A Comprehensive Research Plan for Developing $PM_{2.5}$ Emission Inventories

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ABSTRACT

California is funding numerous research projects to improve particulate matter inventories for area sources, with an emphasis on particles 2.5 microns or less in size ($PM_{2.5}$). This paper discusses how projects were selected, how they are coordinated with other efforts, and a brief summary of each project. The paper also provides a discussion of how we are integrating geographic information systems (GIS) technology into our emissions inventory. Some of the projects currently funded for area sources include: development of GIS based emission estimation models for wildfire, prescribed burning, agricultural burning, and fireplace/woodstove burning; measurements and modeling of ammonia emissions from fertilizer application; development of emission estimates for charbroiling; real-time measurements of paved road dust emissions; estimating vehicle miles traveled (VMT) on unpaved roads using GIS; and, evaluation of dust entrainment, removal, and transport mechanisms using remote sensing technology. Emission inventory improvements for mobile sources are being addressed under a separate program and are not discussed in this paper.

INTRODUCTION

As part of our emission inventory development and improvement programs, the California Air Resources Board (ARB) receives ongoing funding to support PM_{10} and $PM_{2.5}$ emission inventory research for point and area sources. To date, fourteen projects have been funded. This work is designed to assist with developing future $PM_{2.5}$ particulate matter attainment plans and visibility improvement plans.

To maximize our resources, we strive to fund research that directly answers specific emissions inventory related questions – research that clearly helps to understand and improve California's air quality. In addition, we give priority to research that help can also help answer inventory questions at the national or western regional levels. For example, our project to better understand dust entrainment and deposition behavior should be of use to many areas of the country.

Our PM inventory research for area sources focuses in four primary areas:

- *Geologic particulates*: paved road dust, unpaved road dust, and dust dispersion characteristics
- *Smoke and combustion emissions*: wildlands fire, agricultural burning, fireplaces and woodstoves, charbroiling emissions
- *Ammonia emissions*: ammonia from fertilizer application, ammonia from natural soils, overall inventory development
- *Biogenic particulate emissions*: model development, field testing

A commonality between these projects is that most of them incorporate geographic information systems (GIS) technology. GIS based programs and models are used for collecting, storing, processing, and visualizing the emissions input and output data. This approach provides tremendous benefits in making the data easier to use, easier to update, and easier to display and share with people.

This paper describes our process for deciding which projects to fund (and why we have not selected others), how we have selected contractors for the work and who is doing the work. It also provides a brief summary and expected results for each project. As mentioned, improvements to mobile source $PM_{2.5}$ emissions estimates are also being developed, however, these projects are handled under separate programs and are not included in this paper.

EVALUATING $PM_{2.5}$ INVENTORY NEEDS

Background

In anticipation of preparing $PM_{2.5}$ attainment plans for the federal air quality standards, the ARB was allocated approximately six hundred thousand dollars per year for improving $PM_{2.5}$ emission estimates for point and area sources. Preparing $PM_{2.5}$ emission inventories provides some distinct challenges from preparing PM_{10} emission estimates. The key difference is that for PM_{10} non-attainment regions, a large percentage of the overall ambient particulate loading is typically from direct PM emission sources such as wood smoke or geologic dust. However, for $PM_{2.5}$, the source contributions in California are typically a complicated mix of both directly emitted primary particles, as well as secondary particles formed in the atmosphere through reactions of gaseous pollutants.

Therefore, a complete $PM_{2.5}$ inventory for California requires both an inventory of directly emitted particulates, as well as the gaseous precursors. Fortunately, we already have comprehensive precursor inventories for NO_x, SO_x, and VOCs (but not ammonia). For this reason, our current $PM_{2.5}$ inventory research focuses on direct $PM_{2.5}$ emissions and ammonia. As for estimating how the inventoried gaseous precursor pollutants contribute to ambient $PM_{2.5}$ levels, we must rely on the talents of the atmospheric modelers and meteorologists to help answer those questions.

Emissions Source Category Prioritization

In starting our $PM_{2.5}$ inventory improvement research program in 1998, we had many ideas for potential research projects. To help prioritize these projects and effectively utilize our funding, we developed a prioritization method to help identify projects that maximize the benefits of our $PM_{2.5}$ inventory research.

The prioritization method is used to identify which source categories are most in need of improvements. Sources are scored by assigning rating values of 1 to 5 to seven different parameters relevant to the quality of the current emission estimates. These parameters include:

- Relative importance of the source based on policy, health, and other concerns;
- Expected magnitude of emissions from the source;
- Quality of the existing emission factors and activity data;
- Availability of size speciation, spatial, and temporal allocation data for the source.

This prioritization method takes into account what is known, and also what is unknown about the source, and it is designed to give the highest scores to the sources with the greatest uncertainty and the highest potential emissions.

Table 1 shows the results of this analysis for the typical sources of directly emitted $PM_{2.5}$ in California. Values of 1 to 5 are assigned to indicate either the significance of the category, such as for 'source importance' or 'source magnitude', or, the relative quality or trustworthiness of the currently available information, as with 'emission factors' or 'activity data'. Scores are summed across each row to get overall scores. However, to reduce some of the influence of the scores for size speciation, spatial data, and temporal data, which are of secondary importance for the initial inventory, they were divided by three prior to summing.

Note that the emission sources with high scores are a combination of those that are potentially significant contributors during certain high $PM_{2.5}$ events, such as fireplaces and woodstoves, as well as those with high uncertainties, such as $PM_{2.5}$ from vegetative burning. Although the table includes mobile source emissions in the ranking for comparison, this research is addressed through other ARB programs and is not included as part of this paper.

Selection and Development of Projects

The scores in Table 1 help to identify which source categories are most in need of research. The next step is to identify what specific research is needed for the category, such as improved activity data, emission estimation methodology improvements, or new emission factor measurements. Specific research projects are based on the individual deficiencies for each source category. As is described in detail in upcoming sections, the first three years of funding are focused on vegetative burning, geologic $PM_{2.5}$, some ammonia sources, and incorporation of GIS technologies to our inventory methodologies.

For the initial rounds of research, nearly all of our $PM_{2.5}$ inventory funding is applied to activity data collection and estimation method improvement. Developing methods which provide more complete information that answers the questions about what, when, where, and how much

emissions occur, in combination with geographically based methodologies, was the best use of our initial funding.

After identifying our priority projects for each fiscal year, we verify that the projects do not overlap with ongoing work being performed by other agencies, such as the U.S. EPA, the Western States Air Resources Council, the PM Best Available Control Measures Group (western states), the Western Regional Air Partnership, and others. We also coordinate with other programs within the Air Resources Board, as well as other study agencies and stakeholder groups working within California. This is typically done informally which allows us to move relatively quickly in getting projects funded and getting the work started. After these steps, all projects get final approval from ARB management and executive officers.

Initially, we have not funded $PM_{2.5}$ emission factor development projects. There are two reasons for this. First, emissions testing is expensive and we believe that more inventory improvement benefit can initially be obtained through non-testing research. Second, the sources that potentially have the greatest emission factor uncertainty for $PM_{2.5}$ (e.g., geologic sources) tend to be small contributors to ambient $PM_{2.5}$ levels, and the sources that are the largest contributors are predominantly combustion sources, which emit almost exclusively in the $PM_{2.5}$ size ranges. Thus, the existing PM_{10} factors (with a $PM_{2.5}$ size correction) are adequate for our initial efforts.

Contractor Selection & Management of Projects

After we have clearly defined specific inventory projects for research, we seek researchers with the necessary specializations to perform the work. Once a researcher is identified, we work with them to prepare a statement of work. Based on the statement of work, we enter into a contracting agreement with the researcher. The majority of our contract work is performed by researchers affiliated with the California university system. Because we have many qualified academic research organizations available to us, this approach is extremely productive. We can spend more of our time developing and managing projects, and enjoy the many administrative, fiscal, and technical benefits of working with fellow state agencies.

The inventory research projects are directly managed by ARB's emission inventory staff. This has turned out to be more challenging and time consuming than originally anticipated. However, by having the eventual users of the research manage the projects, it keeps the work oriented towards 'real-world' results. This is important because the university researchers have many creative and motivated people available who are interested in exploration and discovery. The project manager must ensure that the less glamorous, more routine aspects of the research are not neglected (such as computing overall emissions), in place of the more interesting, research oriented work.

Because of our close relationships with the universities, we can make midcourse corrections if needed for the project, shift emphasis, or explore options not originally considered. This flexibility helps to ensure that we get useable results from projects. This approach also requires openness, accessibility, and ingenuity on the part or the researchers, as they work to meet project objectives.

Table 1. $PM_{2.5}$ Sources and Priority Scoring for Inventory Development Needs.

		a	b	c	d	e	f	g	h
		Primary Score Categories				Secondary Scores			
Source Type	**Source Name**	**Source Importance**	**Source Magnitude**	**$PM_{2.5}$ EF Quality**	**Activity Data**	**Speciation Data**	**Spatial Data**	**Monthly Temporal**	**Totals**
Geologic	Paved road dust	3	2	3	2	3	2	2	12.3
	Unpaved road dust	3	3	3	4	3	4	4	16.7
	Agricultural dust	4	3	3	2	4	2	1	14.3
	Windblown dust	2	3	3	3	4	2	2	13.7
	Construction dust	2	2	3	4	3	4	3	14.3
Vegetative Burn	Residential wood	5	4	3	3	3	4	2	18.0
	Prescribed burn	5	3	3	3	2	4	4	17.3
	Wildfire	5	3	3	3	3	4	4	17.7
	Agricultural burn	5	3	3	3	2	4	3	17.0
Motor Vehicles	Diesel exhaust	5	3	3	2	2	2	3	15.3
	Gasoline exhaust	3	2	2	2	2	2	3	11.3
	Tire wear	2	1	4	3	4	2	3	13.0
	Brake wear	2	1	4	3	4	2	3	13.0
	Off-road exhaust	3	1	4	3	3	4	4	14.7
Stationary	Charbroilers & fryers	3	3	2	4	4	4	3	15.7
	Industrial combustion	2	1	3	3	1	2	2	10.7
	Mining	1	1	3	3	3	2	2	10.3
	Sand & gravel	1	1	3	3	3	2	2	10.3
	Other stationary	1	1	3	3	3	2	2	10.3
	Livestock dust	1	1	4	4	4	3	3	13.3
	Sea salt	1	1	5	5	5	5	5	17.0
	Scoring Criteria	5 = most important	5 = most important	1 = highest quality	1 = highest quality	1 = highest quality			
						x 1/3			

Description of Scoring Categories

a – Source Importance	Based on magnitude, perception, public awareness, existing resources, industry interest, potential for control, potential toxicity
b - Source Magnitude	Estimated based on previous PM2.5 inventories, number of sources, Chemical Mass Balance (CMB) data
c - EF Quality	Score based on estimated uncertainty and variability of existing emission factors (EFs) and complexity of source category. Highest quality means many tests were performed which are California specific and directly related to the source category.
d - Activity Data Quality	Estimation of quality and availability of overall annual activity data; includes detail available and expected newness of available data
e – Speciation Data*	Quality of size speciation data, age, applicability to CA, applicability to PM2.5
f - Spatial Data*	Availability of spatial data; general quality and resolution expected to be available
g- Monthly Temporal*	Availability of data which could be used to estimate monthly variations in emissions
h- Totals	This is the total prioritization score. Score = (a+b+c+d) + (e+f+g)/3
* Note on e, f, g	*The spatial and temporal column scores are multiplied by 1/3 prior to summing because they are of less significance in preparing an initial inventory

INCORPORATION OF GIS

Several years ago, we saw the value of incorporating geographic information systems (GIS) technology into our emission inventory methods. One of our first efforts was estimating agricultural land preparation PM_{10} emissions by using detailed electronic crop maps, which were overlaid with activity and emission factor data. This produced maps of PM_{10} emissions, by month, for land preparation in the Central Valley.

There are many clear benefits to this approach, a few of which are: emissions can be updated by simply incorporating an updated electronic crop map (or coverage); the emissions can be displayed graphically to help easily identify areas of high emissions; and the data are in a geographic format, which is useful for use by air quality modelers. Because of these and other benefits, we have incorporated geographic spatial and temporal components into all of our applicable inventory research.

For example, our wildlands fire project with UC Berkeley computes emissions within the GIS program ArcView®. It incorporates map-based coverages of historical burns and vegetation types, and then uses this information with an emissions estimation model to produce maps of wildlands fire emissions in California.

The goal of the ARB is to produce a complete emission inventory that has GIS technology at it core. All emission sources (point, area, mobile) would include a spatial component. All of these emissions would be coordinated to a unified GIS backbone, which will make the analysis, updating, use, visualization, and export of the emissions data easier and more reliable.

In parallel to our emission inventory GIS integration efforts, we are also working to coordinate and integrate air quality data, meteorology data, air quality modeling information, and emissions data into common, spatial data libraries. This is a large and challenging project, but there are tremendous benefits for being able to compare and perform map-based analyses. For example, combining demographic information, such as income levels, to a GIS layer showing air toxic risks, provides a powerful analysis tool for exploring and helping to solve environmental justice issues or identifying where controls could provide the greatest health benefits to the most people.

SUMMARY OF PROJECTS

A brief description of each project selected for funding follows. Table 2 tabulates the start date, end date, and funding for each project. More detailed information is available at http://arbis.arb.ca.gov/emisinv/pmnh3/pmnh3.htm.

Geologic Dust

We have funded several projects to better understand the contribution of geologic sources to ambient $PM_{2.5}$ and PM_{10} levels. These projects include:

Evaluation of Geologic Dust Entrainment, Removal, and Transport Mechanisms – A key objective of this work is to help understand why inventory estimates of geologic $PM_{2.5}$ are higher than would be expected based on ambient measurements. This project, being performed by Dennis Fitz of UC Riverside, CE-CERT, and Russell Philbrick of Pennsylvania State University, is designed to better understand the settling rates of geologic PM, how dust plumes behave, and what factors may affect dust removal near sources. The fieldwork includes plume characterization using LIDAR (light detection and ranging), real-time PM measurements, tracer gas studies, and full meteorological measurements. The project is scheduled for completion in the spring of 2002.

Using GIS to Estimate Statewide Vehicle Activity and Roadway Mileage for Unpaved Roads in California – Unpaved roads are a significant source of PM_{10} in California and have the capability to be a meaningful contributor to regional $PM_{2.5}$ levels. This project will reduce the uncertainty in our VMT (vehicle miles traveled) estimates for unpaved road travel in California, and it will provide a geographic information systems based approach to provide spatially and temporally resolved vehicle activity data for agricultural and personal vehicles. The principal investigator for the project is Debbie Neimeier with UC Davis. The project is scheduled for completion in the spring of 2002. This project is a follow on to the previously completed, *Vehicle Activity Estimation for Unpaved Roads: An Exploratory Analysis*.

Measurement of PM_{10} and $PM_{2.5}$ Emission Factors from Paved Roads in California – Our existing emission estimates show paved road dust to be a significant contributor to particulate emissions in urbanized regions of California. This project uses real-time PM_{10} and $PM_{2.5}$ measurement instruments to try to identify on-road PM generation levels related to road type, traffic conditions, vehicle speed, dust trackout and other factors. Because of very low particulate concentrations and a multitude of possible environmental variables, initial results indicate that it may be difficult to reliably characterize real-time measurements using simple parameters. The principal investigator for the project is Dennis Fitz with UC Riverside. A final report is due in the spring of 2001.

Chromium Speciation from Various Area Source Categories – This research will allow the ARB to develop better estimates of statewide hexavalent chromium emissions from various fugitive dust area sources. Current methods simplistically assume that 5% of total chrome is hexavalent chrome, which leads to improbable health risk estimates. Sampling and analysis of soil and entrained dust samples will be performed to accurately

quantify hexavalent chromium levels. The work is scheduled to begin in the summer of 2001 and may be performed by ARB's Monitoring and Laboratory Division.

Simulation and Analysis of the Factors Leading to High PM10 Emissions Fluxes at the Owens Dry Lake Bed Using an Environmental Wind Tunnel – This work, performed by Bruce White of UC Davis, performed innovative laboratory studies of the factors that influence windblown dust generation for soils collected from the Owens dry lakebed. Under windy conditions, this lakebed is responsible for tremendous exceedances of the federal particulate matter standards. A final report is available and information is available on the web at: http://mae.ucdavis.edu/~wind/publications/OwensCarb.html

Open Burning and Charbroiling

This research category includes projects to develop GIS based methods and models to estimate emissions from wildlands fire (both wildfire and prescribed), agricultural burning, fireplaces and woodstoves, and commercial charbroiling. For several of the projects, we are also working to web-enable the projects so that some of the display and analysis capabilities of the emission models can be accessed via the Internet. The projects include:

Creating a Statewide Spatially and Temporally Allocated Wildfire and Prescribed Burn Emission Inventory Using Consistent Emission Factors (Phase I) – California requires all of its air districts to prepare smoke management plans to address potentially harmful smoke impacts from agricultural, forest, and rangeland burning. In support of this program, as well as for our $PM_{2.5}$ inventory, this project develops a method for providing spatially and temporally resolved emission estimates for both prescribed fire and wildfire. The project uses a GIS layer of fire history, combined with a vegetation layer and an emissions model. The researchers are also developing methods to incorporate satellite remote detection of fires to calculate fire perimeters and emissions. Peng Gong at UC Berkeley is the principal investigator of the project and James Scarborough is the primary Staff Research Associate working on the project. A final report for the project is available. For more information, the project website is at: http://camfer.cnr.berkeley.edu/fire/

Input Validation, Sensitivity Analysis and Refinement to the ARB Wildland Fire Emissions Model – This is a follow-on to the previous project. The objectives are to create a wildlands fire emissions estimation and visualization tool that can be used over the web, as well as refining the use of remote sensing for identifying fires, and validating the model input data and algorithms. Peng Gong at UC Berkeley is the principal investigator of the project, which will begin in July 2001, with an approximate end date of October 2002.

Creating a Statewide Spatially and Temporally Allocated Agricultural Burning Emissions Inventory Using Consistent Emission Factors – This project is an evolution of the wildlands fire projects. For this work, agricultural burning data are being compiled into GIS data coverages. These will be combined with currently available emission factors to provide spatially and temporally resolved emission estimates for California agricultural burning. The project is ongoing with a scheduled completion date of August 2001.

Peng Gong at UC Berkeley is the principal investigator of the project, and additional project information is available at: http://camfer.cnr.berkeley.edu/fire/

Model Development for Spatial Allocation of $PM_{2.5}$ Emissions Including Residential Wood Combustion – The principal investigator for this project is John Radke with UC Berkeley. The purpose of the project is to develop GIS-based methods for estimating residential fireplace and woodstove emissions. The project includes a survey component, which will attempt to associate various demographic and geographic parameters to residential wood burning activity. This information will then be used to make statistical inferences that can be applied to regions beyond the survey areas. The final objective for the project is to provide spatially and temporally resolved emission estimates for California fireplaces and woodstoves. Project completion is scheduled for August 2001, and additional project information is available at: http://camfer.cnr.berkeley.edu/fire/

Charbroiling Activity Estimation: Exploratory Analysis – This project includes a survey of establishments that perform charbroiling and deep fat frying. The information will be used to develop GIS based maps of the locations and activity data for these facilities, which will ultimately be tied to available emission factor data to develop emission estimates. The work is being performed by Michael Potepan at the California State University, San Francisco. The project will be completed in the spring of 2001.

Ammonia Emissions

As a precursor to $PM_{2.5}$ emissions, we are preparing a statewide emission inventory for ammonia, as well as sponsoring specific research projects.

Development of Emission Inventories for Ammonia in Agricultural Systems of California Soils – This project measured ammonia emission rates from fertilizer application and then developed regional fertilizer ammonia emissions modeling based on the field test data. The project tested emissions for a variety of fertilizer types and application methods relevant to the major crop types in California's San Joaquin Valley. The modeling includes inputs for soil type, climatic conditions, application calendars, and other relevant factors. The results are provided in a spatially resolved gridded format, with monthly resolution. The researchers involved in the project are Charles Krauter with California State University, Fresno, and Chris Potter, with NASA Ames Research Center, Steve Klooster with the California State University, Monterey Bay, and Dennis Fitz, with UC Riverside. A final report will be available in the spring of 2001.

Improved Statewide Inventory Estimates of Ammonia Emissions From Native Soils in California – This work, a follow-on to the previous study, will measure ammonia emissions from native soils, and incorporate the measured emissions data into a model which includes environmental parameters such as soil type and climatic conditions. The project, also with Krauter and Potter as leads, will begin in the summer of 2001 with completion in the summer of 2003.

Remote Sensing Atmospheric Ammonia using NOAA's mini-MOPA CO_2 LIDAR in Central California – This project is funded to develop and evaluate a LIDAR (Light

Detection and Ranging) laser system to measure real-time, three-dimensional ammonia concentrations. The work is being performed by the National Oceanic and Atmospheric Administration (NOAA, Yanzeng Zhao, Alan Brewer, Mike Hardesty). Work is ongoing as challenges persist in developing and calibrating the necessary instrumentation.

Biogenic Emissions

In addition to evaluating volatile organic carbon from biogenic emissions, we are now also examining the contribution of biogenic emissions to particulate levels. This work will build on a GIS-based biogenics emissions model for California developed by Michael Benjamin of the ARB. Through contractor support, we have an ongoing project to consolidate the various components of the model into a single ArcView® based project which will allow easy modification of input and run parameters. In addition, we are sponsoring a field test project titled: *Biogenic Aerosols: Measurement of Precursor and Validation of Secondary Organic Aerosol Model Output*. This work will be performed Allen Goldstein of UC Berkeley, and will be completed in the summer of 2003.

GIS and Internet Programming Support

For several years, the ARB inventory staff has been exploring how the combination of GIS and web technology can be used to improve the completeness, accuracy, and accessibility of our emissions data. Unfortunately, this work has been performed in our 'spare' time, so our ability to design and develop systems with significant spatial display and analysis functionality has been limited. We have made some good progress in understanding what we want to do and how to do it. However, we have yet to produce significant GIS inventory tools that are readily available, easy to use, flexible, and very importantly, look good.

To help develop tools and prototypes, we have now entered into contracting agreements with professional GIS/web-design companies. We are using their GIS, web programming, and graphic design experience to help package and effectively deliver the important and useful inventory information we generate. This allows us to do the interesting and challenging inventory development and analytical work that we are trained for, while leaving some of the programming, design, and graphical challenges to experts in those areas.

GIS based projects currently funded or planned for funding include:

- Development of a Community Health Air Pollution Information System (CHAPIS), to provide web-based graphical displays of pollutant sources at the state, regional, and neighborhood levels;
- Development of a biomass user mapping system to help biomass users and generators locate each other more easily;
- Incorporation of GIS based vegetative burning emission estimation tools and technologies into a web-based GIS interface;
- Coding of our in-house biogenics model to provide an integrated, easy to use program with flexible run-time options and enhanced output capabilities.

Table 2 provides a brief listing of all of the $PM_{2.5}$ area source emission inventory research projects currently funded by the ARB.

Table 2. $PM_{2.5}$ Research Project Summary.

Research Category	Project	Researcher	Start	End	Funding ($)	Status
Geologic Dust	Evaluation of Geologic Dust Entrainment, Removal, and Transport Mechanisms	UC Riverside, D. Fitz	July 2000	May 2002	240,000	Ongoing
	Using GIS to Estimate Statewide Vehicle Activity and Roadway Mileage for Unpaved Roads in California	UC Davis, D. Niemeier	July 2000	May 2002	90,000	Ongoing
	Measurement of PM_{10} and $PM_{2.5}$ Emission Factors from Paved Roads in California	UC Riverside, D. Fitz	June 1999	June 2001	157,000	Draft report available
	Chromium Speciation for Various Geologic Dust Source Categories	ARB (tentative)	Summer 2001	Summer 2002	In-house	
	Simulation and Analysis of the Factors Leading to High PM10 Emissions Fluxes at the Owens Dry Lake Bed Using an Environmental Wind Tunnel	UC Davis, B. White	July 1998	March 2000	80,000	Final report available
Vegetative Burning & Charbroiling	Creating a Statewide Spatially and Temporally Allocated Wildfire and Prescribed Burn Emission Inventory Using Consistent Emission Factors (Phase I)	UC Berkeley, P. Gong	July 1999	April 2001	164,000	Final report available
	Input Validation, Sensitivity Analysis and Refinement to the ARB Wildland Fire Emissions Model	UC Berkeley, P. Gong	June 2001	August 2002	125,000	Contracting in progress
	Creating a Statewide Spatially and Temporally Allocated Agricultural Burning Emissions Inventory Using Consistent Emission Factors	UC Berkeley, P. Gong	June 2000	Fall 2001	90,000	Ongoing
	Model Development for Spatial Allocation of $PM_{2.5}$ Emissions Including Residential Wood Combustion	UC Berkeley, J. Radke	June 2000	Fall 2001	90,000	Ongoing
	Charbroiling Activity Estimation: Exploratory Analysis	CSU SF, M. Potepan	June 1999	June 2001	52,000	Ongoing
Ammonia	Development of Emission Inventories for Ammonia in Agricultural Systems of California Soils	CSU Fresno, C. Krauter NASA Ames C. Potter	April 1999	Spring 2001	186,000	Final report available
	Improved Statewide Inventory Estimates of Ammonia Emissions From Native Soils in California	CSU Fresno, C. Krauter NASA Ames C. Potter	Summer 2001	Summer 2003	200,000	Contracting in progress
	Remote Sensing Atmospheric Ammonia using NOAA's mini-MOPA CO_2 Lidar in Central California	NOAA Y. Zhao	Spring 1999	TBD	172,000	Ongoing
Biogenics	GIS Based Biogenics Emissions Model and Coding	ARB, M. Benjamin	Winter 2000	Ongoing	In-house	Ongoing
	Measurement of Precursor and Validation of Secondary Organic Aerosol Model Output	UC Berkeley, A. Goldstein	Summer 2001	Summer 2003	200,000	Contracting in progress
GIS	Various Projects to Create Web-Enabled GIS Systems	VESTRA, UC Berkeley, Others	Winter 2001	Ongoing	150,000+	Ongoing & Contracting in progress

CONCLUSIONS

In California, we have implemented a comprehensive and integrated research program for better understanding $PM_{2.5}$ emissions from point and area sources. We receive approximately six hundred thousand dollars a year and have funded numerous projects over the past three years (see Table 2). The projects are carefully prioritized and selected to address our most significant inventory needs first.

Most of the projects include a geographic information systems (GIS) component. This technology will substantially improve the quality, usability, and maintenance of our emission inventory data. We are also working to coordinate the development of compatible GIS based systems for ambient air quality data, meteorology, and modeling applications.

The ARB's $PM_{2.5}$ area source emission inventory research results are available to the public. Project descriptions, statements of work, and final reports are posted on our website at: http://arbis.arb.ca.gov/emisinv/pmnh3/pmnh3.htm.

For the future, we are continuing our process to identify and fund those projects that provide the greatest benefits for the lowest costs. With some of the most pressing needs now addressed, future projects could include:

- Particle size and chemical speciation testing
- $PM_{2.5}$ emissions factor testing
- Further incorporation of GIS analysis and visualization technology
- Development of a GIS based ammonia emission estimation system
- Further analysis and refinement of the contribution of geologic dust sources to $PM_{2.5}$ levels

This is an exciting time. Through the Air Resources Board's $PM_{2.5}$ area source inventory research program, we are providing better information about the quantity of $PM_{2.5}$ emissions produced by sources. In addition, we are creating spatial map-based emission estimates that provide detailed information about when and where the emissions occur. This research, and the results it provides, helps us to more completely understand our air pollution. This in turn leads to developing more effective methods for reducing pollution and improving the air quality in California.

ACKNOWLEDGEMENTS

The main thanks for this paper goes to the many talented and dedicated researchers working on the projects described in this paper. Their efforts are helping to improve the air quality and the health of the citizens of California. In addition, without the vision and support of the ARB's management, and the California Legislature, this work would not be possible.

DISCLAIMER

The opinions, findings, and conclusions expressed in this paper are those of the staff and not necessarily those of the California Air Resources Board.

KEY WORDS

$PM_{2.5}$, inventory, emissions, research, dust, smoke