Macro-System Model
(project #AN4)

2009 U.S. DOE Hydrogen Program and Vehicle Technologies Program Annual Merit Review

May 19, 2009
Arlington, VA

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NREL/PR-6A1-45599

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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.
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
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.

Known issue: Hydrogen losses are estimated in HDSAM but are not included in GREET.
**Approach: MSM development**

### Initial objectives
- Type of information to transfer
- Define implicit calculations
- Model-linking methodology
- Validate use of models

### Experience
- Proof of concept / Initial analysis
- Extensible tool
- Additional models
- Additional capability

### completed previously
- Completed previously
- Completed this year
- Underway
- Future Activities

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**Extensible tool**
- Develop & validate extensible & robust structure
- Develop GUI & web interface
- Component model updates ongoing effort
- Stochastic capability expanded
- Update documentation ongoing effort

**Additional models**
- Revisit analysis issues and MSM requirements
- Select additional models
- Validate use of models
- Develop data-transfer capability

**Analysis community interactions**
- Use MSM for analysis ongoing effort
- Update models using the MSM
- Inputs and pathway results reviewed by industry

**Application**
- Expand GUI & Develop run database

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National Renewable Energy Laboratory

Innovation for Our Energy Future
Progress and Future Work: Overview

- **HyARC (H2 datatable)**
- **H2A (H2 production)**
- **HDSAM (H2 delivery)**
- **GREET (wtw emissions)**
- **Risk analysis (@risk, DAKOTA)**
- **HyPRO (pathways progression)**
- **Distributed Power (combined heat, power and H2 production)**
- **HyDS-ME (production evolution with geo capabilities)**
- **H2W (water model)**

- Completed previously
- Completed this year
- Underway
- Future Activities
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/
Accomplishment: GUI and web interface

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.

- Analyzing hydrogen production / delivery / distribution pathways using H2A Production, HDSAM, and GREET
- Presenting pathway levelized cost and well-to-wheels energy use and emissions
- 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
- Energy company staff and other experts are validating the process and identifying gaps and issues
Approach: linking with HyDRA

HyDRA: http://rpm.nrel.gov
Goal: to bring spatial dimension into the MSM

Geographically specific inputs → MSM → Geographically specific outputs

HyDRA database of geo-specific info

distributed electrolysis region-specific inputs:
i) electricity price
ii) electricity grid mix

HyDRA graphic mapping interface
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**
  - MSM
  - ruby
  - matlab
  - HyPRO
  - completed

- **Data exchange**
  - MSM
  - hypro input file (excel/xml)
  - in progress
  - HyPRO
  - hypro output files (excel)
  - in progress
  - completed
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**
  - Matt Rahill (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
- 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