A Sensor World:

Rapid changes in technology are leading to a new generation of environmental monitoring instruments, software, and applications. The U.S. Environmental Protection Agency (EPA) has sought to build and grow the community of developers, researchers, and stakeholders interested in small, low-cost, user-friendly technology for air pollution. This article presents the vision for a world using low-cost sensors and how that may transform the status quo of air quality monitoring in the United States.

by Peter Preuss and Rebecca French

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Next-Generation Air Monitoring At EPA

We will live in a sensor world. The Internet is becoming the internet of things—devices and apps that are connected, including many different types of sensors. Sensors are all around us, from our cars to our hospitals. This technology is becoming an increasingly important part of experiencing our environment. Rapid technological developments are leading to the production of small, low-cost air pollution sensors. Federal agencies are prime catalysts in helping to encourage this development. For example, the National Science Foundation has awarded an Engineering Research Center grant of $18.5 million to North Carolina State University and its partner universities to develop the next generation of self-powered health and environmental sensors.1

Similarly, the FP7, the European Union’s Seventh Framework Programme for Research, has awarded a grant of nearly 12 million euros (16+ million U.S. dollars) to 30 research groups and companies from 20 European countries for CITI-SENSE.2 CITI-SENSE focuses on citizen participation in environmental monitoring, decision-making, and planning. The research will develop, test, demonstrate and validate the use of portable low-cost microsensor packs with mobile phones for use in community-based environmental monitoring.

These new technologies and their use by academe, government, and the public will have large implications for the future of air quality monitoring.3 Consider the following possibilities:

• in-plant sensor networks and fence-line monitors installed at facilities, allowing them to use sensor networks to detect and control fugitive emissions, preventing and reducing pollution;
• emissions monitored at the source and using that information to educate, engage, and empower environmental justice communities and partners;
• exposure data directly connected to personal and environmental health through the use of wearable sensors to engage citizens in personal monitoring; and
• a high-density sensor network of stationary and mobile sensor platforms to supplement current monitors providing real-time, local, and high-density data on air quality.

Sensors are also helping to solve a problem at the intersection of public policy and public finance—that is, that the federal government, states, and localities cannot continue to afford the expensive air quality monitors that we now use to measure pollutants in our environment. There is hope that the sensors now being developed could be a fraction of the cost of today’s monitors that are in the $100,000 range, perhaps reducing the cost by a factor of 10, or even 100. In addition to lowering the overall cost of monitoring air pollution, such low-cost sensors will allow us to put sensors in many more places than we can currently afford. Subsequently, that information about the environment can be put in the hands of millions of people who, previously, have had no access to this information. With such a future at stake, EPA needs to be prepared to ride the bow wave and help develop this technology to meet a variety of environmental protection needs.

Next-Generation Air Monitoring

EPA is focusing on building a community of developers, users, state agencies, local communities, universities, and the private sector. EPA has worked on sensors across a broad spectrum of activities, including testing sensors, awarding Small Business Innovation Research (SBIR) grants, convening workshops, releasing a draft Next-Generation Air Monitoring Roadmap, improving science outreach to stakeholders, and using open source challenges. These activities have created a space for innovation, information, and communication, provided laboratory assistance that developers don’t have available directly, and created research opportunities for scientists outside of EPA.

Testing and Developing Sensors

EPA’s research laboratories are engaged in a variety of projects to test and evaluate new monitoring technologies, including:

• conducting laboratory and field evaluations of
promising sensor technologies for measuring ozone, NO2, PM, and VOCs;
• developing advanced monitoring technologies that can be deployed in vehicles to assess fugitive and area source emissions;
• assessing the use of infrared cameras for fugitive emissions detection and leak repair; and
• evaluating prototype monitors such as the Village Green, a neighborhood-friendly park bench that doubles as an air quality monitoring station, with data streamed directly to an accessible Web site.

**Small Business Innovation**

EPA also sponsors the development and testing of new technologies through the Small Business Innovation Research Program (SBIR), which announces funding opportunities annually. Recently, the SBIR awarded a grant to develop a real-time flare combustion efficiency monitor.

**Workshops**

To build and engage a community interested in new sensors and other technology for air pollution, EPA convened the Apps and Sensors for Air Pollution Monitoring Workshop in March 2012. The workshop featured current work in technology development and community efforts, and highlighted specific needs, challenges, and potential solutions.

In March 2013, another workshop entitled, Air Sensors 2013: Data Quality & Applications, focused on new technologies, recent applications, emerging issues such as evaluating sensors for data quality and calibration, management, analysis of big data, and emerging technologies in the field. Subsequent articles in this issue will address these topics in more detail.

**Draft Roadmap**

The Draft Roadmap shares EPA's early thinking about how best to support the successful development and use of new monitoring technologies and serves as a framework for engaging other agencies and organizations in this effort. EPA drafted the roadmap to identify key actions to advance the development and use of new monitoring technologies for air pollution. The Draft Roadmap summarizes major findings from literature reviews, workshops, and discussions with experts about next-generation air monitoring, particularly sensor technology. It identifies pressing issues in need of EPA leadership and an ambitious set of priority objectives for EPA and its partners to address. Priorities include working with states and other partners to interpret the data from new technologies; setting reasonable expectations for use of different technologies; engaging communities...
interested in using new technologies; responding to inquiries from concerned citizens; and preparing for managing large sets of data.

**EPA Outreach**

EPA scientists are reaching out to state agencies, community groups, citizen scientists, and others to provide relevant information on using new technologies for air quality monitoring. For example, the EPA Region 2 office has sponsored a series of Citizen Science Workshops. In the workshops, EPA scientists discussed issues such as measurement uncertainty, quality assurance, and design of monitoring programs. These outreach efforts provide valuable technical information to community groups and others to improve the quality and utility of community-based monitoring data.

**Open Source Challenges**

EPA is exploring the use of open source challenges—describing a technical problem and inviting solutions from scientists all over the world. In 2012, EPA and the U.S. Department of Health and Human Services jointly announced an open challenge, My Air, My Health. It called on academics, industry researchers, and do-it-yourselfers to connect wearable air and health sensors, allowing citizens and communities to collect highly localized data, creating a meaningful picture of how the environment affects their well-being. Selected in June 2013, the overall winner was Conscious Clothing, with a prototype that integrates a wearable PM sensor with a stretchy fabric that can measure breathing rate and volume (see Figure 1). Sensors like Conscious Clothing can also enable epidemiologists to assess the relationship between air pollution and public health in ways not possible before. Open source challenges have also generated ideas for benzene and acrolein sensors. EPA will continue sponsoring the challenges for high priority environmental problems.

**Emerging Issues in Next-Generation Monitoring: Data**

This article began with a vision for a world with ubiquitous sensors, but the sensors are only as...
The European Commission has begun to tackle these questions by issuing acceptable data uncertainty values for indicative measurements of air pollution13 (see Table 1). EPA has not issued guidance for indicative measurements of air pollution.

The questions above are not limited to air quality. They should be considered for water quality measurements and pollution monitoring in other media as new sensors are developed in those areas. For example, the XPRIZE recently issued a new challenge to develop an inexpensive and easy-to-use sensor to measure acidity in the ocean.14

As you read the articles in this month’s EM, you are invited to consider these questions for yourself, consider how you would answer them, and join the community of next-generation air monitoring.15

Table 1. Data Quality Objectives of the European Commission Air Quality Directive.

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<tr>
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<th>O3</th>
<th>SO2, CO, NO2/NO/NOx</th>
<th>Benzene</th>
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</thead>
<tbody>
<tr>
<td>Uncertainty for indicative measurements</td>
<td>30%</td>
<td>25%</td>
<td>30%</td>
</tr>
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Notes: The Directives specify that indicative measurements must meet a Data Quality Objective that is about twice less stringent than reference measurements.

good as the data that they provide. Subsequent work in next-generation air monitoring at EPA might focus on the answering the following questions12:

- Who are the primary users of sensor data and how are they likely to use it?
- What are the applicable or appropriate data quality standards, legal standards, and/or best practices for different uses of sensor data?
- How can EPA support users in understanding the capabilities or characteristics of the new devices and software that generate the data?
- How might EPA and others make more air quality data available to the public?
- How should data be presented to provide detailed, real-time, accessible, and understandable information to meet local users’ needs?

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References