What Can Be Learned from Low Cost Air Quality Monitors

Best Uses and the Current State of Technology

New Jersey Clean Air Council

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New Jersey Clean Air Council Website
http://www.state.nj.us/dep/cleanair

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†**NOTE:** Speakers have either provided their own testimony summary, or have agreed to allow their testimony to be summarized by Clean Air Council staff.

I. EXECUTIVE SUMMARY

There is a new generation of air quality monitoring devices emerging that range in cost from $100 to $2,000 per device. This new technology is already getting attention from stakeholders worldwide, and in many cases the collected air quality data are being uploaded to the internet without quality control checks or validation. As with many new and promising technologies, interested stakeholders are excited to understand the potential uses, accuracy, opportunities, risks and pitfalls.

The New Jersey Clean Air Council (CAC or Council) hosted a public hearing on this topic on April 5, 2017. This report contains a summary of the hearing and the Council's recommendations related to the development and use of low cost air quality sensors.

These devices are all at different stages of development. For example, as of the April 5th hearing, one portable ozone monitor had achieved Federal Equivalence, but none of the sensors for other pollutants (NOx, SO_2, CO, PM) have advanced to that level of accuracy and reliability. VOC sensors are also being developed, but likewise have not achieved the accuracy and reliability benchmarks set for ambient measurement of VOC. While the various technologies are all at different stages of development, all are developing rapidly, with updates and improvements on a month-by-month basis. The technologies are so new and developing so quickly that there are limited historical data and evaluations of the many products coming onto the market, and very few long term (greater than two months) evaluations of any sensors/monitors. As the development of these sensors stabilizes in the coming years, the necessary long term testing will be performed and the available body of data will grow.

Considering the early stages of development and ongoing evaluations, it is appropriate for the Clean Air Council to provide recommendations that are near term and long term.

Near term recommendations center around the need for NJDEP to follow the technology development, assess the growing body of online data from these new devices, issue a policy statement on its view towards use of non-Federal Reference and Federal Equivalent Methods (FRM and FEM, respectively) air quality sensors, and promote well-planned air monitoring projects such as those presented during the hearing.

Long-term recommendations include: developing cooperative data collection partnerships, fostering an expanded air quality monitoring network using the Watershed Ambassadors Program as a model, supporting the development of automated pollen detection devices, and further promoting understanding of air monitoring data in general.

II. Introduction

In recent years, there has been rapid development of less expensive, more user-friendly air monitoring devices for pollutants such as ozone, particulate matter, oxides of nitrogen and sulfur, and pollen. Traditionally, air quality monitoring equipment has cost in excess of $100,000 per sampling location. The new generation of devices ranges in cost from $100 to $2,000 per device.

This new technology is already getting attention from stakeholders worldwide, and in many cases the collected air quality data are being uploaded to the internet without quality control checks or validation (i.e., crowdsourcing[1]). As with many new and promising technologies, interested stakeholders are excited to understand the potential uses, accuracy, opportunities, risks and pitfalls. The public, academics, teachers, environmental regulators, representatives from industry, and lawyers are following the developments in this technology closely, understanding the potential value of affordably collecting much more air quality information than ever before.

Some of these new measurement devices are undergoing rigorous quality and accuracy demonstrations, and others are not. The development and standards for this new technology are not controlled by the laws and regulatory agencies that have governed the creation and use of traditional air quality monitoring technologies. Likewise, the uses of the new devices can easily become crowd-sourced, with data directly uploaded to the internet for all to use.

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III. Key Points on Low Cost Air Quality Technology

Based on the testimony received, it is important to highlight a few key points related to the rapid and dynamic development of this new technology prior to considering recommendations for getting the most value from the technology and avoiding possible pitfalls.

1. The low cost air quality monitors being evaluated generally consist of electronic sensors (optical, UV absorption, metal oxide, electrochemical, etc.) coupled with microprocessors that control the device and convert the sensor signals to meaningful outputs. These two main components must both perform their intended function for the monitor to provide useful air quality data.

2. "Low cost," for this category of air quality monitors is generally defined as less than $2,000.

3. Each pollutant requires a different sensor technology. These different sensors are all at different stages of development. For example, as of the April 5th hearing, one portable ozone monitor had achieved Federal Equivalence, but none of the sensors for other pollutants (NOx, SO_2, CO, PM) have advanced to that level of accuracy and reliability. VOC sensors are also being developed, but likewise have not achieved the accuracy and reliability benchmarks set for ambient measurement of VOC.

[1] Crowdsourcing: the practice of obtaining needed services, ideas, or content by soliciting contributions from a large group of people and especially from the online community rather than from traditional employees or suppliers. Merriam-Webster Online Dictionary copyright © 2015 by Merriam-Webster, Incorporated; Merriam-Webster.com. Merriam-Webster, n.d. Web. 20 Apr. 2017.

4. While the various technologies are all at different stages of development, all are developing rapidly, with updates and improvements on a month-by-month basis.

5. The technologies are so new and developing so quickly that there are limited historical data and evaluations of the many products coming onto the market, and very few long term (greater than two months) evaluations of any sensors/monitors. As the development of these sensors stabilizes in the coming years, the necessary long term testing will be performed and the available body of data will grow.

6. There are various forces driving the development of this new air quality sensor technology.

    a. Businesses are seeing the opportunity for sales and profits from new air quality monitoring products.
    b. Organizations like Weather Underground are adding value to their networks and attracting more members and advertisers by promoting air quality monitoring (e.g., WU plans to provide 1,000 particulate matter monitors to their 1,000 most active members).
    c. Public health policy makers and professionals are working to influence a next generation of affordable air quality monitors to provide greater geographic coverage for air quality data and thereby better understand air quality impacts on public health.

7. The success in developing low cost monitoring technologies generally is occurring without minimum or uniform requirements to certify equipment and the range of uses, and without training requirements or best practices to ensure that the data collected can be relied upon by regulators and the public. The lack of minimum requirements and the disparity in the level of training and education of users could lead to the collection of data that is of poor quality and unreliable. Poor data quality could result in misleading information for the public and, if not used correctly, improper implication of legal liability.

Considering the early stages of development and ongoing evaluations, it is appropriate for the Clean Air Council to provide recommendations that are near term and long term.

IV. Recommendations

Note that these recommendations are not necessarily being presented in priority order.

Near Term:

1. NJDEP should advance its knowledge of the development of low cost air quality sensors and monitors and closely follow future developments to better understand the opportunities and risks associated with this fast-developing technology. NJDEP should continue to purchase low cost air quality monitoring devices when possible and deploy these monitors in the field to gather and evaluate data and performance,

including comparisons to reference monitors. Hands-on familiarity with these devices, and learnings from, sources such as SCAQMD's AQ-SPEC website, USEPA's E-Enterprise workgroups, the many ongoing studies, online databases, and monitor vendor developments will help NJDEP manage and use the power of these new tools.

2. The NJDEP should monitor existing and new online crowd-sourced air quality databases to be aware of locally high measured air pollutant concentrations and the relative accuracy of NJ air quality measurements being reported vs. NJDEP's established ambient air quality measurement network.

3. NJDEP should help to establish and promote projects similar to Baltimore Open Air, which works with citizens and the scientific community to build and deploy low-cost air monitors that can supplement NJDEP's air monitoring network and aid in spatial and temporal "event" monitoring. With involvement from academia and the DOH, this type of program can be expanded beyond usual particulate monitoring to include pollen counts.

4. The NJDEP needs to develop a policy statement to inform the public, regulated community, and other stakeholders of its view towards use of non-Federal Reference and Federal Equivalent Methods (FRM and FEM, respectively) air quality sensors. The Clean Air Council envisions, based on testimony provided, that this policy statement would:

    a. acknowledge that air quality sensor technology is rapidly dropping in cost and improving in accuracy and reliability;

    b. recognize the growing number of projects underway around the country that are seeking to leverage these new air quality sensor technologies to engage and educate communities on local air quality issues;

    c. direct the Department to identify areas of air quality concern that might benefit from additional data collection via low cost air quality sensors.

   The policy should state that the NJDEP is focused on engagement with local communities and will assist interested communities in the use of these new air quality sensors and the interpretation of the data for the reasons stated above. The policy needs to clearly state that air quality sensors that are not FRM or FEM certified are not suitable for determining absolute compliance relative to air quality standards. Without such a policy, NJDEP may find itself responding after the fact to initiatives undertaken with poor quality or misleading data that could leave the public alarmed and confused.

5. NJDEP should develop a webpage to provide early guidance to public/citizen scientists on appropriate applications and limitations/strengths of these air quality

monitors as the device manufacturers continue the development and evaluation cycle, with the goals of illustrating the capabilities and avoiding public misconception or confusion. Similarly, NJDEP should provide guidance on comparing sensor collected data to health based standards, using USEPA's pilot messaging project as a starting point. Without such early guidance, NJDEP may find itself responding after the fact to initiatives undertaken by air quality activists that could leave the public alarmed and confused.

6. Most of the comparison testing for accuracy and reliability has been limited to two months or less. NJDEP should look for ways to further the Department's, the public's and the regulated community's understanding of the long term operation of these air quality sensors through new public projects, vendor feedback and/or coalitions with other agencies such as EPA, SCAQMD, etc. If it is determined that other entities (such as SCAQMD) are adequately evaluating and documenting these new devices NJDEP does not need to duplicate those efforts. However, in that instance, NJDEP should follow and use that information as noted in other recommendations in this report, and provide feedback and input to those entities on New Jersey's needs.

Long Term:

1. NJDEP should encourage development of a multi-stakeholder group ("community of practice") in an effort to get interested individuals to better understand sensor types, their development, use, placement, calibration issues, and both capabilities and limitations. This community of practice would:

    a. Develop guidelines for sensor use noting different levels of both accuracy and precision based upon different levels of demonstrated performance (AQ-SPEC or other evaluations), each appropriate for different uses, e.g., screening, regulatory compliance and enforcement;
    b. Create data interpretation guidelines;
    c. As standards of quality for these new technologies develop, maintain a catalog of approved and tested sensors and analytes for which their use is recommended;
    d. Standardize data collection practices to maintain quality, formatting, and consistency;
    e. Develop a sensor use training program;
    f. Manage public expectations regarding the extent to which data collected through citizen science programs can be used by enforcement and regulatory agencies;
    g. Maintain a resource list of groups conducting air quality monitoring and the sensors they deploy.

2. The NJDEP should begin the cooperative development of data collection partnerships partnering with a governmental (as noted in 4 below) or non-governmental keeper (if EPA is unable) of the data base that would select/screen

what goes into the data base from all of the data collected through projects/programs.

3. The Department should consider partnering with the New Jersey State Department of Education to develop citizen scientists utilizing the Science Technology Engineering and Math (STEM) curricula incorporating air quality monitoring.

4. The NJDEP should encourage EPA to continue development of a central catalog of data flowing from registered groups and users. This would minimize NJDEP involvement with data collection and storage. Registered users or groups and studies could be "vetted" by NJDEP, and other citizens or other groups interested in collecting similar data in their community could be directed to contact those registered groups with common interests, similar to NJDEP's Watershed Ambassadors Program.

5. A public monitoring initiative would widen NJDEP's network. Low-cost monitors could be extensively deployed in high concentration emission areas. More monitors could be deployed for a longer duration before and after construction of an emitting facility at little or no cost to NJDEP. Placement of additional monitors throughout the state could more readily address community concerns by expanding NJDEP's capability to collect local-scale micro environmental data. All of these points parallel the needs underlying the development of the NJDEP's Watershed Ambassadors Program. This program is a model that could help New Jersey expand its ambient air monitoring network, in a similar fashion, beyond the existing reference method air monitoring stations. Using low cost air quality monitors and trained volunteers, NJDEP should seek to fill the spatial voids in air monitoring, as has been done on a tiered basis with water monitoring under the Watershed Ambassadors Program, while recognizing that, like the Watershed Ambassadors Program, this will evolve over a number of years.

6. NJDEP should sponsor a workshop to explore how the public can use air sensors and to encourage pilot projects.

7. NJDEP should seek federal seed funding to develop resources to support citizen science studies utilizing sensor technology that can then develop into self-sustaining programs with a 3-5 year period:

    a. Equipment calibration stations near reference sites throughout the State; and,

    b. Library-type checkout of sensors for short-term public use.

8. Pollen Counts - The development of an automated pollen detection device (APD) similar to technology being employed for particulates and other air pollutants would be appropriate for the generation of real-time pollen counts in concert with a data gathering network. The APD would download data to a central relational database

for analysis. These data would be used to generate real-time and forecasting reports for distribution to health departments, media and the general public via social media. The NJDEP in concert with NJ DOH should support, sponsor and fund the development of APD technology to be integrated for the eventual development of "alerts" (similar to ozone alerts) for the general public.

V. <u>Summary of Hearing Testimony</u>

(Note: Summaries are listed in order of speaker testimony.)

Welcome
Bob Martin, Commissioner, New Jersey Department of Environmental Protection

I want to thank the members of the Clean Air Council for your service to New Jersey and for your hearings and recommendations.

I also want to thank the speakers that are here today, including the EPA, South Coast Air Quality Management District, universities, and technology leaders. You are leaders and innovators in your field, and we benefit by having you here today.

I especially want to thank Rick Opiekun, Council chair, Sara Bluhm, Council vice chair, Toby Hanna, today's hearing chair, and Dr. Leonard Bielory, today's hearing co-chair.

While there are still 9 months left to go in this Administration, this will be my last Clean Air Council Public Hearing, and together we have covered a lot of ground. Over the past 7 years, you have advised me on key topics that have an impact on New Jersey's air, including transportation, power plants, interstate transport of air pollution, air toxics, cumulative impacts of air pollution, climate change, and many other air pollution control issues. Your leadership and dedication have made the Clean Air Council a great partner in protecting New Jersey's air.

New Jersey has made great strides with clean air, and we will continue to be a leader committed to healthy air. The work started by previous administrations has continued these last 7 years, and I am proud of the job we have done. This is reflected in a trend of continuously lower emissions in all sectors.

New Jersey has some of the lowest power plant emission rates in the country: our SO_2 and NOx emissions are ranked 45th, highest to lowest, in the country; and our carbon emissions are 40th. And New Jersey is ranked 4th in the nation in total installed solar capacity.

Having achieved such impressive emissions reductions in our energy generating sector, we are focusing even more heavily on air pollution transport from other states. More than 50% of the emissions in our air come from out of state sources. And since Day 1 of this Administration, we identified a clear line to hold other states accountable for their emissions.

We have done this in several ways, including litigation and petitioning the EPA. That led to the precedent-setting 126 Petition to reduce emissions from the Portland Power Plant in Pennsylvania. We continue to work with Pennsylvania on all air emissions, especially NOx.

I am happy to report that Pennsylvania has now implemented updated RACT rules and will also be implementing EPA's Cross State Air Pollution Rule this summer. As part of Pennsylvania's updated RACT rules, they have added a new requirement to operate existing air pollution controls that had been installed, but were curtailed or not operated for the past 3 years. NJDEP will be closely tracking the operation of air pollution controls in Pennsylvania and other states this summer.

Today, our air quality is the cleanest since measurements began – and your recommendations have been helpful to many of NJDEP's air pollution control initiatives that have made this happen. In many cases, NJDEP was able to take your suggestions and turn them into programs that produce great results for air quality.

Your recommendation to implement stricter NOx limits for peak power plants used for High Energy Demand Day plants when ozone is highest resulted in the shutdown of more than 2000 megawatts of old high NOx emitting turbines, and NOx controls were added to another 500 megawatts of turbines. We set an example for other states with our air pollution control performance standards for all power plants, whether they burn coal, oil or gas.

The Council has also helped our focus on mobile sources. Based on your suggestions, we implemented the successful Electric Vehicle Workplace Charging grant program – "It Pays to Plug In" – which aims to tackle mobile source pollution. So far, $850,000 in funds have been allocated for 178 level 2 charging stations. It is my expectation that the grant program will be expanded in the future as other funding sources become available.

We have also tackled emissions from diesel vehicles by replacing dirty diesel engines. I am pleased to report that NJDEP continues to be successful in obtaining grant money to do just that. Just recently, NJDEP received almost $5 million from EPA, NJDOT and the North Jersey Transportation Planning Authority to partner with SeaStreak to repower 3 of their passenger ferries that operate in the Atlantic Highlands. This will replace high emitting diesel engines with the newest and cleanest marine engines available.

I now want to switch gears and focus on the topic of this hearing – What can be learned from low cost air quality monitors?

You have put together an impressive agenda, with experts from all over the country, as well as New Jersey. I'd like to again thank the speakers for sharing your expertise with the Clean Air Council and the NJDEP. Air monitoring is the foundation of our air pollution control program. We are proud of our program, which is robust and well respected amongst the states for high quality data.

We recognize that with low-cost monitoring devices available, the public will be more interested in collecting environmental data. I support local air quality monitoring – however, we need to tackle the thorny issue of how and if we should use this data. We need to ensure that the projects and data have integrity and are collected with valid, calibrated equipment according to protocols and scientifically valid methodologies.

I understand the Watershed Ambassadors Program made a presentation to the Council last month on how to promote community involvement. This program is an example of successful public involvement in collecting water and biological samples. It is a model for the Council to consider as you prepare your recommendations later this year.

In addition, Pete Tenebruso, our Chief Information Technology Officer, gave the Council some insight into the challenges associated with accepting and managing large quantities of data, and suggestions on other possible options for data repositories.

We have had some experience with community air monitoring in Elizabeth and Newark. I had the opportunity to hear presentations by students who performed air monitoring near a busy intersection as a learning exercise. I was impressed by their knowledge and excitement about the project. Even though the student monitoring could not be used for regulatory purposes, it was useful to help grow future scientists and instill appreciation for environmental protection.

As you discuss specific aspects of low cost air quality monitors during your hearing today, I want you to consider the point I mentioned a moment ago. Specifically, for data to be useful, it needs to be collected with valid measurement devices and according to scientific protocols. In addition, the purpose of monitoring can range from educational, to data collection that is used to assess a situation or concern.

Please distinguish between different types of local monitoring; and if and how NJDEP should be involved. Advise how NJDEP can help the public interpret and understand data collected by these monitors. Advise how NJDEP can help ensure that locally generated data is accurate. Discuss whether the NJDEP should accept, review, and use any of the data and if so, how might the data be used.

Just because someone is collecting data, does not mean it is scientific or useful. We do not want to chase phantom problems based on bad data. Unstructured and unscientific data divert NJDEP resources from tackling legitimate air quality concerns. I see value in local monitoring, beyond educational purposes, but we need to ensure that data is valid and can support the work we do in the long run.

I thank you for your service over this past year. And my special thanks to many of you who have served on the Clean Air Council these last 7 years. I enjoy working with all of you. I look forward to your recommendations on local air monitoring.

Andrea Polidori, Ph.D., Atmospheric Measurements Manager
South Coast Air Quality Management District
Air Quality Sensor Performance Evaluation

Because of recent technological advancements in the areas of electrical engineering and wireless networking, manufacturers have recently begun marketing "low-cost" air monitoring sensors to measure air pollution in real-time (e.g., seconds to minutes). Despite new potential applications, there are often no independent or systematic means by which these devices are evaluated, and data from these monitors are usually accepted at face value. In an effort to address this specific problem, the South Coast Air Quality Management District (SCAQMD) has established the Air Quality Sensor Performance Evaluation Center (AQ-SPEC). This program aims at conducting a thorough and systematic characterization of currently available "low-cost" sensors under ambient (field) and controlled (laboratory) conditions. In the field, air quality sensors are operated side-by-side with Federal Reference and Federal Equivalent Method monitors (FRM and FEM, respectively) used to measure the ambient concentration of gaseous or particle pollutants for regulatory purposes. Sensors that demonstrated a nominal level of performance in the field are then brought back to the laboratory, where a custom-made "characterization chamber" is used to challenge them with known concentrations of different particle and gaseous pollutants and under variable temperature (T) and relative humidity (RH) levels. At the time of this writing the AQ-SPEC team has evaluated more than 30 sensors. In general, optical particle counters reporting particle number and/or mass concentrations showed medium to high correlations with more expensive and reliable FEM methods. Our results suggest that, in most cases, particle sensors may need to be calibrated at each location before being used for monitoring purposes. Some of the sensors used to measure primary combustion pollutants such as carbon monoxide (CO) and nitrogen monoxide (NO) also exhibited good correlations with the corresponding FRM instruments. Metal oxide sensors for measuring ozone (O_3) also performed well during our measurements, although previous studies have shown that sensor durability may be an issue for long-term deployments. Finally, O_3 and nitrogen dioxide (NO_2) measurements performed using electrochemical sensors may be complicated by potential interferences between these two pollutants. Detailed technical reports for each device tested within AQ-SPEC and other relevant information about this program can be found online @ www.aqmd.gov/aq-spec. This website is intended to educate the public about the capabilities of commercially available sensors and their potential applications.

Leslie Cronkhite
U.S. EPA/OECA/Office of Compliance
U.S. EPA Sensor Studies and Pilots

Environmental monitoring technology is rapidly evolving, with major implications for U.S. EPA and state environmental programs. New advanced monitoring technologies already are available that are smaller, more portable, and less expensive than traditional methods. These technologies offer unprecedented opportunities to significantly enable alternative approaches for detecting pollution beyond the existing monitoring networks, and the public is responding.
A concerted approach between States and EPA under the E-Enterprise umbrella to establishing a 3rd party certification program, developing a framework for explaining the meaning of short-term data, and enabling data exchange will help prepare agencies, industry, and the public to respond to and maximize the use of these new technologies.

Holger M. Eisl, PhD, Research Associate Professor

Barry Commoner Center for Health and the Environment Queens College
NY City Community Air Survey

New York City Community Air Survey (NYCCAS)
In 2007, the Commoner Center and the New York City Department of Health and Mental Hygiene (DOHMH) developed the methodology and ambient monitoring technology for a collaborative air quality study to monitor and model neighborhood-level air quality across New York City. This project has become known as the New York City Community Air Survey (NYCCAS). The initiative to develop the NYCCAS program came out of the recognition that routine air monitoring, performed by New York State Department of Environmental Conservation (DEC), provides data to assess urban scale temporal variation in pollution concentrations in relation to regulatory standards, but is not well suited to characterizing intra-urban spatial variation in pollutant concentrations from local sources. In 2007, the Commoner Center in partnership with DOHMH launched NYCCAS, a high-density street-level monitoring network designed to assess spatial variation in longer term exposures (seasonal and annual average) at the neighborhood-level. The key objectives of the program are:

- Assess year-round variation in multiple air pollutants across NYC neighborhoods;
- Identify local emission sources contributing to intra-urban pollution patterns;
- Inform the public and city officials on air pollutant levels and efforts to improve air quality;
- Provide high quality air pollution exposure estimates for health surveillance and research.

The NYCCAS program targets pollutants that are of considerable public health concern, which include fine particles ($PM_{2.5}$), black carbon (BC), oxides of nitrogen (NO_X), sulfur dioxide (SO_2) and ozone (O_3). The Commoner Center developed less expensive filter-based monitoring technology than those that meet federal requirements for NAAQS-attainment determination (Federal Reference Methods), to meet the unique needs of the NYCCAS program. The instruments have undergone extensive quality assurance and testing and have been demonstrated to provide accurate and reproducible results. The street-level (sampling height of 10-12 feet above ground) monitoring data from currently 75 (initially 150) city-wide sampling sites are analyzed using a "land-use regression" model, a proven method to characterize air pollution exposure and health effects for individuals residing within urban areas.

All scientific publications, annual NYCCAS reports and periodic online data updates are accessible on DOHMH's website at https://www1.nyc.gov/site/doh/data/data-publications/air-quality-nyc-community-air-survey.page. Neighborhood level data and detailed neighborhood air quality reports are available on DOHMH's "Environment & Health Data Portal at http://a816-dohbesp.nyc.gov/IndicatorPublic/.

Planned Commoner Center / DOHMH Citizen Science Project
We will be developing the "NYCCAS Citizen Science Program," in consultation with DOHMH, over a two-year pilot period. The goal of this project is to work with citizens and communities to use sensors in combination with existing data to understand the air quality in their neighborhoods and to empower them with data to support air quality improvement actions. This project will also provide the opportunity to explore whether high exposures on a fine geographic scale are

adequately captured using current assessment techniques. The NYCCAS monitoring network combined with land-use regression modeling generates smooth surfaces of exposure for NYC. While these exposure surfaces do an excellent job of characterizing sub-neighborhood trends in air pollution, there is uncertainty about whether these surfaces, based on 75-150 monitors spread across an area of 790 square kilometers, adequately capture the fine-scaled variation that occurs, for example, in a traffic congestion zone. The project activities will involve:

- Consultation with academic, government, industry and community groups on best practices and strategies for increased community engagement around air quality monitoring.
- Review of existing low cost air quality sensors for $PM_{2.5}$, NO_2, BC and total VOC (air toxics) for suitability in citizen operation and community/academia/government partnership research projects.
- Design and implementation of two pilot studies (e.g., high traffic zone, marine transfer station) to assess neighborhood air quality levels with a community partner (e.g., We ACT).
- Creating citizen science toolkits.
- Working with community partners to integrate community monitoring with existing networks (e.g., NYCCAS, DEC).
- Development of data portals for communities to view citizen science data (including database development, data analysis tools and data visualization).
- Development of outreach materials.

Anna Scott
Johns Hopkins University
Greater Baltimore Smart City Air Challenge

Baltimore Open Air is a community driven air quality monitoring project using open source and off-the-shelf, low-cost technologies to develop a network of air quality monitors. We are undertaking a number of steps to calibrate and ensure the reliability of each sensor, notably accounting for the cross-sensitivity of each sensor to other gasses, temperature and humidity, but advocate for a different paradigm of measurements, one in which we consider the accuracy of a network rather than a single measurement, and one in which we prioritize understanding spatial variability over having very accurate point measurements. Additionally, we plan to cluster monitors and co-locate with higher cost reference standard equipment in order to make better mathematical comparisons between sites. We recommend that New Jersey consider similar projects that involve citizens, governments, and non-profit stakeholders; we believe that maximizing the number of people involved also maximizes the opportunity to educate everybody on the caveats and challenges that come with low-cost sensor data.

Robert Laumbach, M.D., Associate Professor
Rutgers School of Public Health and EOHSI
Assessing and Using the Technology in a Community Stakeholder Context

The advent of low-cost sensors has enabled users to obtain data about environmental quality that had not been economically or technically feasible to acquire in the recent past. Local-scale, micro-environmental, and personal air quality data have been expensive and technically difficult to obtain. In addition to promising to help scientists and regulators to reduce error in exposure estimates in epidemiological studies and health risk assessments, low-cost sensors are enabling people of all backgrounds to engage in measuring air quality in their personal space and in their communities. The relative ease of collecting copious amounts of real-time data can present major challenges in data processing and interpretation. Data accuracy and precision are important considerations in interpreting results. To avoid frustration and disappointment, "citizen-scientists," professional scientists, and regulators who may engage in community projects using low-cost sensors must understand and acknowledge the purposes and limitations of low-cost sensor technology. The first step to avoiding disappointment and frustration due to unmet expectations are to define the purpose and question(s) of interest to the community members. The next step is to assess whether or not low-cost sensors will be useful for the intended purpose and if they can help to answer those questions. Despite current limitations in sensor technology, they may be useful for a wide range of purposes including raising awareness, education, assessing relative differences in local-scale air quality, personal exposure modeling, or research. None of the currently available low-cost sensors meet accuracy standards for EPA reference monitors, which is a major limitation that community groups should be aware of. In addition to technical difficulties in acquiring representative data on air quality, community members may not have the background and resources to interpret and derive meaningful conclusions from air quality data. The science of air quality and air quality measurement are very complex. Therefore, it is crucial that academic scientists, regulators, and other experts provide assistance in clarifying questions, selecting appropriate monitors, designing approaches, QA/QC, data processing and analysis, and interpreting data. The best approaches to using low-cost sensors will grow out of collaborations between citizens and scientists, experts and non-experts, community members and regulators. NJDEP should provide resources and promote agency involvement in community-based projects with low-cost sensors, at all phases of projects from conception to interpretation of results.

Michael Heimbinder, Founder & Executive Director
Habitat Map
AirCasting: An Open Source Platform for Crowdsourcing Environmental & Physiological Measurements

New Jersey should provide financial and technical support to community driven air quality monitoring initiatives. Support should include a) grants; b) equipment loans; c) opportunities to co-locate low-cost instruments with reference instruments; d) laboratory-based instrument evaluations; e) provision of data analysis/data fusion services; f) source tracking and source apportionment; and g) consultation on public health assessments and messaging related to community collected air quality data.

Jeff Knapp, President and CEO
Smart Connect Technologies, Inc.
Cloud-Based Sensor Data Collection

Communities and municipalities are increasingly aware of the impact of air quality on the health of citizens. They are often unable to identify, attribute, and analyze specific contributing factors to the rate of childhood asthma and other related illnesses and lack the ability to efficiently gather and analyze relevant data. By analyzing the environment, particularly air quality in near real time, municipalities can potentially prevent minor problems from becoming more serious problems. The SmartConnect Gateway, implemented with the appropriate sensors, can enable the access and capture of air quality data, identify the impact of specific components of air quality, and correlate this information with weather data and traffic information. The result will enable the identification of high risk days, and when combined with additional data, leverage this information to reduce risk while enhancing traffic flow.

An ideal solution would require the implementation of specific sensors in designated locations to measure particular air quality indicators. This information would then be captured and streamed to the recommended analytic platform. Existing, and potentially new, cameras can monitor traffic activity and generate ongoing video analytics. This data can be integrated with weather insights and air quality assessments and delivered to a Cloud analytics platform, so it can be analyzed, and then acted upon.

The Smart Connect Gateway can access and capture data from monitoring devices and sensors for pollutants such as ozone, particulate matter, oxides of nitrogen and sulfur, and pollen. The Smart Connect solution will consolidate sensor data, reduce bandwidth usage, reduce storage and processing overhead, support security and privacy concerns, extract data from other repositories, clean data for analysis; and, working with partners, facilitate the use of business intelligence tools e.g., Watson Analytics to correlate and display information on dashboards available in real time across the enterprise, generating operational insights and facilitating access for public administrators and managers, private researchers, health care professionals, and other interested parties.

Tim S. Dye, CCM, Sr. Vice President
Sonoma Technology, Inc.
Using Low-Cost PM Sensors for Industrial, Government, and Educational Applications

Low-cost air quality sensors are now capable of accurately and reliably measuring air quality conditions for a range of applications. Sonoma Technology has been evaluating, deploying, and managing data from air sensor networks since 2008. These air sensor applications include: 1) helping industry detect and mitigate coal dust, 2) working with a local air quality agency to monitor particulate matter from wood smoke in community and environmental justice areas, and 3) creating an educational program called Kids Making Sense that empowers youth to measure air pollution and take action. For each application, a balance between available technology, project objectives, and sensor accuracy must be achieved.

Many organizations from industries to schools can benefit from this new air monitoring approach. The key recommendations for fully utilizing low-cost air quality sensors are to 1) continue to evaluate the quality of all air sensing devices, 2) conduct more pilot and demonstration projects to identify how this new technology can be effectively applied, and 3) develop data management solutions to provide useful and actionable information.

Dr. Geoff Henshaw, CTO and Founder
Aeroqual Ltd
Sensor Development and Market Vision

Lower cost sensor based air quality (AQ) instrument performance is approaching that of regulatory monitors for measurements of O_3, CO, NO_2 and $PM_{2.5}$ enabling the deployment of sensor networks that can augment the spatial coverage of existing infrastructure. This has been largely due to a focus on interference rejection and selectivity because sensors have sufficient sensitivity toward most AQ pollutants. Instrument design and laboratory calibration methods are becoming robust enough to be transferable to the field and achieve "out of the box" repeatability. Challenges remain over long term operation and the influence of siting micro-geography on data quality but short term deployments are proving to be the most common use case. There are relatively few long-term deployments of low cost AQ sensor networks outside of research projects but as the stability and usability of the devices improve this looks set to change. Independent evaluations of commercial instruments are available (e.g., AQ-SPEC) and, in the absence of performance standards, are helping to drive the professionalism of this emerging sector.

VI. Pollen Counts – Information provided by Leonard Bielory, M.D

The effect of pollen on allergic conditions (e.g., asthma and allergies) has been increasing in response to climate change (e.g., increased temperatures, CO_2 levels). The adverse effects of air pollution and pollen exposures increases the intensity, frequency, and duration of clinical allergic/asthmatic symptoms. The U.S. prevalence of allergies has increased from 10% to 30% from 1970 to 2000 and causes adverse health effects for approximately 40% of children, while ~25 million people in the U.S. currently have asthma, and the numbers continue to increase.

Presently, there has been rapid technological development of less expensive, user-friendly air monitoring devices for pollutants such as ozone, oxides of nitrogen and sulfur and particulate matter that are known to have undesirable health effects especially those with respiratory disorders such as asthma. However, one major component of environmental particulate matter remains relegated to predominantly manual monitoring with limited automation --- pollen counting. Traditionally, air quality monitoring equipment has cost more than $100,000 per sampling location with pollen counting devices costing $2,500 to $12,000 per device, but then requiring 2-4 hours' per site daily manual counting of pollen and mold spores "under a microscope".

Reliable pollen exposure measurement is routinely not available (only 2 stations in New Jersey - Springfield and Cherry Hill) to healthcare providers, public health practitioners, individuals suffering from allergy and asthma, as well as researchers. There is a need for a harmonized effort to collect, analyze and disseminate pollen data across states and communities. This network can lay the foundation for an asthma and allergy alert system based on pollen and other environmental pollutants. Specific pollen monitoring questions pertain to ensuring adequate spatial and temporal resolution, how much pollen speciation may be required, and the most appropriate sampling and analysis equipment to use. Forecasting models have been developed to address current data limitations and the potential impact of climate change; however, details regarding the models and their validation are generally lacking.

Human exposure to aeroallergens is changing (often increasing) as growing seasons and plant ranges expand, and as the allergenicity of certain species is increasing in response to our changing climate. At present, pollen monitoring is geographically and temporally limited and dependent on individual collectors, who are often unfunded and do not report data to a centralized network.

Current equipment requires the semi-automated trapping/sampling of air either by a greased rod device (Rotorod™) or a collection tape (Burkhard™) programmed to sample the air over time (e.g., 24-hours or a week) and then manually examining the “traps” (Crisp et al., 2013). The “traps/sample” requires light microscopy with staining to assist in the visual morphology in differentiating different pollens that requires several hours of a highly trained individual to manually stain and “count” individual grains. The pollen count reported is commonly the average of the previous 24-hour period (not real-time).

APPENDICIES

A. LIST OF ACRONYMS

APD	-	Automated Pollen Detection
AQ	-	Air Quality
AQ-SPEC	-	Air Quality Sensor Performance Evaluation Center
BC	-	Black Carbon
CAC	-	Clean Air Council
CO	-	Carbon Monoxide
CO_2	-	Carbon Dioxide
DEC	-	Department of Environmental Conservation (New York)
DOHMH	-	Department of Health and Mental Hygiene (New York)
EJ	-	Environmental Justice
EOHSI	-	Environmental and Occupational Health Sciences Institute
FEM	-	Federal Equivalent Methods
FRM	-	Federal Reference Methods
NAAQS	-	National Ambient Air Quality Standards
NJDEP	-	New Jersey Department of Environmental Protection
NO_2	-	Nitrogen Dioxide
NO_x	-	Nitrogen Oxides
NGO	-	Non-Governmental Organization
NYC	-	New York City
NYCCAS	-	New York City Community Air Survey
O_3	-	Ozone
PM	-	Particulate Matter

$PM_{2.5}$	-	Particulate Matter with a diameter of 2.5 microns
QA	-	Quality Assurance
QC	-	Quality Control
RH	-	Relative Humidity
SCAQMD	-	South Coast Air Quality Management District (California)
SO_2	-	Sulfur Dioxide
SO_x	-	Sulfur Oxides
T	-	Temperature
USEPA	-	United States Environmental Protection Agency
VOC	-	Volatile Organic Compound

B. HISTORY OF THE CLEAN AIR COUNCIL ANNUAL REPORTS

2016 The Clean Power Plan: Impact on New Jersey (not released)

2015 Air Pollution Knows No Bounds: Reducing Smog Regionally

2014 Reducing Air Emissions Through Alternative Transportation Strategies

2013 Addressing the Adverse Effects of Climate Change on Air Quality

2012 Transportation and Small Sources of Air Pollution: Challenges and Opportunities to Achieve Healthier Air Quality in New Jersey

2011 The Cumulative Health Impacts of Toxic Air Pollutants on Sensitive subpopulations and the General Public

2010 Vision for the Next Decade: Air Quality and Pollution Control in New Jersey

2009 Electricity Generation Alternatives for New Jersey's Future: What is the Right Mix for Improving Air Quality and Reducing Climate Change?

2008 Improving Air Quality at Our Ports & Airports—Setting an Agenda for a Cleaner Future

2007 Improving Air Quality through Energy Efficiency and Conservation: The Power of Government Policy and an Educated Public

2006 Indoor Air Quality

2005 Air Pollution—Effects on Public Health, Health Care Costs, and Health Insurance Costs

2004 Fine Particulate Matter in the Atmosphere
- Health Impacts in NJ
- Need for Control Measures

2003 Moving Transportation in the Right Direction

2002 Innovative Solutions for Clean Air

2001 Air Quality Needs Beyond 2000

2000 Air Toxics in New Jersey

1999 The Impact of Electric Utility Deregulation on New Jersey's Environment

1998 CLEAN AIR Complying with the Clean Air Act: Status, Problems, Impacts, and Strategies

1997 Particulate Matter: The proposed Standard and How it May Affect NJ

1996 Clearing the Air Communicating with the Public

1995 Strategies for Meeting Clean Air Goals

1994 Air Pollution in NJ: State Appropriations vs. Fees & Fines

1993 Enhanced Automobile Inspection and Maintenance Procedures

1992 Impact on the Public of the New Clean Air Act Requirements

1991 Air Pollution Emergencies

1990 Trucks, Buses, and Cars: Emissions and Inspections

1989 Risk Assessment - The Future of Environmental Quality

1988 The Waste Crisis, Disposal Without Air Pollution

1987 Ozone: New Jersey's Health Dilemma

1986 Indoor Air Pollution

1985 Fifteen Years of Air Pollution Control in NJ: Unanswered Questions

1984 The Effects of Resource Recovery on Air Quality

1983 The Effects of Acid Rain in NJ

1982 What Should New Jersey do About Air Toxic Pollutants?

1981 How Can NJ Stimulate Car and Van Pooling to Improve Air Quality

1980 (October) Ride Sharing, Car– and Van-Pooling

1979 What Are the Roles of Municipal, County, and Regional Agencies in the New Jersey Air Pollution Program?

1978 How Can NJ meet its Energy Needs While Attaining and Maintaining Air Quality Standards?

1977 How Can NJ Grow While Attaining and Maintaining Air Quality Standards?

1976 Should NJ Change its Air Pollution Regulations?

1975 Title Unknown

1974 Photochemical Oxidants

1973 Clean Air and Transportation Alternatives to the Automobile and Will the Environmental Impact Statement Serve to Improve Air Quality in NJ?

1972 The Environmental Impact of Air Pollution: The Relationship between Air Quality, Public Health, and Economic Growth in NJ

1971 How Citizens of NJ Can Fight Air Pollution Most Effectively with Recommendations for Action

1970 Status of Air Pollution From Mobile Sources with Recommendations for Further Action

1969 Status of Air Pollution Control in NJ, with Recommendations for Further Actions

C. POWERPOINT SLIDES FROM PRESENTATIONS