EPA’s Emerging Low-Cost Sensor Research

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(on Behalf of the ACE EM-2/EM3 Teams)
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EPA’s Air Pollution Sensors Team

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- Alion Science & Technology
  - Sam Garvey
Recognition that Citizen Science is a Reality

Public demand for more personalized information – what about my exposure, my neighborhood, my family – using low-cost sensor technologies
1. Investigate emerging technologies and potential to meet future air quality monitoring needs
2. Establish market surveys of commercially-available air quality sensors
3. Conduct extensive literature survey on the state of sensor technologies
4. Develop sensor user guides
5. Educate sensor developers and users on the state of low cost sensors
6. Facilitate knowledge transfer
7. Work with sensor developers to speed up development
8. Support ORD’s Sensor Roadmap by focusing on high priority issues (NAAQS, Air Toxics, Citizen Science)
9. Establish highly integrated research efforts across EPA
Timeline of Major Activities

2012
- ASAP workshop
- Sensors Evaluation and Collaboration

2013
- Regions workshop
- Short-term sensor field tests
- Designing/building autonomous systems: Village Green Project

2014
- Air sensors workshop
- Short-term sensor field tests
- Long-term testing: Regional Methods Project - CAIRSENSE
- Sensor network intelligent emissions locator tool (SENTINEL)

2015
- Citizen Science Toolbox
- CSAM-Citizen Science
- Designing/building autonomous systems: Village Green Project II
- Data visualization: RETIGO
- Community training

Workshops
Performance testing
Sensor system build
Sensor data tools
Critical Peer Reviewed Articles
Defining Emerging Sensor Technology
Sensor Related Resources

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Online Resources Available at:
http://www.epa.gov/heasd/airsensortoolbox/

Air Sensor Guidebook
CSAM Operating Procedures
Mobile Sensors & Applications for Air Pollutants
Citizen Science Air Monitor (CSAM): Quality Assurance Guidelines
Evaluation of Field-deployed Low Cost PM Sensors
Chamber evaluation of extensive search of low cost VOC monitoring types
Example VOC Sensors: UniTec, ToxRae, & EPA Devices
Example-Cairpol (VOC)
Select Quality Assurance Parameters Involving Continuous Monitoring

- **Bias** - is it routinely high or low with respect to the true value
- **Precision** - how repeatable is the measurement
- **Calibration** - does it respond in a systematic fashion as conc changes
- **Detection limit** - how low and high will it measure successfully
- **Response time** - how fast does the response vary with conc change
- **Linearity of sensor response** - what is the linear or multilinear range
- **Measurement duration** - how much data do you need to collect
- **Measurement frequency** - how many collection periods are needed
- **Data aggregation** - value in aggregating data (1 sec, 1 min, 1 hr, etc)
- **Selectivity/specificity** - does it respond to anything else
- **Interferences** - how does heat, cold, effect response
- **Sensor poisoning and expiration** - how long will the sensor be useful
- **Concentration range** - will the device cover expected highs and lows
- **Drift** - how stable is the response
- **Accuracy of timestamp** - what response output relates to the event
- **Climate susceptibility** - does RH, temp, direct sun, etc impact data
- **Data completeness** - what is the uptime of the sensor
- **Response to loss of power** - what happens when it shuts down

EPA/600/R-14/159 (June 2014)
Laboratory VOC Sensor Evaluation

![UniTec Sens-It and GC-FID Response](image)

- Measured concentration (ppb)
- UniTec Sens-It response (V)
- Time (min)

UniTec Sens-It and GC-FID Response

- UniTec Sens-It
- GC-FID Benzene
Examples of VOC Sensor Response

Both units are PID-based
But differ widely in response
## Generalized Laboratory VOC Sensor Findings

<table>
<thead>
<tr>
<th>Sensor</th>
<th>Benzene $r^2$</th>
<th>Three-Component $r^2$</th>
<th>Benzene Response</th>
<th>Three-Component Response</th>
<th>Three-Component: Benzene Ratio</th>
</tr>
</thead>
<tbody>
<tr>
<td>UniTec Sens-It (V)</td>
<td>0.8973</td>
<td>0.9328</td>
<td>0.0081</td>
<td>0.0213</td>
<td>2.63</td>
</tr>
<tr>
<td>AirBase CanarIT (ppb)</td>
<td>NA</td>
<td>NA</td>
<td>NA</td>
<td>NA</td>
<td>NA</td>
</tr>
<tr>
<td>CairPol CairClip (ppb)</td>
<td>NA</td>
<td>NA</td>
<td>NA</td>
<td>NA</td>
<td>NA</td>
</tr>
<tr>
<td>SPOD PID(V)</td>
<td>0.7799</td>
<td>0.7912</td>
<td>0.0022</td>
<td>0.0060</td>
<td>2.73</td>
</tr>
<tr>
<td>ToxiRAE Pro (ppm)</td>
<td>NA</td>
<td>NA</td>
<td>NA</td>
<td>NA</td>
<td>NA</td>
</tr>
</tbody>
</table>
## Performance Characteristics of VOC Sensors

<table>
<thead>
<tr>
<th>Sensor</th>
<th>Uptime</th>
<th>Ease of Installation</th>
<th>Ease of Operation</th>
<th>Mobility</th>
</tr>
</thead>
<tbody>
<tr>
<td>AirBase CanarIT (ppb)</td>
<td>+</td>
<td>++</td>
<td>+++</td>
<td>+++</td>
</tr>
<tr>
<td>SPOD PID (V)</td>
<td>++</td>
<td>-</td>
<td>++</td>
<td>++</td>
</tr>
<tr>
<td>CairClip (ppb)</td>
<td>+++</td>
<td>++</td>
<td>+++</td>
<td>+++</td>
</tr>
<tr>
<td>Sensotran Benzene (V)</td>
<td>unknown</td>
<td>-</td>
<td>-</td>
<td>-</td>
</tr>
<tr>
<td>ToxiRAE Pro PID (ppm)</td>
<td>++</td>
<td>++</td>
<td>+</td>
<td>+++</td>
</tr>
<tr>
<td>UniTec Sens-It (V)</td>
<td>+</td>
<td>-</td>
<td>+++</td>
<td>-</td>
</tr>
</tbody>
</table>

+ = fair, ++ = good, +++ = excellent
Mid-Tier Research Efforts

• ORD research would suggest that current state of the science for low cost sensors is lacking relative to performance

• Ongoing research investigating higher cost $10-20K (mid-Tier) options
VOC Technology Classes (time-resolved)

- In-plant / Work Truck
- Personal Safety
- Fenceline I
- Community I
- Fenceline II
- Community II

Working in Several technology areas for fugitive emission and fence line applications
Non-Speciated measurements at < ppb level

SPods

Deep-UV Optical Sensor
Speciated measurements at > ppb level

Open-path spectroscopy

Air-inlet compact GC
Conclusions

• VOC technologies appear to be lagging behind those for other pollutants
• Lower cost options appear to lack sensitivity at environmentally relevant concentrations
• Sensors reporting to be “specific” have not shown great potential
• Traditional occupational VOC monitors proved to be useful as sentinel sensors
• Mid-Tier options being investigated to examine specificity and LOD for this class of technology
Thank You

One resource for you is the following website:
(http://www2.epa.gov/air-research/air-sensor-toolbox-citizen-scientists)
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