



EPA's Emerging Low-Cost Sensor Research

**Ron Williams and Eben Thoma
(on Behalf of the ACE EM-2/EM3 Teams)**

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EPA's Air Pollution Sensors Team

- **EPA Office of Research and Development ACE (Air, Climate, and Energy)**
 - **Dan Costa, Alan Vette, Amanda Kaufman (ORISE)**
- **EPA ORD National Risk Management Research Laboratory**
 - **Gayle Hagler, Amara Holder, Sue Kimbrough, Bill Mitchell, Brian Gullett**
- **EPA ORD National Exposure Research Laboratory**
 - **Ron Williams, Vasu Kilaru, Russell Long, Rachelle Duvall, Eric Hall, Paul Solomon, Surender Kaushik, Lindsay Stanek, Tim Watkins**
- **EPA ORD Innovation Team**
 - **Stacey Katz, Gail Robarge**
- **EPA Office of Air Quality Planning and Standards**
 - **Chet Wayland, Tim Hanley, Joann Rice, Neelson Watkins, Kristen Benedict, Melinda Beaver**
- **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



Emerging Technologies Research Agenda

- 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

2015

Citizen Science Toolbox

CSAM-Citizen Science

Designing/building autonomous systems: Village Green Project II

Long-term testing: Regional Methods Project -CAIRSENSE

Sensor network intelligent emissions locator tool (SENTINEL)

Data visualization: RETIGO

Community training

- Workshops
- Performance testing
- Sensor system build
- Sensor data tools



Critical Peer Reviewed Articles Defining Emerging Sensor Technology

em • feature

Sensors and 'Apps' for Community-Based Atmospheric Monitoring

by Richard M. White, Igor Paprotny, Frederick Doering, Wayne E. Cascio, Paul A. Solomon, and Lara A. Gundel

Recent advances in both sensors and wireless communication provide opportunities for improved exposure assessment and increasing community involvement in reducing levels of human exposure to airborne contaminants. These new technologies can enhance data collection to answer science and policy questions related to the health and environmental effects of air pollution.¹

Richard M. White and Igor Paprotny are both with the Electrical Engineering and Computer Sciences Department, University of California, Berkeley, CA, and the Berkeley Sensor & Actuator Center; Frederick Doering is with the Mechanical Engineering Department, University of California, Berkeley, CA, and the Berkeley Sensor & Actuator Center; Wayne E. Cascio is with the U.S. Environmental Protection Agency's Office of Research and Development, Research Triangle Park, NC; Paul A. Solomon is with the U.S. Environmental Protection Agency's Office of Research and Development, Las Vegas, NV; and Lara A. Gundel is with the Environmental Energy Technologies Division, Lawrence Berkeley National Laboratory, Berkeley, CA. E-mail: rwhite@eecs.berkeley.edu.



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of Air Monitoring

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Air & Waste Management Association
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THE MAGAZINE FOR ENVIRONMENTAL MANAGERS

JANUARY 2014

Also in this issue:
CalEvoScreen: A Pathway to Address
Environmental Justice Issues in California
PM File: Storyboarding Builds
Persuasive Presentations

**Air Quality
Sensors, Part 1**
Findings from the 2013 EPA Air Sensors Workshop,
including emerging sensor technologies (e.g. Smartphone
Apps), data challenges and solutions, and sensor
calibration options

ACS Publications
www.acs.org

Sensor Related Resources

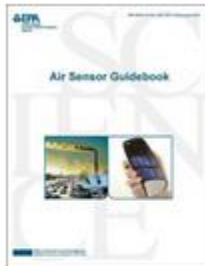


Air Sensor
Citizen Science Toolbox
EPA
Measure • Learn • Share

Contacts:
Ron Williams
919-541-2957
williams.ronald@epa.gov

Amanda Kaufman
919-541-2388
kaufman.amanda@epa.gov

Online Resources Available at:
<http://www.epa.gov/heads/airsensortoolbox/>



Air Sensor Guidebook



CSAM Operating Procedures



Mobile Sensors & Applications for Air Pollutants



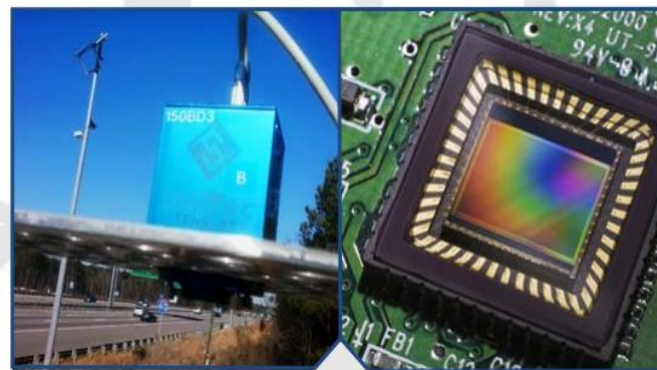
Citizen Science Air Monitor (CSAM): Quality Assurance Guidelines



Evaluation of Field-deployed Low Cost PM Sensors

**Chamber evaluation of
extensive
search of low cost VOC
monitoring types**

Next Generation Air Monitoring (NGAM) VOC Sensor Evaluation Report

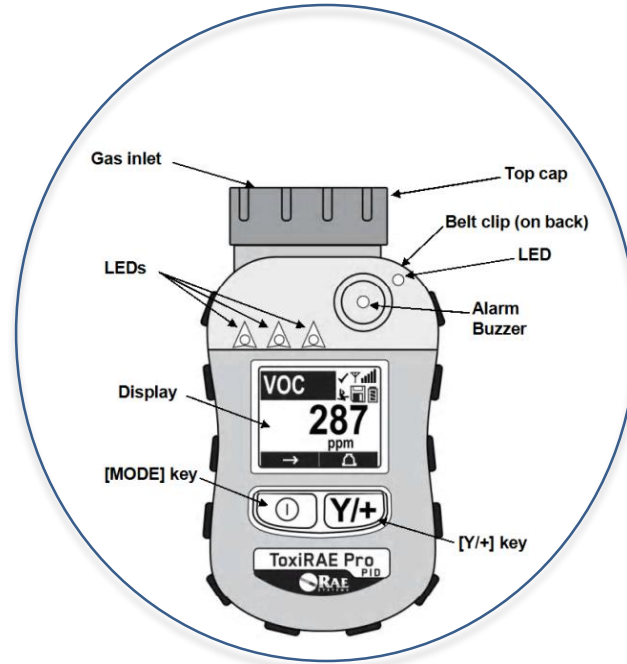


Example VOC Sensors: UniTec, ToxRae, & EPA Devices

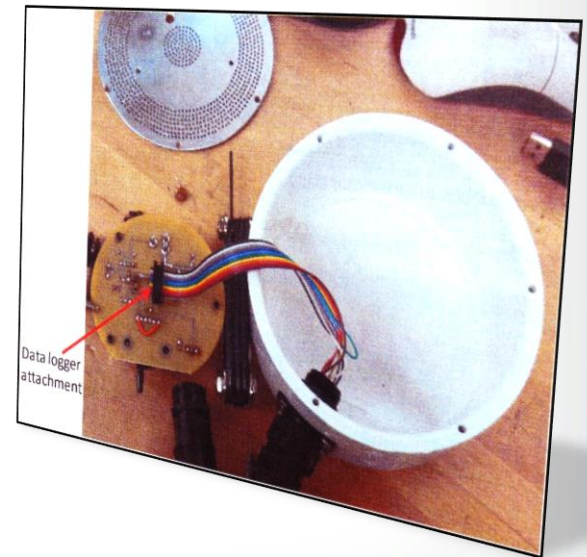
UniTec



ToxiRae



EPA SPOD PID



Example-Cairpol (VOC)



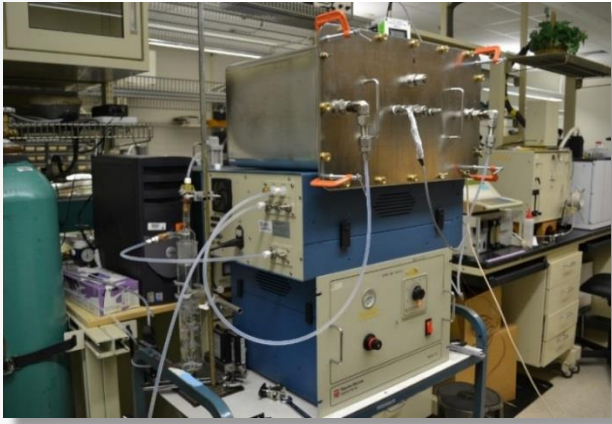
1 inch



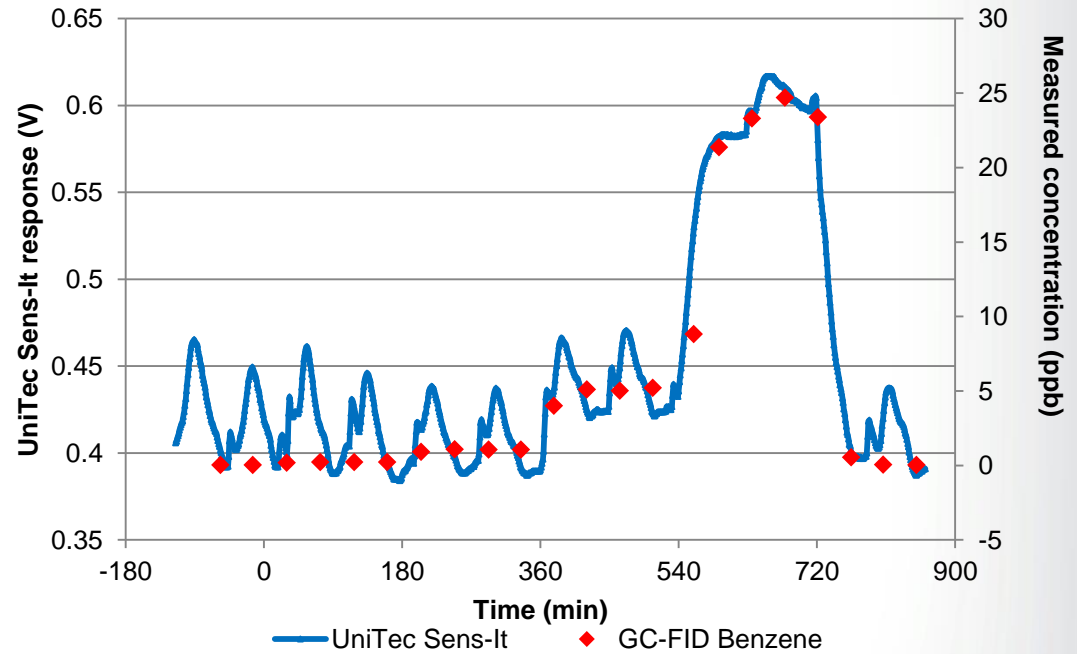
Select Quality Assurance Parameters Involving Continuous Monitoring

- **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

Laboratory VOC Sensor Evaluation

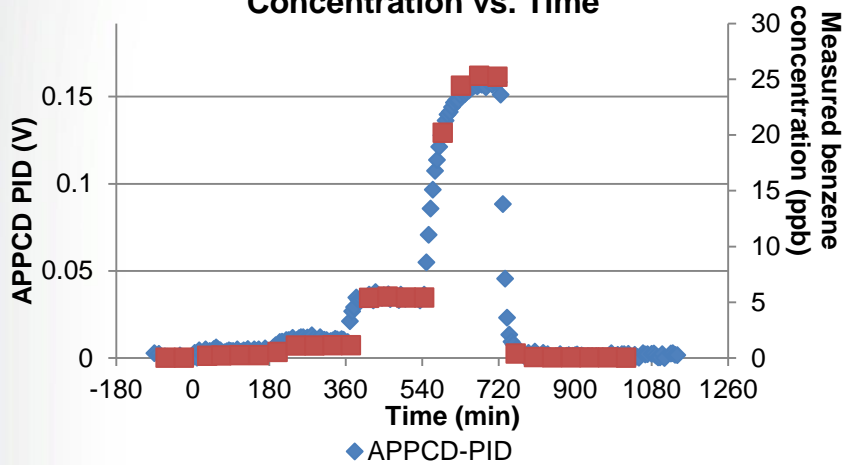


UniTec Sens-It and GC-FID Response



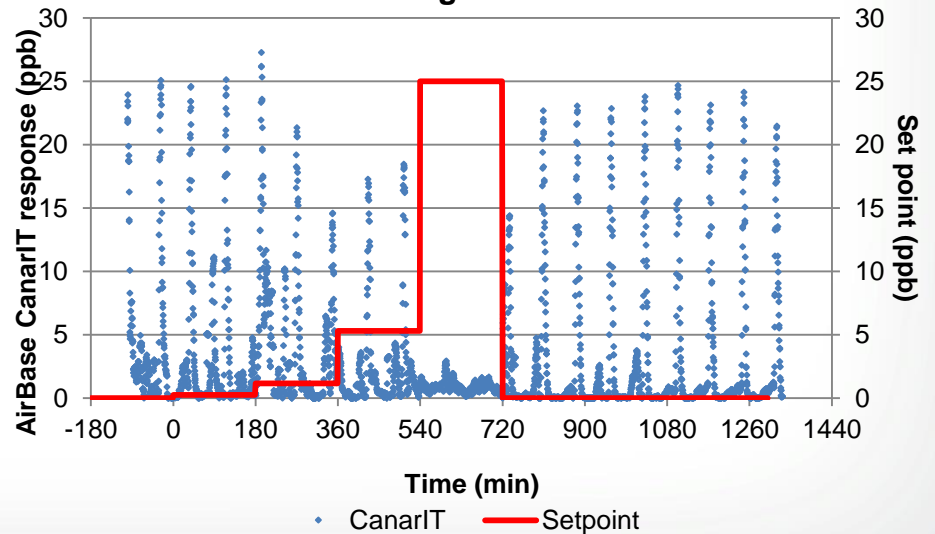
Examples of VOC Sensor Response

Corrected SPOD PID Data and Measured Concentration vs. Time



Both units are PID-based
But differ widely in response

CanarIT Signal vs. Time



Generalized Laboratory VOC Sensor Findings

Sensor	Benzene r^2	Three-Component r^2	Benzene Response	Three-Component Response	Three-Component: Benzene Ratio
UniTec Sens-It (V)	0.8973	0.9328	0.0081	0.0213	2.63
AirBase CanarIT (ppb)	NA	NA	NA	NA	NA
CairPol CairClip (ppb)	NA	NA	NA	NA	NA
SPOD PID(V)	0.7799	0.7912	0.0022	0.0060	2.73
ToxiRAE Pro (ppm)	NA	NA	NA	NA	NA

Performance Characteristics of VOC Sensors

Sensor	Uptime	Ease of Installation	Ease of Operation	Mobility
AirBase CanarIT (ppb)	+	++	+++	+++
SPOD PID (V)	++	-	++	++
CairClip (ppb)	+++	++	+++	+++
Sensotran Benzene (V)	unknown	-	-	-
ToxiRAE Pro PID (ppm)	++	++	+	+++
UniTec Sens-It (V)	+	-	+++	-

+ = 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)

High

Implementation Cost

★ *Working in Several technology areas for fugitive emission and fence line applications*



Fenceline II

Community II

Instruments

Sensors



Fenceline I



In-plant /
Work Truck

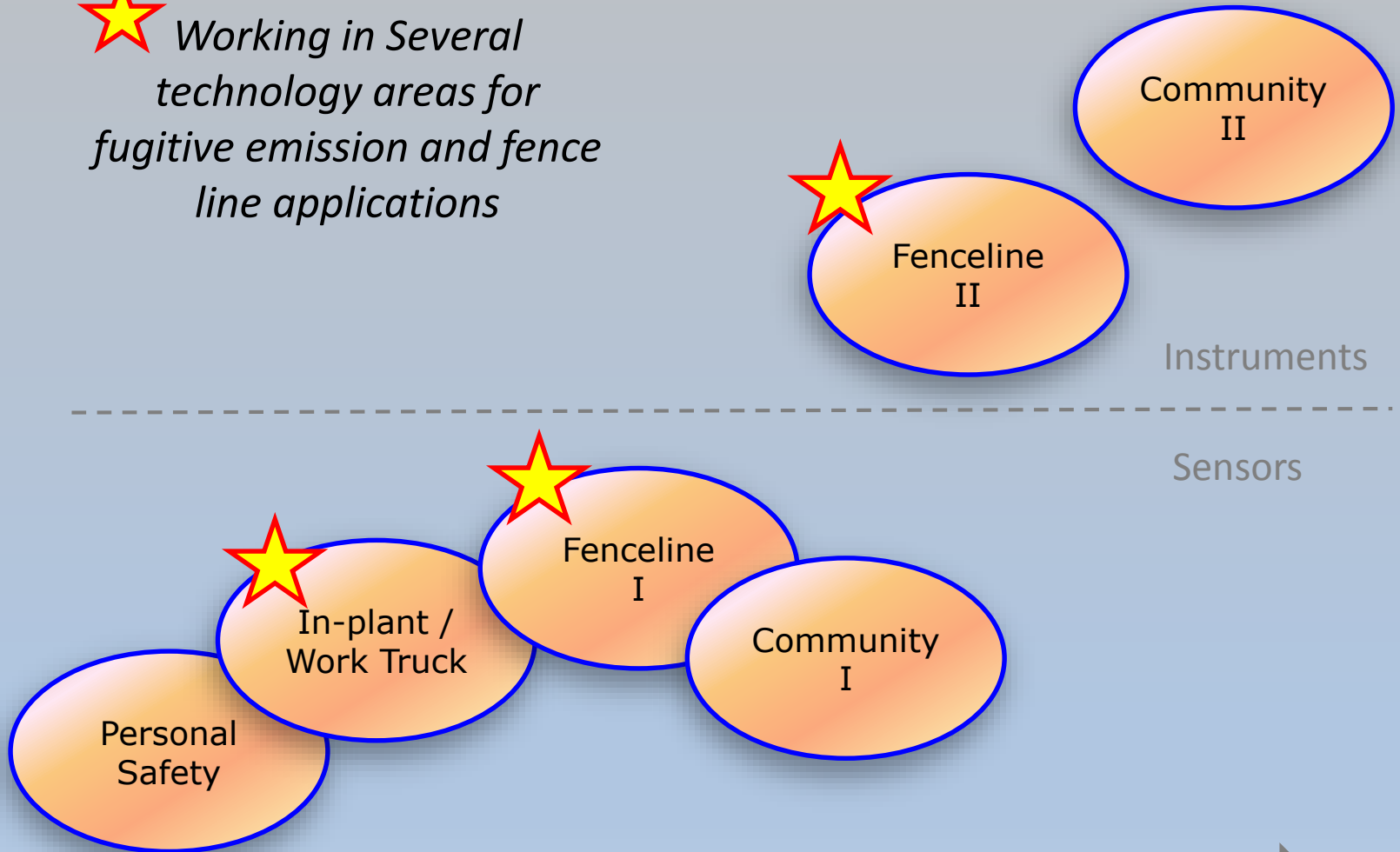
Community I

Personal Safety

Low

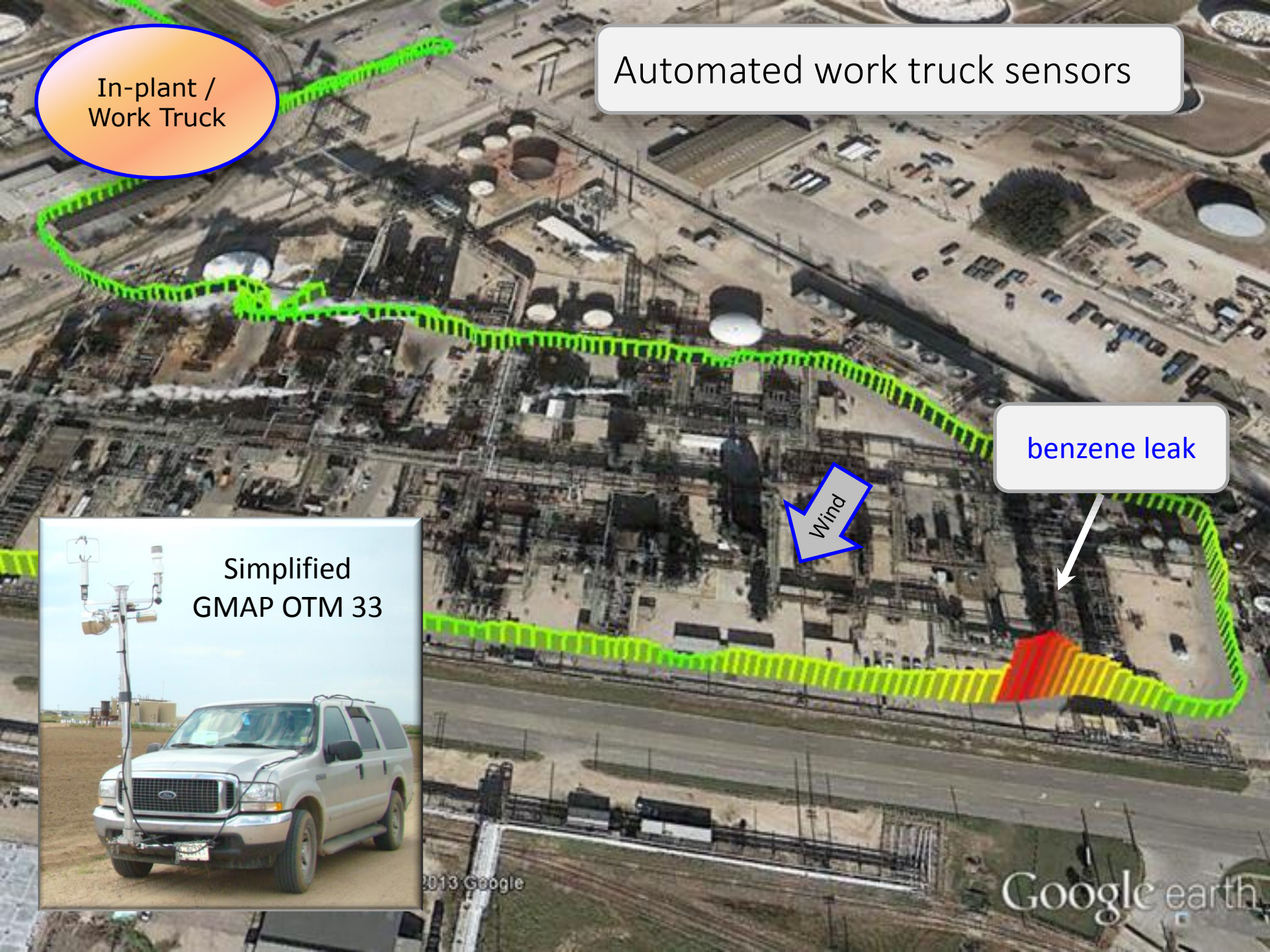
Detection Sensitivity / Speciation / Performance

High



In-plant /
Work Truck

Automated work truck sensors

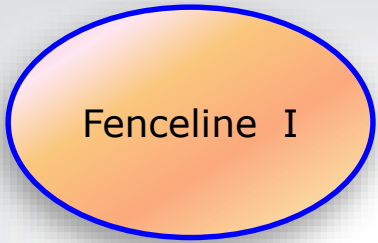


benzene leak

Wind



Simplified
GMAP OTM 33

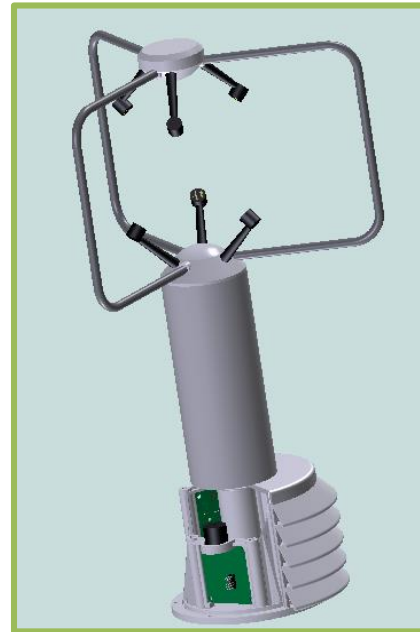
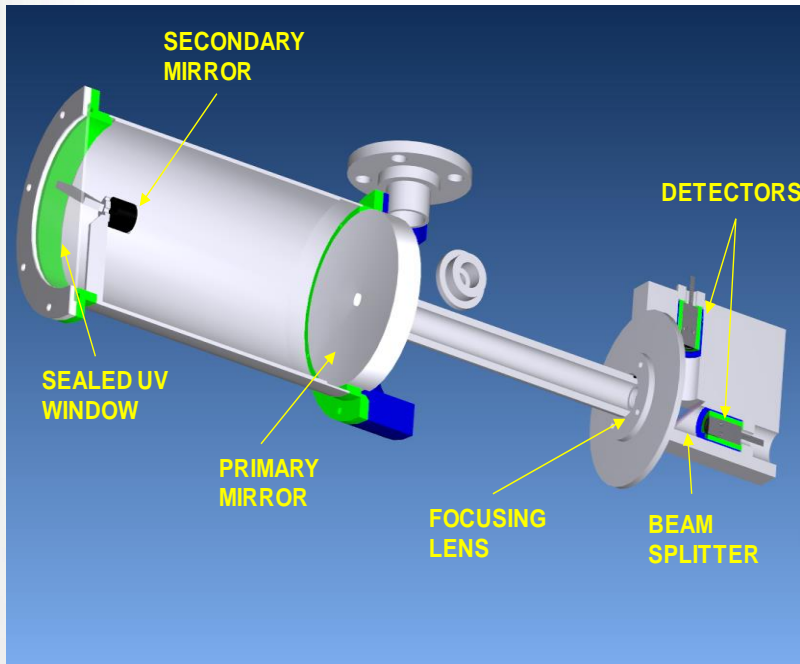


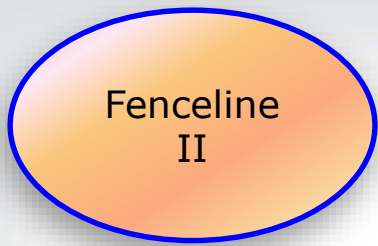
Fenceline I

Non-Speciated measurements at <math>< ppb</math> 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>)



The logo features the text "Air Sensor" in large blue letters on the left. To its right is a green toolbox with a handle, containing the text "Citizen Science Toolbox" and the EPA logo. Below the toolbox is a blue ribbon graphic and the text "Measure • Learn • Share".

Online Resources Available at:
<http://www.epa.gov/heads/airsensortoolbox/>

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Ron Williams
919-541-2957
williams.ronald@epa.gov

Amanda Kaufman
919-541-2388
kaufman.amanda@epa.gov



Contact Information

- **Ron Williams**
- **Project Lead- ACE EM-3 (Emerging Technologies)**
- **National Exposure Research Laboratory**
- **Phone 919 541 2957**
- **Email: Williams.Ronald@epa.gov**



- **Eben Thoma**
- **National Risk Management Research Laboratory**
- **Phone 919 541 7969**
- **Email: Thoma.Eben@epa.gov**

