CCSP Product 2.1A: An Application of Integrated Assessment Modeling

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Integrated Assessment Modeling
Integrated Assessment: A Comprehensive Paradigm

**Atmosphere – Ocean System**
- Atmospheric Chemistry
- Climate
- Oceans, Carbon Cycle, Sea Level, Temperature

**Human Systems**
- Energy System
- Agriculture, Livestock, Forestry
- Other Human Systems
- Anthropogenic Coastal Zone

**Ecosystems**
- Terrestrial Carbon Cycle
- Unmanaged Ecosystems & Animals
- Managed Ecosystems
- Hydrology

Links may be formal or informal depending on the application.

IA models are comprehensive.

IA models are used to inform climate decision-making.

IA models have their roots in energy-economic modeling.
Integrated Assessment Modeling: IA Research and IA Models at JGCRI

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**MiniCAM Energy/Economic**

- SGM Energy/Economic

**MAGICC/Scengen**

- AGLU

- EPIC

- BIOME3
Schematic of MiniCAM

Energy Supply
- Primary Production
  - Coal
  - Oil
  - Gas
  - Biomass
  - Nuclear
- Secondary Fuels
  - Solids
  - Liquids
  - Gases
  - Electricity
  - Hydrogen

Energy Demand
- Total Energy Demand
  - (Economic activity, population, efficiency, prices)
- Demand for specific forms
  - (Service preferences, prices)

Energy Prices

Ag Land-Use
- Land Prices
  - (food & fiber demands) & Biomass Price
- Land-Use & Production
  - Crops
  - Animals
  - Biomass
  - Wood

GHG Emissions
- Carbon
- Dioxide
- Sulfur
- Dioxide
- Methane
- Nitrous Oxide
- Others...

The final equilibrium is based on equating supplies and demands.

Climate and carbon cycle inform the paths/approaches to stabilization.
The CCSP Scenarios
The CCSP Strategic Plan called for 21 synthesis and assessment products

Goal 1: Extend knowledge of the Earth’s past and present climate and environment, including its natural variability, and improve understanding of the causes of observed changes

Goal 2: Improve understanding of the forces bringing about changes in the Earth’s climate and related systems

Goal 3: Reduce uncertainty in projections of how the Earth’s climate and environmental systems may change in the future

Goal 4: Understand the sensitivity and adaptability of different natural and managed systems to climate and associated global changes

Product 2.1: Updating scenarios of greenhouse gas emissions and concentrations, in collaboration with the CCTP. Review of integrated scenario development and application.
Study Design

- Three modeling teams
  - MIT (IGSM) – Henry Jacoby, John Reilly
  - PNNL (MiniCAM) – Jae Edmonds, Hugh Pitcher
  - EPRI (MERGE) – Rich Richels
  - Coordinator – Leon Clarke

- From each team:
  - One reference scenario
  - Four stabilization scenarios

- Explore the emissions, energy, and economic implications of stabilization
Study Design

- Stabilize greenhouse gases, not just CO₂
  - Stabilize total radiative forcing from CO₂, N₂O, CH₄, HFCs, PFCs, and SF₆
  - Other radiatively-important substances (e.g., aerosols) not included
- Long-term (many century) stabilization; study period through 2100.
- Four stabilization scenarios roughly consistent with 450 ppmv through 750 ppmv CO₂, along with one reference scenario.

<table>
<thead>
<tr>
<th>Level</th>
<th>Total Radiative Forcing from GHGs (Wm⁻²)</th>
<th>Approximate Contribution to Radiative Forcing from non-CO₂ GHGs (Wm⁻²)</th>
<th>Approximate Contribution to Radiative Forcing from CO₂ (Wm⁻²)</th>
<th>Corresponding CO₂ Concentration (ppmv)</th>
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<tbody>
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<td>2.6</td>
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<td>Level 2</td>
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<td>3.7</td>
<td>550</td>
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<td>Level 3</td>
<td>5.8</td>
<td>1.3</td>
<td>4.5</td>
<td>650</td>
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<tr>
<td>Level 4</td>
<td>6.7</td>
<td>1.4</td>
<td>5.3</td>
<td>750</td>
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<td>Year 1998</td>
<td>2.1</td>
<td>0.65</td>
<td>1.46</td>
<td>365</td>
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</table>
CCSP Product 2.1A stopped at radiative forcing

Figure 4: Carbon Emissions Pathways for Three Alternative Climate Sensitivity Values

Uncertainty in climate sensitivity has important ramifications for carbon emission pathways to stabilization.

Study Design

- All modeling groups assume existing climate programs (Kyoto, U.S. intensity target) but then assume perfect where, when, and what flexibility going forward.

- Assumptions (e.g., population, economic growth, technological change) developed individually by the modeling groups.

- No likelihoods assigned to any scenarios or parameters.
  - Teams directed to develop assumptions they consider “plausible” and “meaningful”.
  - These are not the only sets of assumptions that these three modeling teams could have developed.
THIS IS NOT A COST-BENEFIT ANALYSIS
The Reference Scenarios
**Primary energy** grows to between three and four times today’s levels by the end of the century.

- All models envision penetration of fossil alternatives for conventional oil
- Substantial growth in sources that don’t emit carbon
- But fossil fuels remain the dominant energy source.
Continually increasing CO$_2$ emissions over the coming century with important transitions in emitting countries.
Radiative forcing trajectories are not consistent with stabilization at any of the four levels considered in the exercise.

- CO₂ takes on an increasingly large share of radiative forcing in all three scenarios.
- Contributions of non-CO₂ GHGs vary among the models.
Stabilization Scenarios
Fossil and Other Industrial Emissions ultimately decline toward the rate at which emissions are balanced by removal processes.

Stabilization at 450 ppmv is fundamentally different than stabilization at 550 ppmv and above.

Emissions pathways are not identical across models.
CO$_2$ emissions mitigation during 2005 to 2050 is just the start

The time scale of emissions mitigation is a century or more.

Energy technology will be needed to help control emissions in the NEAR-, MID-, and Long-term to address climate change.

CO₂ emissions pathways vary across models

Differing contributions from non-CO₂ greenhouse gases
CO$_2$ emissions pathways vary across models

Relationship between cumulative emissions and concentrations
NET TERRESTRIAL EMISSIONS
OCEAN UPTAKE
Stabilization requires substantial changes in the energy system.

The models present very different approaches to this evolution.

All of the scenarios maintain a heterogeneous energy mix.
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PRIMARY ENERGY (Level 2, 550 ppmv)

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The Challenge of Scale—near term

CO₂ Storage—550 ppm Stabilization Case

In the long-term the challenge grows

CO₂ Storage Rate Level 2 (~550 ppm)

Carbon Prices rise until stabilization is reached.

Expectations about the future (e.g., technology) influence carbon prices today.

THESE SCENARIOS ASSUME PERFECT WHERE, WHEN, AND WHAT FLEXIBILITY.

NOTE: All carbon prices are in $/tonne C – Prices in $/tonne CO₂ would be 3/11 as large.
The Effects on GDP have similar characteristics to the carbon price. Economic impacts would be higher without perfect where and when flexibility.
Variation in Economic Implications

1. Required Emissions Reductions

<table>
<thead>
<tr>
<th>Level</th>
<th>IGSM</th>
<th>MERGE</th>
<th>MiniCAM</th>
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<tr>
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<td>520</td>
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</tr>
<tr>
<td>Level 1</td>
<td>1172</td>
<td>899</td>
<td>934</td>
</tr>
</tbody>
</table>

2. Assumptions about future technology
Sources of Differences in Emissions Mitigation

- Reference case emissions
- Carbon cycle
- Non-CO$_2$ GHG’s
The Role of Post-2050 Technology

While the technology stories for the three modeling teams are similar through 2050, they are different in the far future.
All of the models have ample opportunities for decarbonizing electricity.

The ability to switch to low- or zero-carbon fuels in end use sectors plays an important role in cost differences.
End