EFFECTS OF CLIMATE CHANGE AND GREENHOUSE GAS MITIGATION STRATEGIES ON AIR QUALITY

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1. INTRODUCTION

This research is part of an ongoing project funded by the US Environmental Protection Agency to evaluate the air quality impacts of climate change and greenhouse gas (GHG) mitigation strategies in 2050. Detailed air quality model sensitivity analyses and model modifications are required to adapt the simulation capabilities to account for climate change impacts on air quality. In addition, previously developed methodologies for predicting future spatially and temporally resolved emissions fields are adapted to accurately account for air pollutant emissions impacts of likely GHG mitigation strategies. This is followed by simulations of atmospheric chemistry and transport in a set of air quality models to determine air quality impacts of GHG mitigation strategies. The project focuses on three representative regions of the United States: California, Texas and the Northeastern US. The various mitigation strategies that are likely to be adopted in these regions will affect pollutant emissions fields in these regions that are typically plagued by poor air quality.

The project assesses the baseline air quality in the selected US regions in the year 2050, accounting for expected (and unexpected) changes in climate and increases in commercial and industrial activity globally, and in particular in South East Asia, which can affect background pollutant concentrations reaching the US. Sensitivity analyses that account for various changes that can be forced by climate change (e.g., temperature, evaporative emissions, and biogenic emissions) are used to identify the most important considerations for model adaptation to account for the effects of climate change. In addition, this study develops a broad set of future scenarios for greenhouse gas mitigation strategies that account for the spatial and temporal distribution of all major emissions sources. The foci of the mitigation strategies used in the scenario development are (1) transportation and (2) electrical power generation, since these two sectors account for the majority global GHG emissions and are featured prominently in current and proposed GHG mitigation strategies. Finally, air quality impacts of GHG mitigation strategies are evaluated using state-of-the-art air quality models. The ultimate goal of this project is to develop air quality simulation strategies that accurately account for climate change and to determine the most effective GHG mitigation strategies that can concurrently improve air quality.

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2. EFFECTS OF CLIMATE CHANGE

The extent of climate change during the next decades is under continuous debate. Most uncertainties are associated to the wide range of possible future anthropogenic emissions, as discussed in the Intergovernmental Panel on Climate Change (IPCC) fourth assessment report (Forster et al. 2007). If greenhouse gases emissions continue to grow, global temperatures will increase substantially in the next century. Changes in global temperatures may affect the global atmospheric and oceanic circulation patterns, which can in turn affect the transport of pollutants. On the other hand, drastic emission controls could produce a reversion of the increasing trend in global temperatures. Changes in temperatures also impact biogenic emissions and air humidity, which could impact photochemical formation of ozone and particles. Numerous studies have analyzed the impact of climate change on pollutant concentrations (Dawson et al. 2008; Horowitz, 2006; Leung and Guftafson, 2005; Liao et al. 2007; Steiner et al. 2006; Tagaris et al. 2007; Wu et al. 2008; Zeng and Pyle, 2003). The overall conclusion is that increasing temperatures could lead to substantial increases in ozone concentrations, whereas expected reductions in global SO_X and NO_X emissions will decrease particulate matter formation, although the contribution of black carbon to total PM concentrations is expected to increase.

The evolution of anthropogenic emissions at global scale is uncertain as suggested by several future emissions scenarios presented by the IPCC (Forster et al. 2007). Nevertheless, industrial development in South East Asia is expected to continue, and NO_X emissions from fossil fuel combustion are expected to increase in that region which may affect the background pollutant concentrations reaching the coast of California (Wild and Akimoto, 2001, Weiss-Penzias et al. 2004, Weiss-Penzias et al. 2006, Liang et al. 2007, Oltmans et al. 2008). Increase in NO_X emissions since pre-industrial times is the main cause of a long-term increase in global ozone concentrations (Volz and Kley, 1988). In particular, there is evidence of increasing ozone concentration over the Northern Pacific Ocean in the last three decades (Ziemke et al. 2005) which affects the concentration of ozone in air masses reaching California, although some more recent observations suggest that ozone concentration could be leveling off in the last decade (Oltmans et al. 2008).

3. MITIGATION STRATEGIES

One of the main goals of this project is to conduct an extensive review of the current and projected status of technologies and strategies to reduce GHG emissions in the electric and transportation sectors. This discussion is based on a list of 180 literature references not listed here for brevity.

3.1. Electric Sector Analysis

Improving the efficiency with which energy is generated, transmitted, distributed and utilized offers a tremendous opportunity for GHG mitigation, often at net negative cost. Measures to improve efficiency are generally easier to implement and many require no further technological development. Though barriers exist to full deployment, significant GHG mitigation could occur from future advances. Air quality impacts will also be positive as less energy will be required to meet services, lowering emissions of criteria pollutants.

Renewable energy offers an enormous prospective resource base for power generation in tandem with the extremely low life cycle emissions of GHG and criteria pollutants relative to other mitigation strategies. Barriers to large-scale deployment include intermittency and transmission, which will require development of cost-effective energy storage technologies and deployment of new transmission and Smart Grid technologies. Costs are also limiting, particularly for solar PV and CSP. Dependent on displaced technology GHG and criteria pollutant benefits could be extremely large, although necessary co-deployment of ramping natural gas EGUs to deal with variability issues could blunt emissions reductions. Nuclear power is a proven technology that currently provides about 20% of U.S. electricity. Nuclear power could provide a much higher fraction of U.S. electricity but expansion has been constrained by waste disposal and safety concerns. Cost of generation is also a barrier however, future advances in technology or even a modest carbon price will make nuclear power cost competitive with fossil generation. Nuclear energy can provide reliable base load power with very low life cycle emissions of GHG and criteria pollutants, offering important benefits, particularly if coal power is displaced. If nuclear power reaches a high level of deployment in 2050 mitigation of significant amounts of GHG and criteria pollutant emissions are possible.

Table 1: Summary of Results for Electricity Generation Technologies

Technology	Potential GHG Reduction	Technological Maturity	Potential Air Quality Impacts
Energy Efficiency Improvements	23-30%	High	Positive- less generation necessary
Renewable Energy	20-50%	Medium	Positive- Lowest emitting technology
Nuclear Power		High	Positive- Low emissions compared to fossil
Carbon Capture & Storage	11%-93%	Low	Negative- emits criteria pollutants
Fuel Switching to Natural Gas	-50-45%	High	Positive
Increasing Thermal Efficiency of Power Generation	3.7-7.6%	Medium	Positive

Advantages of Carbon Capture and sequestration (CCS) include compatibility with the existing fossil fuel infrastructure and the potential for GHG mitigation with continued reliance on fossil fuels, particularly coal, which the U.S. has in relative abundance. Prior to large-scale deployment, major technical advances in CCS technology are required to lower costs. Further, it will need to be demonstrated that large quantities of CO_2 can be stored safely and effectively long term. Plant retrofits are currently expensive, so new capacity is more likely to be equipped with CCS. If CCS is deployed at high levels significant amounts of GHGs can be mitigated from large point source emissions in the electric power generation sector. Plants utilizing CCS technology still emit criteria pollutants, and if fossil technology with CCS is deployed over other alternative technologies with lower emissions negative air impacts could be observed.

3.2. Transportation Sector Analysis

Improving the fuel efficiency of the light-duty vehicles (LDV) fleet is an effective near-term solution for reducing GHG emissions for the transportation sector, however significantly lowering the carbon intensity of transportation fuels will be required if the deep, targeted reductions will be achieved in the long-term. Improvements in efficiency are mandated by policy and large gains are possible if technological improvement is directed towards fuel economy improvements. Paradigm shifts from conventional drive trains to electric drive trains offer increases in fuel efficiency and the opportunity for use of alternative, low carbon fuels. Hybrid Electric Vehicles (HEV) are currently the most fuel efficient LDV and could offer large improvements in fuel economy relative to conventional vehicles (CV), offsetting significant GHG emissions. Improving the energy efficiency of vehicles will reduce emissions of criteria pollutants by requiring less fuel combustion to meet equivalent travel demand. Depending on the magnitude of the efficiency improvements and the level of deployment reached in the LDV sector, the emissions savings could be large enough to

Substantial reductions in GHG emissions from the LDV fleet will almost certainly require a shift to hydrogen, electricity, or a combination of the two as the primary fuel source. Hydrogen Fuel Cell Vehicles (HFCV) operating on hydrogen produced from supply chain strategies with low emissions of GHG and criteria pollutants offer one option for providing travel from zero emissions vehicles. Though vehicle operation results in no direct emissions, emissions from other stages in hydrogen production and distribution can be significant and must be considered. Battery Electric Vehicles (BEV) operating on electricity using renewable, nuclear, or fossil energy with CCS offer the potential for very low emissions of both GHGs (potentially 90 to 100%) and criteria pollutants but face substantial technological hurdles. Plug-in HEV (PHEV) are more likely for near-term deployment and can significantly reduce emissions, but still require some portion of travel to be met with combustion of liquid fuel that will result in GHG and criteria emissions. If electricity generated to meet BEV vehicle charging demands comes from high emissions sources such as coal, net GHG mitigation benefits may be lessened or even reversed. Air quality impacts from electrification of some portion of travel relate to the shifting of emissions from distributed vehicle tail pipes to centralized power generation facilities. Most studies report net decreases in pollutants, although the use of coal-fired power could potentially result in increases in some criteria pollutants. Air quality studies of BEV and HFCV deployment have demonstrated wide spread improvements in response to vehicle exhaust displacement with some localized areas experiencing worsening, usually in response to a point source emission. The positive and negative changes in temporal and spatial species concentrations highlight the importance of addressing electricity sector emissions in tandem with transportation strategies.

Corn based ethanol is currently the dominant biofuel used by volume; however cellulosic ethanol production could expand significantly in response to policy mandates. Accounting for land use changes corn ethanol, even with the best energy-savings practices, provides only modest reductions in GHG emissions relative to baseline gasoline. Cellulosic ethanol can provide significant reductions, up to 90% relative to baseline gasoline, but is limited by feedstock availability. In order for biofuels to provide effective emissions reductions they must be produce without land-use changes. Bio-diesel could offer benefits in sectors where electrification is not feasible near-term, but is limited by a lack of economic, large-scale feedstock.

Ethanol use may offer some advantages in reducing direct PM and CO emissions, however life cycle emissions may negate vehicle emissions benefits. In addition, ethanol use substantially increases emissions of acetaldehydes and ethanol, and may increase emissions of NOx, contributing to higher ozone formation potential. Air quality studies have demonstrated small, but significant, increases in surface level ozone concentrations in response to increased ethanol use in the transportation sector, although some localized areas experienced improvements.

Reducing Vehicle-miles Travelled (VMT) by developing communities to increase travel efficiency could reduce VMT by 1.5 to 11% by 2050, although the reported higher reduction is controversial and a more realistic upper bound is 5%. Increasing the use of transit could potentially lower emissions but ridership must increase dramatically and transit vehicles must become more efficient and operate on less carbon intensive fuels. Car pooling or ridesharing also could allow for VMT reductions but portfolios of approaches have reported reductions of less than 1% in most cases. Though many modal shift strategies have smaller reduction potentials than technology and fuel related strategies, taken as a whole they could be significant. Also, as the targeted reductions of 50 to 80% below 2005 levels will be attainable only with extensive changes in the transportation sector energy use, all potential reductions are important.

Table 2: Summary of Results for GHG Mitigation Strategies in the Transportation Sector

Technology		Potential GHG Reduction	Potential Air Quality Impacts
Efficiency Improvements		5-50%	Positive- will reduce vehicle emissions
Electrification	HEVs	37-87%	Positive- will reduce vehicle emissions
	PHEVs	15-68%	Positive/Negative –dependent on regional electricity mix used for charging
	BEVS	28-100%	Positive/Negative- dependent on regional electricity mix used for charging
	HFCVs	35-100%	Positive/Negative- dependent on hydrogen supply chain strategy
Biofuels	Cellulosic Ethanol	75-100%	Positive/Negative- dependent on life cycle and direct vehicle emissions
	Corn Ethanol	10-67%	Positive/Negative-dependent on life cycle and direct vehicle emissions
Modal Shift(s)	Compact Development	1-11%	Positive- will reduce vehicle emissions
	Transit/Carpooling	.4-2%	Positive- will reduce vehicle emissions

4. SCENARIO DEVELOPMENT

A series of scenarios evaluate the changes in emissions from the transportation and electric sector. Changes in transportation include technology changes in vehicle and fueling technologies and infrastructure. In addition, changes in ship and rail technologies will also be considered, including mass transit. Finally, potential changes in transportation fuels and concomitant supporting infrastructure will be analyzed to account for emissions changes throughout the transportation sector. Changes in the utilities sector include increased penetration of distributed generation that improves energy use efficiency and reduces transmission losses, and increased penetration of renewable electricity production required by the current RPS goals and the possibility of more demanding RPS in the future.

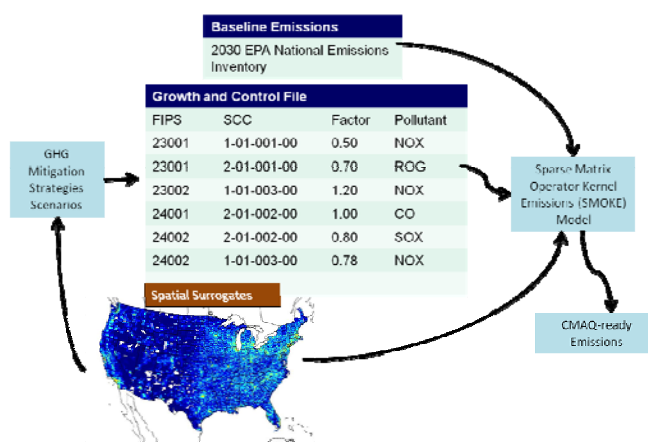


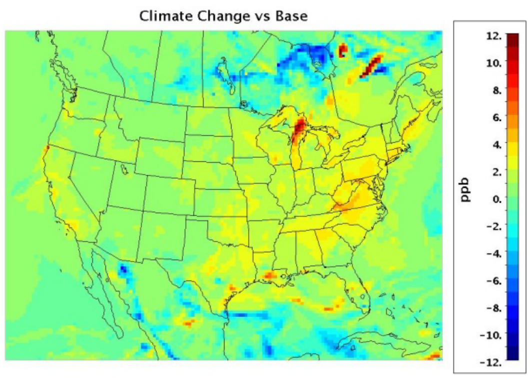
Figure 1: Methodology to spatially allocate criteria pollutant emission changes

The methodology used to spatially allocate emissions from electricity and fuel infrastructure in was developed previously for California and the NEUS (Rodriguez et al. 2006, Medrano et al.

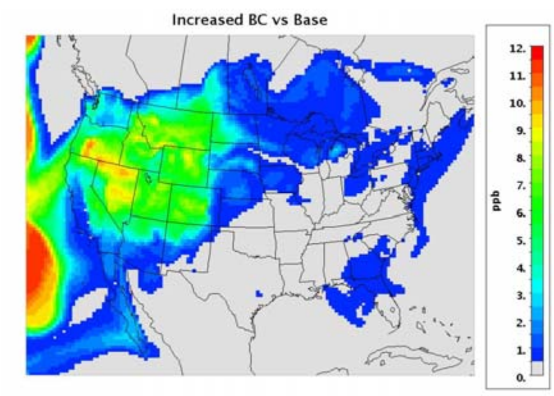
2008, and Carreras-Sospedra et al. 2008, Stephens-Romero et al., 2009). An illustration of the methodology for the current project is shown in Figure 1.

5. RESULTS

The project is currently underway, and a complete set of results are expected to be released at the end of 2012. The presentation at the CMAS conference will showcase some initial air quality simulations that evaluate mitigation strategies and contrast the effect with the effects of climate change and increased industrial activity in Asia.



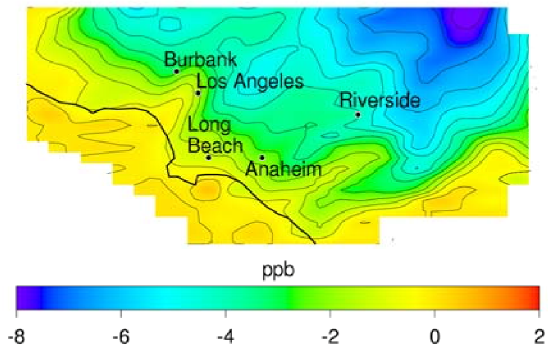
(a)



(b)

Figure 2: Effects of (a) 2 K increase in temperature and (b) increased west-boundary concentrations, on ozone concentrations

Results show that increases of 2 K in average temperature and projected increases in O_3 concentrations over the Pacific Ocean could lead to increases in ozone concentrations (Figure 2) that could offset the ozone reductions achieved by greenhouse gases mitigation strategies that require significant and paradigm technology and infrastructure shifts in the transportation and electric sectors (Figure 3). Conversely, effective greenhouse gases mitigation strategies could provide compounded benefits due to the effects of mitigating of climate change and reduction of air pollutants associated with mitigation strategies. Additional results and future directions on the assessment of GHG strategies will be presented at the conference.



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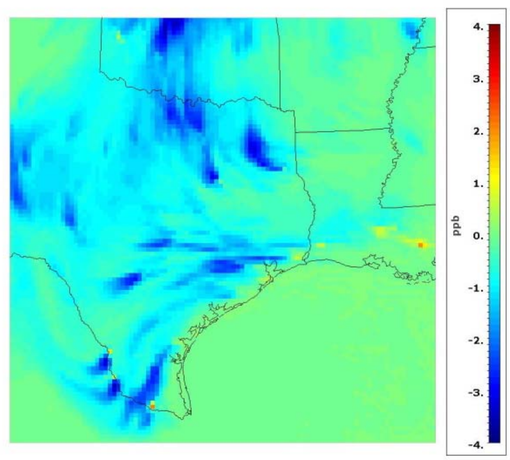

(b)

Figure 3: Effects on ozone concentrations of (a) widespread implementation of hydrogen infrastructure and HFCV in Southern California, (b) widespread commercialization of electric vehicles and renewable electricity to support vehicle charging in Texas.

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