POTENTIAL ENVIRONMENTAL IMPACTS OF HYDROGEN-BASED TRANSPORTATION & POWER SYSTEMS

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OVERVIEW

Timeline

- Start: Sept 2007
- Finish: Sept 2009
- 24 % Complete

Barriers Addressed

- Contribute consistent set of data and assumption/scenario definitions and assessment tools to support program decisions
- Contribution to environmental studies that are necessary to assess technology readiness

Budget

- Total project funding: $573K
- Funding received in FY07: $265K
- Funding for FY08: $167K

Partners

- Stanford University, Mark Z. Jacobson
- Potomac-Hudson Engineering

OBJECTIVES

- Compare emissions of hydrogen, the six criteria pollutants (CO, SO_x, NO_2, PM, ozone, and lead) and GHGs from near and long-term methods of generating hydrogen for vehicles and stationary power systems
- Evaluate effects of emissions on climate, human health, ecosystem and structures

MILESTONES

Milestones	Month/Year
Project Kick-off Meeting	December 2007
Technical Brief on Vehicle Penetration & Stationary Source Scenarios & Emission Profiles	July 2008
Draft Report on Hydrogen and Criteria Pollutants Impact Assessment Model	October 2008
Revised Draft Report on Impact Assessment Model with Preliminary Results	February 2009
Final Report on Inputs, Methodologies, and Outputs	April 2009
Final Report on Impact Assessment Model	June 2009
Final Conclusions of Comprehensive Impact Assessment	September 2009

TECHNICAL APPROACH

Problem Definition (70 % Complete)

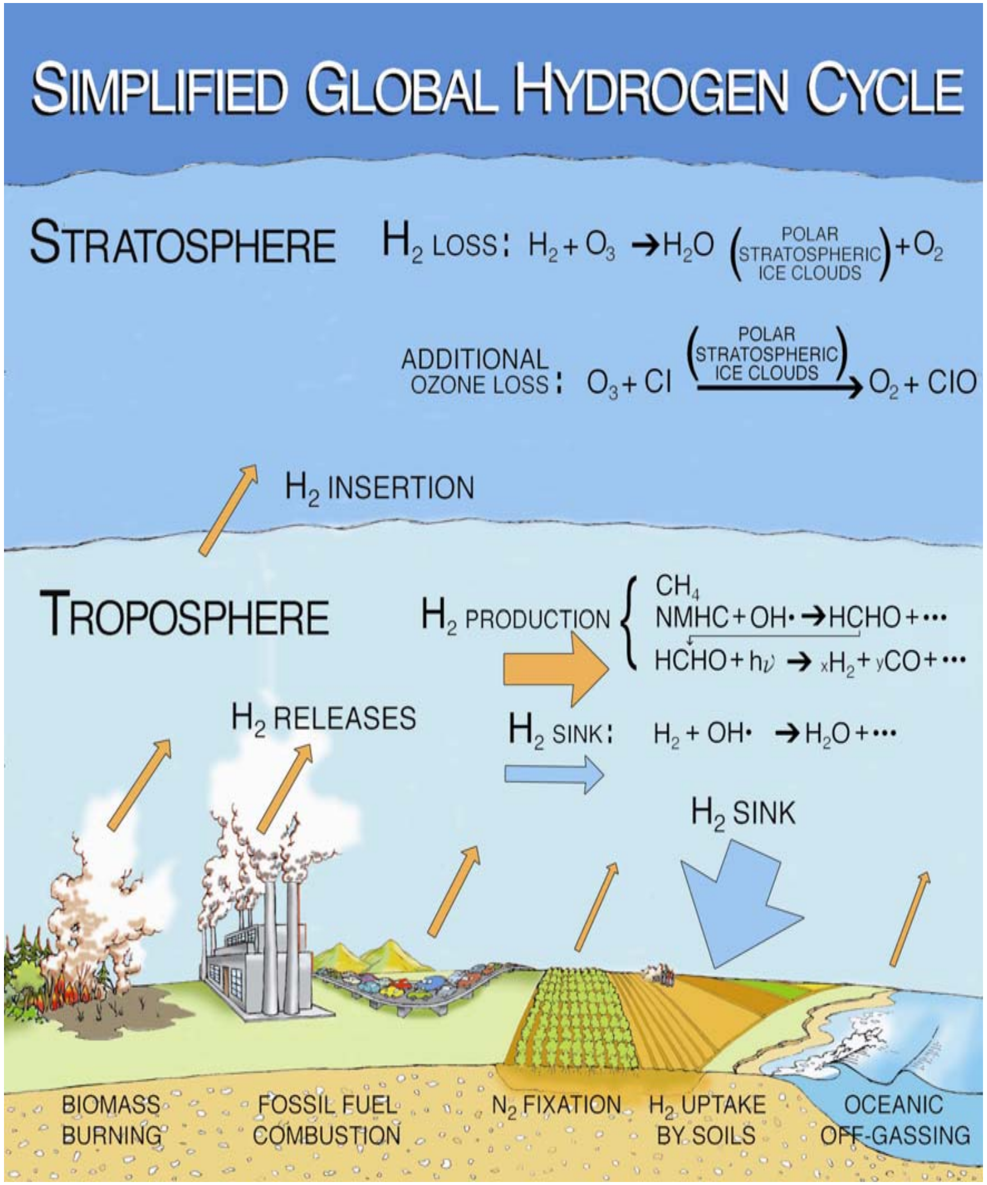
- Develop market penetration scenarios for vehicles
- Develop market penetration scenarios for electricity generation
- Develop emission-profile databases

Environmental Simulations (20 % Complete)

- Develop soil uptake model
- Predict changes in hydrogen and other atmospheric gases and aerosols in troposphere and stratosphere

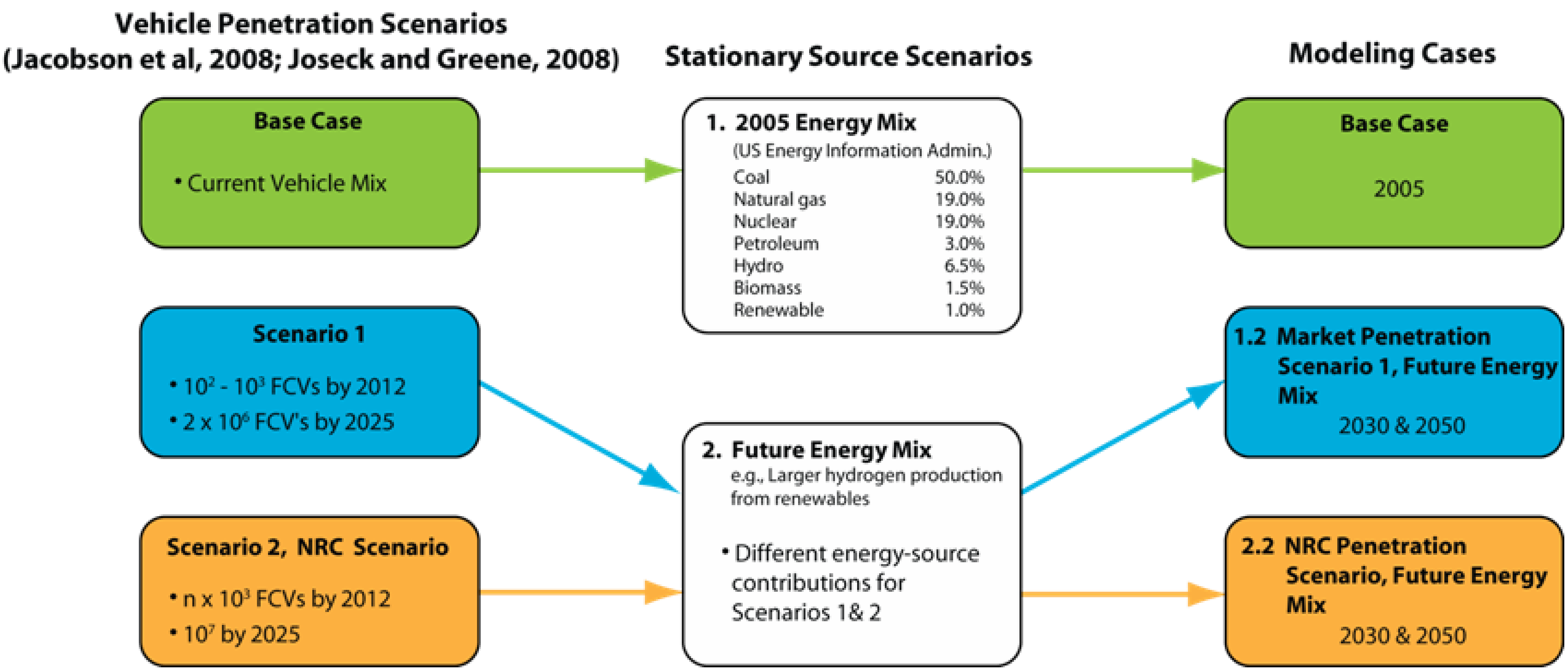
Environmental Assessment (10 % Complete)

- Quantify effects due to implementation of two market penetration scenarios


SIMPLIFIED GLOBAL HYDROGEN CYCLE
STRATOSPHERE
H_2 LOSS: $H_2 + O_3 \rightarrow H_2O$ (POLAR STRATOSPHERIC ICE CLOUDS) $+ O_2$
ADDITIONAL OZONE LOSS: $O_3 + Cl \xrightarrow{\text{(POLAR STRATOSPHERIC ICE CLOUDS)}} O_2 + ClO$
H_2 INSERTION
TROPOSPHERE
H_2 PRODUCTION
CH_4
$NMHC + OH\cdot \rightarrow HCHO + \cdots$
$HCHO + h\nu \rightarrow {}_xH_2 + {}_yCO + \cdots$
H_2 RELEASES
H_2 SINK: $H_2 + OH\cdot \rightarrow H_2O + \cdots$
H_2 SINK
BIOMASS BURNING
FOSSIL FUEL COMBUSTION
N_2 FIXATION
H_2 UPTAKE BY SOILS
OCEANIC OFF-GASSING

PROBLEM DEFINITION: VEHICLE PENETRATION AND STATIONARY SOURCE SCENARIO OPTIONS

Existing data summarized and model scenarios selected to identify likely emissions and effects on climate, human health, ecosystem and structures.



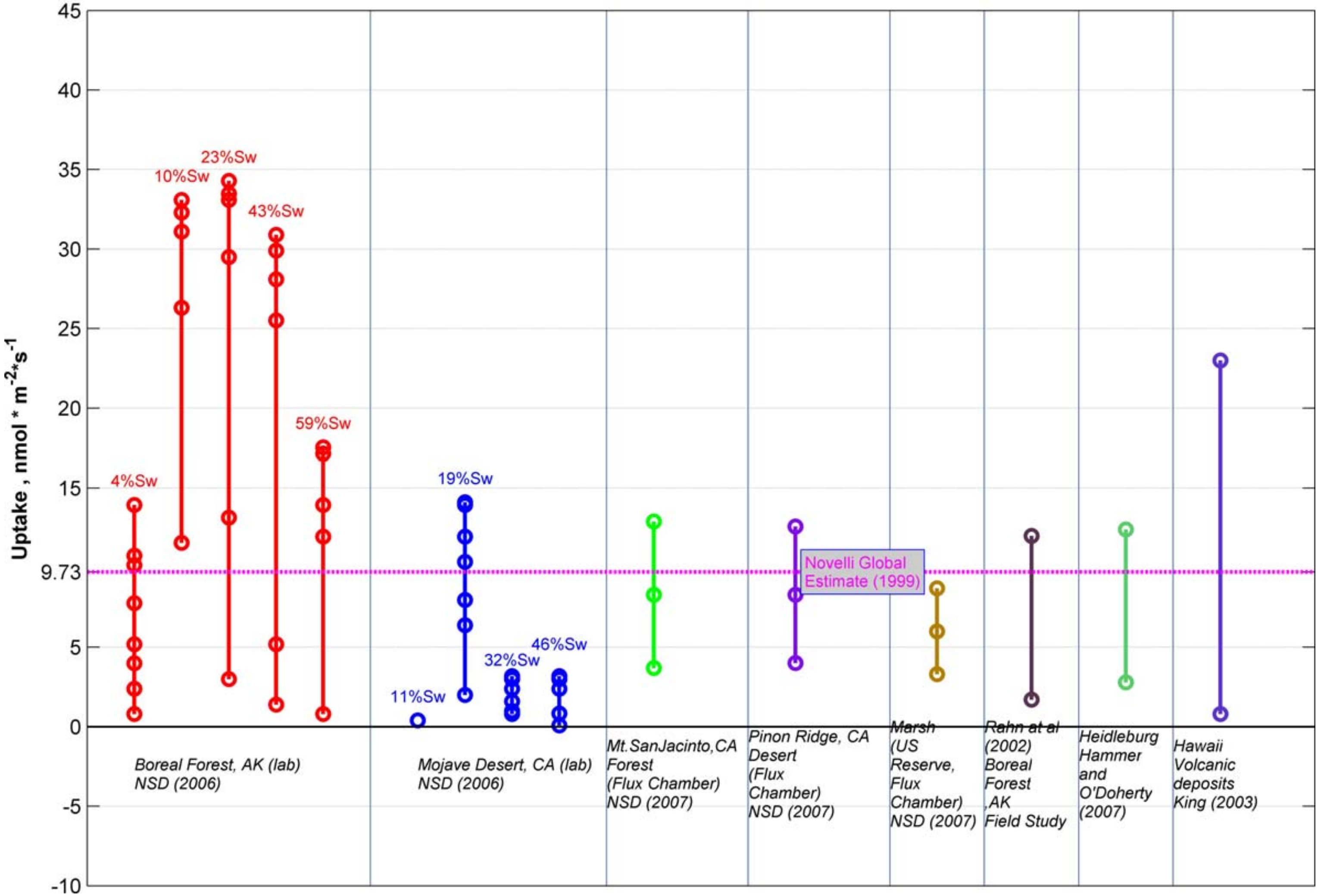
NEXT STEPS IN PREPARATION FOR FOR GATOR-GCMOM SIMULATIONS

- 2030 IPCC SRES A1B global emission growth factors; 8 energy use categories quantified
- Emission growth factors for 2050 IPCC SRES A1B under development
- Set-up data files for GATOR-GCMOM model
  - Scale 2025 hydrogen vehicle miles to 2030 and 2050
  - Adjust US A1B emission factors to account for shift to hydrogen vehicle miles; then for production using distributed SMR in 2030 and specified centralized methods in 2050
  - Adjust A1B emission growth factors for OECD Europe and Japan to include H_2 production using distributed SMR (2030) and
  - Centralized H_2 production (2050)
- Run base line cases and scenarios for 2030 and 2050

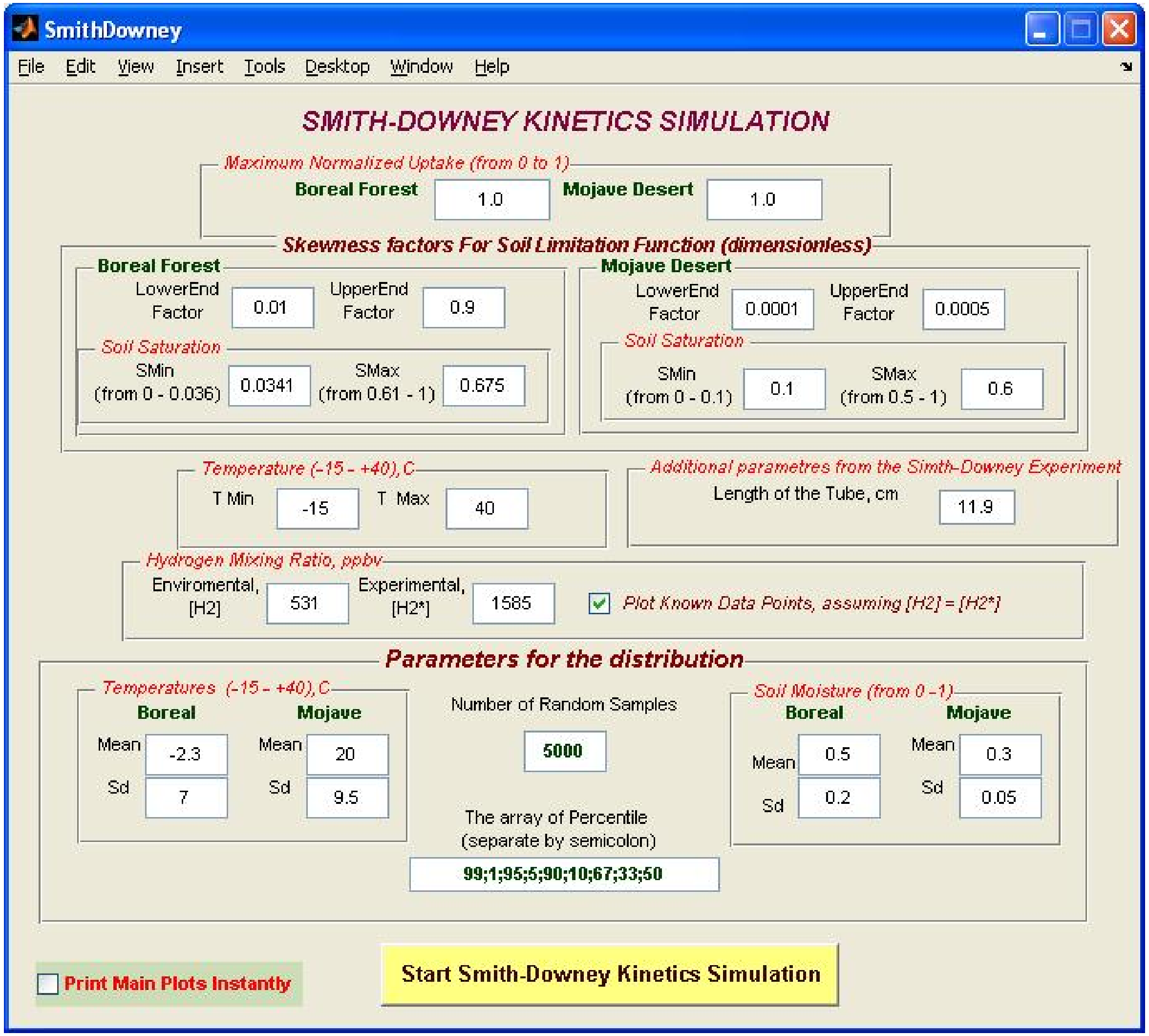
SOIL UPTAKE MODEL DEVELOPMENT

- Soil is the largest sink for hydrogen
- Model prepared by Tetra Tech based on literature review and work done by Smith-Downey (2006)
- Soil uptake approach assumes that diffusion is the primary mechanism for hydrogen to enter soil; first-order depletion of hydrogen over depth
- Uptake rate-limited by temperature, soil moisture, and soil organic carbon content
- Model includes Monte Carlo routine to account for soil temperature and moisture

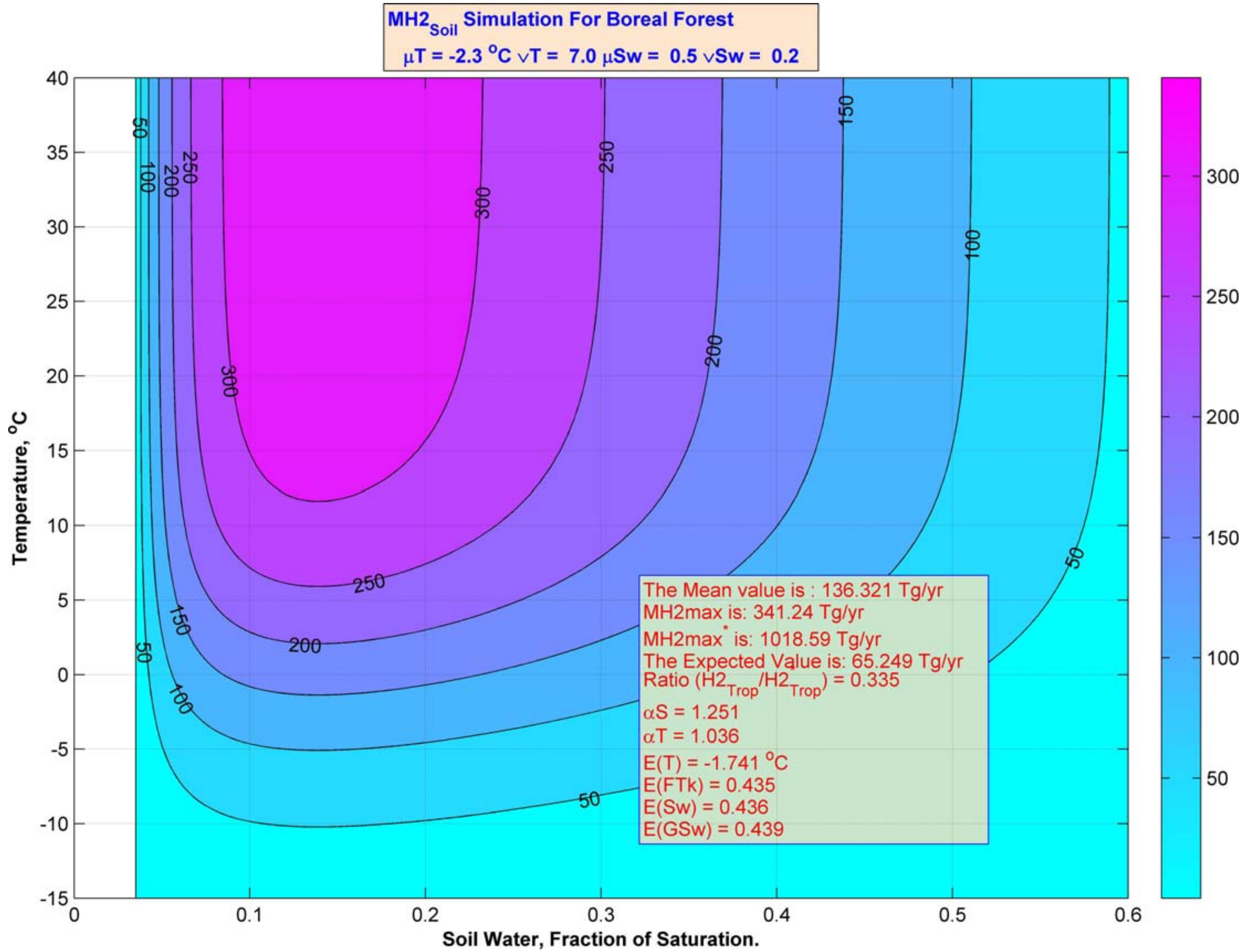
FIELD AND LABORATORY STUDIES OF HYDROGEN UPTAKE



TETRA TECH


SmithDowney
File Edit View Insert Tools Desktop Window Help
SMITH-DOWNEY KINETICS SIMULATION
Maximum Normalized Uptake (from 0 to 1)
Boreal Forest 1.0
Mojave Desert 1.0
Skewness factors For Soil Limitation Function (dimensionless)
Boreal Forest
LowerEnd Factor 0.01
UpperEnd Factor 0.9
Soil Saturation
SMin (from 0 - 0.036) 0.0341
SMax (from 0.61 - 1) 0.675
Mojave Desert
LowerEnd Factor 0.0001
UpperEnd Factor 0.0005
Soil Saturation
SMin (from 0 - 0.1) 0.1
SMax (from 0.5 - 1) 0.6
Temperature (-15 - +40), C
T Min -15
T Max 40
Additional parametres from the Simth-Downey Experiment
Length of the Tube, cm 11.9
Hydrogen Mixing Ratio, ppbv
Enviromental, [H2] 531
Experimental, [H2*] 1585
Plot Known Data Points, assuming [H2] = [H2*]
Parameters for the distribution
Temperatures (-15 - +40), C
Boreal
Mojave
Mean -2.3
Sd 7
Mean 20
Sd 9.5
Number of Random Samples
5000
The array of Percentile (separate by semicolon)
99;1;95;5;90;10;67;33;50
Soil Moisture (from 0 -1)
Boreal
Mojave
Mean 0.5
Sd 0.2
Mean 0.3
Sd 0.05
Print Main Plots Instantly
Start Smith-Downey Kinetics Simulation

EXAMPLE RESULTS: SOIL UPTAKE MODEL



FUTURE WORK

❑ FY08

- Quantify H2 and criteria pollutants released from each technology used to generate hydrogen (fuel cells & electricity) for two market penetration scenarios
- GATOR-GCMOM Model simulations to predict changes in atmospheric concentrations of hydrogen and other constituents
  - Enhancement of soil routines to simulate H_2 uptake & conversion by soils
  - Output on global scale with more detail for the US
  - Output includes: atmospheric concentrations of H_2, GHGs and PM, oxidative capacity of the atmosphere, stability of the ozone layer, and microbial ecosystems involved in hydrogen uptake
- Explore use of simplified model of hydrogen dynamics in the troposphere and stratosphere

FUTURE WORK

- **FY09: Quantify Effects of Implementing Market Penetration**
  - Climate: air temperature, cloud production, ozone levels, photochemical smog
  - Human health: six criteria pollutants, lead, GHG compared to health-effect levels and national ambient air quality standards
  - Ecosystems: use effects levels for criteria pollutants and GHGs to evaluate impacts on aquatic and terrestrial biota
  - Structures: effects of acids, ozone, PM, and GHGs on materials, buildings, structures, historical sites, roadways
  - Other environmental effects: e.g. mining and processing of trace metals used as catalysts or in PV cells

PROJECT SUMMARY

Objective:

- Quantify near and long-term air quality, human health, ecosystem, and structure effects associated with shift to hydrogen-based economy

Approach:

- Develop emission profiles for viable market penetration scenarios
- Simulate changes in hydrogen and other atmospheric gases
- Assess effects using model projections

Technical Accomplishments and Progress:

- Synthesis of emissions associated with broadly accepted market penetration scenarios
- Advancement and testing of soil uptake model
- Exploration of simplified model of hydrogen dynamics in troposphere and stratosphere

Next Steps:

- Initiate model simulations; Publication of results: soil model
- Development of environmental information to support assessment of technology readiness

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