STATE OF CALIFORNIA

AIR RESOURCES BOARD

MEETING OF THE

RESEARCH SCREENING COMMITTEE

March 9, 2012
9:00 a.m.

Air Resources Board
Research Division
Cal/EPA Building
1001 I Street
Sacramento, CA 95814
(916) 445-0753

State of California
AIR RESOURCES BOARD

Research Screening Committee Meeting
Cal/EPA Headquarters Building
1001 I Street
Conference Room 510, 5th Floor
Sacramento, California 95814
(916) 445-0753

&

California State Polytechnic University
Engineering IV, Building 192
Room Number: 206
Street location: Corner of California Blvd. and Highland Drive
San Luis Obispo, California

March 9, 2012
9:00 a.m.

AGENDA

I. Corrections to the minutes of the October 28, 2011 meeting and minutes to the December 2, 2011 meeting — iii-viii

II. Discussion of a Response to a Request for Proposals:

1) "Investigate the Durability of Diesel Engine Emissions Controls," RFP No. 11-309 — 1

- University of Denver
  Proposal No. 2734-273, $289,678

III. Discussion of New Research Projects:

1) "Benefits of High Efficiency Filtration to Children with Asthma," University of California, Davis, $3,350,000, Proposal No. 2735-273 — 7

2) "Quantification of the Emission Reduction Benefits of Mitigation Strategies for Dairy Silage," University of California, Davis, $400,000, Proposal No. 2736-273 — 19

3) "Emissions of Potent Greenhouse Gases from Appliance and Building Waste in Landfills," California Polytechnic State University, San Luis Obispo, $299,826, Proposal No. 2737-273 — 25

4) "Quantifying the Comprehensive Greenhouse Gas Co-Benefits of Green Buildings," University of California, Berkeley, $180,000, Proposal No. 2738-273 31

5) "Modeling Household Vehicle and Transportation Choice and Usage," University of California, Davis, $300,000, Proposal No. 2739-273 37

6) "PIsCES: the Personal InteraCtive Eco-driving System," University of California, Davis, $297,913, Proposal No. 2740-273 43

7) "Effects of Complete Streets on Travel Behavior," University of California, Los Angeles, $200,000, Proposal No. 2741-273 49

8) "Analyzing the Economic Benefits and Costs of Smart Growth Strategies," University of California, Berkeley, $300,000, Proposal No. 2742-273 55

IV. Review of Draft Final Reports:

1) "Effects of Ozone Exposure on Cardiovascular Responses in Healthy and Susceptible Humans," University of California, San Francisco, $399,029, Contract No. 04-322 61

2) "In-Vehicle Air Pollution Exposure Measurement and Modeling," University of California, Irvine, $500,000, Contract No. 07-310 65

V. Other Business:

1) "ARB Staff Update on Annual Research Plan"

State of California
AIR RESOURCES BOARD

Research Screening Committee Meeting
Cal/EPA Headquarters Building
1001 I Street
Conference Room 550, 5th Floor
Sacramento, California 95814
(916) 445-0753

December 2, 2011
9:00 a.m.

MINUTES

RSC Members in Attendance

Harold Cota
Chung Liu
Steven Japar – via teleconference
Daniel Costa – via teleconference
Tracy Thatcher – via teleconference
Matthew Kahn – via teleconference

The Research Screening Committee (RSC or Committee) convened the meeting at 9:07 a.m., temporarily adjourned at 10:16 a.m., and reconvened at 11:08 a.m. The meeting adjourned at 11:45 a.m.

I. Minutes

The minutes of the October 28, 2011 were approved with the following corrections in bold italics:

Draft Final Reports

1) "Spatiotemporal Analysis of Air Pollution and Mortality in California Based on the American Cancer Society Cohort," University of California, Berkeley, $749,974, Contract No. 06-332

   Written comments were submitted by the close of business on October 26 by members of the public: Frederick W. Lipfert, James E. Enstrom, Matthew A. Malkan, William B. Grant, Gordon J. Fulks, William Matt Briggs, John D. Dunn, and Norman R. "Skip" Brown. There were seven ***members of the*** public ~~***commenters***~~ who ***requested to make comments and*** read from or summarized the letters from Malkan, Dunn, Lipfert, Briggs, Brown and Enstrom. After the public comment***s*** ~~***period***~~, the Committee proceeded to discuss the draft final report. There were a number of questions from the

Committee regarding the methods described in the draft final report. There was an extensive discussion on the findings of all-cause mortality and mortality from cardiovascular (CVD) and ischemic heart disease (IHD). The Committee pointed out that there is a comprehensive body of literature that supports the association between PM2.5 and CVD and IHD. In addition, the Committee recognized that from a health perspective, the association between PM2.5 exposure and CVD and IHD was biologically more plausible than for all-cause (which includes deaths unrelated to PM2.5 exposure, such as accidental deaths). Furthermore, all the models showed CVD and IHD associations with PM2.5, whereas only the most refined model showed an effect from PM2.5 on all-cause death. Therefore, the Committee felt that the report should emphasize the CVD and IHD results, in the "conclusions" and "abstract" sections of the report, consistent with the results in the body of this report. Overall, the Committee believed that the report used state-of-the-art techniques, and presented an extensive amount of work, and provided ***good estimates*** ~~***the best estimates possible***~~ for PM2.5 exposure and health outcomes in California.

2) "Assessing Near-Field Exposures from Distributed Residential Wood Smoke Combustion Sources," California Polytechnic State University, San Luis Obispo, $320,286, Contract No. 07-308

   Motion: Move to accept subject to the inclusion of comments from staff and the Committee. ***Note: Dr. Thatcher left the room and Dr Cota abstained from discussion and the vote. Dr. Williams presided.***

3) "Physicochemical and Toxicological Assessment of the Semi-Volatile and Non-Volatile Fractions of PM from Heavy-Duty Vehicles Operating with and without Emissions Control Technologies," University of Southern California, $677,950, Contract No. 05-308

   The Committee noted that the dithiothreitol (DTT) and reactive oxygen species (ROS) tests do not meet the reader's expectation generated by the word "toxicological" in the title, and suggested ~~***that a different word be used in future reporting.***~~ ***toxicological be removed from the title.***

Minutes of the December 2, 2011 Meeting:

II. New Research Projects

1) "Reducing In-Home Exposure to Air Pollution," Lawrence Berkeley National Laboratory, $1,300,994, Proposal No. 2733-272

   The Committee expressed general support for the proposal and noted the innovative approach of the project, the well-qualified research team, and the extensive amount of data that will be generated from the ambitious fieldwork. Several Committee members expressed concern over the project's high price, and especially Lawrence Berkeley National Laboratory (LBNL) high indirect costs, but acknowledged the quality research associated with the contractor. Staff noted that an administrative fee waiver, typically granted to state governments, will almost certainly be waived as staff has requested. In

response to one question, staff clarified that this project will not prevent the funding of other projects in the annual research plan approved by the Air Resources Board (ARB or Board) in September, 2011.

A Committee member asked whether the State could achieve a cost savings by shifting some of the proposed fieldwork to a laboratory setting and whether the initial literature search could be reduced. Staff responded that most systems have been tested for their basic performance in laboratory settings by the manufacturers and/or third parties, and that ARB is interested in obtaining real-world performance data as a basis for future recommendations. It was clarified that the initial tasks include not only a detailed literature search but scoping and modeling tasks, which will be used to reduce the more costly fieldwork tasks.

Another Committee member asked whether this project will measure reductions in indoor pollutants and whether the results will be applicable to other homes. Another Committee member responded that LBNL will measure basic parameters in the test home, and use the results to create a model that can be applied to most other homes, and will generate a basic understanding of how each system reduces indoor contaminants.

Finally, one Committee member raised concern regarding the acceptability of manufacturers providing their prototype systems for testing by LBNL at no cost to the State, which is expected to occur. Staff indicated they will check with the Legal Office regarding this possibility.

Motion: Move to accept subject to the inclusion of comments from staff and the Committee.

The Committee approved the proposal.

2) "Reducing Air Pollution Exposure in Passenger Vehicles and School Buses," University of California, Los Angeles, $150,000, Proposal No. 2730-272

The Committee asked several questions and expressed general support for the proposal. They suggested that the proposal was not clear regarding what is meant by placing the monitor intakes near the "breathing zone" (cautioning that they not be placed too near the face of the driver to avoid sampling exhaled breath), and that the principal investigator (PI) consider using the carbon dioxide (CO_2) from the exhaled breath of the driver to estimate the air exchange of the cars while they are being driven during the tests. Staff passed these comments on to Dr. Zhu, who revised her proposal accordingly.

Motion: Move to accept subject to the inclusion of comments from staff and the Committee.

The Committee approved the proposal.

3) “Modeling the Formation and Evolution of Secondary Organic Aerosol During CalNex 2010,” University of Colorado, $350,000, Proposal No. 2731-272

A member of the Committee believed that the project would be a comprehensive and extremely ambitious investigation into secondary organic aerosol (SOA) formation and evolution, but was also concerned that the researchers had possibly “bitten off more than they could chew.” The concerns raised were with the many uncertainties in the analysis and interpretation of field study data, in specific model implementations for SOA to be used in the project and, more widely, with what the results will mean in terms of SOA model improvements. Staff expressed the view that although uncertainties are associated with aspects of the proposed analyses and modeling studies, significant recent progress in these areas had greatly reduced many of these uncertainties, and that with the extensive gas and particle-phase measurements from CalNex 2010, the proposed research will test and constrain SOA models at a level of detail that has not been possible previously.

Motion: Move to accept subject to the inclusion of comments from staff and the Committee.

The Committee approved the proposal.

4) “Long Range Transport of Air Pollutants into California,” University of California, Davis, $506,084, Proposal No. 2729-272

The Committee was concerned about the tone of the proposal, and asked whether the material was reflective of ARB policy, or just the author’s rhetoric. Staff noted that it was rhetoric, but that ARB must attain national ambient air quality standards. Staff noted that several states are concerned about the contribution of ozone transport to air quality problems and are attempting to get the United States Environmental Protection Agency (U.S. EPA) to recognize and address the issue. A Committee member noted that the U.S. EPA had not felt it necessary to recognize the role of dust transport from Africa on attaining particulate matter (PM) air quality standards in Texas. The Committee member noted that the hypothetical scenario presented where emissions in California could go to zero and the State still might not attain the ozone standard was worrisome.

Motion: Move to accept subject to the inclusion of comments from staff and the Committee.

The Committee approved the proposal.

5) “Atmospheric Measurement and Inverse Modeling to Improve Greenhouse Gas Emission Estimates,” Lawrence Berkeley National Laboratory, $680,000, Proposal No. 2724-272

Motion: Move to accept subject to the inclusion of comments from staff and the Committee.

The Committee approved the proposal.

6) “Source Speciation of Central Valley GHG Emissions using In-Situ Measurements of Volatile Organic Compounds,” University of California, Berkeley, $360,000, Proposal No. 2732-272

Two members of the Committee concentrating on staff comments, page 32 of the Agenda book, questioned whether the complexities and other approaches staff had identified and discussed complicated or compromised the effort. Because of a long-term pilot program at the Walnut Grove Tower during July and August of 2011, the method has been thoroughly tested and given the wealth of information on speciated volatile organic compounds (VOC) in terms of source data. There is every confidence that the study can succeed.

Motion: Move to accept subject to the inclusion of comments from staff and the Committee.

The Committee approved the proposal.

7) “Development of a New Methodology to Characterize Truck Body Types along California Freeways,” University of California, Irvine, $350,000, Proposal No. 2727-272

Motion: Move to accept.

The Committee approved the proposal.

8) “Evaluating Mitigation Options of Nitrous Oxide Emissions in California Cropping Systems,” University of California, Davis, $400,000, Proposal No. 2728-272

Staff presented an update on additional comments from agricultural stakeholders on the proposal. The stakeholders requested that two of the five crops (almonds and grapes) be dropped. The project can then focus on the other three crops (tomatoes, lettuce and corn), which have greater mitigation potential.

Motion: Move to accept subject to the inclusion of comments from staff and the Committee.

The Committee approved the proposal.

9) “Assessment of the Emissions and Energy Impacts of Biomass and Biogas Use in California,” University of California, Irvine, $169,997, Proposal No. 2726-272

The Committee asked which greenhouse gas emissions will be studied. Staff replied that the University of California, Irvine (UCI) will be contacted to determine if any gases other than CO_2 and methane will be studied.

The Committee asked for clarification that the use of hydrogen for light-duty fuel cell vehicles would result in less nitrogen oxides (NO_X) emissions than the use of methane. Staff replied that, although this may be true, the proposal should provide some discussion of this issue.

In response to Committee concern that the proposal states that biomass fuel scenarios "could" provide some emission reduction benefits compared to non-biogas fuels, UCI should clarify that these benefits will occur.

Motion: Move to accept subject to the inclusion of comments from staff and the Committee.

The Committee approved the proposal.

III. Draft Final Reports

1) "Is Disparity in Asthma among Californians due to Higher Pollution Exposures, Greater Vulnerability, or Both?" University of California, Los Angeles, $299,794, Contract No. 07-309

   Staff informed the Committee that the report was sent for external review. The reviewers suggested additional analyses and commented that the tables in the report needed revisions to improve the clarity. The Committee had no questions on the external reviewers' comments.

   One of the Committee members suggested that graphs be added to the report to make the results of the study easier to understand. Another Committee member suggested that the data from California Health Interview Survey (CHIS) subjects living in source and receptors areas of ozone (O_3) be examined to see if there is a health effect in the lower income subjects with higher O_3 exposure. Staff informed the Committee that this may not be feasible since the size of the CHIS population might not be large enough, but staff will ask the investigator to explore this possibility.

   Motion: Move to accept subject to the inclusion of comments from staff and the Committee.

   The Committee approved the report.

2) "Retail Climate Change Mitigation: Life-Cycle Emission and Energy Efficiency Labels and Standards," University of California, Berkeley, $265,144, Contract No. 07-322

   Motion: Move to accept.

   The Committee approved the report.

3) "SF_6 Replacement Evaluation in Magnesium Sand and Investment Casting," California State Polytechnic University, Pomona, $49,995, Contract No. 09-366

   Motion: Move to accept.

   The Committee approved the report.

RESPONSE TO A REQUEST FOR PROPOSALS
ITEM NO: 1
DATE: March 9, 2012
PROPOSAL: 2734-273

STAFF EVALUATION OF A SOLICITED RESEARCH PROPOSAL

TITLE:	Investigate the Durability of Diesel Engine Emissions Controls
RFP NO.:	11-309
BIDDER:	University of Denver, $289,678
CONTRACT TERM:	72 Months

For further information, please contact Dr. John Collins at (916) 327-8097.

I. SUMMARY

Introduction of new engine emissions standards for particulate matter (PM) and oxides of nitrogen (NO_X) will result in a substantial decrease of these pollutants over the course of the next several years. This reduction is generally achieved by using aftertreatment devices such as diesel particulate filters (DPF) and selective catalytic reduction (SCR) to reduce PM and NO_X respectively. The Air Resources Board's (ARB) recently revised fleet rules will lead to gradual introduction of these technologies on California highways and ports, thereby reducing emissions from diesel engines.

While various studies have been performed to assess the efficiency of these devices, so far minimal data exists on durability and deterioration. The primary reason for limited data includes fairly recent introduction of these devices along with the challenges related to sampling thousands of trucks over a course of multiple years. The available data is especially sparse in terms of PM measurement and has often utilized technologies that don't measure PM directly. In essence, while the available data can demonstrate fleet emission changes due to improvement in engine technology, it does not provide a good understanding of emission changes related to the introduction of aftertreatment devices over an extended period of time. It is important to measure pollutant concentrations in the real world because trucks with malfunctioning aftertreatment devices could emit tens to hundreds of times higher emissions than a truck meeting certification standards. Potential aftertreatment failures and related emissions increases would reduce the air

quality and health benefits of the new engine standards and also generate inaccurate emission inventories. Additionally, the data generated from this study may provide clues about tampering/mal-maintenance of these devices that could cause increases in pollutant concentrations.

The proposed project will build upon existing databases of on-road measurements (remote sensing, vehicle chase studies, etc.), to provide a comprehensive analysis of pollutant profiles over the course of several years. At a minimum, data will include measurements of criteria pollutants, such as carbon monoxide (CO), total hydrocarbons (THC), black carbon (BC), NO_X, and PM. Particle number and size distribution will also be collected based on instrumentation availability from ARB.

II. TECHNICAL SUMMARY

Objective

The objective of this study is to collect on-road heavy-duty diesel emissions data over a course of multiple years in the State of California. The data gathered from this study will be used to assess durability and deterioration of aftertreatment devices utilized to reduce PM and NO_X concentration. This in turn will help assess the effectiveness of the ARB's diesel fleet rules, aid in the development of accurate emissions inventories for heavy duty diesel engines, and shed light on any need for consideration of additional durability requirements.

Project Summary

The RFP required that Contractor shall:

- Provide detailed research plan that includes work schedule, quality assurance/quality control procedures, project schedule and annual budget by tasks for various years.
- Perform sampling campaigns in 2013, 2015 and 2017 at two different locations in Southern California. Locations must be (i) near a port and (ii) near the vicinity of general vehicular population area alongside a highway. Collect data on at least 1500 vehicles at each location during a campaign.
- At minimum, collect CO, THC, BC, NO_X and PM mass. And collect PM number and size and number concentration data if possible.

- Provide interim data/progress reports as well as raw data after each campaign. The data analysis should clearly be able to delineate effectiveness (and hence the durability and deterioration) of the aftertreatment device.
- Provide draft final report at the completion of the contract.

Proposal Summary

One proposal was received in response to the RFP. The proposal met administrative requirements. The following is a brief summary of the proposal.

University of Denver

The proposal describes a novel remote sensing technology, namely, Truck Tent Testing (TTT) that investigators will use for this study. This methodology is a significant improvement from their previous campaigns as it allows capture of a plume for a sustained period of time (as the truck traverses through a tent), integrating the exhaust into a single concentrated signal which otherwise would be faint in ambient air. This should drastically improve the signal-to-noise ratio and the capture rate of valid emission readings. The available hardware and software would measure CO, carbon dioxide (CO_2), THC, nitric oxide (NO), NO_X, PM mass and size and BC. Speed and acceleration will be monitored as well. Finally, integrated pollutant ratios to CO_2 will be calculated and converted to fuel-based emissions.

The license plate information will be captured and matched to the Department of Motor Vehicle database to generate engine model and year profiles. Exhaust temperature measurement will be qualitatively recorded using infra-red (IR) cameras. The investigators also plan to monitor the presence of SCR by capturing video images and looking for a blue-cap which is often used on top of an SCR tank.

The investigators will take measurements in 2013, 2015 and 2017 in the Los Angeles area. The investigators have proposed the Peralta weight station in the Los Angeles basin as the near-highway site. They monitored there in 1997, 2008, 2009, and 2010 and will monitor again this year. The investigators will consult with ARB staff to finalize a site near the Port of Los Angeles. They performed measurements near the port in 2008, 2009 and 2010.

The University of Denver proposed a budget of $289,678 for this study. Of this amount, $196,525 (68 percent) is the direct cost and $93,153 (32 percent) is the indirect cost. The indirect (overhead) rate is therefore 47 percent. Combined labor and benefits for Dr. Gary A. Bishop and Dr. Donald H. Stedman are $141,973 which is 72 percent of the total direct cost.

III. STAFF COMMENTS

Comments from staff are summarized in the following section with proposal scores summarized in Table 1.

University of Denver

The sole proposal received from the University of Denver was strong in terms of familiarity with the subject matter, reflected investigators expertise in the area of on-road measurements, clearly and completely incorporated requirements from the Scope of Work, and presented a thorough and detailed approach to develop a research plan to address our needs. The University of Denver has performed nine different on-road remote sensing studies, for trucks, in California (including the Port of Los Angeles) with others in Texas, Colorado and Switzerland. Additional light-duty remote sensing on-road measurements have also been taken by the investigators in California and other parts of the world. The findings from a variety of these studies have been published in peer-reviewed journals. The principal investigators, Drs. Bishop and Stedman, have been collaborating on on-road measurement projects for more than two decades and possibly are the leading world experts in heavy-duty diesel remote-sensing measurements. Together, they will spend approximately 14 months of effort towards this study. They plan to make use of a consultant, Mr. Ian Stedman, who has participated in many on-road measurement projects, and is an expert in site selection and transcription of data from recorded videos to data logs.

Because the investigators have collected remote sensing data at the proposed sites, the current study will complement the previously collected data. This multi-year cumulative data will allow a robust analysis of durability and deterioration of aftertreatment devices. The data will also support benefits evaluation of diesel fleet rules, and in development of more accurate emissions inventories.

The investigators have all the necessary monitors/analyzers as required in the RFP. Staff expressed the following concern about their proposed PM measurement methodology:

- The instrumentation proposed to measure PM size distribution may not be ideal to provide realistic results due to low PM concentrations (from retrofitted trucks). ARB may ask investigators to use supplemental methods (like an engine exhaust particle sizer) to measure size distributions. ARB may loan the instrument to the investigators depending upon the availability.

The requested funding was within the maximum specified in the RFP. The requested funding includes salary for 14 person-months of effort by the principal investigators and travel for three sampling campaigns in California, and is adequate to complete the work.

IV. STAFF RECOMMENDATION

Staff recommends that the Research Screening Committee approve the qualifying scores for the proposal submitted by the University of Denver. The proposal was within the proposed $300,000 budget. Staff recommends that the proposal from the University of Denver be approved for funding at a total amount not to exceed $300,000, subject to any changes and additions specified by the Committee.

Table 1: RATING CRITERIA for "Investigate the Durability of Diesel Engine Emissions Controls"

RATING CRITERION	MAXIMUM POINTS POSSIBLE	UNIVERSITY OF DENVER REVIEWER CONSENSUS SCORE
1. Technical approach and work plan, including understanding of the problem and incorporation of the proposal requirements described in the scope of work	25*	24
2. Previous related experience in on-road measurements similar to the proposed research.	15	13.5
3. Availability of measurement instruments and other materials for sampling campaigns.	10	7
4. Level and quality of effort to be provided, including project management plan.	10	7
5. QA/QC plan	10	8
6. Cost	30	30
TOTAL SCORE	**100**	**90**

A proposal must have a total score of at least 85 points to be qualified for consideration for this contract.

*Proposals receiving less than 20 points for this criterion will not qualify for further consideration

DISCUSSION OF A NEW RESEARCH PROJECT
ITEM NO: 1
DATE: March 9, 2012
PROPOSAL NO.: 2735-273

STAFF EVALUATION OF A RESEARCH PROPOSAL

TITLE:	Benefits of High Efficiency Filtration to Children with Asthma
CONTRACTOR:	University of California, Davis
PRINCIPAL INVESTIGATOR:	Deborah H. Bennett, Ph.D.
TOTAL AMOUNT:	$3,350,000
CONTRACT TYPE:	Interagency Agreement
CONTRACT TERM:	48 Months

For further information, please contact Peggy Jenkins at (916) 323-1504.

I. SUMMARY

Particulate matter (PM) and ozone levels continue to be elevated in California urban areas, and a number of studies have shown that ultrafine PM (UFP) is elevated near busy roadways. These pose a significant health issue, because elevated ambient PM and ozone and near-roadway exposures have been associated with numerous adverse effects, including exacerbation of symptoms in children with asthma. The objectives of this project are to determine the extent to which high efficiency air filtration in homes reduces indoor exposures to PM and ozone, and whether there is a concomitant reduction in asthma symptoms in children with moderate to severe asthma. Two hundred children will be enrolled for two years to test the effects of central system or portable high efficiency filters or filtration units. It is anticipated that this project will find that both the in-duct and stand-alone high efficiency filtration units will result in reduced indoor air pollution and a lower prevalence of asthma symptoms. As a result of this study, ARB should be able to determine whether these interventions will reduce exposures to key air pollutants and be cost effective in reducing health costs associated with asthma care.

II. TECHNICAL SUMMARY

Objective

The general objective of this study is to quantify the exposure and asthma reduction benefits of high efficiency filtration. The specific objectives are to:

1. Determine the extent to which the use of high efficiency in-duct filtration and high efficiency portable air cleaners in homes of children with moderate to severe asthma reduce their indoor exposures to ambient and indoor PM, UFP and ozone.
2. Determine the extent to which the use of high efficiency in-duct filtration and high efficiency portable air cleaners in their homes reduces the children's asthma symptoms, emergency room visits, hospitalizations, use of rescue inhalers, missed school days due to asthma, and other measures of asthma reduction.
3. In the course of obtaining data to meet the above objectives, measure the current indoor, outdoor and personal exposures of children with asthma to PM, UFP and ozone.

Background

Particulate matter has long been known to cause serious adverse respiratory and cardiovascular health effects. Numerous studies have shown that elevated PM levels increase asthma symptoms of individuals with asthma, and can negatively affect the lung function of healthy children. Exposure to ozone also is a concern. Several studies have shown a correlation between areas with high ozone and increased asthma symptoms, extra asthma medication use, rescue medicine use, and emergency department visits in adult populations.

Approximately 8.5 percent of children in the United States suffer from asthma. Some counties in California have considerably higher levels. For example, in Fresno County 20.2 percent of 5-17 year olds have ever been diagnosed with asthma, and 12.6 percent have asthma currently. Asthma puts a considerable burden on the health care system and treatment costs $3.2 billion per year in the United States. Should air filtration improve symptoms, there could be a cost savings from implementing air filtration as an asthma intervention tool on a larger population, particularly in a region with high air pollution levels, such as parts of California. California experiences some of the highest air pollution in the United States, with 8 of the top 10 cities for ozone pollution and 6 of

the top 10 for particle levels. Therefore, California is the ideal location to conduct a study to evaluate the potential benefits of high efficiency air filtration.

Because people spend on average two-thirds of their time indoors at home, indoor levels of air pollution, whether originating from outdoor or indoor sources, have an impact on health. Pollutant levels indoors result both from movement of outdoor air into the indoor environment and emissions from indoor sources and activities such as cooking, smoking, candle burning and ozone chemistry. Future infill development will place new residential housing closer to major roadways and transportation hubs. Because major roadways are a significant source of UFP and black carbon in the outdoor environment, homes close to these outdoor sources will experience higher indoor UFP and black carbon levels due to infiltration of the outdoor air.

Recent studies indicate that the use of high efficiency filtration in homes may be an effective strategy to mitigate indoor exposures. A common scale used to indicate filter efficiency is the Minimum Efficiency Reporting Value, or MERV rating. Most homes with a central air conditioning and heating system use low efficiency glass fiber filters with a low (1-4) MERV rating, as shown in Table 1, below. Such filters capture only the largest particles (>PM 10) and protect the blower motor from damage. However, these filters do very little to improve air quality in the home. Pleated filters with higher MERV ratings provide far greater surface area and filtration efficiency. Medium efficiency filters (MERV 5-12) remove from about 20 percent of PM10 at the bottom of the range to about 80 percent of particles 1 µm and larger at the top of the range. High efficiency filters range from MERV 13-16, and true HEPA filters are essentially MERV 17-20. High efficiency filters or filtration systems remove from less than 80 percent to more than 95 percent of particles 0.3 µm and larger, and also remove a fraction of the smaller particles. True HEPA filters are targeted toward particles smaller than 0.3 µm and remove virtually all particles larger than 0.3 µm. Both portable high efficiency filtration units and high efficiency filters installed in the central air system have been shown to reduce indoor concentrations of particulates. However, higher efficiency filters must be carefully selected for homes to assure the central system can handle the increased airflow resistance, and some high efficiency filters are 2 or 4 inches deep, requiring wider filter holders.

Table 1. MERV Ratings*					
MERV Rating	**Average Particle Size Efficiency (PSE), microns – % Removal**			**Typical Controlled Contaminant or Material Sources (ASHRAE 52.2)**	**Typical Building Applications**
	0.3-1.0	**1.0-3.0**	**3.0-10.0**		
1-4			<20%	**> 10 Microns** Textile Fibers Dust Mites, Dust, Pollen	Window AC units Common Residential Minimal Filtration
5			20-35	**3.0 to 10.0 Microns** Cement Dust, Mold Spores, Dusting Aids	Industrial Workplace Better Residential Commercial
8			>70		
9		<50	>85	**1.0 to 3.0 Microns** Legionella, Some Auto Emissions, Humidifier Dust	Hospital Laboratories Better Commercial Superior Residential
12		>80	>90		
13	<75	>90	>90	**0.3 to 1.0 Microns** Bacteria, Droplet Nuclei (sneeze), Most Tobacco Smoke, Insecticide Dust	Superior Commercial Smoking Lounge Hospital Care General Surgery
16	>95	>95	>90		
17**	≥ 99.97			**<0.3 Microns (HEPA/ULPA filters)**** Viruses, Carbon Dust, Fine Combustion Smoke	Clean Rooms Carcinogenic & Radioactive Matls., Orthopedic Surgery
18**	≥ 99.99				
19, 20**	≥ 99.999				

* Adapted from EPA 2009; originally from ANSI/ASHRAE Standard 52.2-2007.
** Not part of the official ASHRAE Standard 52.2 test, but added by ASHRAE for comparison purposes.

Several studies have been conducted to determine if installation of a portable air cleaner can reduce asthma symptoms, with either a reduction of symptoms or improved lung function found in a number of them. However, other studies have failed to find a relationship, and those that did often failed to find improvements across a range of outcomes. Those studies suffered from numerous shortcomings. First, many of the studies had a small sample size: all but one of the 12 studies reviewed in two comprehensive reviews had 45 or fewer participants. Additionally, some studies did not use high efficiency filtration or did not document the level of filtration achieved. Another significant shortcoming is that a majority of studies had intervention periods less than 3 months. It has been suggested in a review by the American Academy of Allergy, Asthma & Immunology Indoor Allergen Committee that interventions should be sustained for at least 12 months to yield meaningful clinical results.

To fully evaluate the impact of air filtration, more comprehensive studies are needed that avoid the weaknesses of prior research by having a larger study population and a longer intervention period, using high efficiency filters, and using a suitable control. The

proposed study addresses these shortcomings and should provide valuable information regarding ways to improve indoor air quality and reduce asthma symptoms.

Proposal Summary

Two hundred children 6-12 years of age with asthma will be enrolled to determine the effectiveness of high efficiency filtration (MERV 15 rating) of indoor air to reduce indoor exposures and asthma symptoms in regions with high outdoor air pollution. One intervention group (about 100 children) will have high efficiency filters or filtration systems installed in their central forced air heating and air systems (with modifications to enable the installation, if needed). The second intervention group (about 100 children) will have high efficiency portable air cleaners placed in the child's bedroom and in the main living area. One half of this group also will have ozone and VOC filtration. Improvements in asthma symptoms will be evaluated in a randomized cross-over design, with each participant receiving true air filtration for a year and no filtration for a year, allowing the investigators to compare matched calendar months and seasons with and without filtration and to isolate the improvements related to the air filtration from effects that might result from simply being enrolled in the study. The cross-over study design has the advantage that each individual serves as his or her own control, thereby strengthening the study design. During the no filtration period, a filter with a MERV rating of 1-4 typically used in homes will be used in the central forced air system to protect the blower motor; these provide only minimal improvement of air quality. For the portable air cleaners, the high efficiency filter will be replaced with a sham filter that removes virtually none of the particles, to simulate not having a portable air cleaner.

To assess exposure outcomes, integrated 2-week indoor and outdoor air pollution samples will be collected every 6 months, with one measurement pre-enrollment and two measures in each sham and true filtration period. Samples will be obtained for PM0.2, PM2.5, and PM10, and ozone. The samplers will be placed in the participant's bedroom. PM0.2, PM2.5 and PM10 will be collected using a cascading impactor with the PM0.2 mass collected on a Teflon filter and the PM0.2-2.5 and 2.5-10 mass collected using polyurethane foam (PUF). PM10 and PM2.5 will be determined by summing the mass on the relevant stages. Samples will be collected for 14 days to provide a 2-week integrated measure. The PM0.2 sampler provides a long-term, integrated measure of UFP and near-UFP sized particles needed for exposure assessment comparisons. Real-time UFP

monitors may be used in a few homes to provide ancillary data, but they are cost-prohibitive for the large number of homes in this study, and minute-by-minute measures of UFP are not useful for meeting the objectives of this project. The PM0.2 samples also will be measured for reflectance, which correlates with black carbon; the reflectance measures can be used to approximate the indoor to outdoor ratio of particles of outdoor (vehicular) origin. The principal investigator suggests an option to use UC Davis co-funding to collect PM2.5 samples on Teflon filters to measure black carbon by reflectance.

Indoor and outdoor ozone measurements will be obtained in all homes during the high ozone months (May-October). Ozone sampling in the homes without ozone filtration will provide data on the extent to which indoor ozone levels in the current housing stock are reduced from the incoming air due to central system and indoor surface interactions and reactivity. Two-week integrated ozone samples will be obtained using passive Ogawa badges, which have been used successfully in numerous studies. During the non-ozone months (November-April), indoor NO_2 samples will be collected in all homes for the relevant sampling visits.. NO_2 can be a significant indoor pollutant during winter months (primarily due to gas appliances) and is known to cause or exacerbate respiratory conditions in children.

About 25-30 of the participants 9-12 years of age will also be asked to wear personal PM2.5 samplers to collect 48-hour samples of PM2.5 on Teflon filters. Samples will be collected during the weeks of indoor and outdoor sampling so that correlation of personal exposures with reductions in indoor concentrations can be assessed to a limited extent. Pumps with 4 liter per minute flow rates will be placed with the samplers in small backpacks, which have been used successfully in prior field studies.

Measures of health effects will include changes in unplanned utilization of the healthcare system for asthma-related illness, short-term medication use, symptom diaries, peak exhaled flow, spirometry, and exhaled nitric oxide (eNO). Health outcomes will be assessed by 2-week symptom diaries and 1-week peak flow measurements collected seasonally. During the intervention (true filtration) and control sham periods, a 2-week recall questionnaire will always be obtained along with a 2-week symptom diary. Unplanned utilization of the healthcare system, short-term medication use, symptom

diaries, and peak exhaled flow will be recorded just prior to intervention and quarterly both during the intervention and control sham periods. In addition, exhaled nitric oxide levels (eNO) − an indicator of inflammation − will be collected every six months, at the end of the air pollution monitoring periods. Spirometry data will be collected just once a year for each participant, as it is more taxing on the participant and has not been well correlated with interventions in previous studies. However, the investigator is considering the reduction or elimination of the self-administered peak flow measurements and a concurrent increase in the spirometry measurements based on weak compliance with self-administered peak flow measurements by children in other studies. A detailed field schedule has been developed by the investigator to assure that measurements for air pollution and asthma endpoints are collected in the same months of the year for the sham and true filtration periods. This is necessary to allow direct comparison due to the seasonal differences in both pollutant levels and asthma triggers.

III. STAFF COMMENTS

ARB staff consulted with staff from the State Asthma Program at the California Department of Public Health (CDPH) prior to initiating the development of the proposal. ARB and CDPH staff reviewed the first draft of the proposal, and comments were provided to the investigator. Staff asked the investigator to make a number of revisions, such as to ensure that the intervention period runs for a full year, to provide more QA/QC data on the Harvard cascade impactor planned for use to obtain near-UFP measurements, and to include some personal monitoring. The proposal was revised accordingly, and was subsequently submitted to an expert advisory committee for review. The committee will also review the questionnaires, diaries and protocols to be used in the study; the pilot study results and final main study plan; and the draft final report. The advisory committee consists of six members:

- Diane Gold, DTM&H, M.D., Harvard University. Dr. Gold's research focuses on the relationships between environmental exposures and the incidence or severity of respiratory diseases, including asthma. She was a co-investigator of a large study of asthma in inner city schools.
- Rick Kreutzer, M.D., California Department of Public Health. Dr. Kreutzer is principle investigator for California Breathing, the CDC-sponsored program to address asthma

from a public health perspective. Dr. Kreutzer has also helped develop a framework for environmental health tracking (surveillance) and better asthma surveillance in the State.

- Kari Nadeau, M.D., Ph.D., Stanford University. Dr. Nadeau is a pediatric asthma specialist. She has studied how pollution, such as diesel exhaust, disrupts immune function.
- Richard Shaughnessy, Ph.D., University of Tulsa. Dr. Shaughnessy has published extensively on particulate research, air cleaner evaluation, indoor chemistry, school studies, flooring studies, asthma/housing research, ozone-initiated indoor reaction, and resolution and remediation of bioaerosol-related problems.
- Linda Sheldon, Ph.D., Associate Director, Human Exposure, National Exposure Research Laboratory, U.S. EPA. Dr. Sheldon has conducted and overseen many large indoor and personal exposure studies, including several on VOCs and PM, and studies of children's exposures.
- John Spengler, Ph.D., Harvard University. Dr. Spengler has conducted or overseen many large field studies on air pollution exposure, including an asthma intervention study in low income/public housing. Dr. Spengler has conducted several exposure and health studies in southern California and chaired National Academy of Sciences committees on indoor air quality and various health topics.

The comments from the committee were generally positive, and the consensus was that this is an important study that has long been needed. There were several suggestions made by the committee that they felt would improve the study. First, it was recommended that all participants be given mattress covers in order to minimize exposure to asthmagens (primarily house dust mites) that would not be removed by filtration and might overwhelm any benefit of filtration. Second, it was agreed that the original plan to collect air pollution measures at six month intervals for one week duration be extended to two weeks duration in order to provide a more robust characterization of the exposure measures. It was also recommended that separate peak flow measurements not be collected and instead collect more spirometry data (which includes a peak flow measure) because of non-compliance with the self-administered peak flow measurements. The advisors generally agreed the air samplers should be placed in the participants' bedrooms as opposed to the main living areas. When asked about possible

cost-cutting measures, the committee suggested that the number of ozone measurements and the amount of personal monitoring might be reduced. Suggestions for air exchange rate (AER) measurements and collection of settled dust (to identify the asthmagens that would be removed from the air by the filters) were discussed, but consensus was not reached. Meaningful AER measurements are not feasible over such a long period of time, and are not necessary as the tracking of window opening behavior can be used as a surrogate. The methods of collection of dust that would be meaningful for data analysis of the asthmagens removed by the filters were not agreed upon. After receipt of the advisory committee's comments, the proposal was revised to incorporate the committee's suggestions on which consensus was reached, except that the peak flow vs. spirometry decision was left until later because some alternate opinions were received from other asthma investigators subsequent to the meeting. The revised proposal was submitted for the Research Screening Committee's (RSC) review.

The investigators undertaking this large and complex study are of a high caliber. The team covers the areas of expertise needed to conduct a high quality, successful study, including knowledge of asthma management and assessment, exposure monitoring and assessment, filtration, indoor air quality, epidemiology and statistics. Dr. Deborah Bennett has expertise in indoor-outdoor pollutant relationships, monitoring, exposure measurement and modeling, and environmental epidemiology. She recently completed a successful study of indoor air quality, ventilation and energy use in 40 small and medium commercial buildings in California for ARB and the California Energy Commission, and a study of children's exposures to a number of environmental contaminants. Dr. Nicholas Kenyon and Dr. Marc Schenker from the University of California, Davis bring expertise in asthma and epidemiology to the project, and Bill Fisk from Lawrence Berkeley National Laboratory is an internationally respected expert in indoor air quality and filtration. Other members of the team add strength in statistics, asthma and the health effects of air pollution.

Because a clear consensus was not reached for all of the issues considered by the advisory committee and the timeline between receipt of the committee's comments and the mail out of the proposal was short, the principal investigator has left a number of key questions open for decision. However, staff believes some of these issues should be

resolved now. Because of the importance of vehicle - related exposures, and because particles entering the homes are likely to be “aged,” staff believes a measure of PM2.5 indoor and outdoor black carbon levels (reflectance as a surrogate is acceptable given cost constraints) needs to be included in the proposal as a task for 50 homes closest to busy/major roadways, so that the extent to which high efficiency filters remove those particles associated with traffic emissions can be examined. Additionally, while staff agree that the peak flow vs. spirometry decision can be postponed until more information is obtained and the compliance of the study cohort is assessed, staff would like to see a statement in the proposal of the number of spirometry measurements that would be made for each child if the self-administered peak flow measurements are replaced with spirometry, to assure that sufficient measurements can be obtained within the budget. Staff believes the use of PUF for collection of PM2.5 over a 2-week period needs to be better documented as an effective method for obtaining PM2.5 samples prior to the main study, either through publication of results by others or a robust comparison test as part of the pilot in this study. Additional details for side-by-side testing with other accepted PM2.5 indoor sampling methods as part of the pre-pilot should be provided in the proposal. Concerns regarding moisture absorption by PUF and possible mold or bacterial growth in PUF over the 2-week sampling period should be addressed. Staff agrees with the extension of particle sampling from one to two weeks, but there is no quantitative assessment of the number of sampling weeks that would be adequate for the purposes of this study; such discussion needs to be included in the proposal. Additionally, the original solicitation was for a study to examine the extent to which exposures would be reduced by high efficiency filtration (as specified in the objectives stated above), but recent changes in the wording of the objectives in the proposal have now eliminated “exposure” estimation from the objectives. Staff believes that language closer to that of the original objectives should be used, with a more complete personal exposure modeling effort described in the proposal to take full advantage of the extensive information obtained in this study. The calculation method described briefly on page 53 of the proposal should be expanded to include not only the simple estimation of the reduced indoor exposures of the children, but an estimate of the percent reduction in total personal exposure that the indoor reductions would represent. This can be done using the indoor and outdoor residential data collected in this study and general values for school concentrations from the literature. Finally, in light of the size and scope of the

project and the widespread interest in the final report anticipated for this project, staff recommends that a technical editor be added to the proposal for editing the draft final and final reports.

IV. STAFF RECOMMENDATION

Staff recommends the Research Screening Committee approve this proposal for a total amount not to exceed $3,350,000, subject to the changes suggested by staff in comments above, and any changes and additions specified by the Committee.

DISCUSSION OF A NEW RESEARCH PROJECT
ITEM NO: 2
DATE: March 9, 2012
PROPOSAL NO.: 2736-273

STAFF EVALUATION OF A RESEARCH PROPOSAL

TITLE:	Quantification of the Emission Reduction Benefits of Mitigation Strategies for Dairy Silage
CONTRACTOR:	University of California, Davis
PRINCIPAL INVESTIGATOR:	Frank Mitloehner, Ph.D.
TOTAL AMOUNT:	$400,000
CONTRACT TYPE:	Interagency Agreement
CONTRACT TERM:	36 months

For further information, please contact Mike FitzGibbon (916) 323-2389.

I. SUMMARY

Recent studies indicate that dairy silage (chopped plants preserved by fermentation) is likely a significant source of volatile organic compounds (VOC) and nitrogen oxides (NO_X), both of which are ozone precursors. Out of the approximately 1,700 dairy farms in California, more than 80 percent are located in the San Joaquin Valley (SJV), which has been classified as an extreme ozone nonattainment area. More research is needed to better quantify both the total silage emissions and the various emission species. The proposed research expands upon previous flux chamber measurements (Schmidt, 2009), with additional measurements using Fourier Transform Infrared (FTIR) spectroscopy and wind tunnels. By using multiple sampling techniques, this research will significantly increase the quantity and quality of data available with a goal of publishing the results in a peer reviewed journal. The project further expands on past work by including emissions measurements through the entire silage management cycle, from the creation of the silage pile to the feeding process. The research will evaluate typical piles at typical dairies (i.e., dairies implementing commonly established measures such as standard chop-size and minimum pile density) and will also quantify reductions from less common practices (such as Ag-bags and feed additives) included as compliance

options in the SJV Air Pollution Control District (SJV District) Rule 4570. One other mitigation strategy, water addition, will also be evaluated. The tasks were selected in consultation with the SJV District.

The SJV District currently estimates that silage accounts for at least 60 percent of total dairy VOC emissions. During a recent study on fermentation of alfalfa and corn silage, the Mitloehner research team found that NO_X emissions from silage may be significant, a finding that is supported by previous studies (including Maw et al, 2001). Other studies (including Augusto et al, 2002) have proposed potential biochemical pathways for NO_X formation. The evaluation of the emissions impact from various mitigation strategies will improve quantification of the benefits of the Rule 4570 as well as the overall emissions profile for dairies.

II. TECHNICAL SUMMARY

Objective

This project will measure VOC and NO_X emissions from silage processes and evaluate mitigation measures specified in Rule 4570 at three commercial dairy farms, perform controlled experiments and modeling to evaluate factors affecting silage emissions, and quantify the emission reduction benefits of the various silage management practices. Carbon dioxide (CO_2), nitrous oxide (N_2O), methane (CH_4), ammonia (NH_3), and hydrogen sulfide (H_2S) will also be measured. The expected outcome of this research will improve the understanding of baseline emissions and the effectiveness of mitigation strategies.

Background

High ozone concentrations at ground level are one of the major air quality problems in California, particularly in the SJV, which is in nonattainment of the federal 8-hour ozone air quality standard. VOC emissions can arise from many discrete sources at dairies, but current estimates suggest that silage is the largest contributing source. Recent measurements of dairy silage pile and feedlane emissions (Schmidt, 2009) resulted in an estimate of 43 tons per day of VOCs (12 percent of the total inventory) for the SJV. Sufficient data exist to suggest that silage is a significant source of VOC emissions, but more data are needed to understand the full extent of VOCs as well as other ozone-forming emissions, particularly NO_X.

Silage itself can be described as essentially whole plants (most commonly corn) that are chopped and preserved by fermentation, then later fed to animals. The silage-making process, and its feeding to animals, results in significant emissions of multiple pollutants (including VOCs and NO_X) at various stages. For example, when the whole corn plant is harvested, chopped, and piled, the damaged plant cells release chemicals (such as peroxidase) which react with nitrogen (such as nitrate) to form a yellowish-brown, NO_X-laden gas (called silage gas) during the first few days of piling. During this initial period, a typical pile gets covered with a white plastic tarp and tires, which promotes anaerobic fermentation. This process preserves the food for later use. When the pile is opened and silage is scraped off for feedings daily, emissions of VOCs and NO_X are released from the pile face as well as from removed silage, including during mixing and feeding of the total mixed ration (TMR).

A growing body of research points to silage as a significant source of ozone-forming emissions. OC emission fluxes measured from silage and other animal feed (Alanis et al., 2008; Schmidt and Card, 2009) were found to be higher than the comparable fluxes from animal manure. A recent study at the University of California, Davis (U.C. Davis) (Howard et al., 2009) investigated the ozone formation potential of seven types of animal feed and feed ingredients with results showing that the emissions of silage (corn, alfalfa, and cereal) had the highest ozone forming potential, and ethanol and other alcohol species accounted for more than 50 percent of the ozone formation. Other relevant work on dairy emissions includes Dr. Chuck Schmidt's flux chamber study on various dairy sources (including lagoons, manure piles, silage piles, bunker feed, etc.), and Dr. Frank Mitloehner's environmental chamber measurements of volatile fatty acids and alcohols from dairy cows, fresh waste, and silage. Furthermore, previous dairy emissions research funded by multiple sources such as the U.S. Department of Agriculture's (USDA) National Air Emissions Monitoring Study have addressed many of the other sources of emissions on dairies, making silage emissions the last and largest remaining piece of the puzzle needing further quantification.

In 2003, a National Academy of Sciences report recommended that the U.S. Environmental Protection Agency's (U.S. EPA) emission factor approach should be improved by using process-based models. The report indicated that emission estimates should take into account the site-specific variations in emissions among dairies due to

different management strategies and environmental conditions. Following these recommendations, ARB previously funded research to develop a simple, process-based silage VOC model (Zhang, 2010). However, in order to make use of the model, more comprehensive data on silage are needed because it represents such a significant source of emissions.

Proposal Summary

Measurements: Overall, this project will evaluate VOC, NO_X and other gaseous emissions through all phases of silage management, from pile creation through the feeding process, using several different emissions measurement methods. The onsite measurements will be conducted with multiple techniques, including open path Fourier Transform Infrared (FTIR) spectroscopy, flux chamber, and wind tunnel methods; offsite analysis of VOC species will also take place. The selection of the measurement techniques will be determined during the course of the research. For example, it is expected that measurements at the pile face will use all three techniques, while measurements during mixing may just use FTIR. Other parameters to be monitored include silage density, surface exposure area, chop size, moisture content, lactic acid bacterial population, oxygen content, and meteorology.

The proposed project consists of the following tasks:

Task 1: Evaluate the effects of silage defacing methods on emissions.
Silage removal practices will be compared on three commercial farms. These will include: removing silage with a front-end loader and leaving a jagged face; removing silage with a front-end loader and then using it to smooth the face; and removing silage with a de-facer that shaves silage smoothly which minimizes the surface area of the newly disturbed face. Measurements and analyses as described in the measurement summary above will be performed for this task.

Task 2: Compare emissions from a conventional silage pile versus silage in an “Ag-bag”.
Gaseous emissions from a conventional silage pile and an Ag-bag will be compared. Emission measurements will be carried out during the early ensiling and open face period when the difference in emission rate is expected to be most pronounced. Measurements and analyses as described in the measurement summary above will be performed for this task.

Task 3: Evaluate differences in emissions among types of silage and bacterial additives.

The most widely used microbial additives used to inoculate silage piles at SJV dairies will be tested in laboratory bioreactors in order to quantify the relative effects of the different inoculants on emissions from common silage types. This will also allow direct comparisons to be made among crop types such as corn, cereal or wheat, and alfalfa silage. The results will be used to compare silage types and treatments. To the extent possible, piles in the field treated with additives will be tested. Data from bioreactors will not be used in lieu of in-field measurements for establishing emission factors. Measurements and analyses as described in the measurement summary will also be performed for this task.

Task 4: Evaluate effects of adding water to silage or TMR.

Many of the VOCs of interest (such as alcohols) are water-soluble, so adding water could suppress these abundant silage VOC emissions. Water can be added at various stages, such as during mixing of the feed or after the TMR is delivered to the animals in the feeding lane. Measurements and analyses described in the measurement summary will be performed for this task.

Task 5: Expand and refine an existing silage process-based model for predicting emissions.

The emissions data collected from the above experiments as well as those from other studies will be used to expand, refine, and validate the silage component of the process-based model previously funded by ARB.

III. STAFF COMMENTS

This proposal is technically sound and meets a critical need to develop a broader and deeper understanding of silage emissions and quantify the emission reduction benefits of silage management practices. U.C. Davis as an institution is uniquely capable to perform this research, given its state-of-the-art laboratories and equipment, and previous experience of its researchers. Dr. Mitloehner is the director of the Agricultural Air Quality Center, and an internationally regarded expert on dairy and agricultural air quality issues. His team is well-positioned to carry out the research tasks, having authored over 50 peer-reviewed publications on agricultural air emissions. The team possesses a broad expertise in emissions testing, with access to some of the most advanced,

field proven equipment. Their previous research in agricultural emissions and dairy silage fermentation (including preliminary work on NO_X) as well as their experience with the National Ambient Emissions Monitoring Study, further enhance the strengths of the proposal. The project is particularly cost effective; only two of the researchers are using project funds for a small portion of their salaries (the rest are not receiving project funds), plus the project will build upon previous project funding in excess of $1.5 million from the USDA, ARB, and the National Milk Producers Federation.

Overall, the data will improve our understanding of silage emissions and assist in the quantification of the emission reductions achieved by the implementation of the silage management practices required by Rule 4570.

IV. STAFF RECOMMENDATION

Staff recommends that the Research Screening Committee approve this proposal for a total amount not to exceed $400,000, subject to inclusion of appropriate additions and revisions specified by stakeholders and the Committee.

DISCUSSION OF A NEW RESEARCH PROJECT
ITEM NO: 3
DATE: March 9, 2012
PROPOSAL NO.: 2737-273

STAFF EVALUATION OF A RESEARCH PROPOSAL

TITLE:	Emissions of Potent Greenhouse Gases from Appliance and Building Waste in Landfills
CONTRACTOR:	California Polytechnic State University, San Luis Obispo, Global Waste Research Institute
PRINCIPAL INVESTIGATOR:	Nazli Yessler, Ph.D.
TOTAL AMOUNT:	$299,826
CONTRACT TYPE:	Interagency Agreement
CONTRACT TERM:	36 Months

For further information, please contact Pamela Gupta at (916) 327-0604.

I. SUMMARY

High-global warming potential (high-GWP) greenhouse gases (GHG) contained in waste insulating foam may potentially be a significant source of GHG emissions, estimated to be upwards of 2.7 million metric tonnes of carbon dioxide equivalents ($MMTCO_2E$) in California in 2010, and expected to increase to 8.2 $MMTCO_2E$ annually by 2020. However, these estimates are uncertain, as no waste foam GHG emissions have been measured from California landfills, and research is necessary to confirm the extent to which waste foam in landfills is biologically attenuated or captured and reduced by landfill gas collection and combustion systems. The objective of this research is to determine the high-GWP GHG emissions from waste insulating foam in landfills. The high-GWP GHGs used as foam expansion agents in insulating foam include chlorofluorocarbons (CFCs), hydrochlorofluorocarbons (HCFCs), and hydrofluorocarbons (HFCs), which have high-GWPs ranging from 700 to 4750. Findings from this study will help determine if the business-as-usual process of disposing appliance and building waste foam into California landfills is a significant source of high-GWP GHG emissions and whether there is a need for any action to reduce these

emissions to help meet GHG reduction goals of Assembly Bill 32. This project will also provide sufficient information to verify or assist in revising the foam destruction offset assumptions used in the protocols for ozone-depleting substance destruction programs.

II. TECHNICAL SUMMARY

Objective

The proposed effort will determine the potent greenhouse gas emissions from landfilled insulating foam from recycled appliances and demolished buildings. The current uncertainty of the emissions estimates from waste foam in landfills is quite high, with estimates ranging from negligible to as much as 2.7 million metric tonnes of CO_2 equivalents per year. The major objectives of the project are to: 1) develop a waste flow analysis of each stage of foam waste (from recycling to landfilling); 2) determine GHG emissions from each stage of foam waste prior to landfilling; 3) determine maximum potential GHG emissions from landfilled foam; 4) determine actual emissions of foam GHGs from landfills measuring surface flux emissions, and landfill gas collection and combustion system emissions; 5) determine destruction efficiency of foam GHGs captured by landfill gas collection systems; 6) determine reductions of waste foam GHGs within landfill, through biological attenuation or capture/combustion; and 7) scale emissions and reductions results statewide.

Background

Waste insulating foam from refrigerator-freezers and building insulation that has been landfilled is assumed to be a significant source of GHGs because the insulation contains foam expansion agents of chlorofluorocarbons (CFCs), hydrochlorofluorocarbons (HCFCs), and hydrofluorocarbons (HFCs), which have high-GWPs ranging from 700 to 4750. However, previous limited studies suggest that actual foam GHG emissions from landfills may in fact be negligible. Laboratory research in Denmark suggests that much of the CFC foam expansion agent in the landfilled foam is biologically attenuated and reduced prior to emissions (HCFCs and HFCs are not attenuated). Additionally, limited landfill gas studies in Canada suggest that in a landfill with a methane gas collection and combustion system in place, up to 95 percent of the foam expansion agents are reduced to non-global warming constituents from auto-decomposition at high combustion temperatures (1150 to 1350 °F).

An ARB-funded 2010 study (Caleb Management Services) on insulating foam GHG emissions in California confirmed the significant potential of GHG emissions from landfilled foam, but actual emission measurements from landfills were not part of the scope of work. Although previous international and national landfill emission studies have not indicated any significant emissions of CFCs, HCFCs or HFCs from landfills, the studies focused on municipal solid waste landfills and not those that accept large quantities of waste insulation foam. Therefore, we would not expect these previous studies to accurately reflect GHG emissions from landfilled foam. Additionally, none of the studies were conducted in California landfills, which have different requirements for alternative daily cover, maximum methane emissions, and other environmental requirements than non-California landfills. The previous studies were also inadequate because they did not take into account different climatic conditions typically found for landfills in California.

Proposal Summary

The research project will meet the objectives of the research by identifying a representative landfill, or landfills, with significant amounts of waste insulating foam that contain the high-GWP foam expansion agents. A materials flow analysis will be conducted for waste foam, using a mass-balance approach, to determine foam GHG emissions at the time of appliance recycling (and building demolition), during transportation and storage of waste foam, and during use of foam as an alternative daily cover. Emissions estimates from waste foam that has not yet been landfilled will be supported with actual measurements and data where necessary.

After the waste foam is landfilled, emission measurements of GHGs from waste foam will be collected using flux chambers located at identified landfill gas emitting “hot spots” and also through random placement on the landfill surfaces. Flux chamber gases will be collected in canisters and analyzed for the compounds of interest. Measurements will be taken over a year in different seasons and landfill cover moisture conditions to account for the different landfill conditions. Additionally, the landfill gas collection system piping inlet gas will be measured prior to gas combustion, and after gas combustion, to determine the destruction efficiency of the landfill gas combustion system concerning the CFCs, HCFCs and HFCs of interest.

III. STAFF COMMENTS

The proposal effectively demonstrates the research team's knowledge in the subject area and presents a sound methodology and research plan to complete the proposed work. In addition to ARB staff, experts from the California Department of Resources Recycling and Recovery, the Department of Toxic Substances Control, and the U.S. Environmental Protection Agency reviewed the proposal and offered valuable advice on proposal improvements. Their expertise included a depth of knowledge in landfills and waste management, landfill emissions, and appliance recycling and building construction and demolition, both of which are the primary sources of waste foam.

The current version of the proposal has incorporated staff comments to improve the clarity of the proposed methodology and research plan. The level and quality of effort is deemed adequate; and the investigators have proposed enough labor to ensure successful completion of this study.

Dr. Nazli Yessler will serve as the principal investigator coordinating the effort for the overall project. As director of the Global Waste Research Institute (GWRI) of California Polytechnic State University, Dr. Yessler is well-situated to lead a successful research project, as the GWRI has knowledgeable staff and resources, with an ongoing collaboration with government agencies, academia, and businesses in the waste management industry.

Dr. Jean Bogner will also assist in the research design and implementation of the landfill emissions measurements. Dr. Bogner is perhaps the most pre-eminent researcher in the field of landfill gas emissions in the nation. As founder and president of Landfills + Inc., and as research professor in the Department of Earth and Environmental Sciences at the University of Illinois at Chicago, Dr. Bogner has created a solid body of research work in the last 40 years into all aspects of landfill gas emissions, as indicated by authoring or co-authoring more than 50 peer-reviewed publications and government agency reports.

Dr. Donald Blake of Rowland-Blake Laboratory at the University of California, Irvine will provide analysis services for the field gas sampling tests. He has extensive experience and his lab has unique capability to detect really low concentrations of target fluorine

containing gases from all sources. The capabilities of his laboratory are not available elsewhere.

We anticipate that the research results will significantly improve our understanding of the magnitude of greenhouse emissions from waste insulating foam in California. The improved understanding will better inform policy towards potential foam GHG reduction programs, including appliance recycling, building demolition, and ozone-depleting substance destruction programs.

IV. STAFF RECOMMENDATION

Staff recommends the Research Screening Committee approve this proposal for a total amount not to exceed $299,826 subject to any changes and additions specified by the Committee.

DISCUSSION OF A NEW RESEARCH PROJECT
ITEM NO.: 4
DATE: March 9, 2012
PROPOSAL NO.: 2738-273

STAFF EVALUATION OF A RESEARCH PROPOSAL

TITLE:	Quantifying the Comprehensive Greenhouse Gas Co-benefits of Green Buildings
PRIME CONTRACTOR:	University of California, Berkeley
PRINCIPAL INVESTIGATORS:	Edward Arens, Ph.D. Louise Mozingo, M.L.A.
TOTAL AMOUNT:	$180,000
CONTRACT TYPE:	Interagency Agreement
CONTRACT TERM:	18 Months

For further information, please contact Annmarie Rodgers at (916) 323−1517.

I. SUMMARY

Buildings represent the second largest source of California's greenhouse gas (GHG) emissions when evaluating energy usage alone. Commercial buildings generated 10.8 percent of statewide GHG emissions in 2008. As California moves towards better quantifying greenhouse gas emissions reductions associated with energy efficiency improvements in buildings, research is needed to fully account for the GHG emissions reductions associated with related improvements in the water, waste, and transportation components of building projects. The Climate Change Scoping Plan states that further research is needed to quantify these additional GHG emission reductions of green buildings. The objective of this research is to develop a database of certified commercial green buildings in California that includes performance metrics to measure GHG emission reduction co-benefits due to water savings, waste reduction and minimized transportation impacts. This information will be useful in quantifying additional GHG emission reductions beyond energy savings in commercial buildings to assist with meeting the goals of Assembly Bill (AB) 32 and Executive Order # S-03-03.

II. TECHNICAL SUMMARY

Objective

The main objective of this research is to create a database of certified green buildings in California to measure the comprehensive GHG co-benefits of building-related water savings, waste reduction, and minimized transportation impacts. Using key performance metrics that relate to these sectors, the research team will compile a dataset of certified green buildings to compare the GHG emission reduction potential outlined in the literature with the actual measured GHG savings of these certified green buildings. This research is critical to assist with better quantification of GHG emission reductions from new construction, maintenance and operation of commercial green buildings.

Background

Green buildings are not just energy efficient buildings. They are designed, built, operated, and maintained to reduce water consumption, solid waste, and transportation-related impacts. These ancillary greenhouse benefits are not typically reflected in the current GHG emission reductions estimates for the building sector. As part of this research project, investigators will develop a database of California green buildings. The database can be used to quantify the comprehensive GHG co-benefits of the water, waste and transportation related components of green buildings. The results of this study will fill a critical research gap to quantify additional non-energy GHG emission reductions of California green buildings. This work will assist the state in meeting the 2020 and 2050 GHG emission reduction targets.

Proposal Summary

The project consists of the following tasks:

<u>Gather available data on LEED-certified commercial buildings</u>

The research team will examine California buildings certified under two green building rating systems, Leadership in Energy and Environmental Design for new construction (LEED-NC) and LEED for existing building maintenance and operations (LEED-EBOM). The target population is 1300 LEED certified buildings. They will collect data on the points each building achieved through the rating system to identify specific measures that may be evaluated under the next task.

Researchers will compile three types of data that could be used to estimate GHG emission reductions. They will obtain data on predicted values that can be used to forecast potential GHG emission reductions. They will gather actual values for water consumption, waste generation, and vehicle miles traveled, which could be used to calculate measured GHG emission reductions. Lastly, they will collect baseline values for typical water usage, waste generated, and transportation impacts in commercial buildings. All 1300 LEED certified buildings will be contacted for developing the database of baseline and predicted values. Of those contacted, the research team expects a response rate between 15 to 30 percent. The research team will select at least 100 buildings from the survey responses to follow through with taking measured values and collecting more detailed, research based predicted values. For example, measured transportation data may be more difficult and costly to gather through a survey approach. For the study group of 100 buildings, the research team proposes to compile land use characteristics and evaluate the mix of use, density, and transit proximity as the methodology to estimate measured transportation co-benefits. If measured water data is not available, the research team will follow-up with utilities to obtain water use information. If measured waste data is not available, the research team proposes to gather data from the Green Halo data management system that tracks waste generation for LEED certified projects.

Compile and select methods and additional data inputs for inclusion in the database

Researchers will compile three types of data that could be used to estimate GHG emission reductions. They will obtain data on predicted values that can be used to forecast potential GHG emission reductions. They will gather actual values for water consumption, waste generation, and vehicle miles traveled, which could be used to calculate measured GHG emission reductions. Lastly, they will collect baseline values for typical water usage, waste generated, and transportation impacts in commercial buildings.

Populate database with data and calculations

All of the data gathered in the first two tasks will be compiled into a single database or series of coordinated data sets. Additional information on building characteristics, supporting data and equations will also be compiled into the database.

Conduct analyses of the co-benefits of LEED-certified commercial buildings

Using the data collected in the first three tasks, the research team will run analyses to calculate the GHG co-benefits of LEED-certified commercial buildings. Comparing predicted and measured values will reveal whether green buildings are performing as projected. By comparing the measured values with the baseline values, we will gain a better understanding of how green buildings compare to standard buildings.

Identify opportunities to expand existing building datasets

The research team will identify opportunities to expand existing building energy use forecasts and surveys to include non-energy features such that they capture the comprehensive range of energy and greenhouse emission benefits associated with all building related improvements.

III. STAFF COMMENTS

This project will address a critical research gap needed to better quantify GHG reduction estimates of commercial green buildings. The draft proposal was reviewed by ARB and California Energy Commission staff. One of the main issues raised with the proposal was related to developing a data set that will represent a statistically valid sample of commercial green buildings in California. The review team noted that the Commercial Building Energy Consumption Survey (CBECS) failed to deliver data of a quality on par with EIA standards, and as such appears to be suspended indefinitely (see http://www.eia.gov/emeu/cbecs/). ARB staff requested more information on how the research team could learn from and avoid duplicating whatever mistakes were made in CBECS' 2007 attempt to gather statistically valid estimates of the endpoints of concern. The research team addressed this concern by explaining that CBECS is a sample survey, whereas the proposed research will be a comprehensive survey. They outlined an approach in the proposal to gather information about all green buildings in California. They propose to compare green buildings to calculated baselines, not to a representative sample of standard buildings. Therefore, sampling issues do not apply.

Professor Edward Arens, co-Principal Investigator, is the Director of both the Center for the Built Environment and the Center for Environmental Design Research. Professor Louise Mozingo, co-Principal Investigator, serves as the Director of the Center for Resource Efficient Communities. Both co-principal investigators and two of the three

project team researchers (Eliot Rose and Dr. William Eisenstein) are working on a related project to analyze residential energy use and GHG emission impacts as a function of land use planning factors. The third researcher, John Goins, has experience collecting data on energy use and occupant experience for over 500 buildings in five continents. He continually analyzes the data for trends on building design and performance.

This project addresses the research need to better quantify GHG emission reductions of green commercial buildings compared to standard commercial buildings. It leverages existing efforts underway and will assist California's efforts to quantify GHG emission reductions to achieve the goals of AB 32 and Executive Order # S-03-03.

IV. STAFF RECOMMENDATION

Staff recommends the Research Screening Committee approve this proposal for a total amount not to exceed $180,000, subject to any changes and additions specified by the Committee.

DISCUSSION OF A NEW RESEARCH PROJECT
ITEM NO: 5
DATE: March 9, 2012
PROPOSAL NO.: 2739-273

STAFF EVALUATION OF A RESEARCH PROPOSAL

TITLE:	Modeling Household Vehicle and Transportation Choice and Usage
CONTRACTOR:	University of California, Davis
PRINCIPAL INVESTIGATORS:	David S. Rapson, Ph.D. Patricia Mokhtarian, Ph.D.
TOTAL AMOUNT:	$300,000
CONTRACT TYPE:	Interagency Agreement
CONTRACT TERM:	36 Months

For further information, please contact Annmarie Rodgers at (916) 323-1517.

I. SUMMARY

The Assembly Bill (AB) 32 Scoping Plan points out that significant reductions in greenhouse gas (GHG) emissions from transportation are necessary to reach the State's GHG reduction goals for 2020 and beyond. ARB is already pursuing passenger vehicle related GHG emissions reductions through AB 1493 (Pavley, 2002), Senate Bill (SB) 375 (Steinberg, 2008), the Low Carbon Fuel Standard, the Advanced Clean Cars (LEV III) regulation, and various vehicle efficiency programs (such as the Tire Pressure Regulation). Additional research is needed to support the successful implementation of several of these programs, particularly SB 375 and Advanced Clean Cars.

Research to support SB 375 and Advanced Clean Cars should illuminate Californians' motivations for, and barriers to, voluntarily adopting lower-emissions transportation behaviors, such as purchasing and using vehicles that are more efficient and/or use alternative fuels, and reducing vehicle miles traveled (VMT). In addition, this research will improve ARB's ability to forecast the future light-duty fleet, and associated emissions, and will also improve ARB's understanding of motivations for low-emissions

transportation behavior (such as low vehicle ownership or low VMT) and consumer choices about what vehicle to buy and how much to drive. The project contains two major components that are designed to be complementary by providing insights into low emissions travel and consumer choices using different methodologies and datasets. Insights from the first component will help guide the modeling in the second.

The first major component of the proposed project will focus on understanding the factors that lead some Californians to a small transportation emissions footprint. It will identify the geographic and demographic characteristics of these low transportation emissions households. The second major component of the proposed project will focus on jointly modeling the consumer decision process about when to buy a vehicle, what type of vehicle to buy, and how much to drive the vehicle. This will allow for a more rigorous evaluation of the effects of policies that influence either the choice of vehicle or the usage of vehicles and provide insights into consumer valuation of different vehicle attributes. The results of this project will shed light on the effects of many policies to reduce emissions from the light duty fleet.

II. TECHNICAL SUMMARY

Objective

The proposed project's objectives are to:

- Identify the geographic and demographic characteristics of low-VMT and low-vehicle ownership households, including a deeper understanding of the factors that influence their transportation footprint
- Develop a model of household vehicle and transportation choice and usage that will allow more rigorous evaluation of policies intended to reduce transportation emissions

Background

ARB has previously sponsored research related to forecasting new vehicle purchases, but the current model (CARBITS) has focused exclusively on the vehicle purchase decision without regard to expected vehicle usage or market factors (beyond fuel prices), and doesn't account for consumer acceptance of advanced vehicles. ARB requires additional research to better understand: 1) households that choose to have low or zero VMT; 2) consumer acceptance of emerging low-emission vehicles; and 3) considerations

that affect vehicle purchase choice, such as anticipated or actual vehicle use and market factors (beyond fuel price).

Proposal Summary

The central tasks that this proposal will support are divided into two parts (A and B) to support the two objectives.

PART A: MARKET SEGMENTATION ANALYSIS OF ZERO- AND LOW-VEHICLE/VMT HOUSEHOLDS:

This portion of the project will analyze vehicle ownership (VO) and vehicle-miles traveled (VMT) in existing datasets. The researchers plan to use data from the 2009 National Household Travel Survey (NHTS), which included a large California sub-sample (N=18,000), and provides the needed information on vehicle ownership, estimated VMT, as well as mobility limitations and socioeconomic data. The mobility limitation and socioeconomic information is important for separating out households which are constrained to being low-VO or low-VMT (due to mobility or financial limitations), as opposed to voluntarily selecting a low-VO or low-VMT lifestyle. If the California Household Travel Survey (CHTS) and California Vehicle Survey (CVS), the results of which will be available at the end of 2012, collect sufficient information on vehicle ownership and VMT, the team will use this data as well.

The researchers will use the NHTS data (and CHTS and CVS data if possible) to classify households as zero-, low-, medium-, or high-VO and -VMT (relative to “typical” households of the same size), and will develop models that predict VO category as a function of household income and mobility limitations. They will use attitudinal data (from previous attitudinal surveys conducted by Dr. Mokhtarian in California) to investigate the extent to which including attitudes can improve the VO model’s predictive ability. They will classify zero- and low-vehicle-owning households based on the likely reason for their status.

Part A of this project will also explore the role of geographic factors, particularly land use, in a household’s VO and VMT status. This analysis would ideally rely on both land use and attitudinal data in order to account for the effect of “residential self-selection” (RSS), when households locate in dense, urban areas specifically because they want to own

fewer vehicles or drive less. If the CVS does contain attitudinal data, it could be a good data source for this analysis, but if not then the researchers will use at least one method of accounting for RSS with the NHTS dataset (e.g., instrumental variables, sample selection, and propensity score and simultaneous equation approaches – none of which require explicit attitudinal data), and will analyze how the outcomes differ when RSS is taken into account and when it is not.

PART B: VEHICLE CHOICE AND USAGE MODEL:

This portion of the project will develop an empirically estimable model of household vehicle choice and usage. First, the researchers will obtain, clean and merge the datasets, including California Department of Motor Vehicles (DMV) Registration Data (which form the basis for the analysis by allowing the researchers to follow an individual household's vehicle holdings over time), The Ward's Automotive Databook (detailed vehicle attribute data for every make, model, and series available), the California Bureau of Automotive Repair (BAR) Smog Check Data (which contains the results of the mandatory smog check program in California), the National Automotive Dealers Association (NADA) Dataset (which contains used vehicle prices and an adjustment of these prices for higher odometer readings), the 2010 Census (for detailed demographic information at the Census block level), the Bureau of Labor Statistics county-level unemployment estimates (as an economic indicator, along with the national-level Consumer Confidence Index), and Gasoline Price data from the Energy Information Administration and the Oil Price Information Service (OPIS).

Once the datasets are ready for analysis, the researchers will consolidate vehicles into household-level vehicles, and examine the prior evolution of the vehicle fleet and driving behavior over time for different parts of the light duty fleet to inform the forecasting to be done through the discrete choice model. They will examine the relationships among: VMT, gasoline price, and fuel economy; household income and response to gasoline price and fuel economy; population density and other locational characteristics and gasoline price/fuel economy; and will minimally explore the diffusion of low-emissions vehicle (including where they are and attributes of households holding them, to see whether the data will permit including them in the model).

The team will build a dynamic discrete choice model to produce probabilities associated with vehicle types and amount of driving. The model will attempt to represent the choices that consumers face when they decide whether or not to purchase a car (such as the trade-off between buying a car that better suits their needs and amount of driving now but which they will be stuck with for several years, versus waiting to purchase a car next year which may meet their needs better in the future). They will determine vehicle classifications (vintage, EMFAC class, fuel type) for choice mode and counterfactual scenarios (both in collaboration with ARB), determine the framework for (and then code) the structural model, and ultimately run the model on a subsample of data and then on the full dataset. Finally, they will perform suitable robustness checks, calculate summary statistics (elasticities, survival curves), and calculate vehicle fleet projections under counterfactual scenarios.

III. STAFF COMMENTS

The proposal was reviewed by ARB staff as well as external reviewers from the U.S. Environmental Protection Agency, the California Department of Transportation, and the California Energy Commission.

They were impressed with the project's scope, and thought that the novel contribution of applying discrete choice modeling to vehicle purchase decisions was likely to be an important step forward in forecasting fleet composition.

The research team members are all well-qualified to perform the work, and have published extensively on closely-related topics, such as applying econometric modeling to travel behavior, examining the roles of residential self-selection and land use on travel behavior, developing dynamic discrete choice models, developing joint vehicle choice and usage models for California, and research into how firms and consumers make transportation-related decisions that affect California's environment.

The collective experience of this research team makes them uniquely qualified to perform this project, which has such a broad scope. Co-Principal Investigator Dr. Patricia Mokhtarian is a key researcher on an ongoing ARB project that will quantify the effect of local government actions on vehicle miles traveled. She has extensive experience surveying Californians on their transportation-related attitudes, applying

econometric modeling to travel behavior, and examining the impacts of residential self-selection and land use on travel behavior. Co-Principal Investigator Dr. David S. Rapson is an expert in the development of dynamic discrete choice models to explain consumer behavior. Dr. Kenneth Gillingham has worked for the past several years developing a joint vehicle choice and driving model for California drivers based on the Bureau of Automotive Repair smog check data odometer readings and California registration data. Dr. Christopher Knittel has published a number of papers on innovation in vehicle markets, vehicle choice, and driving in California, exploring how firms and consumers make decisions that affect the environment in California.

This research will inform the development of sustainable communities' strategies under SB 375, support Advanced Clean Cars by modeling how anticipated vehicle usage (and acceptance of new vehicle technologies) affects vehicle purchase decisions, and improve ARB's forecasting of the light-duty vehicle fleet and associated emissions.

IV. STAFF RECOMMENDATION

Staff recommends the Research Screening Committee approve this proposal for a total amount not to exceed $300,000, subject to any changes and additions specified by the Committee.

DISCUSSION OF A NEW RESEARCH PROJECT
ITEM NO: 6
DATE: March 9, 2012
PROPOSAL NO.: 2740-273

STAFF EVALUATION OF A RESEARCH PROPOSAL

TITLE:	PIsCES: the Personal InteraCtive Eco-Driving System
CONTRACTOR:	University of California, Davis
PRINCIPAL INVESTIGATOR:	Kenneth S. Kurani, Ph.D.
TOTAL AMOUNT:	$297,913
CONTRACT TYPE:	Interagency Agreement
CONTRACT TERM:	30 Months

For further information, please contact Annmarie Rodgers at (916) 323-1517.

I. SUMMARY

The Assembly Bill (AB) 32 Scoping Plan points out that significant reductions in greenhouse gas (GHG) emissions from transportation are necessary to reach the State's GHG reduction goals for 2020 and beyond. ARB is pursuing passenger-vehicle related GHG emissions reductions through various policies, but the Scoping Plan specifically mentions "eco-driving" as a key strategy that individual drivers can employ to reduce emissions and save money. Additional research is needed to understand how to effectively foster and sustain eco-driving, and to estimate the likely emissions reductions that would result from widespread adoption of eco-driving behavior in passenger vehicles.

The investigators will research the fuel economy and vehicle miles traveled (VMT) impacts of driver feedback systems in personal vehicles by employing an eco-driving smartphone "app" designed for the open source Android phone operating system. Researchers will examine the effect of in-vehicle feedback (delivered through the driver's Android phone) on driver behavior for a full year on a sample of 500 households. Researchers will determine the effects of the feedback on fuel economy and VMT, and will examine the role of putting the feedback into various personal and social contexts by

comparing driver behavior to personal goals or to the behavior of other drivers. This research will also test the effectiveness of visual versus auditory feedback, and will record the persistence of any observed driving behavior changes during the period of study. This project will quantify the effect of eco-driving feedback delivered through Android smartphones and the existing cellular network on a large study sample, and will estimate both the potential for market penetration of the eco-driving "app", and the cost of expanding this type of feedback system statewide.

II. TECHNICAL SUMMARY

Objective

The proposed project's objective is to identify the potential for in-vehicle feedback systems to reduce transportation-related emissions through changes in driving behavior.

Background

In-vehicle feedback systems (such as on-board, real-time fuel efficiency display technologies) are available but have only penetrated select, atypical niches of the market place. Providing drivers with appropriate in-vehicle feedback may foster a broader awareness of eco-driving, and encourage not only better fuel economy but possibly also a reduction in vehicle miles traveled (VMT). Observations of impacts associated with the limited penetration of in-vehicle feedback technologies suggest that they may offer a viable, low-cost approach for voluntary greenhouse gas emissions reductions from personal vehicles. This project will explore the fuel economy and VMT impacts of in-vehicle feedback systems in personal vehicles deployed through a mobile phone "application" (app), with a particular emphasis on how to most effectively influence driver behavior, and will examine the impact of various types of feedback and the role of personal goals and social motivations. The investigators will examine the fuel use impacts of in-vehicle feedback on 500 study participants over the course of one year to evaluate the persistence of the feedback effects on a large population. The project will investigate traveler behaviors and quantify potential reductions in transportation emissions, and will estimate the cost of deploying this study's feedback system statewide. Results will be used to develop policies that foster reduced emissions from transportation through effective use of on-board technologies.

Proposal Summary

The research team will develop a mobile phone application ("app") for deployment on Android smartphones, extending unpublished research conducted by the group, and using software code already developed by an open-source software working group of university students and researchers. They will create a MySQL database for the subject enrollment data and link it to each smartphone enrolled in the study, and a separate but linked database will record driving data. They will also develop a module for the mobile app to communicate with the server to record driving trips based on automated start/end points or driver input. The software will record GPS and accelerometer data and creates a data file for each trip. At the end of each trip it will connect to the server and upload the trip data.

The key experimental "treatment" of this project will be the feedback screens that will be presented to drivers. Each will include a combination of feedback information, e.g., real-time fuel economy or vehicle acceleration, and presentation style, e.g., visual or audible feedback. The selection of information and presentation will be based on combinations that are likely to produce positive effects as ascertained from previous research, literature reviews, and pilot testing. To reduce any potential problems associated with in-vehicle feedback, subjects will be provided an in-vehicle smartphone mount free of charge when they enroll in the study.

Five hundred study participants who both drive and own Android smartphones will be recruited, and this study will last for one year. Participants will be recruited from all over California using a quota sampling scheme to ensure that a broad geographic spread is included. Subjects will be recruited using multiple mechanisms: 1) the App-store, wherein interested parties will be able to find and download the app themselves; 2) In collaboration with the Bay Area Metropolitan Transportation Commission the study will be advertised on governmental websites including the 511.org website; 3) Android specific web searches using Google Ad-sense to display targeted advertisements for the study. AAA Northern California, Nevada & Utah has supported Dr. Kurani's past research and is participating in the on-going I-80 fuel economy feedback study, and could be helpful in recruiting additional participants for the proposed study. The subjects will be offered a free phone cradle and power supply for use while driving as an additional incentive.

All study participants will complete questionnaires prior to installing the app and again after one year, and will receive incentives to do so ($5 for the introductory survey and $10 for the exit survey). The surveys will track drivers' attitudes and goals that may influence driving behavior, and the survey design will follow from previous research by the project team as well as a literature review of other behavior-change projects. For subjects that discontinue use or uninstall the app, there will be a drop-out questionnaire. Drop-outs will be included in the overall analysis of efficacy; they require special analysis to understand why they dropped out and if it is possible to increase future retention. To answer these questions the drop-out survey will probe a subject's reasons for discontinuing the use of the app. The subjects will be instructed in the use of the app, and a subset will additionally be given printed educational material about eco-driving practices. The subjects' driving data including speed, acceleration, and road grade will be uploaded to our project server for later energy analysis. The app will collect data for one year. After the one-year data collection period the App will be deactivated and drivers will be encouraged to remove it from their phones.

This project will involve both energy and behavior modeling. The PIsCES system will directly measure driver behavior via speed, acceleration, and topographical measurements, but it will not directly measure energy consumption. Energy consumption will be estimated by a model using vehicle and driving data. The energy model will follow accepted vehicle energy modeling practices, and will be calibrated using the data from the GPS/OBD sub-sample of the Caltrans CHTS - funded California Vehicle Survey, as well as data from the 150 households in the ongoing Eco-drive 1-80 study. The energy modeling can answer the question – how much did each group (if at all) improve their fuel economy? The behavior model will answer the questions – why did some groups change their behavior more than others? What driver goals and attitudes are related to eco-driving behavior, and which are most likely to change when exposed to driving feedback? The results will be compared by geographic and demographic factors to determine if the effects are distributed evenly across the population and to estimate how best to estimate the effects for larger populations.

III. STAFF COMMENTS

The proposal was reviewed by ARB staff and external reviewers from the U.S. Environmental Protection Agency, the California Department of Transportation, and the California Energy Commission. Reviewers endorsed the project's large (500 household) sample size and yearlong duration, as well as the relative ease and low cost of providing driver feedback through a smartphone (as opposed to a device installed in the vehicle).

The research team members are all well-qualified to perform the work, are currently funded to conduct several closely-related research projects, and have published extensively on the relationships among driver behavior, eco-driving, vehicle markets, and new vehicle technologies. Dr. Kenneth S. Kurani is the Principal Investigator. He and the other researchers on this project, Dr. Tai Stillwater and Dr. Thomas Turrentine, have extensive experience researching the relationships among driver behavior, eco-driving, vehicle markets, and new vehicle technologies. The team is currently funded by the U.S. Department of Energy (through Oakridge National Laboratory) for a related project titled "EcoDrive I-80" which is examining the effects of fuel economy displays on the behavior of 150 conventional vehicle drivers from five different regions along the I-80 corridor between San Francisco and Reno, Nevada. Previously, Drs. Stillwater and Kurani were funded by ARB and the University of California, Davis' Sustainable Transportation Center to develop a custom in-vehicle feedback device to quantify driver behavior change in response to various types of feedback (fuel economy, carbon dioxide generation, driving cost, social comparisons, personalized driver goals) in order to estimate the strength of the relationship between driver attitudes and other cognitive factors to driver behavior (and changes in behavior).

Eco-driving has the potential to significantly reduce passenger-vehicle-related transportation emissions, and to save drivers money. This research will improve estimates of the likely emissions reductions that would result from widespread adoption of eco-driving behavior in passenger vehicles in California. This research will support ARB's efforts to engage the public in voluntary strategies to reduce emissions that cannot be achieved through regulatory approaches alone.

IV. STAFF RECOMMENDATIONS

Staff recommends the Research Screening Committee approve this proposal for a total amount not to exceed $297,913, subject to any changes and additions specified by the Committee.

DISCUSSION OF A NEW RESEARCH PROJECT
ITEM NO: 7
DATE: March 9, 2012
PROPOSAL NO.: 2741-273

STAFF EVALUATION OF A RESEARCH PROPOSAL

TITLE:	Effects of Complete Streets on Travel Behavior
CONTRACTOR:	University of California, Los Angeles
PRINCIPAL INVESTIGATORS:	Yifang Zhu, Ph.D.
TOTAL AMOUNT:	$200,000
CONTRACT TYPE:	Interagency Agreement
CONTRACT TERM:	36 months

For further information, please contact Dr. Barbara Weller at (916) 324-4816.

I. SUMMARY

The Complete Streets Act (Assembly Bill 1358), which was signed into law in September of 2008, requires cities and counties to account for the needs of all roadway users when updating their local general transportation plan. Also, the California Department of Transportation (CalTrans) revised an internal policy to adopt a Complete Streets Implementation Action Act (2008). As a result, California became the second state to implement a Complete Streets policy by designing roadways that are compatible to all types of transportation, including walking and cycling, as well as private vehicles and public transportation, with the goal of reducing the number of vehicle miles traveled (VMT) and their associated emissions. So far, there is little evidence on whether and how complete streets result in changes in travel behavior such as reductions in VMT. Although there has been active research on the relationship between the built environment and travel behavior, most of the studies tend to focus on a larger scale of the built environment such as land-use density and street networks. Traffic engineering studies, on the other hand, focus mostly on individual road design elements and their traffic flow impact. Currently, there is little research on how complete street designs impact travel behavior. Therefore, the goal of this project is to collect information in Southern California on the impacts of complete streets on travel behavior, including how

such impacts would differ among different population groups and across different land-use contents (e.g. downtown business districts, urban mixed-use areas, and suburban residential areas) in roadways selected to represent typical arterial and local road types. This study will use two different designs, one will examine before-after comparisons by taking advantage of the conversion of an existing corridor to a complete street, and the other design will use six pairs of complete and incomplete streets matched to reduce differences in community location and socio-demographics. Both designs will evaluate the effectiveness of complete streets on local travel behaviors for different land-use contexts using traffic counts of all motorized and non-motorized travel modes and surveys to measure travel behavior changes. The results of this study will help to determine the effectiveness of complete streets conversions on the reduction in VMT. The study will quantify the effects of complete streets on travel behavior, as well as providing some information on barriers to changes in travel behavior. This information will help ARB in advising urban planners on complete streets designs that encourage the usage of active and public transportation.

II. TECHNICAL SUMMARY

Objective

The objectives of this study are (1) to understand the impact of complete streets on travel behaviors of local residents; (2) to assess how travel behavioral changes will impact subpopulations with different demographic and socio-economic characteristics; and (3) to illustrate how the impact of complete streets on travel behavior may vary across different typical land-use contexts and road types. Potential barriers to the usage of complete streets or behavioral change will also be explored.

Background

Complete streets is a transportation facility/strategy which ensures that transportation planners and engineers consistently design and operate streets with all users in mind such as bicyclists, pedestrians, drivers and riders of public transportation vehicles including users of all ages and abilities. With the growing interest in smart growth, climate change mitigation, and social equity, increasing numbers of communities have adopted complete street policies to make streets accessible for all users, including people with disabilities. During the past few years, the number of state and local jurisdictions adopting complete street policies increased rapidly in the United States.

Various proved and/or assumed benefits have been linked to complete street conversions including decreased VMT, improved pedestrian, bicyclist, and car safety, enhanced active travel (walking and bicycling), and reduced transportation costs (especially for the poor). However, there is little evidence on whether and how complete streets would result in changes in travel behavior, and reductions in VMT and emissions. Although the relationship between the built environment and travel behavior has been an active field of research by transportation, planning, and health investigators for some time, most studies focus on land use density, diversity, and/or network pattern. Traffic engineering studies, on the other hand, focus mostly on individual road design elements and their traffic flow impacts. There is little evidence on how street design impacts travel behavior based on rigorous research designs and real-world data.

Proposal Summary

This study conducted in Southern California employs two empirical strategies: before-after comparison and spatial difference-in-differences (DID). In the before-after conversion, individual travel behaviors will be compared at a study site before and after a complete street conversion project. Travel behavior data will be collected through surveys mailed to the homes of potential street users in the surrounding neighborhood before and after the street conversion. This before-after comparison will allow the investigators to control for a wide range of confounding factors that are commonly found in cross-sectional travel behavior studies. The survey data will include the participants' demographic information, their general type and mode of commutes, recent commutes, and attitudes, perceptions, and barriers in their choice of commute and will be collected before and after the street conversion and statistically tested to evaluate to what extent such conversion changes their travel behavior. These data will also be used to assess travel behavior changes across different population groups based on gender, age, income level, household structure (e.g. with and without school-age children), and residential distance from the complete street. In addition the investigator will also videotape and count the traffic on the complete street before and after conversion. The spatial difference-in-differences strategy applies to complete streets in three different land use contexts, including downtown business districts, urban mixed-use areas, and suburban residential areas. Under each land use context, a complete street will be identified together with a comparable "incomplete" street, matched with minimum

changes in community location and socio-demographics and will usually be selected to be an adjacent and/or parallel street. Each pair of streets will be selected to represent typical arterial and local road types within the three different land use contexts. A total of six complete streets will be compared to incomplete streets to determine the impact of local travel behavior through two sets of comparisons. Traffic counts of buses, trucks, cars, motorcycles, cyclists, and pedestrians will be simultaneously conducted on each pair of streets. For each street, full-day (7:00 a.m.-7:00 p.m.) traffic will be videotaped and counted for a total of four days, including a typical weekday and a Saturday in the fall season and again in the spring season. At the same time, road-side intercept surveys of pedestrians, cyclists, and transit users on the six pairs of complete and incomplete streets will be conducted. To access the differences of travel behaviors between complete and incomplete streets for different street types and land use contexts, information such as the purpose of the travel, the choice of mode of transport, and attitudes and perceptions, including perceived barriers to travel behaviors, toward the complete and incomplete streets will be obtained via the inception survey. This study will select typical days in terms of meteorology and avoid special social events to ensure the chosen sampling days are representative. Traffic behaviors on complete streets will then be compared to those on the matched incomplete streets.

In summary, this study will quantify the effects of complete streets on travel behavior, as well as provide some information on barriers to change in travel behavior.

III. STAFF COMMENTS

Staff feels that this project has the potential to provide guidance to urban planners, local governments, and others with an interest in pursuing complete streets design. In addition to ARB staff, the proposal was also reviewed by staff at CalTrans and the University of California, Davis (U.C. Davis). The reviewer from U.C. Davis recommends that the study focus on the before-and-after component of the project and that staff work with the investigators on the protocols to be used. The difference-in-difference analysis should first be investigated as a pilot on the same street as the one used for the before-and-after comparison, before a full difference-in difference analysis is considered. The reviewers' comments were forwarded to the principal investigator for her consideration in drafting the final version of the proposal.

The principal investigator has gathered a team of experienced researchers to develop, conduct, and analyze the data in order to achieve the proposed project goals. Dr. Yifang Zhu is an expert in conducting field studies, especially air pollution and exposure assessment research studies. Nancy McGuckin, the consultant for this proposed study, has considerable experience implementing travel behavior surveys and is an internationally respected behavioral analyst. The main focus of Dr. Rui Wang's research has been policy analysis, and environmental and urban transportation development. He has substantial experience in conducting field studies related to transportation and environmental issues and travel behavior analysis.

IV. STAFF RECOMMENDATION

Staff recommends the Research Screening Committee approve this proposal for a total amount not to exceed $200,000, subject to any changes and additions specified by the Committee.

DISCUSSION OF A NEW RESEARCH PROJECT
ITEM NO.: 8
DATE: March 9, 2012
PROPOSAL NO.: 2742-273

STAFF EVALUATION OF A RESEARCH PROPOSAL

TITLE:	Analyzing the Economic Benefits and Costs of Smart Growth Strategies[1]
PRIME CONTRACTOR:	University of California, Berkeley, $170,431
SUBCONTRACTOR:	University of California, Los Angeles, $129,569
PRINCIPAL INVESTIGATOR:	Daniel Chatman, Ph.D. University of California, Berkeley,
CO-PRINCIPAL INVESTIGATOR:	Randall Crane, Ph.D., University of California, Los Angeles
TOTAL AMOUNT:	$300,000
CONTRACT TYPE:	Interagency Agreement
CONTRACT TERM:	30 months

For further information, please contact Fereidun Feizollahi at (916) 323-1509.

I. SUMMARY

To achieve the regional greenhouse gas emission reduction targets required by Senate Bill (SB) 375, (Sustainable Communities and Climate Protection Act of 2008), local governments and landowners must implement the smart growth plans developed and adopted by regional planning organizations. Therefore, the success of SB 375 is subject to decisions made by local land use authorities and local developers. Incentives have been introduced to influence these decisions, and more are planned, but their effectiveness is unproven.

This project will estimate the economic costs and benefits of implementing smart growth plans and projects, both from a regional perspective and from the perspectives of local agencies and other interest groups. It will do so by studying cases of smart growth

[1] The proposal's title name changed from, "Analyzing the Economics of Smart Growth Strategies," to "Analyzing the Economic Benefits and Costs of Smart Growth Strategies."

strategies implemented in California. The purpose of the project is to clarify which smart growth strategies work best from a benefit-cost perspective in different land use and planning contexts, and to inform the design of municipal incentives to promote those strategies.

II. TECHNICAL SUMMARY

Objective

ARB seeks objective information to help local governments better evaluate the economic impacts of potential smart growth policies, plans and projects. Examples of such information are rare, although many advocacy-oriented or otherwise incomplete reports and analyses are available. Our goal is to develop and systematically apply a complete, objective, and reliable framework of benefit-cost analysis – including both financial and non-financial metrics – to a series of smart growth case studies. Results will assist local officials to make informed tradeoffs and decisions about designing and implementing smart growth strategies.

Background

The smart growth movement promotes good governance in urban planning to reduce sprawl and counter the effects of global climate change. Smart growth strategies include imposing urban growth boundaries, reforming zoning codes to allow denser development, reducing off-street parking requirements, re-zoning under-used industrial land for residential uses, subsidizing dense housing near transit stops, and improving public transit. In California, “smart growth” also refers to long-range regional plans intended to modify how growth would occur under the “status quo.” The San Diego region’s sustainable community’s strategy, for example, would increase the share of new housing built near transit and infill areas to achieve greater density, consume less land, and reduce vehicle miles traveled.

The benefits and costs of smart growth strategies are likely to vary with market, spatial, and demographic conditions. For example, the costs of infrastructure to serve new growth vary by place, due to current under- or over-capacity. The incidence of smart growth benefits and costs may also vary across policy stakeholders. A small municipality, for example, might bear most of the costs of a smart growth project but reap few of the regional benefits.

Local government officials making land use and transportation planning decisions to implement smart growth strategies need to evaluate their economic impacts. Although research has been conducted on various aspects of smart growth, including economic impacts, there is a need for a comprehensive, objective assessment, especially related to strategies suitable for California.

Proposal Summary

The proposed research would provide information to assist local and regional governments to implement sustainable communities strategies developed under SB 375. The project would identify and quantify economic benefits and costs associated with specific smart growth strategies, including impacts on local governments, communities, and individuals.

The following steps will be taken to achieve the project goals:

1) Define smart growth strategies. Conduct focused review of the literature that identifies and quantifies relationships between smart growth strategies and economic impacts. Identify valid, portable methods of assessing the benefits, and costs of specific smart growth strategies.
2) In interviews with local and regional land-use and transportation policy-makers and other domain experts, identify key smart growth implementation issues, data sources for benefit-cost analysis, and criteria for case study selection. With ARB approval, select cases for study.
3) Perform 4-6 case studies of completed smart growth projects in California, providing qualitative and quantitative economic analysis of benefits and costs, including both market goods and non-market goods, such as environmental co-benefits. Some case studies may evaluate potential approaches to mitigation designed to maximize benefits by incentivizing key actors. Investigators will analyze cases with the widest possible applicability to California's local government decision-makers.
4) Produce and present a final report on research findings and methods. The final report will assist ARB and local government agencies to successfully design and implement sustainable communities ("smart growth") strategies by identifying the circumstances under which smart growth strategies are likely to have net benefits, including the lessons of their implementation.

III. STAFF COMMENTS

The proposed research seeks information to assist local and regional governments in developing sustainable community's strategies. Local agencies are key actors in implementing smart growth policies and many do not have adequate resources to undertake comprehensive economic assessment of proposed smart growth policies or projects.

Staff believes the research team will meet expectations. The principal investigator, Professor Daniel Chatman, is uniquely qualified to work with research staff to ensure the research results and methods are consistent with the goals of the project. He serves as assistant professor in the Department of City and Regional Planning, College of Environmental Design at the University of California, Berkeley. Chatman has published on smart growth strategies and has been principal investigator on a relevant series of state-and federally-funded research projects totaling $2.4 million. He leads a concurrent nationwide research project quantifying the wider economic impacts of employment densification and population growth from transit investments, and is also principal investigator on a nationwide study of how density and smart growth affects the success of rail investments.

Randall Crane, the co-principal investigator, is a professor in the Department of Urban Planning at the Luskin School of Public Affairs, at the University of California, Los Angeles. Crane co-wrote the leading monograph on the transportation impacts of the built environment is editor of the Journal of the American Planning Association and has performed groundbreaking work evaluating the role of local tax incentives in local development decisions.

Reviewers endorsed the project's approach to analyzing the economic benefits and costs of specific local initiatives, and the incidence of those impacts on local stakeholders. The research team has extensive experience in evaluating the implementation of sustainable transportation and land-use policies.

ARB hopes to encourage the implementation of the sustainable communities' strategies it validates through the SB 375 process. Highlighting smart growth strategies with net

economic benefits, and assisting local agencies to assess the economic impacts of smart growth policies should encourage implementation of those strategies.

Assessing the economic benefits and costs of smart growth strategies in the abstract is of limited value because the impacts of those strategies vary widely across regions and localities. The case study method permits the study team to account for local and regional variations, as they retrospectively and comprehensively assess the impacts of completed smart growth projects in California.

IV. STAFF RECOMMENDATION

Staff recommends the Research Screening Committee approve this proposal for a total amount not to exceed $300,000, subject to any changes and additions specified by the Committee.

REVIEW OF A DRAFT FINAL REPORT
ITEM NO.: 1
DATE: March 9, 2012
CONTRACT NO.: 04-322
Link to Report

STAFF EVALUATION OF A DRAFT FINAL REPORT

TITLE:	Effects of Ozone Exposure on Cardiovascular Responses in Healthy and Susceptible Humans
CONTRACTOR:	University of California, San Francisco
PRINCIPAL INVESTIGATOR:	John R. Balmes, M.D.
TOTAL AMOUNT:	Interagency Agreement
CONTRACT TYPE:	$399,029
CONTRACT TERM:	59 months

For further information, please contact Dr. Alvaro Alvarado at (916) 445-4843.

I. SUMMARY

Recent epidemiologic studies report associations between ozone (O_3) exposure and increased risk of cardiovascular morbidity and mortality. While several biological mechanisms that mediate respiratory-related effects of O_3 exposure are known, no biological mechanisms have been identified for cardiovascular effects. Decreased heart rate variability (HRV) is a well-known risk factor for adverse cardiovascular outcomes that can be non-invasively measured in human subjects. Other pathways that have been proposed include coagulability, and inflammation in the lungs and/or systemically. The objective of this project was to investigate these plausible biological pathways through which O_3 could alter cardiovascular function in healthy and asthmatic adults who each completed exposures to 100 and 200 ppb O_3, and filtered air. Each exposure lasted for four hours, and included intermittent exercise.

The investigators found that filtered air exposure with intermittent moderate-intensity exercise induced a pro-inflammatory systemic response, but no significant changes in HRV. Exposure to 200 ppb O_3, with exercise, induced a decrease in lung function, airway injury, and airway inflammation. Exposure to 100 ppb O_3 with exercise caused no

decrease in lung function, only mild airway inflammation, and a small non-significant reduction in HRV. There was little evidence of a systemic inflammatory response related to either ozone exposure, nor was there evidence of a pro-coagulatory response to O_3 exposure. However, despite this lack of a systemic response, exposure to 200 ppb O_3 induced changes in two parameters of HRV that had a dose response pattern, suggesting that O_3 exposure may influence HRV. The results of this project address a gap in our understanding of the biological basis for epidemiologic findings that O_3 exposure can induce adverse cardiovascular effects.

II. TECHNICAL SUMMARY

Objective

The objective of this project was to determine the effects of controlled exposure to O_3 on HRV, airway and systemic inflammation, components of the renin-angiotensin system, and coagulability in healthy and asthmatic humans.

Background

O_3 is a major gaseous component of air pollution in urban environments. While the acute pulmonary effects of O_3 inhalation have been extensively documented in previous studies, recent epidemiological evidence suggests that O_3 exposure may increase cardiovascular morbidity and mortality. Short-term increases in ambient O_3 concentrations have been associated with both an increase in hospital admission rates for cardiopulmonary causes, as well as an increase in cardiovascular morbidity and mortality. The specific biological mechanisms mediating O_3-associated cardiovascular effects remain uncertain.

It has been hypothesized that O_3 can affect cardiovascular health through alteration of heart rate variability (HRV), which is a biomarker of cardiovascular health. Reduced HRV is a risk factor for adverse cardiovascular events, such as heart attacks. HRV reflects the balance between the influences of the two branches of the autonomic nervous system on the heart muscle. Other plausible mechanisms for O_3-related cardiovascular effects are induction of systemic inflammation and/or a pro-coagulant state.

Methods

Twenty five subjects (15 healthy and 10 asthmatic subjects) were exposed to three conditions (filtered air, 100 ppb O_3, and 200 ppb O_3) in random order. The investigators studied asthmatic subjects who were otherwise healthy as a potentially susceptible subgroup because of their pre-existing airway inflammation. Several investigators have shown that asthmatic subjects have greater airway inflammatory responses to O_3, which would enhance ability to detect an effect if HRV effects are mechanistically related to inflammation.

Exposures were for 4 hours with intermittent exercise (30 minutes of each hour) at a minute ventilation of 20 L/kg/m2 body surface area. HRV was measured and blood samples were obtained immediately prior to, immediately after, and 20 h after each exposure period. Bronchoscopy to obtain bronchoalveolar lavage (BAL) fluid was performed at 20 h after exposure. The data were analyzed in two steps. First, the effect of exercise on HRV variability and biomarkers of systemic inflammation and coagulabilty was evaluated by comparing data across the time periods of the filtered air (FA) exposure. Second, the effect of O_3 on HRV parameters and the biomarkers of interest were investigated; using the data collected at the two different concentrations to assess whether there was evidence of exposure-dependent responses.

Results

Intermittent moderate-intensity exercise during filtered air exposure induced a pro-inflammatory systemic response characterized by increases in peripheral blood leukocyte counts, and C-reactive protein (CRP), monocyte chemotactic protein, and interleukin-6 concentrations. Exercise did not substantially alter levels of fibrinogen, angiotensin-converting enzyme, markers of coagulability, or HRV.

Exposure to 100 ppb O_3 caused no decrease in lung function and only mild airway inflammation, while exposure to 200 ppb O_3 induced a decrease in lung function. Increased total BAL protein, along with increased BAL neutrophils, eosinophils, and several pro-inflammatory cytokines indicated airway injury and inflammation.

There was little evidence of a systemic inflammatory response to O_3, or evidence of a pro-coagulatory response to O_3 exposure. Despite this lack of a systemic response, the

results suggest an exposure-response relationship in sub-components of HRV when all concentrations and time points were analyzed by linear regression. This suggests that O_3 exposure can influence HRV.

Conclusions

This is the first controlled exposure study to find a change in HRV with O_3 alone. The strengths of this study include a relatively large number of subjects for a controlled human exposure study, careful assessment of potentially confounding exercise effects, use of two different concentrations of O_3 that allowed an exposure-response analysis, and measurement of biomarkers of both systemic and airway inflammation. Limitations include relative lack of power to study small changes (e.g., the trend toward an increase in CRP at 24 h after exposure might have become significant with a larger sample size) and study subjects that were relatively young and healthy due to safety reasons. The results suggest that alterations in autonomic balance may be a mechanism through which O_3 can cause cardiovascular morbidity, although systemic inflammation and coagulation pathways do not seem to be the mediating mechanistic pathways. The results also suggest that ambient levels of O_3 are unlikely to cause systemic inflammation and increased coagulability.

III. STAFF COMMENTS

ARB staff members and staff from OEHHA reviewed and commented on the report. The consensus was that the report was well written, and generally easy to understand. Staff noted several minor editorial suggestions. These will be conveyed to the investigator for inclusion in the final version of the report. The legends on several tables could be more clearly written so that the reader better understands the comparisons made. Staff also suggests that the tables be relocated to the appropriate points in the text, rather than being grouped at the end of the report.

IV. STAFF RECOMMENDATIONS

Staff recommends the Research Screening Committee accept this draft final report, subject to inclusion of appropriate additions and revisions in response to the staff comments and any changes and additions specified by the Committee.

REVIEW OF A DRAFT FINAL REPORT
ITEM NO.: 2
DATE: March 9, 2012
CONTRACT NO.: 07-310
Link to Report

STAFF EVALUATION OF A DRAFT FINAL REPORT

TITLE:	In-Vehicle Air Pollution Exposure Measurement and Modeling
CONTRACTOR:	University of California, Irvine
PRINCIPAL INVESTIGATOR:	Ralph J. Delfino, Ph.D.
TOTAL AMOUNT:	$500,000
CONTRACT TYPE:	Interagency Agreement
CONTRACT TERM:	36 months

For further information, please contact Dr. Barbara Weller at (916) 324-4816.

I. SUMMARY

On-road concentrations of traffic-related pollutants are typically much higher than the concentrations measured at ambient monitoring stations. Moreover, large numbers of Californians receive a significant proportion of their air pollution exposures during their commute time. However, there are many factors that determine in-vehicle exposures. While in-vehicle exposures are frequently as high as on-road outdoor concentrations, under conditions of low in-vehicle air exchange rate, certain air pollutants, such as particulate matter (PM), can have concentrations that are significantly lower in the vehicle than those found outside the vehicle. The main purpose of this study was to collect in-vehicle air pollution data in Southern California, and develop and validate in-vehicle exposure models. In this study a large sample of vehicles representative of the current California fleet was tested for in-vehicle air exchange rates (AER) at various speeds. The study found that AER is predictable based on vehicle age or mileage, speed, and the ventilation setting used (outside air, recirculation, or open windows). AER was found to be the dominant factor in determining the inside/outside ratio for pollutants such as ultrafine particles (UFP). Models were developed that explained over 80 percent

of the variability in AER and UFP inside/outside ratios, within the California fleet and across the expected range of normal driving conditions. To better determine on-road outdoor concentrations, extensive on-road measurements were conducted using a mobile platform hybrid vehicle with real-time instrumentation. Models were developed and validated to estimate on-road traffic-related pollutant concentrations that can be combined with information about the vehicle, ventilation choices, and commute route of subjects to estimate in-vehicle exposures. The models developed from this research will facilitate the estimation of in-vehicle air pollutant exposures. These models use information that can be gathered in large part by questionnaires and GIS-based exposure assessment methods. It is expected that the models developed will help to predict in-vehicle exposure with sufficient accuracy for large epidemiologic studies of chronic disease outcomes and can also support emission regulations for vehicles and effective pollution control strategies.

II. TECHNICAL SUMMARY

Objective

The main objectives of this study are to collect in-vehicle air pollution data in Southern California, and to develop and validate in-vehicle exposure models. In order to accomplish these objectives the following tasks were performed: 1) examine differences between vehicles for in-vehicle pollutant concentrations by vehicle type and age during realistic driving conditions; 2) examine the impact of major factors that contribute to in vehicle pollutant concentrations; 3) estimate emission factors of particle concentrations based on roadway and background measurements; 4) develop and validate in-vehicle exposure models and on-road exposure models; 5) validate in-vehicle exposure models for particle-bound PAHs against studies using human subjects.

Background

In-vehicle concentrations of traffic-related pollutants can be up to an order of magnitude higher than regional ambient levels for pollutants such as UFP and black carbon (BC). For example, for nonsmoking Los Angeles urbanites, such exposures have been estimated to contribute as much as half of the total daily exposure to UFP, for open window driving conditions. However, under conditions of low AER (e.g., low speed, newer vehicles, and recirculating air setting) particle losses on the inside surfaces of vehicles are significant and in-vehicle concentrations can be significantly reduced. In this

assessment, in-vehicle concentrations of key air pollutants were measured in the Los Angeles air basin and modeled for the factors determining their variability. The results of this work were then applied to develop models for use in estimating in-transit exposures of subjects in epidemiological studies.

Project Summary

In-vehicle pollutant monitoring was conducted in counties of the South Coast Air Basin, namely, Los Angeles, San Bernardino, Riverside and Orange Counties. A number of factors that impact in-vehicle pollutant concentrations were investigated in order to develop a model of in-vehicle exposure. First, the investigators tested 59 vehicles representative of California's fleet, to estimate AER. They developed a simplified method for determining AER at various fixed speeds and ventilation conditions, using the occupant's production of exhaled CO_2. The models captured 70 percent of the variability in observed AER using only the vehicle's age, mileage, manufacturer and speed. AER increased strongly with increasing vehicle age, mileage and speed, and was high if windows were open or outside air ventilation settings were chosen.

In-vehicle UFP concentrations can be significantly affected by particle loss. To examine this factor, UFP levels were monitored in six vehicles at different driving speeds, fan settings, cabin filter conditions, and ventilation conditions (outside air or recirculation). Several filter conditions, such as no filter, used and new filters, were tested to determine the effect of cabin filters on UFP losses inside the vehicle. During outside air conditions (e.g. when air is allowed to flow freely from outside into the cabin), the fraction of UFP removed averaged 0.33 ± 0.10 SD. The fraction removed did not vary with vehicle speed but decreased at the higher ventilation flow rates with higher fan settings. During recirculation conditions, AER was much lower and the removal fraction was higher, averaging 0.83 ± 0.13 SD, and was highly correlated with AER. Under both ventilation condition types, UFP removal was primarily due to losses unrelated to filtration. Filter condition, or even the presence of a filter, played a minor role in the particle fraction removed.

To develop the models for in-vehicle pollutant exposures, on-road levels of pollutants needed to be determined. Real-time measurements were conducted for BC, UFP, particulate matter 2,5 µm or smaller (PM2.5), nitrogen oxides (NO_X), and particle bound

polycyclic aromatic hydrocarbons (PAH). This information was incorporated into the models to estimate these in-vehicle concentrations. Fuel-based emission factors (EF), which were also needed for model development, were calculated based on on-road outdoor pollutant and CO_2 measurements. EFs for light-duty vehicles were generally in agreement with recently published values, but were lower than published EFs for heavy-duty vehicles.

To aid in development of the final in-vehicle exposure models, interim models were constructed for predicting in-vehicle UFP concentrations when roadway concentrations were known, taking into account vehicle characteristics, ventilation settings, driving conditions and AER. UFP concentrations were measured in 43 vehicles, and AER was measured in 73 vehicles, under various ventilation settings and driving speeds. AER was the most significant determinant of UFP indoor/outdoor ratios, and was most strongly influenced by ventilation setting (recirculation or outside air intake). Inclusion of ventilation fan speed, vehicle age and/or mileage, and driving speed accounted for more than 79 percent of the variability in measured UFP indoor/outdoor ratios.

Predictive models were developed and validated for on-road concentrations of PAH, UFP, PM2.5, NO_X and BC. These models when combined with the information resulting from the investigations outlined above can evaluate exposure to in-vehicle pollutants among study subjects. To validate the predictive models, personal in-vehicle PAH exposure data and geographic information system (GIS) data for 25 human subjects were used. Compared to the predictive models described above, the overall power of these human subjects models to predict exposure was low. One of the factors that reduced the predictive power in the human subject models was the limitation of sample size. Another factor is that the data collected by questionnaires was subject to errors.

The models developed from this research will facilitate the estimation of in-vehicle air pollutant exposures. It is expected that the models will help predict in-vehicle exposure with sufficient accuracy for large epidemiologic studies of chronic disease outcomes using information that can be gathered in large part by questionnaire and GIS-based exposure assessment methods.

III. STAFF COMMENTS

ARB staff reviewed and commented on the first draft of the final report. The current version of the report is formatted so that each chapter relates to a specific task of the study. There are few linkages between the chapters that would explain the subsequent chapters and link the document together as a whole. The report contains a summary and conclusions section. However, there is no overall discussion of the results in the context of the existing literature.

IV. STAFF RECOMMENDATION

Staff recommends that the Research Screening Committee approve this draft final report, subject to inclusion of appropriate revisions in response to the staff comments and any changes and additions specified by the Committee.