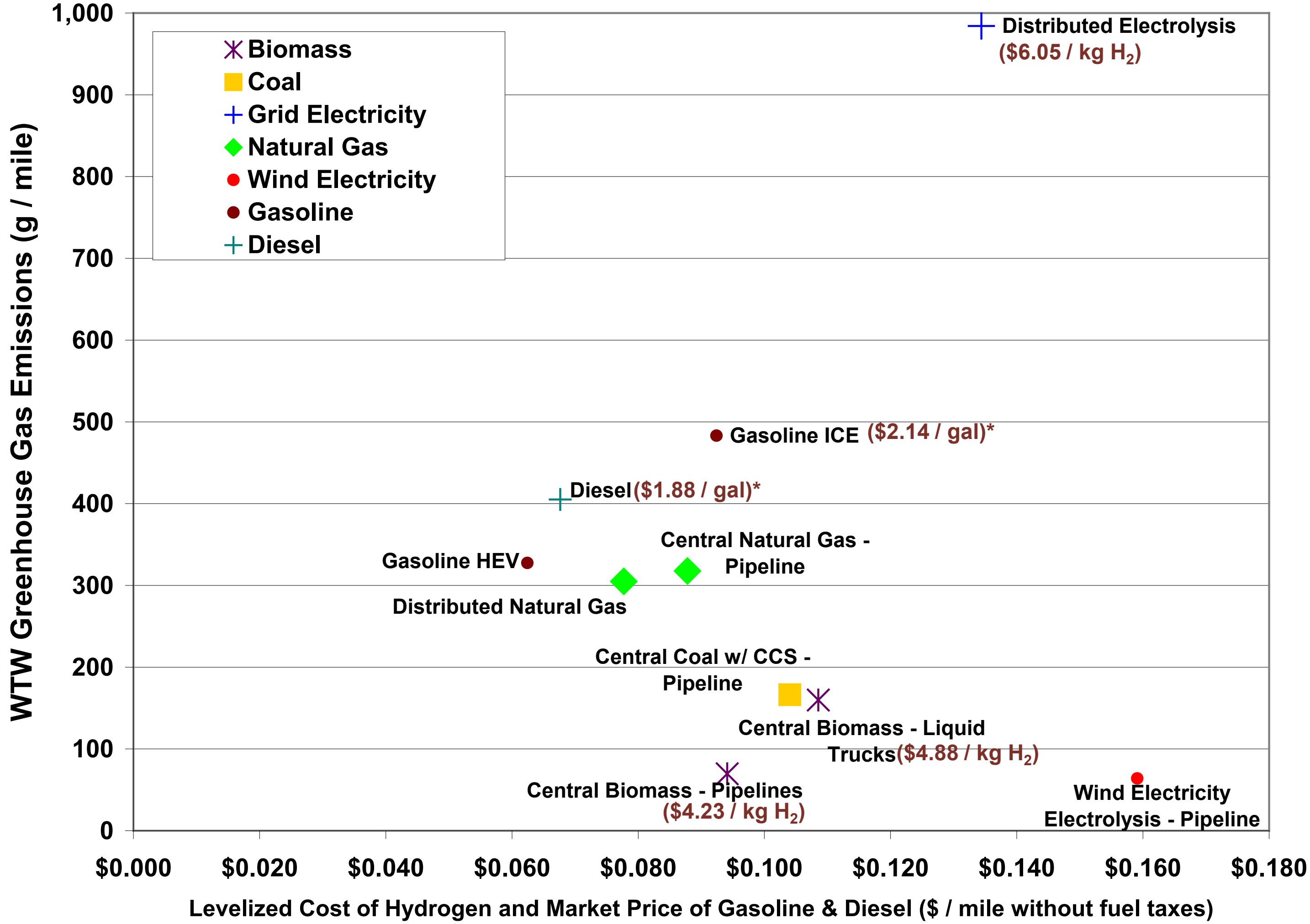
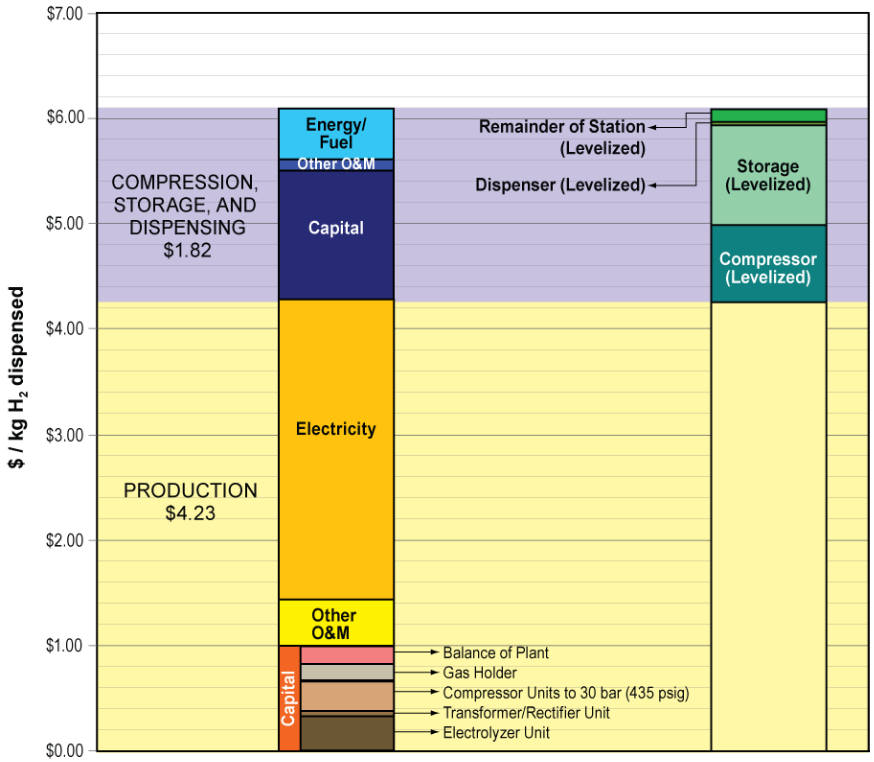


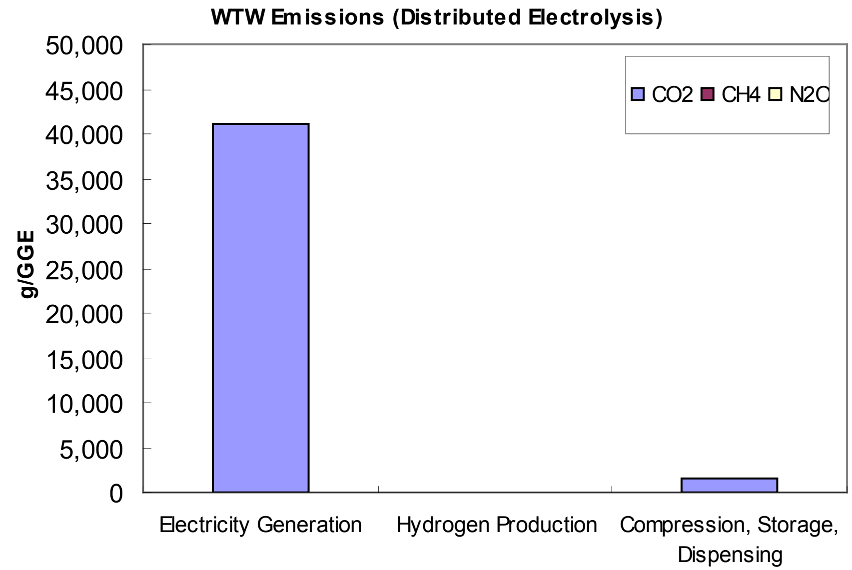
Figure shows results based on current technology status scaled to full utilization of production capacity as represented in H2A and HDSAM. Parameter values referenced at http://www.nrel.gov/docs/fy10osti/46612.pdf

Stochastic analysis can be run to estimate variability of each result.

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

Distributed Electrolysis Cost & GHG Breakdown



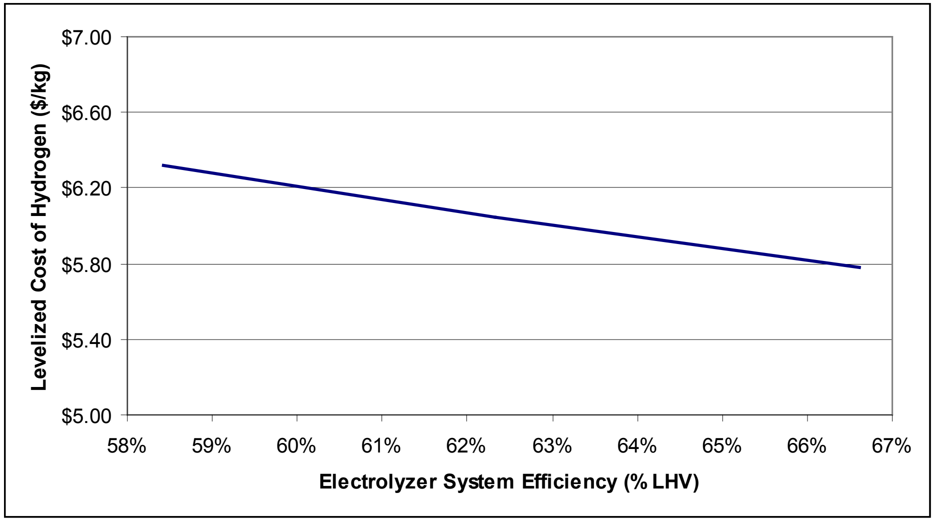


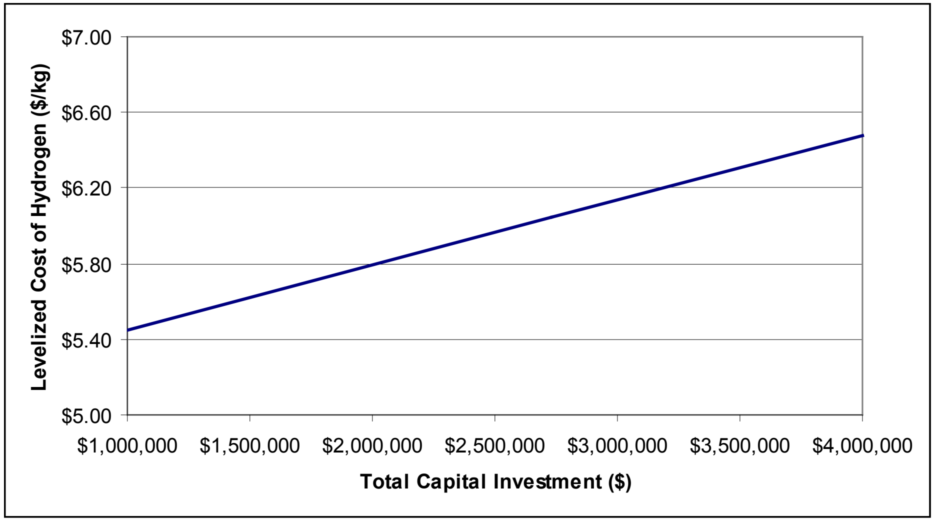
Purchasing electricity is the largest driver of hydrogen cost so reducing electricity purchase price and increasing electrolysis efficiency have the greatest potential for reducing cost.

Generating electricity for hydrogen production generates 96% of the WTW greenhouse gases (GHG) based on the US average grid mix. Electrolysis efficiency and grid mix have the greatest potential for reducing GHGs.

Basis: 1500 kg/day design capacity, production electricity use of 53.44 kWh/kg H_2 (62% efficiency – LHV basis), electricity cost of $0.055/kWh, electrolyzer system capital cost of $675/kW, total capital investment of $2,730,000, and 2005 US$

Cost Sensitivities





Improved system efficiency and reduced capital cost have the potential to reduce the levelized cost.

Electricity price has the greatest effect on levelized cost of hydrogen but it is driven by location and policies.

Basis: 1500 kg/day design capacity, production electricity use of 53.44 kWh/kg H_2 (62% efficiency – LHV basis), electricity cost of $0.055/kWh, electrolyzer system capital cost of $675/kW, and 2005 US$

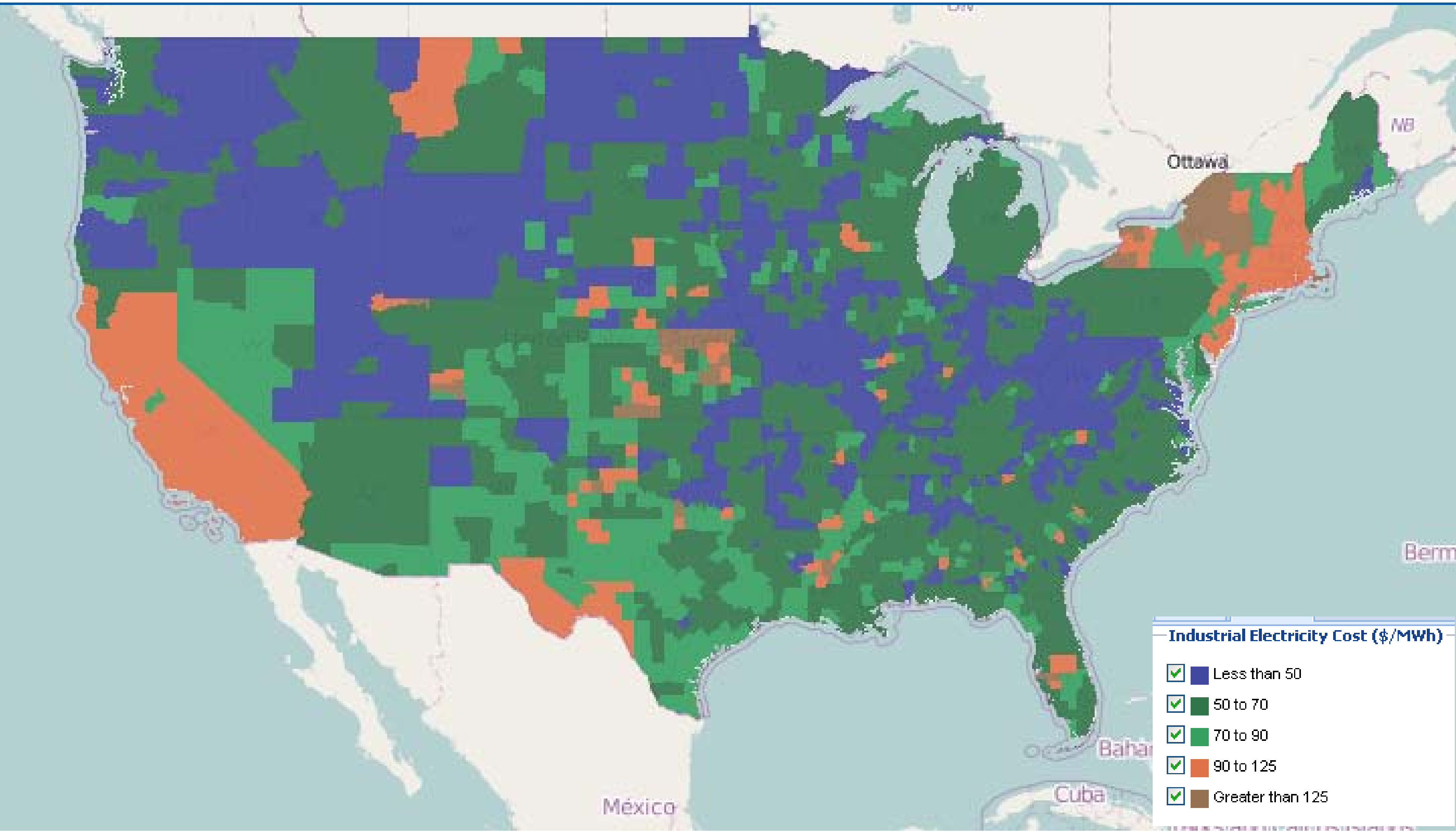
HyDRA: Hydrogen Demand and Resource Analysis Tool

Web-based geographic information system (GIS) tool that allows analysts, decision-makers, and general users to view, download, and analyze hydrogen demand, resource, and infrastructure data spatially and dynamically.

It is a repository for spatial data inputs and results and is designed to display and aggregate that data

HyDRA can be accessed at http://rpm.nrel.gov. The user must request a login ID and password.

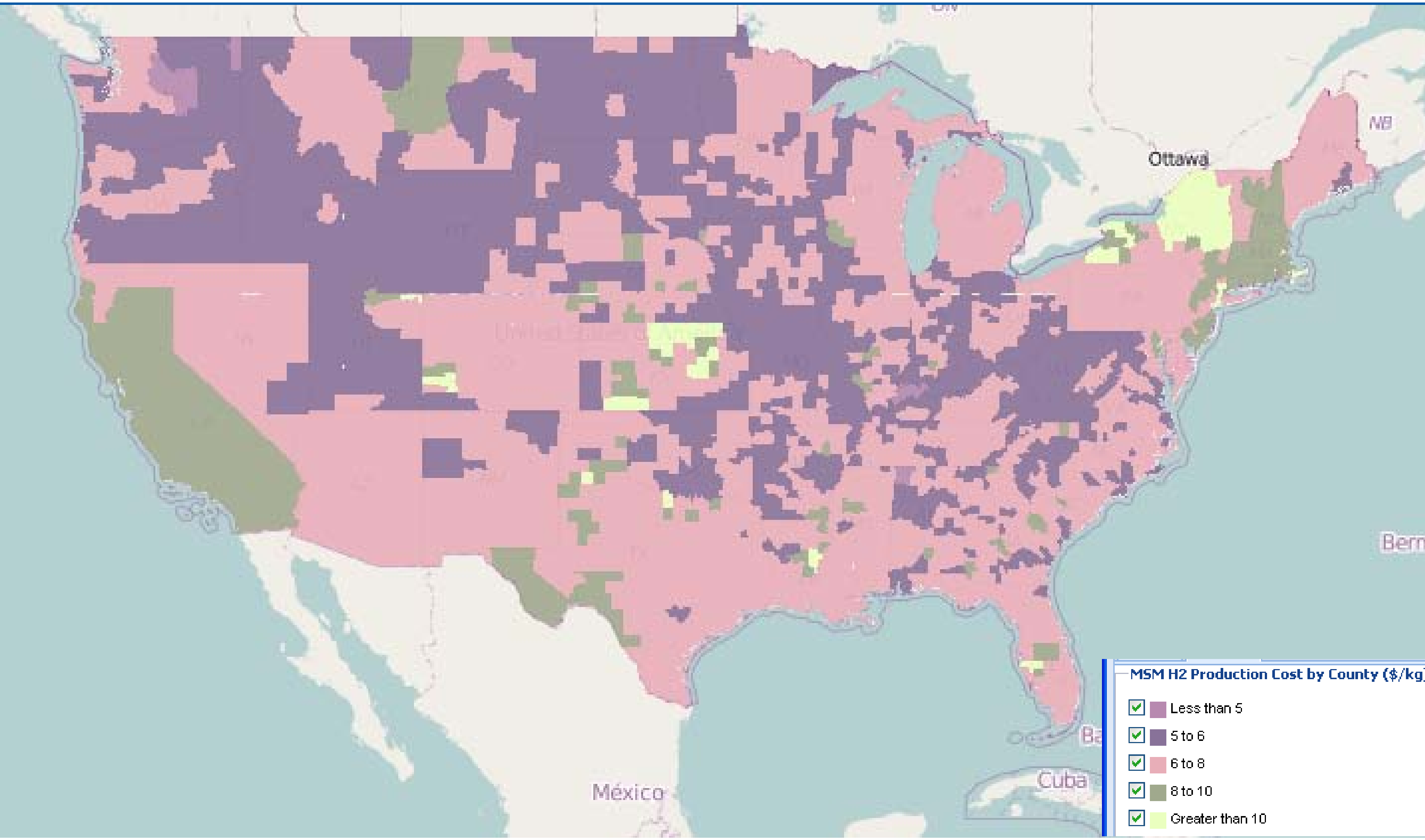
Industrial Electricity Price by US County



Grid mix and electricity cost vary

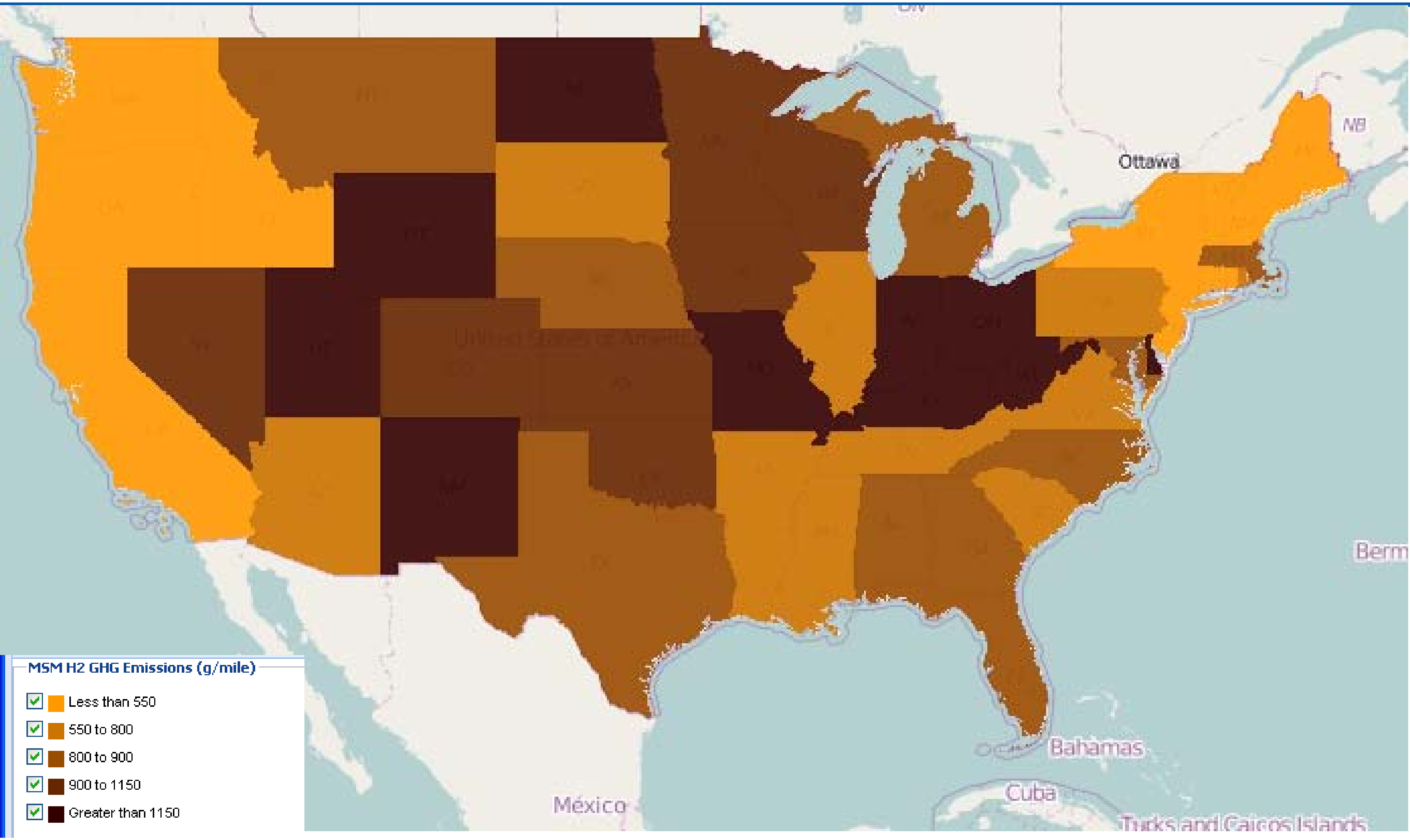
– HyDRA provides layers with residential, commercial, and industrial electricity cost from EPA

Distributed Electrolysis Cost by US County



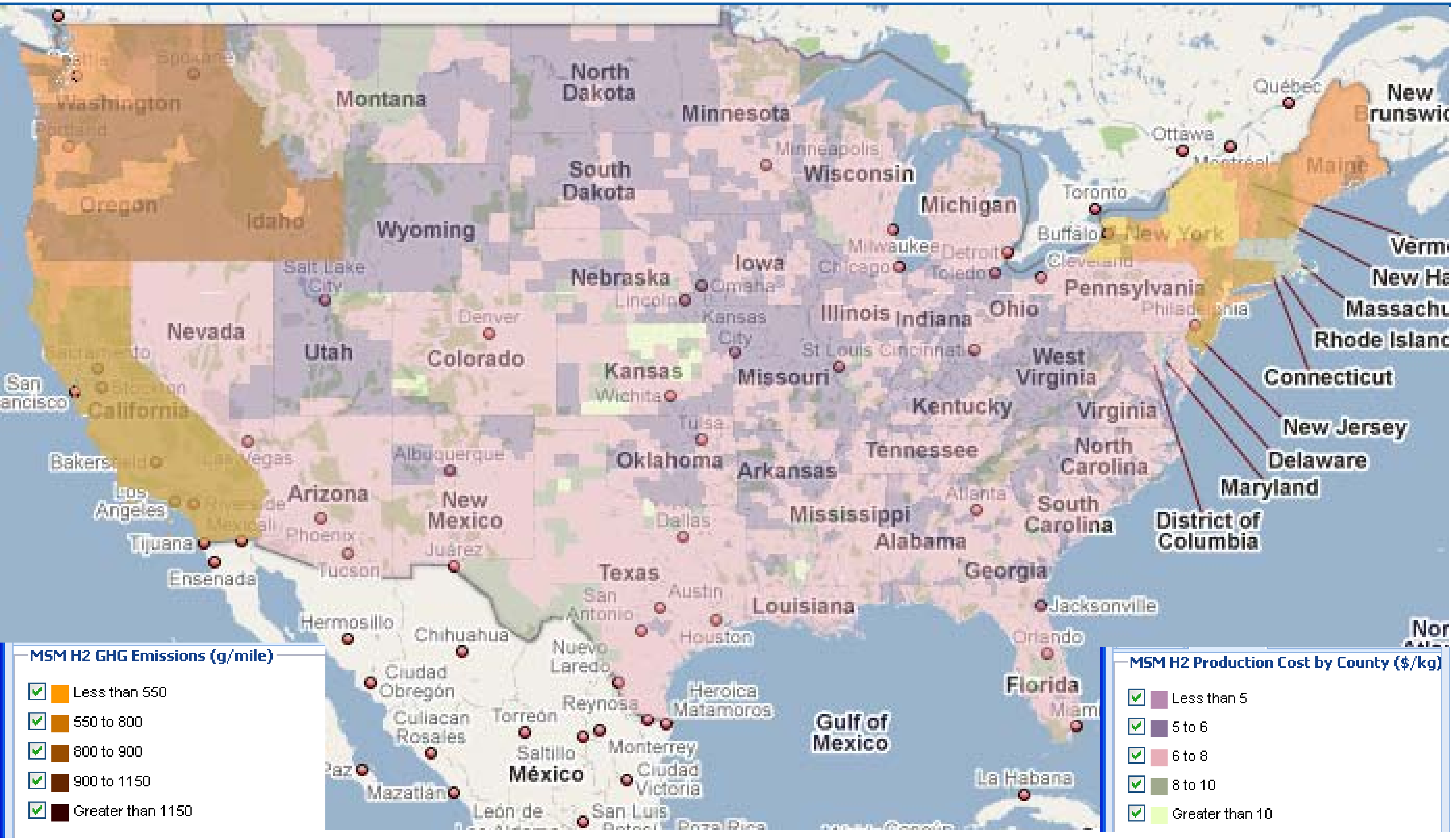
Industrial electricity price by county was entered into the MSM to generate levelized costs of hydrogen by distributed electrolysis.

Distributed Electrolysis GHG Emissions



HyDRA also has grid mix by state. Grid mix was entered into the MSM to estimate WTW GHG emissions. HyDRA now has county-level data and that data will be used to generate a new layer.

Distributed Electrolysis Cost and Emissions



Overlaying levelized cost and GHG emissions indicates opportunities for distributed electrolysis.
The MSM and HyDRA are being linked to allow users to vary electrolysis capital cost and efficiency.

Electrolysis Independent Review

- NREL commissions independent reviews at DOE's request
- Recently, a review of central and distributed electrolysis status was completed.
- Four independent experts reviewed information provided by electrolysis system providers, interviews, public data, and their own knowledge to estimate the current status of central and distributed production.
- They concluded that "significant technology advancements in reducing capital costs and improving efficiency have led to substantially improved electrolysis production costs."
- Their results and rationale are presented in a report available at http://www.hydrogen.energy.gov/peer_reviews.html

Panel's Conclusions

	H2A Levelized Cost	Panel's Cost Range	Panel's Base-Case Estimate
Distributed Electrolysis (1500 kg/day)	$6.05 / kg	$4.90 - $5.70 / kg	$5.20 / kg
Central Electrolysis (50,000 kg/day)	$4.50 / kg	$2.70 - $3.50 / kg	$3.00 / kg

Improvements Panel Identified for Dist. Electrolysis

	H2A	Vendor Range	Panel Base Case Value	Effect on levelized cost
Electrolyzer System Capital Cost	$675 / kW	$170 - $420 / kW	$360 / kW	-$0.61 / kg H_2
Electrolyzer System Electricity Use (kWh / kg)	53.4	48 – 59	50	-$0.19 / kg H_2
Electrolyzer System Efficiency (LHV)	62%	57% - 70%	67%	Same as above
Maintenance, replacement, CSD, and water requirements				-$0.05 / kg H_2

Basis: 1500 kg/day design capacity, electricity cost of $0.055/kWh, and 2005 US$

Conclusions

- MSM performs pathway analysis and gives users the ability to vary many input parameters
- HyDRA provides spatial resource data and some spatial pathway results
- MSM and HyDRA are being linked to allow users to run pathway analyses and sensitivities with spatial results
- An independent review panel has identified improvements made since the H2A cases were developed that make electrolysis more attractive.
- The MSM and HyDRA will be demonstrated this evening.

Acknowledgements

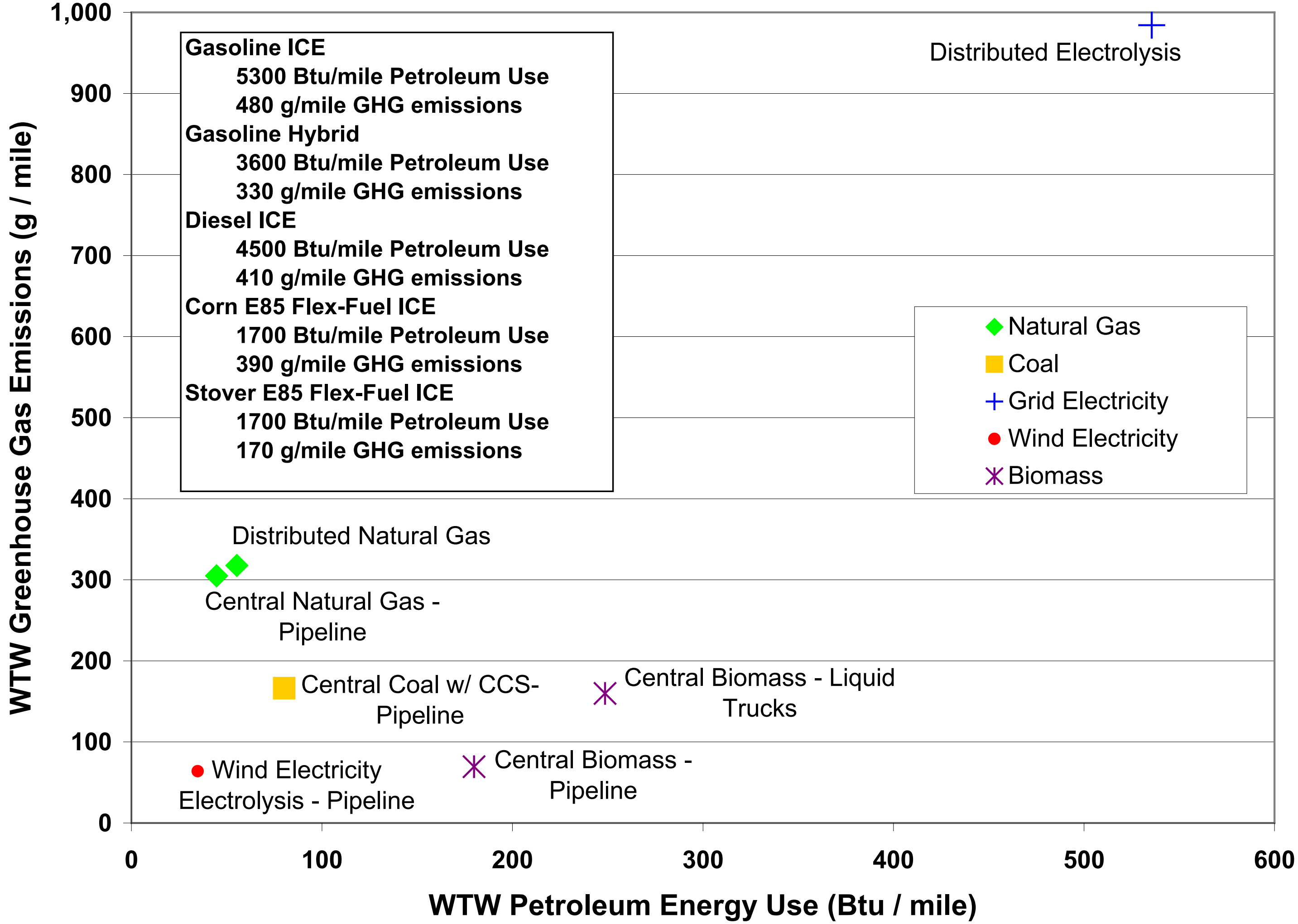
NREL is a national laboratory of the U.S. Department of Energy Office of Energy Efficiency and Renewable Energy Operated by the Alliance for Sustainable Energy, LLC.

The author would like to thank Johanna Levene from NREL for the description of HyDRA and for interactions necessary to produce the HyDRA example.

Questions

Supporting Slides

Comparative Petroleum Use and GHG Emissions



Most hydrogen technologies use less petroleum and are likely to produce fewer GHG emissions than other fuels.

Stochastic Analysis

MSM allows stochastic analysis to present results in ranges – necessary to quantify the results' variability

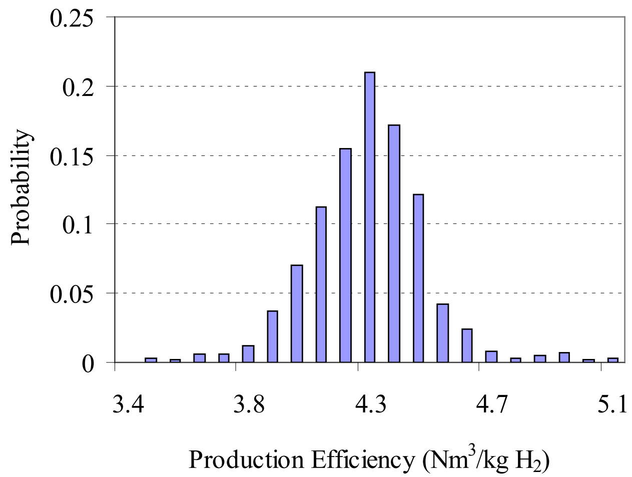
Example Scenario:

– Advanced distributed SMR production technology case with a fuel economy of 50-70 mile/kg H_2

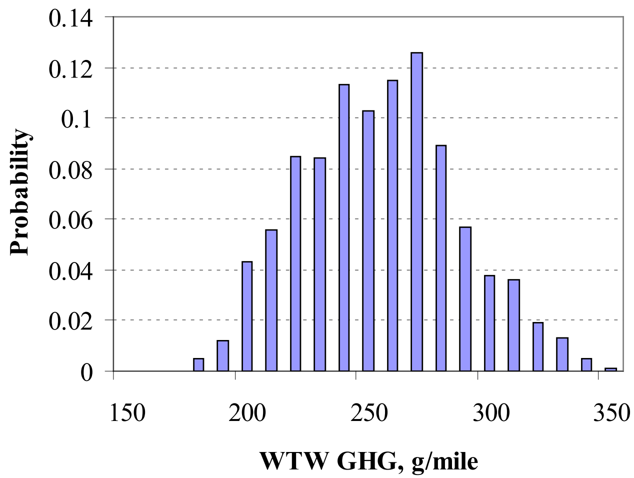
Varied inputs:

– Total capital investment; Operating and maintenance costs; Capacity factor; Production efficiency; Natural gas cost; Vehicle fuel economy

Input Distribution



Result Distribution



Result Scatter Plot