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INTEGRATED MODELING OF METHANE SOURCE, SINKS, AND EMISSIONS CONTROL COSTS

Final Report

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The overall objective of this three-year collaborative project between the University of Illinois at Urbana-Champaign (UIUC) and Battelle Pacific Northwest National Laboratory (PNNL) was to develop a framework which would incorporate computationally efficient representations of the latest knowledge concerning science, scenarios, and technical change, to allow for the effective and efficient analysis of possible future strategies to control methane. As part of this research project, we developed a model that takes into account more explicit treatment of the mechanisms controlling each important methane regional source and sink to study non-linear effects involved in methane chemistry in the atmosphere. On the policy front, we developed the relationship between economics and climatic impacts of methane emission reductions. On the application front, we applied the newly developed advanced methane modeling capabilities to study the effects of a wide range of possible scenarios of future methane emissions on climate and to examine the costs associated with achieving specific greenhouse gas reduction targets for a range of emission pathways. In the following, the significant findings from the DOE supported study are outlined.

1. Estimation of Emissions and Cost Curves for the Methane Sources

The global climate change group at PNNL has been actively developing its ability to model future methane emissions and methane control options. As part of this project, the emissions modules for both the SGM and the MiniCAM have been revised in order to improve the quality of the drivers and to reflect the latest baseline information received from the Methane Branch at EPA. In addition, the ability of the SGM to implement control options for methane has been improved. Two systems have been implemented. The first uses carbon tax levels to determine a percent control level for each of the major sources of methane, allowing the emissions levels to be adjusted in accordance with carbon equivalent tax levels. This system is fully implemented, and will be used to develop new marginal abatement cost curves for all regions in the SGM in

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support of the work being done in preparation for COP 6. The second version incorporates the cost estimates for methane control into the production and investment decisions made in the SGM, thus allowing for cost related feedbacks that cannot be reflected using the first system. This latter system is still under development and will be initially implemented only for the United States.

Moreover, the MiniCAM model has been substantially revised and improved over the last three years in three primary areas: the agriculture land use sub-model, the emissions and control options for non-CO₂ gases, and the structure of the energy supply system. For agriculture, we have developed and integrated a new model into the MiniCAM structure. This model incorporates a declining marginal productivity of land as land under management is expanded, new estimates of the carbon content of land under various forms of management, and a restatement of the demand for food in terms of calories, allowing us to much more readily improve the demand functions. The empirical values of important parameters in the new version are still being refined, but we already see the basis for substantially revised estimates of land use and carbon emissions from land use changes. This will allow us to improve estimates of the agricultural contribution to methane emissions and to more accurately reflect the implications of biomass options in a carbon management regime.

2. The Multi-Box Chemistry Model

One of the main components of this proposal was the development and implementation of a multi-box chemistry transport model for the calculation of future atmospheric methane concentrations and other atmospheric constituents. As part of this project, we developed atmospheric multi-box chemistry model for our Integrated Science Assessment Model (ISAM) framework. Our multi-box model contains 30 boxes, each defining distinct regions of the atmosphere in terms of chemistry and background concentrations. The computational foundation for this multi-box model is the 0D UIUC chemistry box model, which is essentially a pared-down version of the UIUC 2D-chemistry transport model. The model includes important atmospheric constituents NO_x, HO_x, ClO_x, BrO_x, CH₄, CO, along with CFCs, HCFCs, HFCs and others. The box model is initialized with observed background conditions (in terms of species concentrations) for each of the regions, in order to accurately calculate atmospheric chemical reactions in each region that depend on background concentrations of other species. Surface emissions are released into the appropriate boundary-layer box, namely urban, continental or marine, in each latitude band. Advective & diffusive transport between these regions in the zonal, meridional and vertical directions were parameterized based on observations of non-reactive tracer species and model results from the 3D CTM. In contrast to previous box-modeling approaches, we implement the resolution of different environments; i.e. urban, continental, and marine, within the lower atmosphere in order to improve the accuracy of background-dependent

chemistry in those regions. We tested our box model performance using the observational data and model results from the NCAR's 3-D Chemical Transport Model and found that model estimated results are compared well observation data and as well as model detailed model results. Currently we writing a journal article describing the model's framework, including initial testing of the model relative to the historical and current atmosphere, and initial applications of the model, for comparison with published climate studies.

3. Contribution of Methane to Reduction

One of the main components of this proposal was the development of empirical cost functions for methane (CH_4) abatement in the U.S., and their application to relevant policy issues. In order to accomplish this goal, we first developed methane cost functions based on the cost curve data found in an open literature. We have written a report that describes a set of CH_4 emission abatement cost functions that have been developed based on detailed bottom-up analysis of methane emission reduction technologies available in the United States and the net costs associated with implementing those technologies (Jain et al., 1999). The purpose of these cost functions is to facilitate the calculation of CH_4 emission reduction costs. The functions derived in this report can be applied in many ways, one of which is to compare the price of meeting abatement targets through the reduction of multiple greenhouse gases to that of CO_2 reductions alone.

As the next step, we then compared the costs of controlling emissions of CO_2 and CH_4 , and examined the cost of complying with emissions reduction targets for the U.S. through simultaneous CO_2 and CH_4 reductions. The CH_4 costs used were based on the cost functions we developed here. CO_2 cost functions were also derived, based on results of PNNL's Second Generation Model. The results of this comparison are discussed in a research paper entitled 'Cost implications of multi-greenhouse gas reduction targets for the U.S.', which was published in the interdisciplinary journal *Science* (Hayhoe et al., 1999). In this study, we used the example of CH_4 , as it is the second most important greenhouse gas (GHG) listed in the Kyoto Protocol after CO_2 , to show how the inclusion of more than one gas in an abatement strategy can provide greater flexibility and lower the costs of meeting international commitments. This is the first time, to our knowledge, that this combination of gases was considered in a detailed cost evaluation of emission targets such as those set forth in the Kyoto Protocol on climate change. We found that the implementation of economically viable CH_4 control projects in U.S. can offset CO_2 reductions and reduce costs by more than 25 percent relative to strategies involving CO_2 alone, a percentage that increases for smaller emission reductions.

4. The Impact of Atmospheric Chemistry on CH_4 GWPs

Weighting indices can be used to express emissions of different greenhouse gases (GHGs) in CO_2 -equivalent terms. The choice of a specific weighting index is often

thought to determine the emphasis on non-CO₂ GHGs in a multi-gas target. Although the choice of a 100-year Global Warming Potential (GWP), as proposed for the Kyoto Protocol, does narrow the range of possible values, in a recent study (Hayhoe et al., 2000) we use the example of CH₄ to show that this choice does not constrain the GWP to a single number. Projected changes in atmospheric CH₄ concentrations due to interactions with CO, NO_x, and OH produce direct GWPs ranging from 12.5 to 15.5. When the indirect effects due to tropospheric ozone (O₃) and stratospheric water vapor are included, GWPs range from 14 to 24. Our results show that for a 100-year GWP there is still significant variation in the effective use of CH₄ reductions in a multi-gas target. This has implications for the overall contribution of CH₄ and other non-CO₂ GHGs to both short-term and long-term strategies focussed on the mitigation of climate change impacts.

5. Estimation of Regional and Seasonal Radiative Forcing for Methane and Other Important GHGs.

We evaluated the radiative forcing due to changes in the concentrations of methane and other important GHGs (Jain et al., 2000). In general, IAMs use a simple relationship to calculate the radiative forcing of greenhouse gases. These relationships come from diverse sources and are generally based on a single global and annual mean background atmosphere. In contrary to the previous studies, we investigated the role of spatial and temporal resolution in estimating the radiative forcing of methane and other important greenhouse gases using distributions of major greenhouse gases based on chemical transport model results and measurements, in combination with a more accurate modeling approach - a narrow-band radiative transfer model of the global atmosphere (Jain et al., 2000). As a result of this study, we concluded that significant seasonal and latitudinal variations in the radiative forcing of methane and other major GHGs exist because of their dependence on assumed temperature, water vapor, ozone and cloudiness, all of which vary with latitude and season. In particular, our ISAM-estimated radiative forcing due to CH₄ concentration change from pre-industrial time to present was 0.58 Wm⁻², which is about 20% higher than the value reported in IPCC second (SAR) and upcoming third (TAR) assessment reports.

6. An Analysis of Substitution of Natural Gas for Coal and Its Impact on Climate

Substitution of natural gas for coal is one option to reduce carbon dioxide (CO₂) emissions. However, natural gas and coal use also results in emissions of other radiatively active substances including methane, sulfur dioxide (SO₂), a sulfate aerosol precursor, and black carbon (BC) or soot particles. This study addresses the role of CO₂, CH₄, SO₂ and black carbon emissions in determining the effectiveness of substituting natural gas for coal in the electric utility sector.

Most previous studies have concluded that although natural gas has a lower carbon content than coal, its production and use may result in larger methane emissions, with a significant impact on net CO₂-equivalent emissions. However, our study shows that the assumption of significantly higher CH₄ emissions is strongly dependent on a number of assumptions and choices, some of which could be chosen to minimize this effect. Depending on regional characteristics of coal and natural gas extraction and transportation, we found that methane emissions could either increase or decrease following a switch from coal to gas.

Despite the importance of methane emissions, our results indicate that it is the aerosol emissions that determine the net climatic impact over the first few decades following a coal-to-gas switch. For example, this study shows that coal-to-gas substitution produces an initial warming due to reduced SO₂ emissions and possible increases in CH₄ emissions that can last from 1 to 30 years, depending on the initial sulfur controls assumed. This is followed by a net decrease in temperature resulting from lower emissions of CO₂ and BC relative to continued coal use. The length of this period and the extent of the warming or cooling expected from fuel substitution is found to depend on key uncertainties and characteristics of the substitutions, especially those related to SO₂ emissions and consequent sulfate aerosol forcing, and the relative efficiencies of the power plants involved in the switch. This work has recently been accepted for publication in *Climatic Change*.

7. An Analysis of Key Feedbacks between the Chemistry of Atmospheric Methane and Future Climate Change

Both sources and sinks of atmospheric methane are strongly affected by climate and chemical feedbacks. These include feedbacks between tropospheric temperature, water vapor, hydroxyl concentrations and CH₄ removal rates; between CH₄ wetland emissions, surface temperature, and precipitation; and between emissions and formation of other trace gases that affect CH₄ removal, including carbon monoxide, nitric oxides, and tropospheric ozone. Insight into these feedbacks is crucial to understanding the potential role of CH₄ in climate change policy over the next century. We would like to emphasize that the importance of feedbacks is already recognized as some feedbacks have been studied on an individual basis. However, to the best of our knowledge, this is the first attempt to integrate full climate and atmospheric chemistry models into a single modeling framework in order to evaluate the full impact of emissions scenarios of an important greenhouse gas such as methane and its related chemistry.

In order to study the complex relationships between climate, atmospheric chemistry, and methane, we used the newly developed multi-dimensional chemistry transport component of our Integrated Science Assessment Model. This framework couples the methane atmospheric module (developed under this

proposal) to the radiative forcing module (also developed under this proposal), climate, carbon cycle, and biospheric modules, enabling a unique assessment of the relationships between climate and trace gas emissions, concentrations, and sinks. In this study, we used our model framework in combination with the trace gas emissions and temperature change projections under the new IPCC SRES scenarios to examine the effect of these feedbacks on future atmospheric methane concentrations and long-term climate change. Our results indicate that climate and chemistry interactive feedback processes are capable of significantly modifying methane concentrations, thereby affecting future climate and climate change mitigation policies. The results of this study were presented at the 2001 AGU Fall meeting in San Francisco.

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