Evaluation of the Potential Environmental Impacts from Large-Scale Use and Production of Hydrogen in Energy and Transportation Applications

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May 19, 2009

AN_13_Olsen

Overview

Timeline

- Start: September 28, 2007
- End: September 27, 2009
- ~70% complete

Barriers

- Barriers addressed
  - Environmental Quality
  - System Analysis / Environmental Analysis

Budget

- Total project funding
  - UIUC - $450K
  - LANL - $150K

	FY07	FY08	FY09
UIUC	0	180K	270K
LANL	0	150K	0

Partners

- UIUC - Project lead
- LANL
- PNNL
- University of Calgary
- Stanford

Project Relevence

The purpose of this project is to systematically identify and examine possible ecological and environmental effects from the production and use of hydrogen from various energy sources based on the DOE hydrogen production strategy and the use of that hydrogen in transportation and power applications.

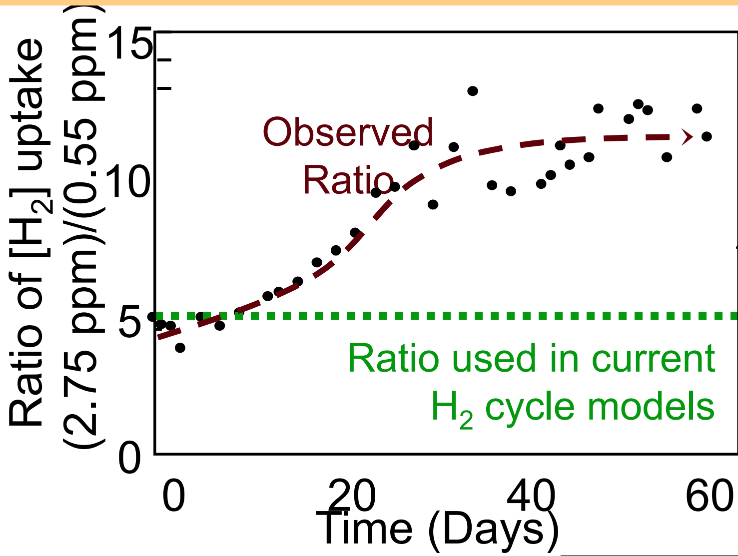
Project Objectives

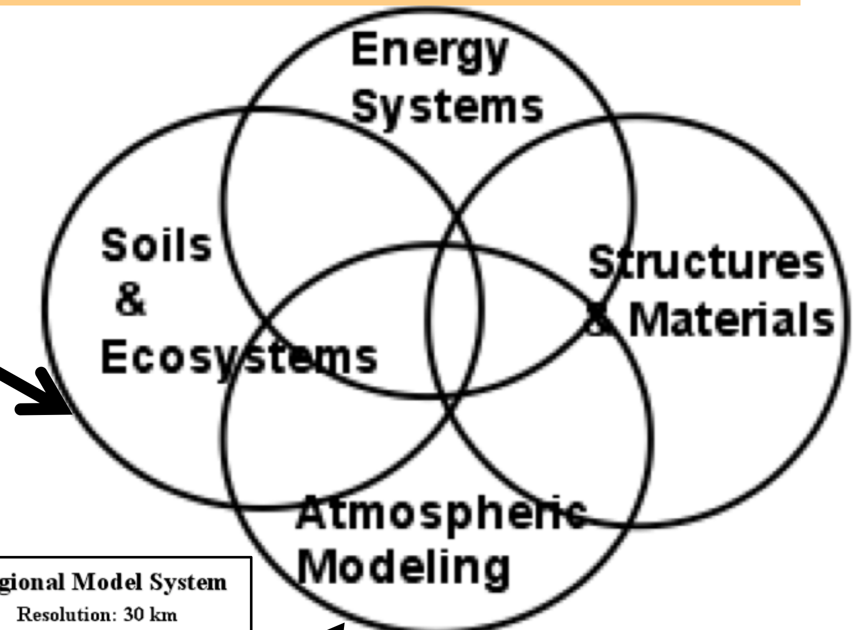
- **This project uses state-of-the-art numerical models of the environment and energy system emissions in combination with relevant new and prior measurements and other analyses to assess the understanding of the potential ecological and environmental impacts from hydrogen market penetration.**
- **In the process, DOE will be provided with a capability for further assessing current understanding and remaining uncertainties for addressing the potential environmental impacts from hydrogen technologies.**

Specific Objectives

- **Evaluate criteria pollutants emitted from distributed and centralized hydrogen production pathways**
- **Evaluate criteria pollutants emitted for different scenarios of vehicle market penetration**
- **Determine impact of hydrogen releases on the oxidative capacity of the atmosphere.**
- **Determine long-term stability of the ozone layer due to changes in hydrogen emissions.**
- **Evaluate impact of hydrogen emissions and resulting concentrations on climate.**
- **Evaluate impact on microbial ecosystems involved in hydrogen uptake.**
- **Evaluate role of biological impacts in causing indirect effects on the atmosphere and climate**
- **Evaluate impact of criteria pollutants on human health, air quality, ecosystems and structures under different penetration scenarios**

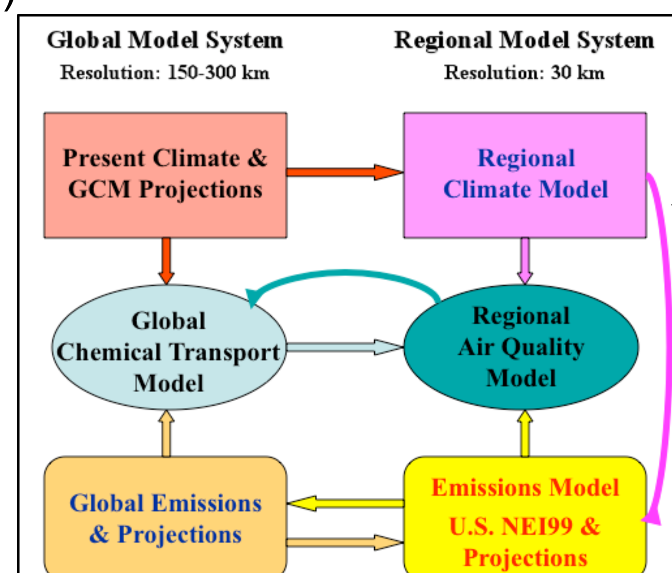
Technical Approach
Combine measurements, modeling, and analysis into a comprehensive picture





Energy System Projections and Analysis

Global and Regional Modeling of Air Quality, Ozone Layer, and Climate Effects



H_2 Leak Assessment, Sensitivity studies, Analyses of Structures and Materials; Embrittlement

Project Milestones – FY2009

- Extend laboratory H_2 soil sink studies.
- Commence field studies of industrial H_2 emissions.
- Continue field studies of ecosystem H_2 uptake .
- Complete environmental modeling studies.
  1. Tropospheric simulations complete.
  2. Regional air quality simulations under way (50%).
  3. Stratospheric simulations well underway (60%).
  4. H_2 feedback adaptive soil sink simulations analysis underway.
  5. Interactive CH_4 source simulations underway.
- Complete reports on environmental impacts.
- Finish development and testing of H_2 Integrated Assessment Model.

Accomplishments/Progress/Results

This presentation describes some of the project accomplishments

- Evaluation of H_2 embrittlement risk.
- Evaluation of oxygen plume risk.
- Laboratory and field studies of soil H_2 uptake.
- Likely future changes in soil H_2 uptake.
- Global tropospheric composition model simulations for high emission scenario.
- Continental US regional air quality modeling studies.
- Development and preliminary studies with H_2 integrated assessment model

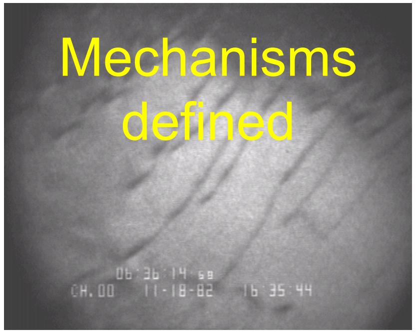
Atmospheric H_2 Not a Threat to Structures

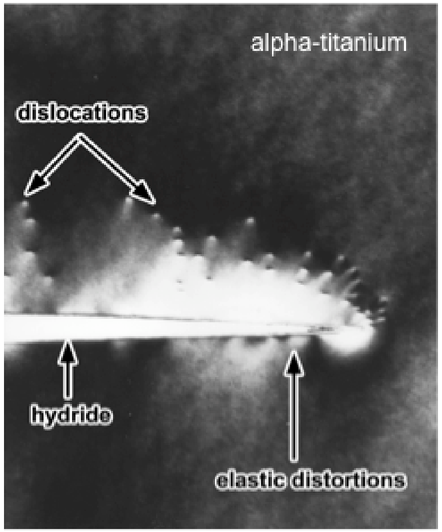
UIUC Materials Science and Engineering, A Rockett, I Robertson, P Sofronis

Hydrogen embrittlement studied in a variety of metals under a variety of conditions

Embrittlement can be a concern.

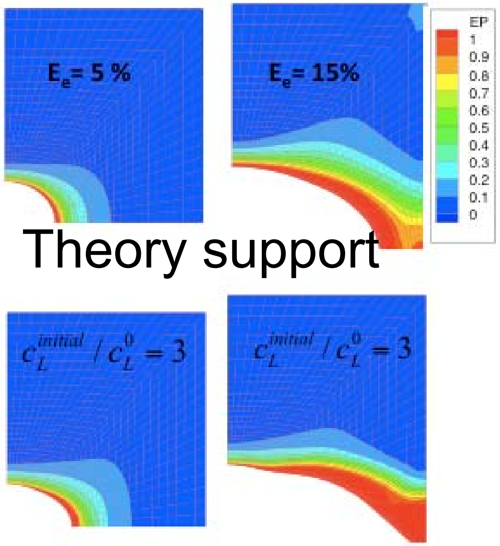
Experimental analysis





Findings:

- **At projected atmospheric H_2 concentrations embrittlement of structural metal alloys will not be an issue.**
- Native oxides provide sufficient protection.
- Decomposition of H_2 is slow enough to reduce ingress of hydrogen.



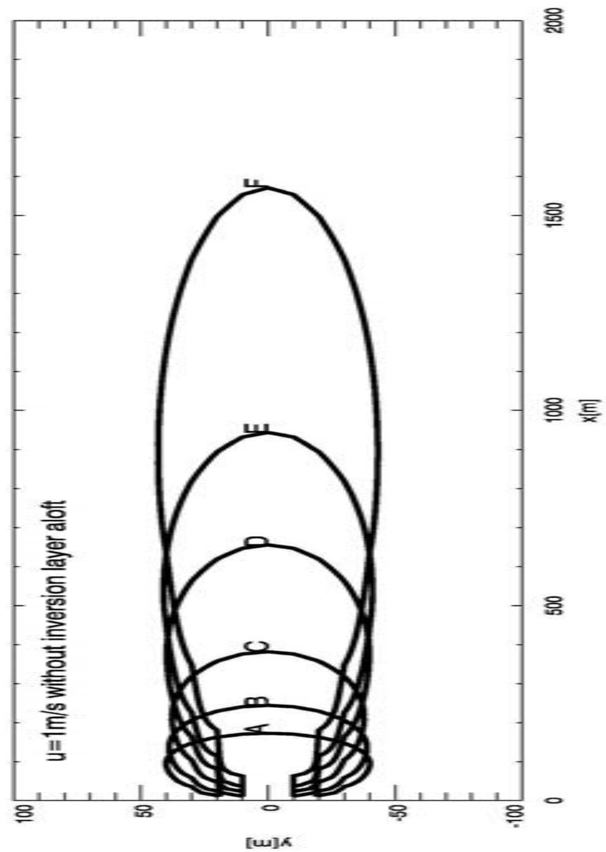
Oxygen Discharge from H_2 Production

UIUC Atmospheric Science & Material Science and Engineering

Large scale production of H_2 through electrolysis would produce large amounts of O_2 presenting a potential fire hazard.

Findings:

- **Probably Not a problem**
- 2 GW stored energy releases about 83 kg of O_2 per second.
- Except in almost completely stagnant conditions the concentration would not accelerate fires beyond 1 km from the discharge point.
- Plant siting/operation considerations may be required in case of very stagnant air over the discharge source.



Gaussian Plume Model

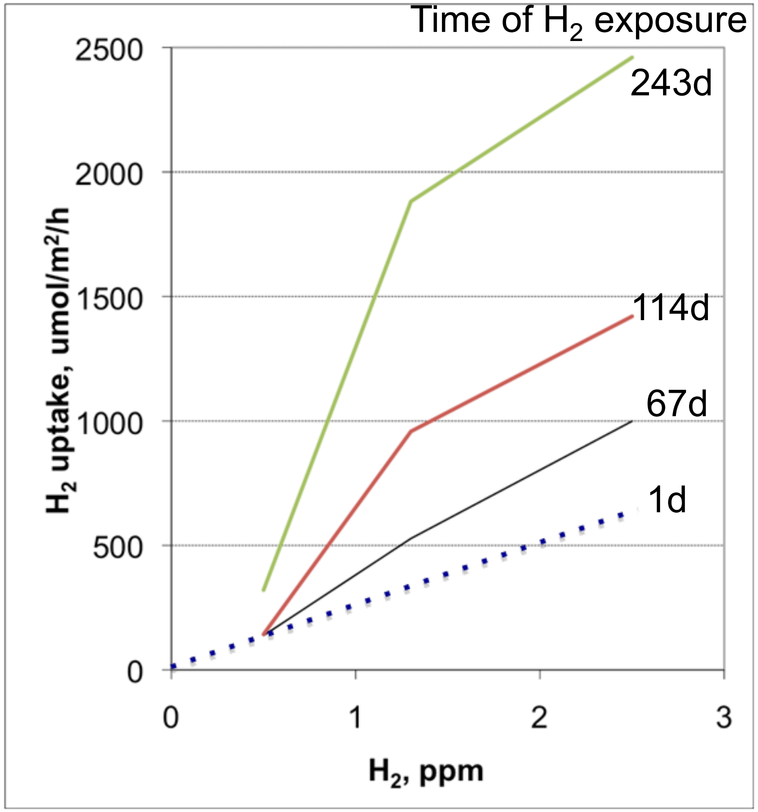
Adaptive Soil H_2 Uptake

University of Calgary, (D. Layzell) & Queen's University (Y. Cen & N. Scott)

H_2 uptake rate…

- Is linear with ambient H_2 concentration when first exposed to elevated H_2;
- Continues to rise with time of exposure to elevated H_2;
- Becomes non-linearly with H_2 concentration after months of exposure

Long term exposure to elevated H_2 stimulates the growth and H_2 uptake activity of microbial populations, especially in the first few cm. of soil (i.e. closest to the H_2 source in air).



Laboratory studies of the effect of long term H_2 exposure on H_2 uptake by soil.

Adaptive Soil H_2 Uptake

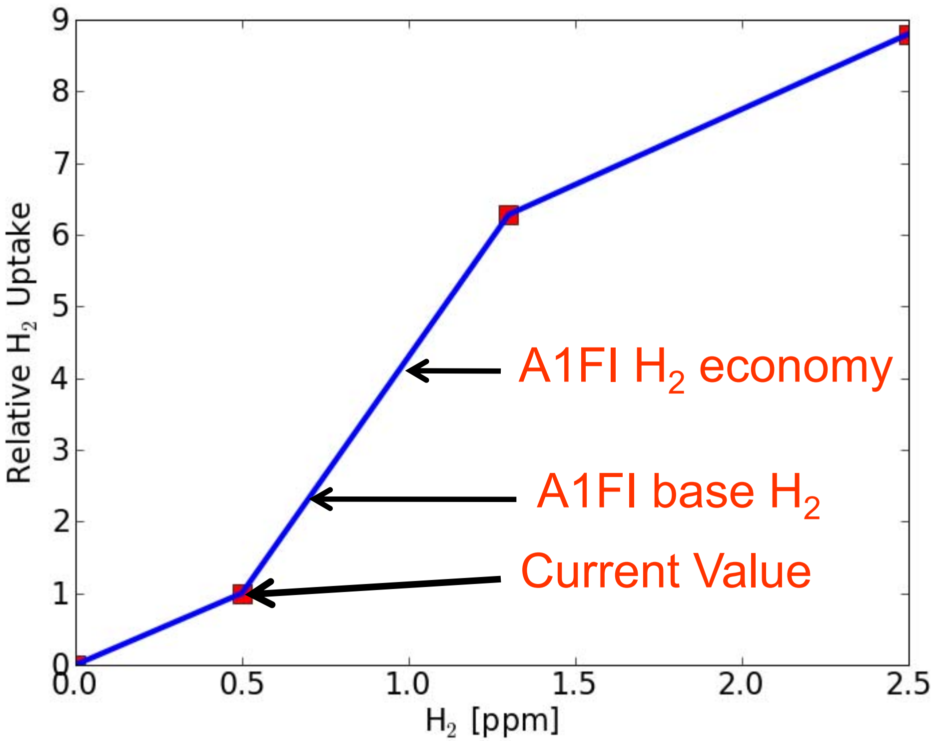
University of Calgary, (D. Layzell) & Queen's University (Y. Cen & N. Scott)

H_2 uptake would be nearly

- 2.5 X greater than present in A1FI base
- 4.0 X greater than present in A1FI H2

Must be included for accurate simulations of future H_2 concentrations

Has been included in our newest atmospheric impact studies



Soil H_2/CO Deposition Velocity

LANL, T. Rahn

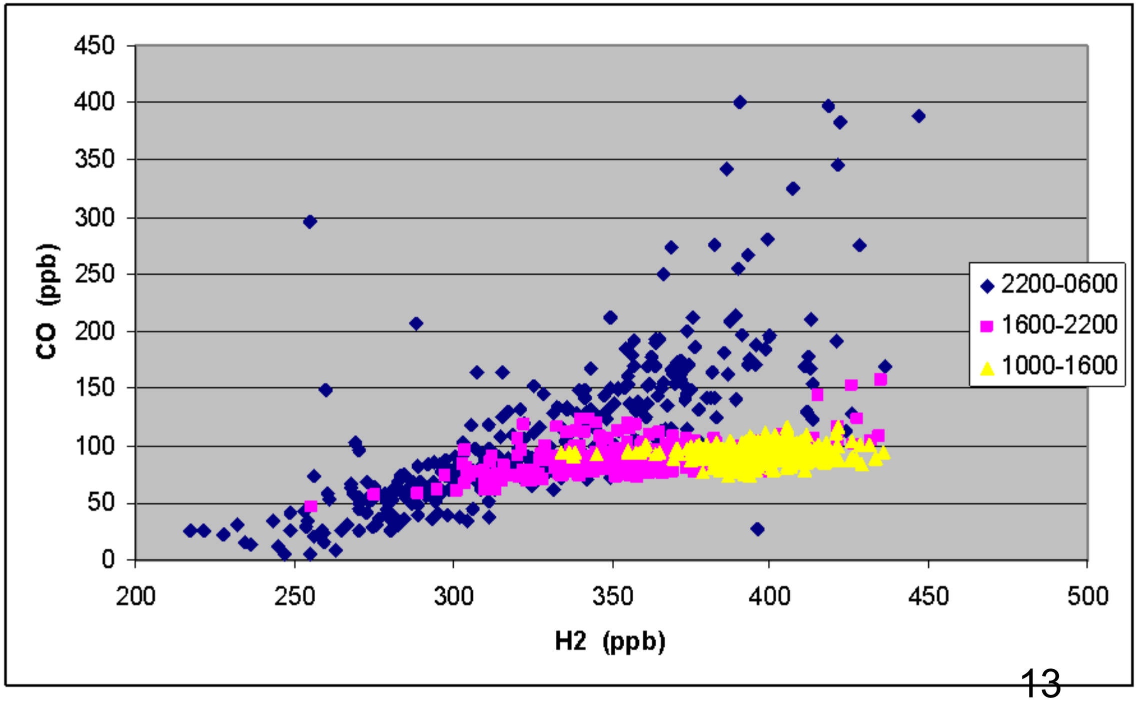
Preliminary Data:

CO/H_2 Slope depends on time of day

1) Near 0 in daytime (yellow symbols)
2) Almost 1.3 during nighttime (blue symbols)

Preliminary findings:

Constant deposition velocity of H_2 relative to CO may not be correct



Work In Progress:
Instrument site with met tower to study fetch, temperature and moisture effects

Realistic H_2 Leak Quantification

LANL, M. Dubey

- Used H_2/CO observations to quantify leaks from refineries (Tula, Mexico City, Last period).
- Planned studies at commercial US refinery put on hold due to legal objections, pursuing plans with alternative refineries.
- LANL-MOU with NRC Institute for Fuel Cell Innovation, Vancouver being leveraged to do system level leak measurements on fuel cell vehicles in the sole N. American Hydrogen Environment Chamber facility.
- To complete project additional resources may be necessary.

Emissions Scenarios

UIUC Dept. of Atmospheric Science

- **Assume all road transportation switch to H_2 economy in future**
  - IPCC SRES A1FI scenarios (fossil fuel intensive with higher emissions)
  - IPCC SRES B1 scenarios (technology/environment intensive with lower emissions)
- **Assume 2% leakage of H_2 to the atmosphere**
- **Other emissions (e.g. NOx, CO, NMVOCs, SO_2, Soot) related to land transportation will decrease**

	Total emissions change (%)	
	A1FI H_2	B1 H_2
H_2	+88	+74
NOx	-29	-24
CO	-25	-10
NMVOCs	-14	-8
SO_2	-4	-3
Soot	-17	-8

Emissions Scenarios

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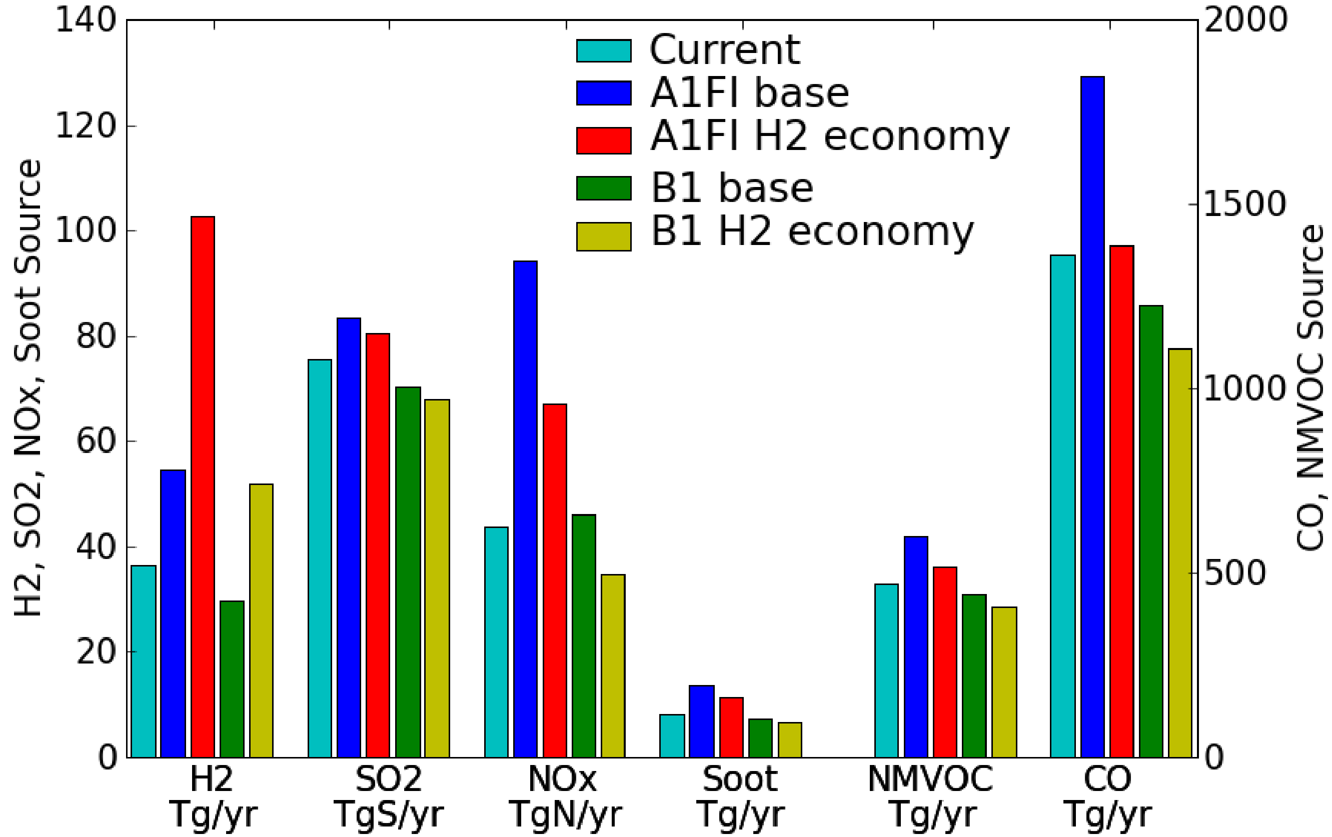
Large increase in H_2 emissions, Large decreases in NO_x, CO upon conversion to H_2 economy

2050 emissions for A1FI and B1 baseline and H_2 scenarios



Atmospheric Impacts Analysis

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We use state-of-the-art, well documented and published models of the physics and chemistry of the atmosphere.

Global Models

- Community Atmosphere Climate Model with Chemistry (CAMChem)
  Tropospheric studies
- Extended CAMChem
  Tropospheric and stratospheric studies

Regional Air Quality Model

- EPA Community Multiscale Air Quality Model (CMAQ)

Model simulated 2050 global mean tropospheric concentrations of various gases

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Scenario	H_2 [ppb]	O_3 [ppb]	CO [ppb]	NOx [ppt]	SO_2 [ppt]	OH ($1e5/cm^3$)	ISOPRENE (ppt)
A1FI-B	830	44	132	99	44	9	41
A1FI-HS	**+39%**	**-7%**	**-14%**	**-16%**	-0.5%	**-4%**	+24%
B1-B	577	38	90	60	39	10	48
B1-HS	**+25%**	**-5%**	**-4%**	**-11%**	-0.3%	**-4%**	+19%

A1FI 2050 annual mean surface H_2

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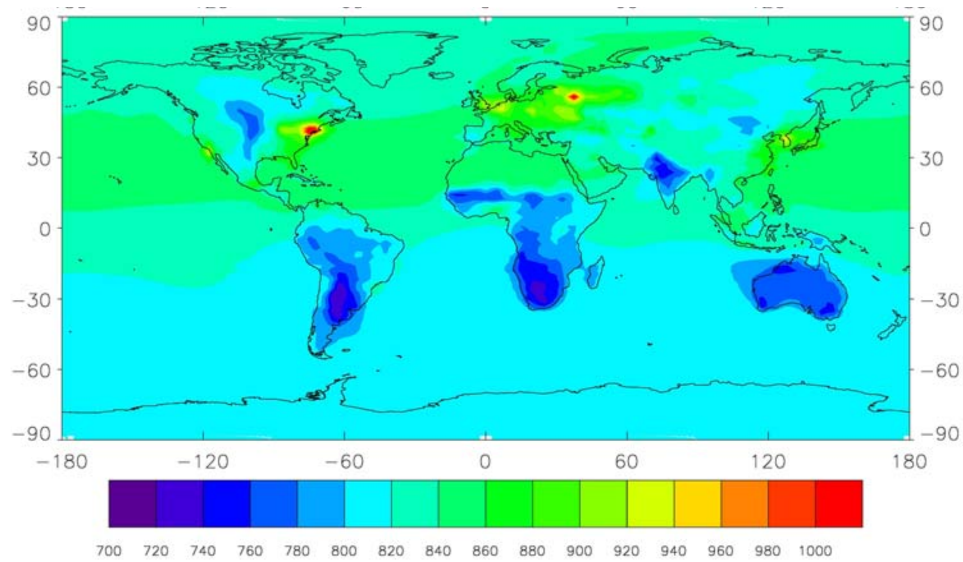
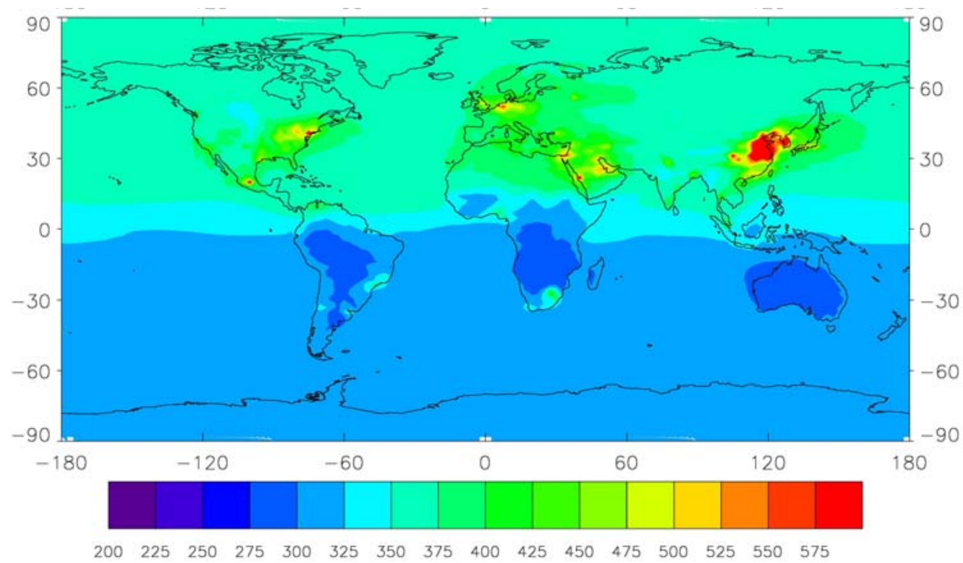
A1FI base

- **Range ~0.75 to 1 ppm**
- NH concentrations > SH
- Present H_2 = 0.5 ppm



A1FI H_2 economy

- **Increase by 0.3 - 0.6 ppm**
- NH increase > SH



A1FI 2050 HS annual mean O_3 change at surface

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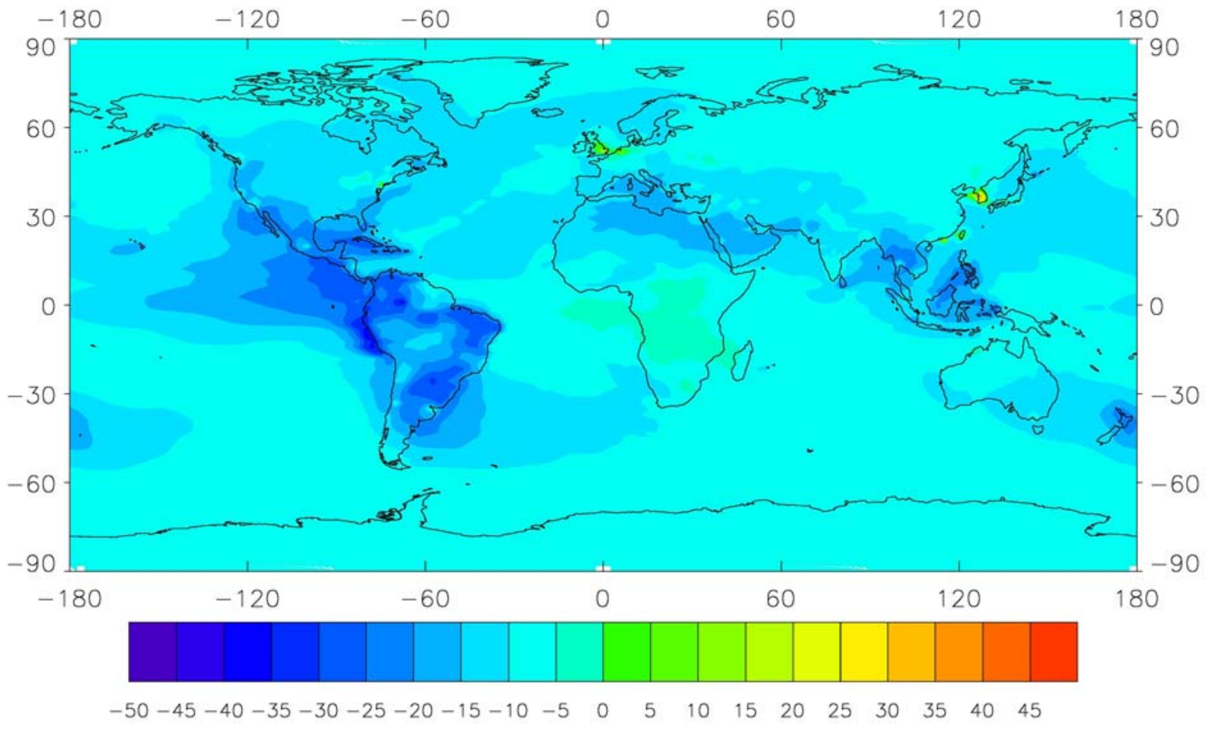

Nearly uniform 10% reduction in ozone with Decreases of as much as 50% over some regions

A1FI 2050 HS annual mean Soot change at surface

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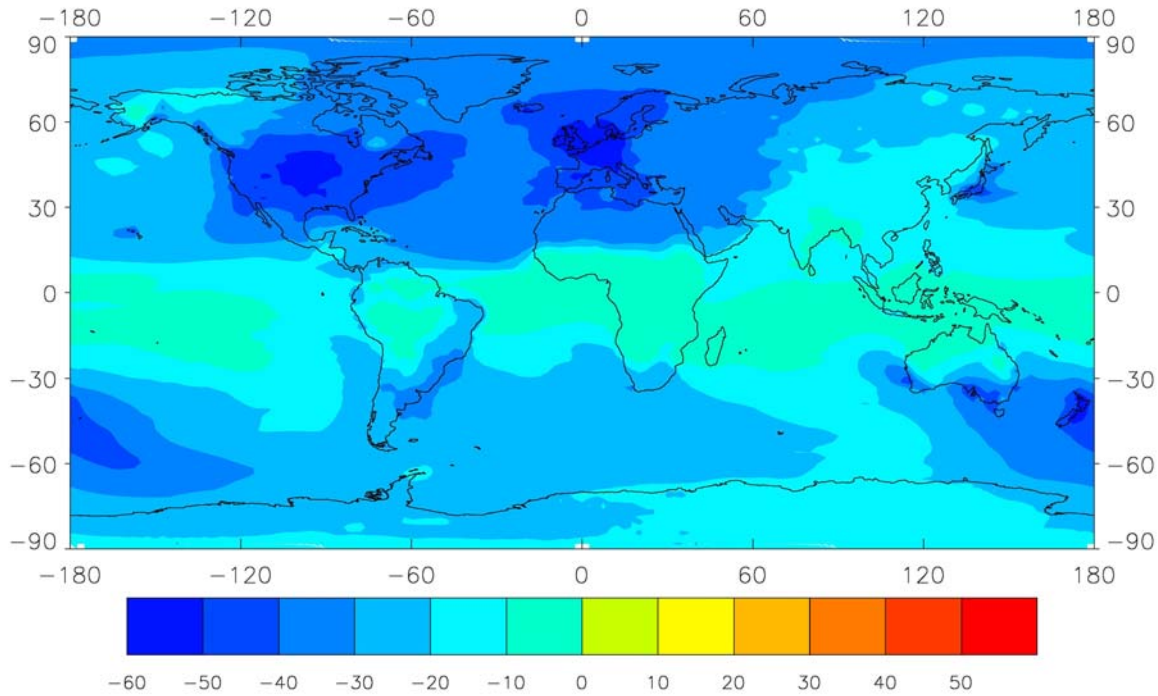

~40% Soot decrease over US, Europe
~20% Soot reduction over the rest of NH

Regional O_3 Impact of 2050 H_2 Economy

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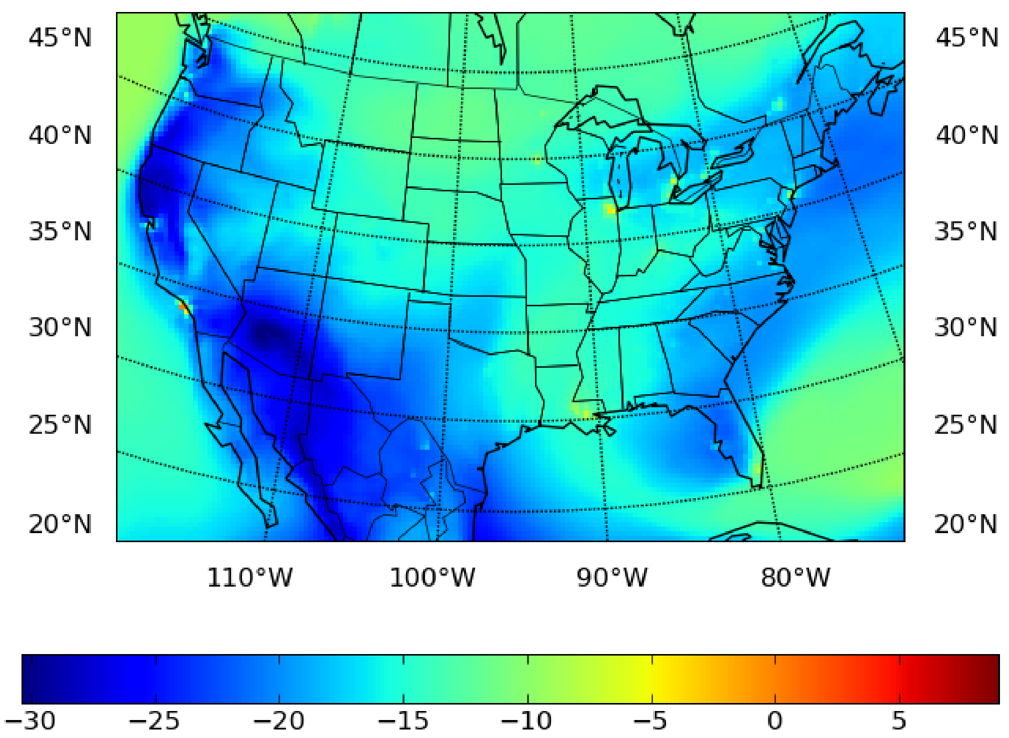
O_3 decrease over entire US with large decreases on the coasts

~ 25% decrease along West coast

~ 20% decrease along East coast

Average July O_3 change [%]



Regional PM 2.5 Impact of 2050 H_2 Economy

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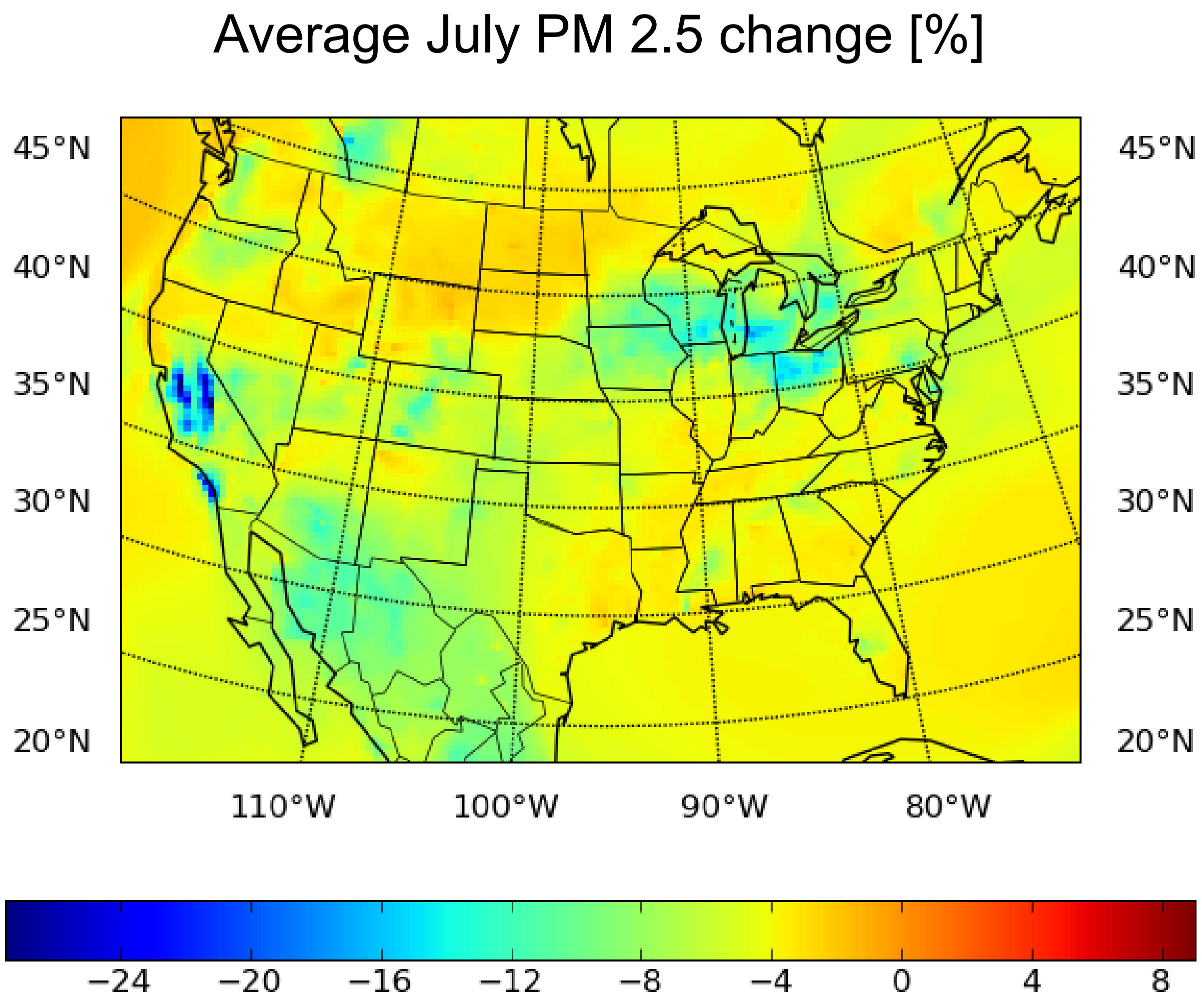
Uniform (4%) decrease in PM 2.5 across US with larger (20%) local reductions in California and Midwest



Regional CO Impact of 2050 H_2 Economy

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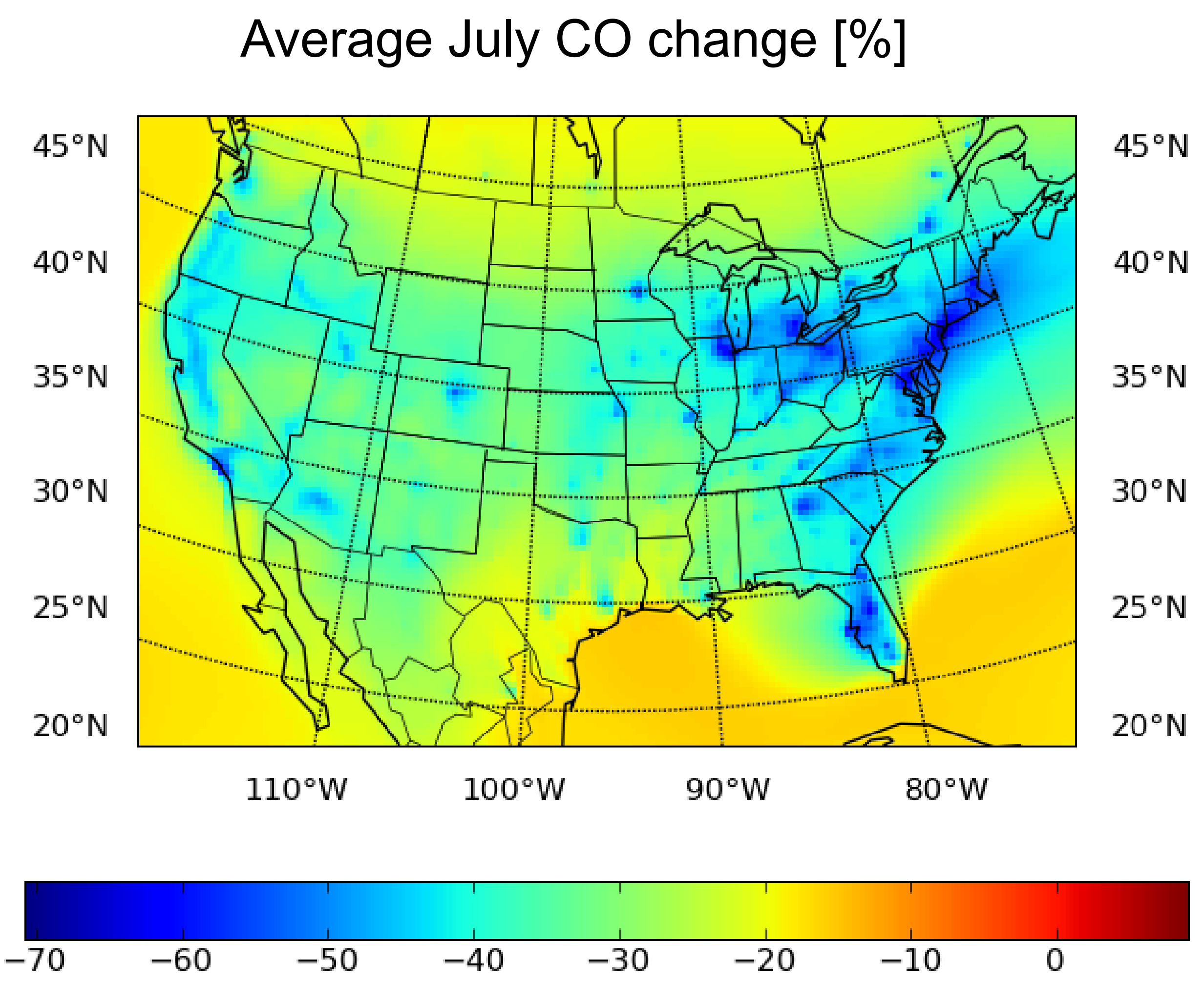
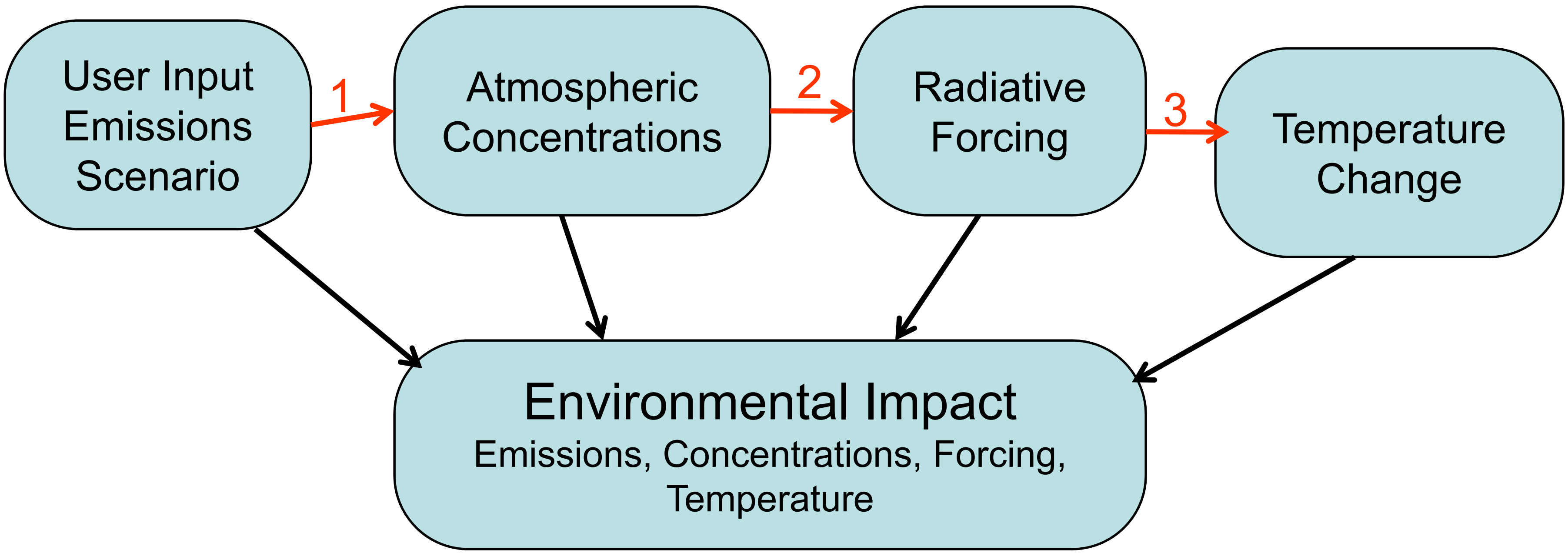
CO decreases across US with largest decreases along the East coast

CO decreases ~65% in NYC area



Integrated Assessment Model



Boxes = Data Products

1) Emissions, H_2, CO, VOC, NO_x
2) Atmospheric Concentrations
3) Radiative Forcing (RF)
4) Temperature Change

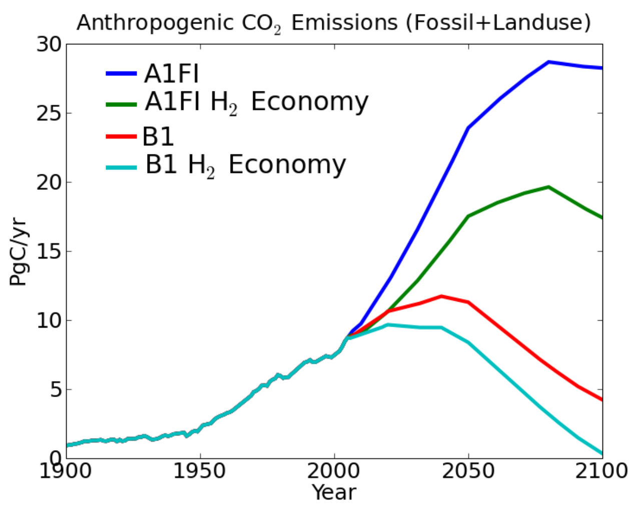
Arrows = Computational Modules

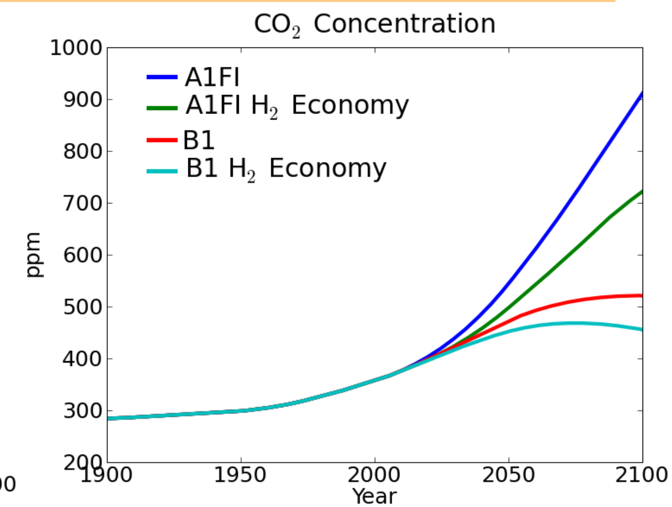
1) Emissions => Concentrations
2) Concentrations => RF
3) RF => Temperature Change

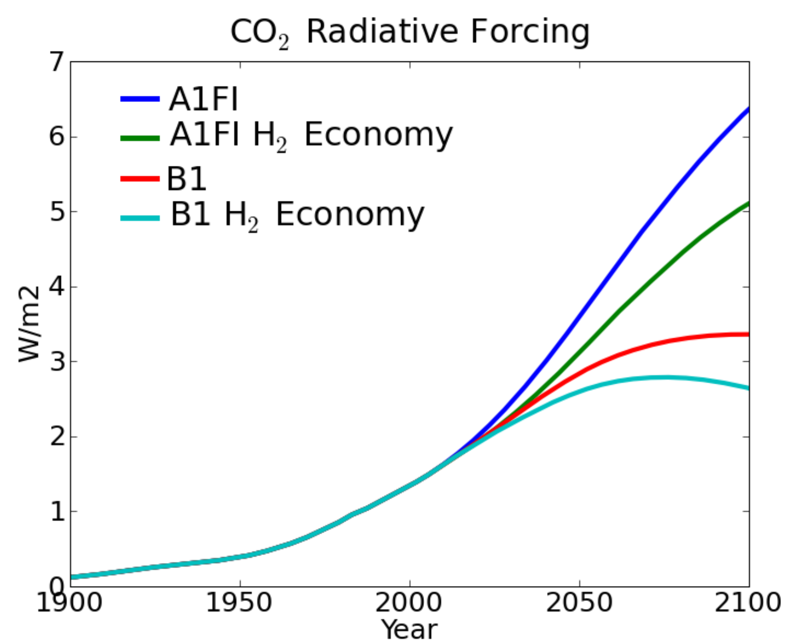
Radiative Forcing of H_2-Displaced CO_2

Radiative Forcing due to displaced transportation CO_2 emissions.

Assumes full conversion to non-carbon emitting H_2 production.







2100 H_2 Economy CO_2 RF change:

-1.3 W/m^2 (A1FI)
-0.8 W/m^2 (B1)

2005 CO_2 RF ~ 1.7 W/m^2

Collaborators

- University of Illinois at Urbana Champaign
  - Department of Atmospheric Science, Project Lead

    Management, emissions scenarios and modeling
  - Department of Materials Science and Engineering

    Impact of H_2, O_2 on structures
- University of Calgary

  Institute for Sustainable Energy, Environment and Economy

  Laboratory studies of microbial H_2 uptake dependence on ambient H_2
- Queen’s University

  Laboratory studies of microbial H_2 uptake dependence on ambient H_2
- Los Alamos National Laboratory

  Earth and Environmental Science Division

  Lab and field studies of H_2 uptake and H_2 urban and industrial emissions

Future Work

FY09

- Incorporate new soil uptake parameterization into models
- Complete analysis of tropospheric impacts
- Refine regional modeling studies and analysis
- Complete stratospheric modeling studies and analysis
- Fully implement, test, and evaluate H_2 integrated assessment model

Future

- Continue soil H_2 sink adaptation studies
  - Different soils types and environmental conditions
- More detailed model studies with adaptive soil H_2 sink
  - Impact on tropospheric and stratospheric ozone chemistry
- Top down atmospheric model constraints on H_2 soil sink
  - Constrain current sink with atmospheric models and measurements
  - Explore use of HD isotope source/sink/chemistry as additional constraint
- Interactive climate and chemistry analysis
- Incorporate H_2 soil sink into microbial ecosystem model

Summary

Determining the KEY environmental quality impacts of a future H_2–based transportation sector

- Laboratory studies determined H_2 uptake dependence on ambient atmospheric H_2 concentrations
- Field studies of ecosystem H_2 uptake are continuing
- Emissions scenarios completed
- Resulting global and regional environmental impact analysis
  - Air quality issues (ozone, CO, PM) decrease dramatically
  - Decrease in oxidizing capacity of the troposphere (OH)
  - Decreases in tropospheric and stratospheric ozone
- Atmospheric H_2 effects on structures and embrittlement not likely to be important
- Oxygen plumes from H_2 production not likely to be important

Additional Slides

A1FI 2050 HS annual mean PM2.5 change at surface

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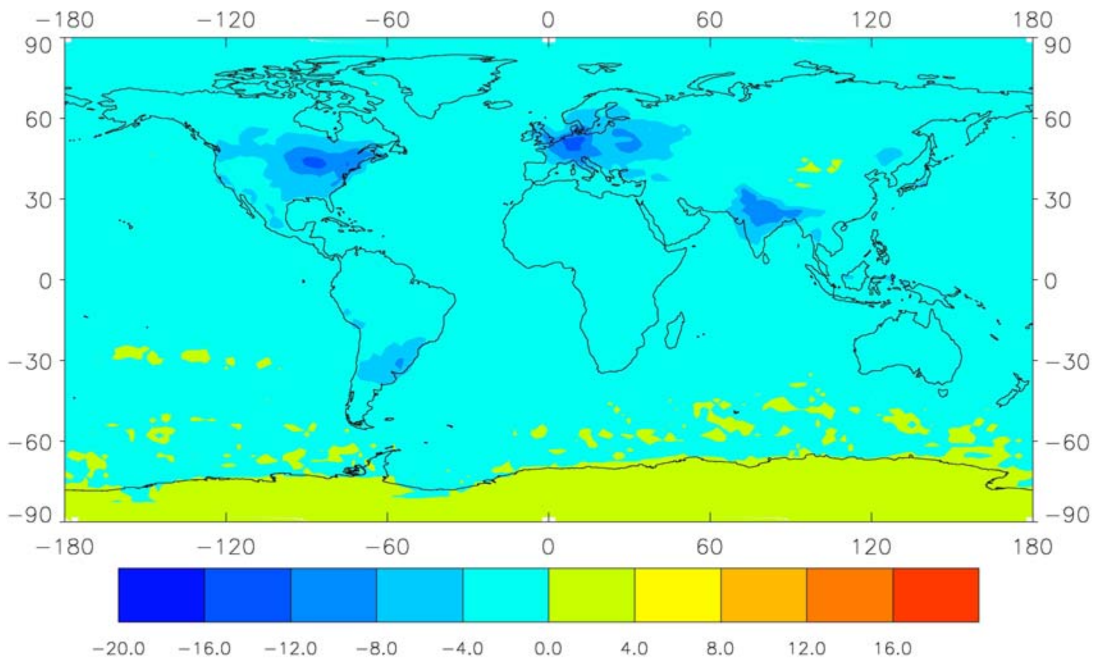

Significant (15%) regional PM2.5 decreases over Northeast and Midwest US, Europe, India