

# DEVELOPMENT OF YEAR 2050 ANTHROPOGENIC EMISSIONS INVENTORY IN SUPPORT OF FUTURE REGIONAL AIR QUALITY MODELING

Jung-Hun Woo\*, Shan He, and Praveen Amar  
NESCAUM, 101 Merrimac Street, 10th Floor, Boston, MA 02114

Efthimios Tagaris, Kao-Jen Liao, Kasemsan Manomaiphiboon, Armistead G. Russell,  
School of Civil and Environmental Engineering, Georgia Institute of Technology, GA 30332

## 1. INTRODUCTION

The future of regional air quality under the long-term, interactive change of climate and emissions is considered as an important and challenging question. Several research projects under the support of the U.S. Environmental Protection Agency (EPA) have been conducted to evaluate this through various approaches.

A future-year (here, mid-21st century) emissions inventory (EI) for North America has been developed in support of our modeling study of regional ozone and fine particle matter concentration levels in the continental U.S under influence of global climate change. Since the time span of such a long projection is beyond that of regular State Implementation Plan (SIP) EI's used in typical regional air quality modeling (about 10~20years), it is necessary to identify a practical approach that allows the future-year projection to account for possible emission controls and climatic and socio-economic changes. However, a technical challenge arises because doing so requires considering and combining various different types of information (with which emissions from human activities are associated) in an integrated way. Often, information given or generated for global-scale studies has less detail and uses coarser spatial-temporal resolution.

We have extensively researched and reviewed a number of existing regional- and global-scale emissions projection efforts and then set up a methodology, which, we believe, is a good candidate for the current application, based on data availability and accessibility, spatial-temporal coverage and resolution, and future-scenario consistency (i.e. IPCC SRES A1B, the driving future emissions scenario adopted). Methods used and results from the study are discussed below, focusing primarily on future emissions development.

---

\* *Corresponding author:* Jung-Hun Woo, NESCAUM, 101 Merrimac Street 10<sup>th</sup> Floor, Boston, MA 02114, Voice: 617-259-2087, e-mail: [jwoo@nescaum.org](mailto:jwoo@nescaum.org)

## 2. APPROACH

### 2.1 USA

We make an effort to make our future emissions as consistent as possible to the Inter governmental Panel on Climate Change (IPCC) SRES A1B scenario that is used to develop our future climate (IPCC, <http://www.grida.no/climate/ipcc/emission/>). The SRES A1B describes a future world of rapid economic growth and global population that peaks in mid-century and declines thereafter, rapid introduction of more efficient technologies, and balanced usage between fossil fuels and other energy sources. We, however, try not to restrict ourselves to the A1B if there is better information available. As a base year inventory, we choose the 2001 Clean Air Interstate Rule (CAIR) rulemaking emissions inventory prepared by the EPA after considering data availability, spatial-temporal extent and resolution, and modeling consistency (US EPA, 2005).

Our method of growing 2050 emissions from the 2001 base year consists of two steps: 1) get the projected EI for near-future which already incorporates all of “visible” growth and control (up to year 2020) and 2) perform a distant-future EI projection (up to mid-century) using more coarse-but-integrated modeling approach. The former is based on the US EPA CAIR 2020 EI while the latter follows approaches given by the Netherlands’s National Institute for Public Health and the Environment (RIVM)’s Integrated Model to Assess the Global Environment (IMAGE) model (RIVM, <http://www.mnp.nl/image/>). We selected year 2020 CAIR EI as our near-future emissions because it: 1) is readily available, 2) is “official” data that is used for rule making, 3) uses the most recent national database for base year 2001 when we conducted our research, 4) uses the most updated growth and control assumptions, and 5) has the content and format which is the most consistent with our needs. The base-year and year 2020 inventories were developed in a “SMOKE-ready” format and includes the following pollutants: carbon monoxide (CO),

nitrogen oxides (NO<sub>x</sub>), non-methane volatile organic compounds (NMVOC), sulfur dioxide (SO<sub>2</sub>), ammonia (NH<sub>3</sub>), particulate matter less than or equal to 10 microns (PM<sub>10</sub>), and particulate matter less than or equal to 2.5 microns (PM<sub>2.5</sub>). As noted above, RIVM's Integrated Model to Assess the Global Environment (IMAGE) was selected to project emissions from year 2020 to year 2050 (<http://www.mnp.nl/image/>). We selected this model because it: 1) is the model that covers the time horizon up to the year 2050 (year 2100 maximum) and is readily available, 2) was used for a US EPA's inter-continental scale transport modeling project (Streets and Fernandes, 2002), 3) has other sub-models which can incorporate interactions among components (i.e. integrated model), and 4) uses widely used scenarios (i.e. IPCC SRES) which are consistent with the scenario that our climate/meteorological model is based on (A1B). For particulate species, we incorporate work of Street et al. (2004), research that also uses IPCC A1B as the reference scenario.

Combining two future emissions inventories was conducted as follows: 1) EPA CAIR inventories for year-2001 and year-2020 were processed with SMOKE programs (SMKINVEN and SMKREPORT) to ensure consistency in data formatting and generate an emissions summary by each SCCs, 2) Emissions and surrogates (agricultural production and black/organic carbon for missing NH<sub>3</sub> and PM, respectively) from IMAGE and Streets et. al. (2004) were estimated for USA/Canada/Mexico and for Y2001/Y2020/Y2050 to get growth factors for these periods, 3) The cross-references from US Source Classification Code (SCC) to IMAGE sector/fuel combination were developed, 4) The growth factors were applied to the year inventories, using cross references described above to estimate year 2050 inventory for North America.

## 2.2 Canada and Mexico

In our initial work (Manomaiphiboon *et al.*, 2005a and 2005b) and EPA CAIR EI, Canada and Mexico emissions were held constant for base and future year. This approach may be good enough for near future (i.e. year 2020) but is insufficient for distant future because the air quality impact would be affected by this "constant emissions assumption." We therefore decided to apply a simple growth approach for Canada and Mexico even though their emissions information is limited and emissions amounts are relatively small compared to the US at present. For Canada, we update the present emissions inventory from US EPA's 1996 Canadian inventory to the combination of Environmental Canada (EC)'s emissions (year 2000 for point sources and year 2020 for area, nonroad, on-road mobile, available at

<http://www.epa.gov/ttn/chief/net/canada.html>) and New York State's Department of Environmental Conservation (NYS DEC)'s point source inventory. For Mexico, we update present the emissions inventory from US EPA's 1999 BRAVO inventory to the combination of BRAVO EI and Mexico NEI (<http://www.epa.gov/ttn/chief/net/mexico.html>). Since Mexico NEI only covers 6 states, we merged it with BRAVO EI to cover our entire modeling domain. Since Mexico NEI does not have fugitive dust in it, we use BRAVO EI's value instead for the six-border states. After getting a merged inventory, we apply year 2050/1999 growth factors to the datasets. The same source sub-sectors to Canada's case, however, were not "grown" to maintain consistency with US data.

## 3. RESULTS AND DISCUSSION

### 3.1 Present and future years emissions from IMAGE model (Y2001 – Y2020 – Y2050)

We analyzed the IMAGE emissions (A1B) by fuels and by source sectors for three IPCC regions (USA/Canada/Mexico) and three years (Y2001/Y2020/Y2050). For SO<sub>2</sub>, the dominant fuel is coal (CL) for US and Canada and heavy oil (HO) for Mexico (Mexico is part of Central America region in IMAGE). In the U.S., and Canada, SO<sub>2</sub> emissions are forecast to decline substantially between 2001 and 2020 (~70%) but the rate of decline is lower between 2020 and 2050 (~15%). For Mexico, emissions are forecast to increase between 2001 and 2020 (~100%) but decline after 2020 (70% of 2020). Power generation (POWGEN) is dominant sector for SO<sub>2</sub> emissions for all three countries (60~80% in US). For NO<sub>x</sub>, the dominant fuels are light oil (LO) and coal for US and Canada (70~80% overall) but light oil and heavy oil are the important contributors in Mexico (75%). In the U.S., and Canada, NO<sub>x</sub> emissions are forecast to decline throughout all future years. Mexico shows an opposite trend as emissions increase. Transportation (TR) is dominant sector for Y2001 for all three countries but power generation (POWGEN) sector becomes more important as total emissions decrease in the future. In the U.S. and Canada, NO<sub>x</sub> emissions decline because of the implementation of emission controls on vehicles and major stationary sources, while power generation seems to drive the NO<sub>x</sub> emissions increase in Mexico. For NMVOC, the country-by-country emissions trend shows similar patterns to SO<sub>2</sub> and the dominant fuel is light oil (more than half of emissions from fuel in US, 2001). The transportation, industrial process (INDPRO) and fugitive emissions (LOSS) are the dominant sectors for NMVOC (more than 95% overall). This trend is consistent with high growth rates in such things as

industrial solvents, paints, glues, and chemicals production. Such industrial commodities are typically associated with economic development. Emissions of NMVOC from such activities are also typically high and not easy to control. Only recently have the developed countries instituted measures to capture organic compounds and re-use them. Hydrocarbon emissions from growing transportation fleets of Mexico would add to NMVOC emissions. Since NH<sub>3</sub> emissions are not calculated in the IMAGE model, we decided to use agricultural activities as surrogates. Only livestock production from the IMAGE model was used to “grow” NH<sub>3</sub> emissions because NH<sub>3</sub> emissions from fertilizer application are set as a constant through years in CAIR emissions. PM species from Streets et al., (2004) show similar pattern to NO<sub>x</sub>.

### 3.2 Present and Future emissions from our approach

#### 3.2.1 USA

In this section, we present year-2050 emissions inventory developed using year 2020 CAIR emissions inventory and growth factors from the IMAGE model and the work of Streets et al. (2004). Since the purpose of this section is to describe projected emissions, we do not include sectors which remain constant over years, for example, fire and fugitive dust. Figure 1 shows SO<sub>2</sub> emissions by states and by source types (point, area, nonroad, and on-road mobile) for year 2001, 2020, and 2050. Based on the CAIR emission inventory, point source is a dominant source type due to high emissions of the power generation sector. As for regional distribution, the Midwest region shows higher SO<sub>2</sub> emissions due to its coal-fired power generation capability. Area source contribution is relatively high in the Northeast compared to other regions due to its higher residential oil combustion. Due to control and fuel change, the year 2050 SO<sub>2</sub> emissions decrease by more than 50% compared to its 2001 level. Note that we use CAIR emission control case for year 2020 that has more control on IPM sector than CAIR base case. NO<sub>x</sub>, NMVOC, and PM<sub>2.5</sub> emissions will also be presented.

#### 3.2.2 Canada and Mexico

Figure 2 shows 1999 and 2050 Mexico emissions for all seven species. Most emissions except PM species will drop more than 30%. We did similar analysis for 2001 and 2050 Canadian emissions (not shown). NO<sub>x</sub> emissions increase more than twice due to growth of the power generation industrial sector. SO<sub>2</sub>, however, increases at much lower rate compared to NO<sub>x</sub> due to point source controls. CO and PM

emissions show decreases and agricultural activities seem to drive NH<sub>3</sub> emissions increase in Mexico.

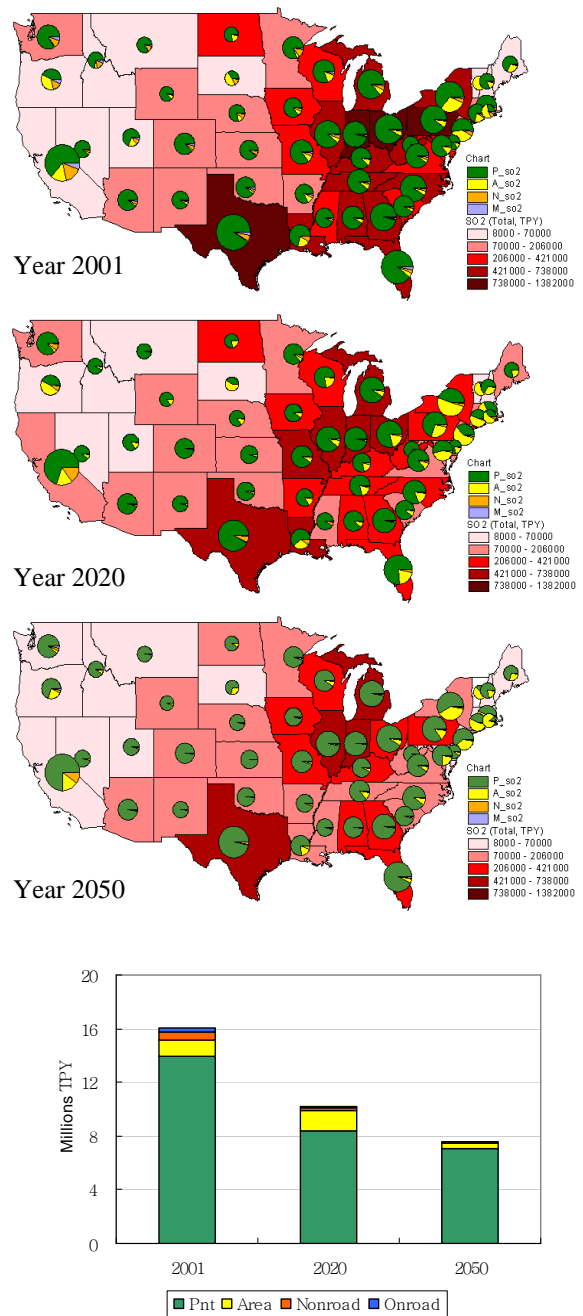
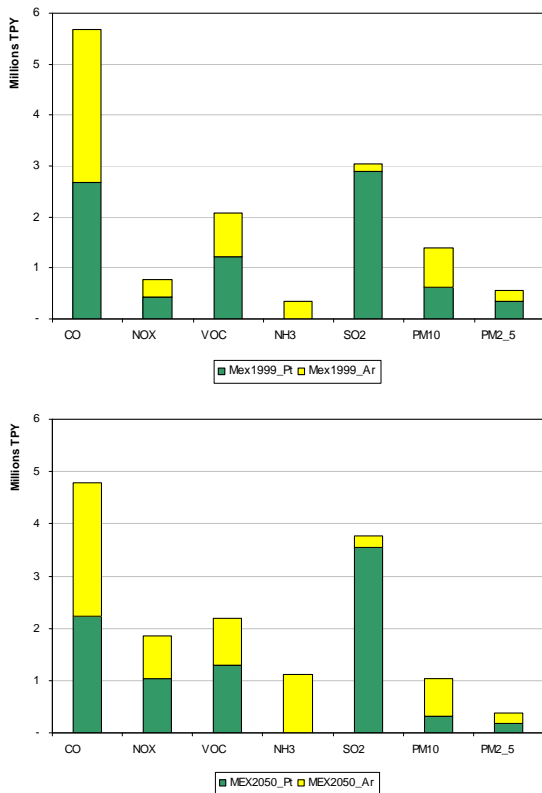


Figure 1. Present and future years SO<sub>2</sub> emissions by state and by source types



**Figure 2.** Year 1999 and Year 2050 Mexico point and area (stationary area, nonroad, on-road mobile) source emissions

### 3.2.3 Emissions processing and air quality modeling

We ran SMOKE to generate emissions for GCM-MM5/CMAQ to test several cases of air quality impact in present and future cases including: 1) base-year emissions with base-year climate data, 2) base-year emissions with future-year climate data (accelerated climate change case – only point/mobile/biogenic emissions are affected), and 3) future-year emissions with future-year climate data. The detail methodology about air quality modeling is described in the Tagaris et al. (*manuscript in preparation*).

## 4. ACKNOWLEDGEMENTS

This study has been financially supported by the US EPA under Grant No. R830960.

## 5. REFERENCES

Kasemsan Manomaiphiboon, Kuo-Jen Liao, Armistead G. Russell, Chien Wang, Cassandra B. Roth, Lai-Yung (Ruby) Leung, Jung-Hun Woo, Praveen Amar, and Shan He, “Accounting for Uncertainty

in Future Climate Change and Evaluating Its Effects on Regional Air Quality” Presented at the U.S. Climate Change Science Program (CCSP) workshop, Arlington, VA, November, 2005b

Kasemsan Manomaiphiboon, Armistead G. Russell, Sergey L. Napelenok, Mehmet T. Odman, Jung-Hun Woo, Shan He, Praveen K. Amar, Lai-Yung Leung, “A Modeling Study of Particulate Matter and its Sensitivity to Emissions Under Influence of Climate and Emission Changes”, Presented at AAAR 24th Annual Conference, Austin, Texas, October, 2005a

Marc Houyoux, *Clean Air Interstate Rule Emissions Inventory Technical Support Document*, U.S. EPA, 2005. 3.

National Institute for Public Health and the Environment (RIVM), *The IMAGE 2.2 implementation of the SRES scenarios: A comprehensive analysis of emissions, climate change and impacts in the 21st century*, Bilthoven, The Netherlands. 2001.

Streets D.G.; Fernandes S., *Development of Future Emission Scenarios for Global Atmospheric Models*, Argonne National Laboratory, IL, 2002.

Streets D. G.; Bond T. C.; Lee T.; Jang C., “On the future of carbonaceous aerosol emissions”, *Journal of Geophysical Research*, 2004, 109, D24212, doi:10.1029/2004JD004902

Tagaris E, K.-J. Liao, K. Manomaiphiboon, A. G. Russell, J.-H. Woo, S. He, P. Amar, and L.-Y. Leung, “Global Climate Change Impacts on Regional Ozone and Fine Particulate Matter Concentrations over North America”, manuscript in preparation