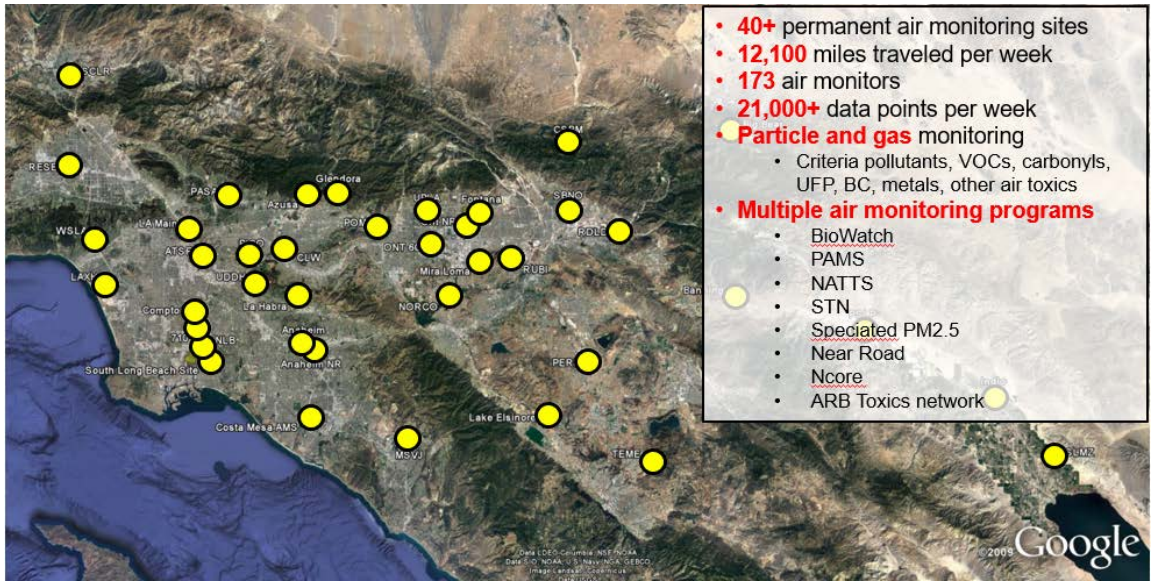
2018 National Air Quality Conference
January 24-26, 2018; Austin, TX

Air Quality Sensor Performance Evaluation Center (AQ-SPEC): Results from Three Years of Field and Laboratory Testing

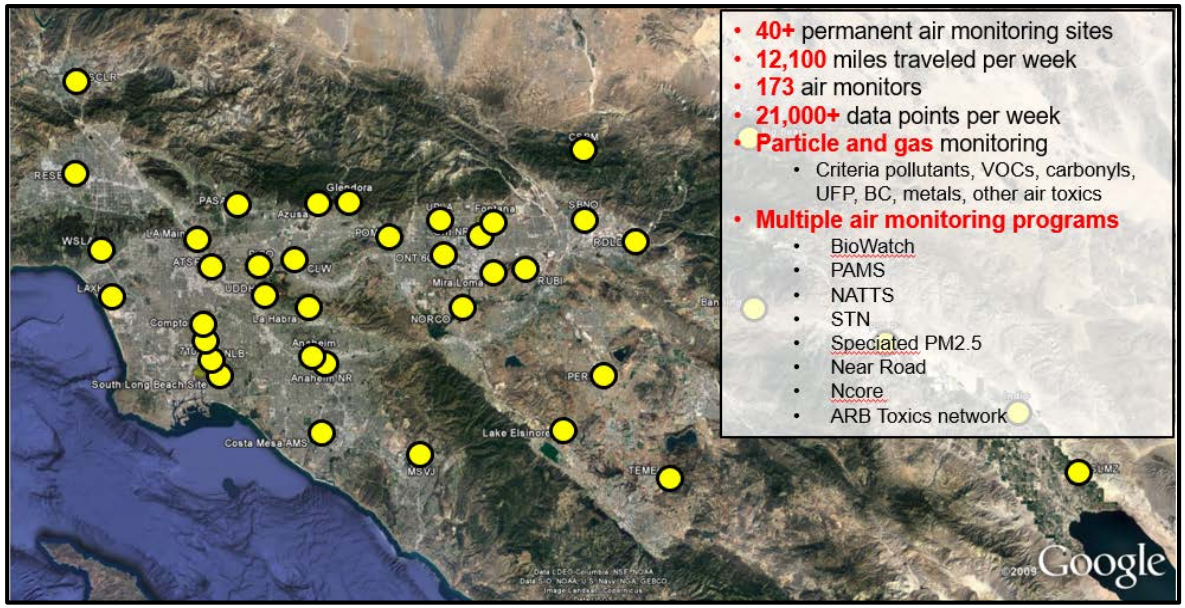
Andrea Polidori, Ph.D.
Atmospheric Measurements Manager
South Coast Air Quality Management District
Diamond Bar, CA

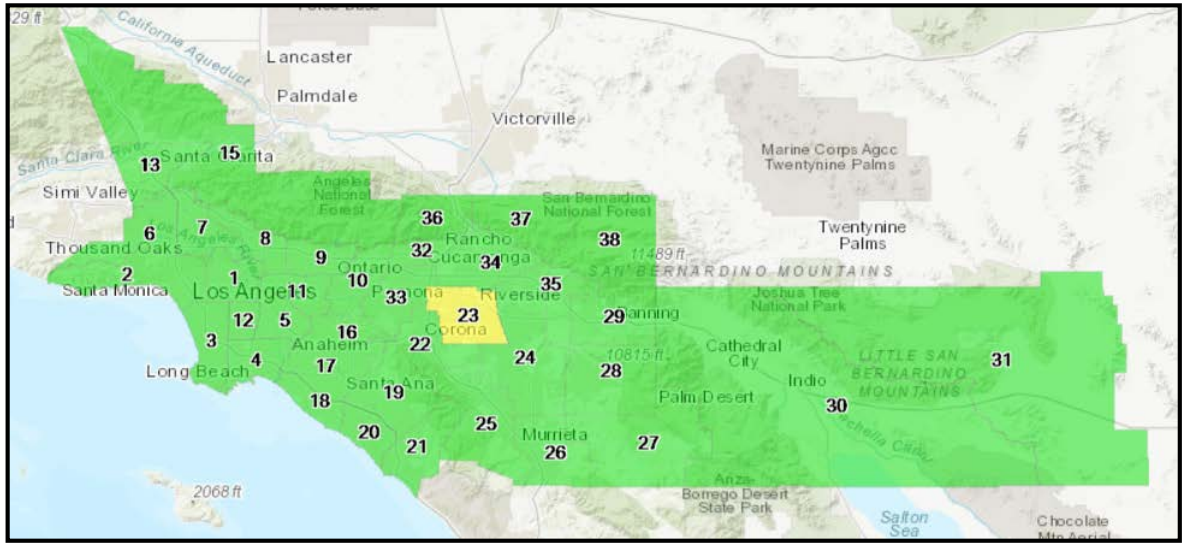
Background

- SCAQMD is the air pollution control agency for all of Orange County and the urban portions of Los Angeles, Riverside and San Bernardino counties
- Monitoring and analysis division
  - 40+ monitoring stations (criteria pollutants and air toxics)
  - State-of-the-art laboratory



Background



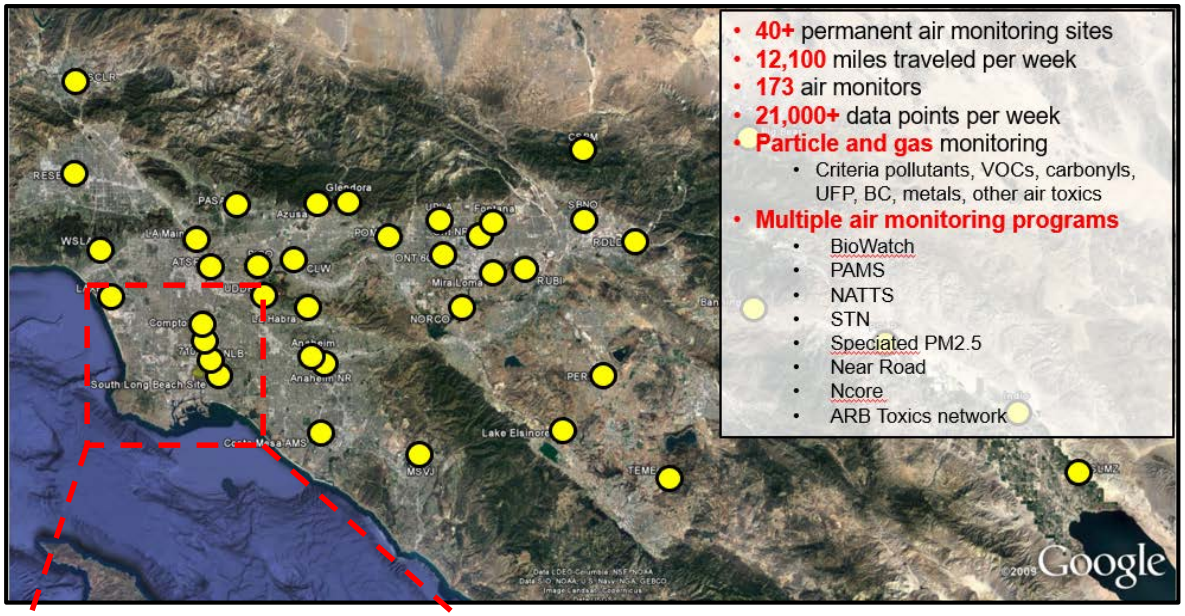


AQI Value

- Hazardous (301-500)
- Very Unhealthy (201-300)
- Unhealthy (151-200)
- Unhealthy for Sensitive Groups (101-150)
- Moderate (51-100)
- Good (0-50)

01/21/18 @ 9:00pm

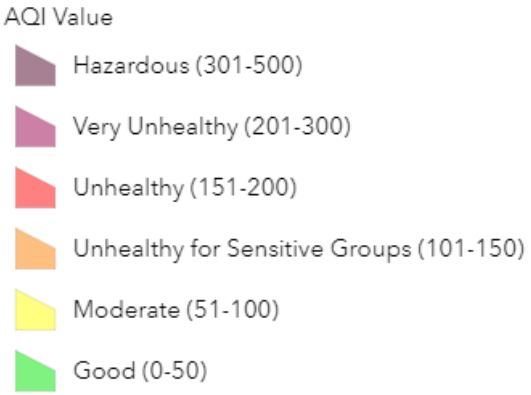
Background



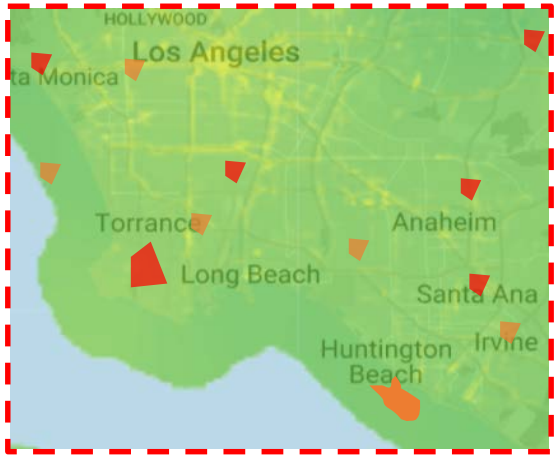
AQI Value

- Hazardous (301-500)
- Very Unhealthy (201-300)
- Unhealthy (151-200)
- Unhealthy for Sensitive Groups (101-150)
- Moderate (51-100)
- Good (0-50)

Background



- How would this map change if…
  - …we could monitor criteria pollutants at a lot more locations?
  - …we could include accurate air toxics info into the AQI calculation?



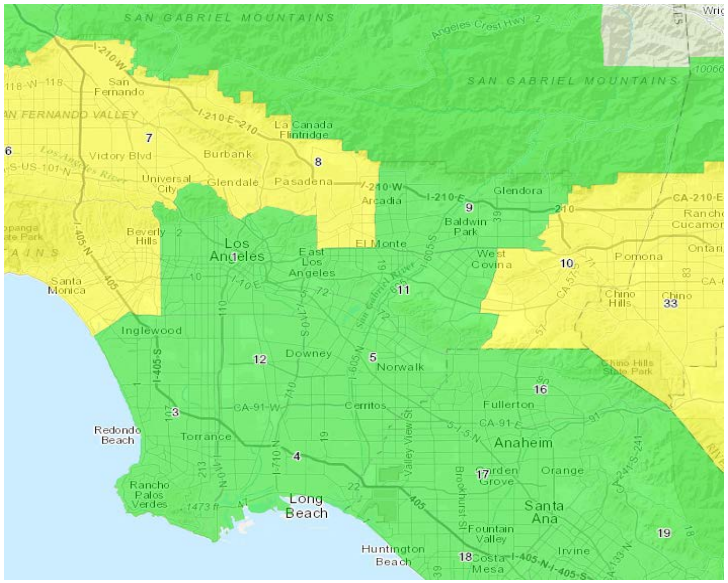
Used for example purposes only

- Other potential sources:
  - Traffic
  - Refineries
  - Oil wells
  - Gas stations
  - Marine vessels
  - Ports
  - Metal processing
  - Power plants
  - Waste disposal
  - Etc.

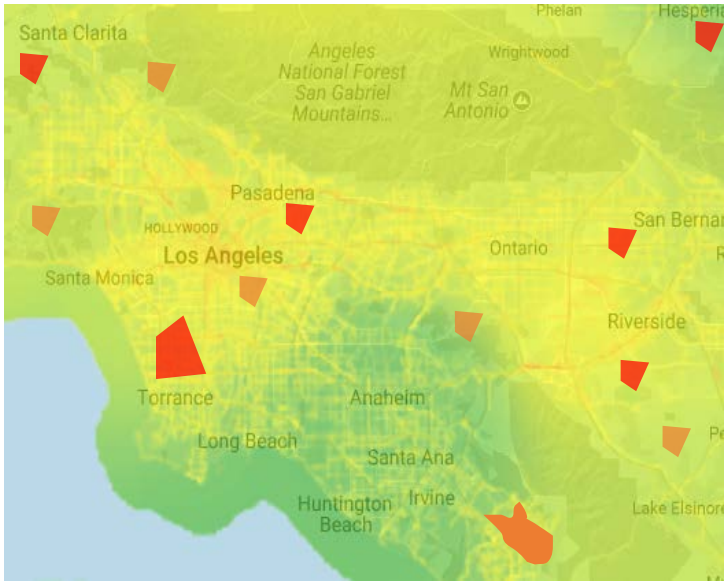
Background

- How do we go…

From



To



- Next generation monitoring (optical remote sensing, low-cost sensors, other)
- Aerial, fenceline, community, and mobile monitoring
- Satellite measurements
- Air pollution modeling
- Other

Low-Cost Air Quality Sensors

- Rapidly proliferating
- Tremendous potential
  - Low-cost
  - Ease of use
- Multiple applications
  - Spatial/Temporal air quality info
  - Fence-line monitoring
  - Community monitoring
- Need to systematically evaluate their performance
  - Accuracy, precision, durability and overall reliability
  - Calibration and drift
  - Other performance issues

uHoo

Clarity

aeroqual

aeroetris

PurpleAir

AQMesh

habitat map

foobot

TSI

SPEC SENSORS

Dylos Corporation
air quality monitoring innovation

…and more!

AQ-SPEC

Air Quality Sensor Performance Evaluation Center

- Established in July 2014
- Over $600,000 investment
- Main Goals & Objectives
  - o Provide guidance & clarity
  - o Promote successful evolution and use of sensor technology
  - o Minimize confusion
- Sensor Selection Criteria
  - o Commercially available
    - *Optical*
    - *Electrochemical*
    - *Metal oxide*
  - o Real- or near-real time
  - o Criteria pollutants & air toxics

AQ-SPEC

Air Quality Sensor Performance Evaluation Center

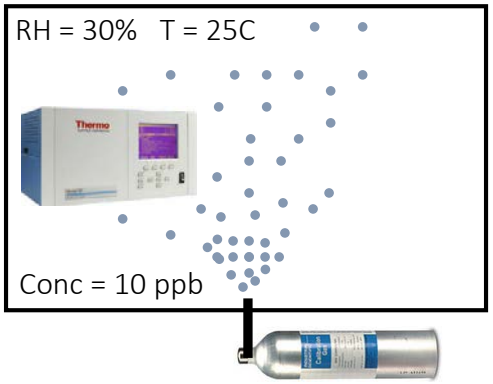
FIELD TESTING

(Side-by-side comparison w/ FRMs)

VS

LAB TESTING

(Controlled conditions)



RESULTS

(Categorize sensors based on performance)

Field Testing

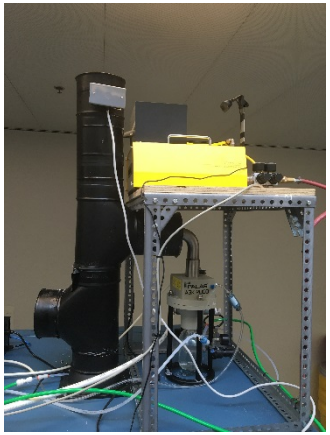
- Started in September, 2014
  - 30+ sensors evaluated
- Process
  - Sensor tested in triplicates
  - Two month deployment
  - < ~ $2,000: purchase
  - > ~ $2,000: lease or borrow
- Locations:
  - Rubidoux station (main)
    - Inland site
    - Fully instrumented

AQ-SPEC

Air Quality Sensor Performance Evaluation Center

Laboratory Testing

Aerosol Test



Gas Test

Laboratory Testing (cont.)

T and RH controlled: T (0-50 ^{0}C); RH (5-95%)

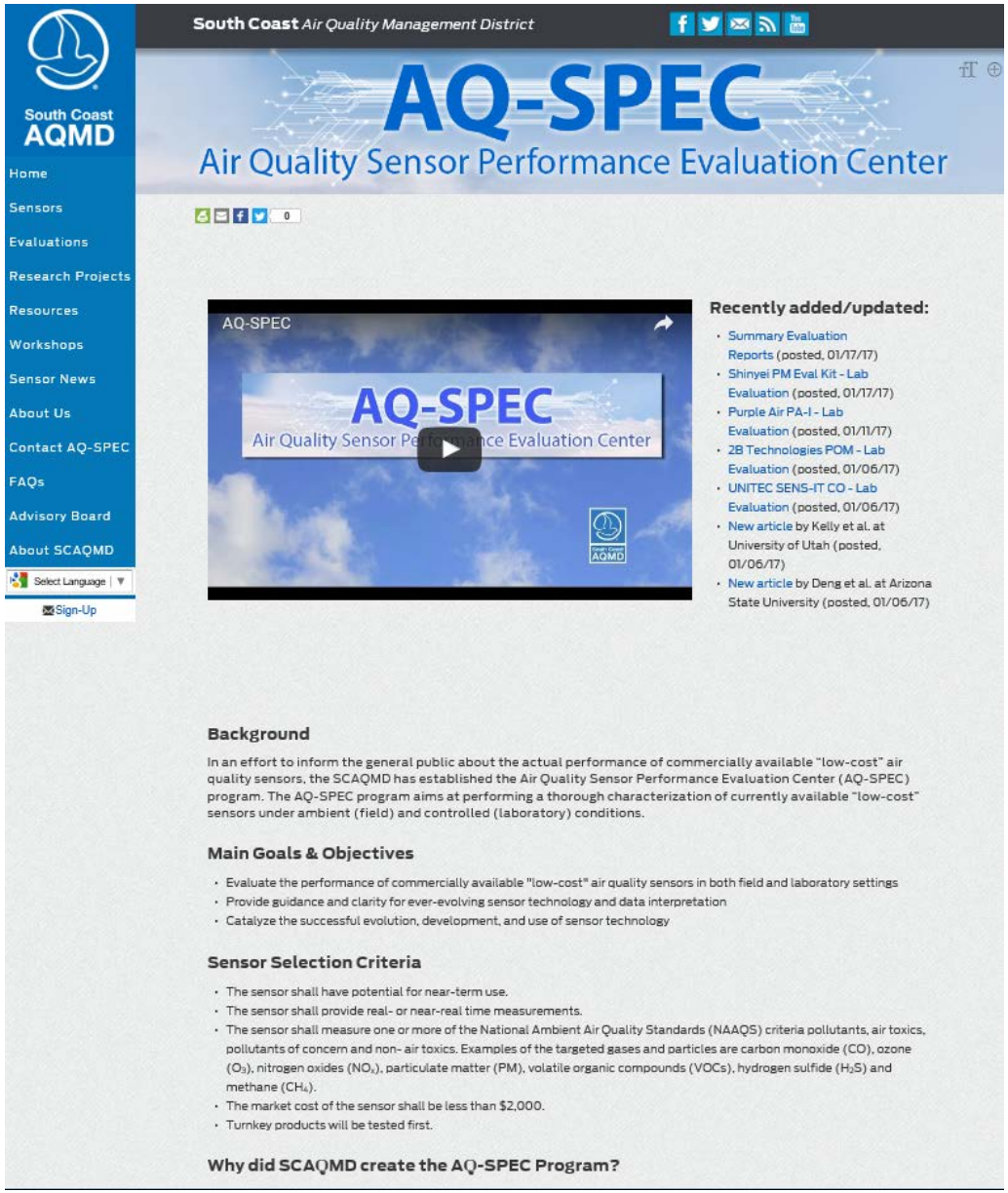
Particle testing

- Particle generation systems
- Particle monitors: mass concentration and size distribution

Gas testing

- Gas generation / dilution system
- Gas monitors: CO, NO_X, O_3, SO_2, H_2S, CH_4/NMHC

www.aqmd.gov/aq-spec



www.aqmd.gov/aq-spec

South Coast AQMD

- Home
- Sensors
- Evaluations
- Research Projects
- Resources
- Workshops
- Sensor News
- About Us
- Contact AQ-SPEC
- FAQs
- Advisory Board
- About SCAQMD

Select Language

Sign-Up


PurpleAir


PurpleAir PA-II


RTI - MicroPEM


Shinyei - PM Evaluation Kit


Spec Sensors

TSI - AirAssure


Unitec - SENS-IT

28 products

Items per page: 12 24 36 View All

South Coast *Air Quality Management District*

AQ-SPEC

Air Quality Sensor Performance Evaluation Center

Back to Sensors Page

Unitec - SENS-IT

UNITEC SENS-IT CO - Summary Report
UNITEC SENS-IT - Field Evaluation
UNITEC SENS-IT CO - Lab Evaluation

General Description

The SENS-IT (TF-MOS: Thick Film Metal Oxide Semiconductor) measures CO (carbon Monoxide) (0.1-80 ppm), NO_2 (nitrogen dioxide) (10-250 ppb), O_3 (ozone) (10-250 ppb), C_6H_6 (benzene) (0.1-30 ppb) and CH_4 (methane) (1-1,500 ppm).

Principle of Operation

The active surface of the sensor is based on a specific nano-structured semiconductor metal oxide. The first reaction which happens on the surface of the sensor is the adsorption of atmospheric oxygen with consequent charge transfer from semiconductor to oxygen molecules. The second reaction is related to specific gas to monitor, which while reacts with adsorbed oxygen (through Red-Ox reactions) allows the electrons to be released in the conduction band of the semiconductor. Taking the current signals from the sensors during these reactions, the direct concentration of the specific gas can be measured. Selectivity and sensitivity are reached using special doped semiconductor metal oxides.

Features

- Dimensions: 50 x 50 x 90 (H) mm
- Weight: 200 g
- Battery: No
- Power supply: Yes (+12 V DC)
- Power consumption: 3.0 - 4.0 W
- Sensor lifetime: N/A
- Clock function: No (No internal clock, must be connected to computer for time/date stamp)
- Sampling mechanism: Fan
- Environmental operating conditions: N/A
- PC data logging: Yes (USB to RS485 cable)
- Signal Output: Linear 0-5 V / Digital RS485
- Weatherproof: No

PM Sensors

Sensor Image	Manufacturer (Model)	Type	Pollutant(s)	Approx. Cost (USD)	*Field R^2	*Lab R^2	Summary Report
	**AethLabs** (microAeth)	Optical	BC (Black Carbon)	~$6,500	R^2 ~ 0.79 to 0.94		
	**Air Quality Egg** (Version 1)	Optical	PM	~$200	R^2 ~ 0.0		
	**Air Quality Egg** (Version 2)	Optical	PM	~$240	$PM_{2.5}$: R^2 ~ 0.79 to 0.85 PM_{10}: R^2 ~ 0.31 to 0.40		
	**Alphasense** (OPC-N2)	Optical	$PM_{1.0}$, $PM_{2.5}$ & PM_{10}	~$450	$PM_{1.0}$: R^2 ~ 0.63 to 0.82 $PM_{2.5}$: R^2 ~ 0.38 to 0.80 PM_{10}: R^2 ~ 0.41 to 0.60	R^2 ~ 0.99	PDF (1,291 KB)
	**Dylos** (DC1100)	Optical	$PM_{(0.5\text{-}2.5)}$	~$300	R^2 ~ 0.65 to 0.85	R^2 ~ 0.89	PDF (1,384 KB)
	**Foobot**	Optical	$PM_{2.5}$	~$200	R^2 ~ 0.55		
	**HabitatMap** (AirBeam)	Optical	$PM_{2.5}$	~$200	R^2 ~ 0.65 to 0.70	R^2 ~ 0.87	PDF (1,144 KB)
	**Hanvon** (Hanvon N1)	Optical	$PM_{2.5}$	~$200	R^2 ~ 0.52 to 0.79		
	**MetOne** (Neighborhood Monitor)	Optical	$PM_{2.5}$	~$1,900	R^2 ~ 0.53 to 0.67		
	**Moji China** (Airnut)	Optical	$PM_{2.5}$	~$150	R^2 ~ 0.81 to 0.88		
	**Naneos** (Partector)	Electrical	PM (LDSA: Lung-Deposited Surface Area)	~$7,000	$PM_{1.0}$: R^2 ~ 0.1 $PM_{2.5}$: R^2 ~ 0.2		
	**Origins** (Laser Egg)	Optical	$PM_{2.5}$ & PM_{10}	~$200	$PM_{2.5}$: R^2 ~ 0.58 PM_{10}: R^2 ~ 0.0		
	**Perkin Elmer** (ELM)	Optical	PM	~$5,200	R^2 ~ 0.0		
	**PurpleAir (PA-I)**	Optical	$PM_{1.0}$, $PM_{2.5}$ & PM_{10}	~$150	$PM_{1.0}$: R^2 ~ 0.93 to 0.95 $PM_{2.5}$: R^2 ~ 0.77 to 0.92 PM_{10}: R^2 ~ 0.32 to 0.44	$PM_{1.0}$: R^2 ~ 0.95 $PM_{2.5}$: R^2 ~ 0.99 PM_{10}: R^2 ~ 0.97	PDF (1,072 KB)
	**PurpleAir (PA-II)**	Optical	$PM_{1.0}$, $PM_{2.5}$ & PM_{10}	~$200	$PM_{1.0}$: R^2 ~ 0.96 to 0.98 $PM_{2.5}$: R^2 ~ 0.93 to 0.97 PM_{10}: R^2 ~ 0.66 to 0.70	$PM_{1.0}$: R^2 ~ 0.99 $PM_{2.5}$: R^2 ~ 0.99 PM_{10}: R^2 ~ 0.95	PDF (1,328 KB)
	**RTI** (MicroPEM)	Optical	$PM_{2.5}$	~$2,000	R^2 ~ 0.65 to 0.90	R^2 ~ 0.99	PDF (1,087 KB)
	**Shinyei** (PM Evaluation Kit)	Optical	$PM_{2.5}$	~$1,000	R^2 ~ 0.80 to 0.90	R^2 ~ 0.93	PDF (1,156 KB)
	**Speck**	Optical	$PM_{2.5}$	~$150	R^2 ~ 0.32		
	**TSI** (AirAssure)	Optical	$PM_{2.5}$	~$1,500	R^2 ~ 0.82		

Results

Most PM sensors showed:

- Minimal down time
- Moderate intra-model variability
- Strong correlation (R^2) with EPA "approved" instruments (e.g., FEM)

However…

- Sensor calibration is needed in most cases
- Very small particles (e.g. < 0.5 µm) are not detected
- Bias in algorithms used to convert particle counts to particle mass

Gaseous Sensors

Sensor Image	Manufacturer (Model)	Type	Pollutant(s)	Approx. Cost (USD)	*Field R^2	*Lab R^2	Summary Report
	**2B Technologies** (POM)	UV absorption (FEM Method)	O_3	~$4,500	R^2 ~ 1.00	R^2 ~ 0.99	PDF (1,295 KB)
	**Aeroqual** (S-500)	Metal Oxide	O_3	~$500	R^2 ~ 0.85	R^2 ~ 0.99	PDF (1,197 KB)
	**Air Quality Egg** (Version 1)	Metal Oxide	CO, NO_2 & O_3	~$200	CO: R^2 ~ 0.0 NO_2: R^2 ~ 0.40 O_3: R^2 ~ 0.85		
	**Air Quality Egg** (Version 2)	Electrochem	CO & NO_2	~$240	CO: R^2 ~ 0.0 NO_2: R^2 ~ 0.0		
	**Air Quality Egg** (Version 2)	Electrochem	O_3 & SO_2	~$240	O_3: R^2 ~ 0.0 to 0.20 SO_2: R^2 n/a		
	**AQMesh** (v.4.0) (Discontinued)	Electrochem	CO, NO, NO_2 & O_3	~$10,000	CO: R^2 ~ 0.42 to 0.80 NO: R^2 ~ 0.0 to 0.44 NO_2: R^2 ~ 0.0 to 0.46 O_3: R^2 ~ 0.46 to 0.83		
	**Perkin Elmer** (ELM)	Metal Oxide	NO, NO_2 & O_3	~$5,200	NO: R^2 n/a NO_2: R^2 ~ 0.0 O_3: R^2 ~ 0.89 to 0.96		
	**Smart Citizen Kit**	Metal Oxide	CO, NO_2	~$200	CO: R^2 ~ 0.50 to 0.85 NO_2: R^2 ~0.0		
	**Spec Sensors**	Electrochem	CO, NO_2 & O_3	~$500	CO: R^2 ~ 0.84 to 0.90 NO_2: R^2 ~ 0.0 to 0.16 O_3: R^2 ~ 0.0 to 0.24		
	**UNITEC** (SENS-IT)	Metal Oxide	CO, NO_2 & O_3	~$2,200	CO: R^2 ~ 0.33 to 0.43 NO_2: R^2 ~ 0.60 to 0.65 O_3: R^2 ~ 0.72 to 0.83	CO: R^2 ~ 0.99 O_3: R^2 ~ 0.82 to 0.90	CO: PDF (1,283 KB) O_3: PDF (1,177 KB)

Results

<u>Most gaseous sensors showed</u>:

- Acceptable data recovery
- Wide intra-model variability range
- CO; NO; O_3 (when measured alone): good correlation with FRMs
- O_3 + NO_2: low correlation with FRM (potential O_3/NO_2 interference)
- SO_2; H_2S; VOC: difficult to measure with available sensors

AQ-SPEC - What's Next?
Sensor Certification Program?

- Which pollutant(s) / sensor type(s)?
  - Are PM (e.g., particle counters) and Ozone (e.g., electrochemical) sensors good candidates?



- "Certified" for which use?
  - Regulatory?
  - Fenceline?
  - Improve network design?
  - Permitting?
  - Other?

…….for what?

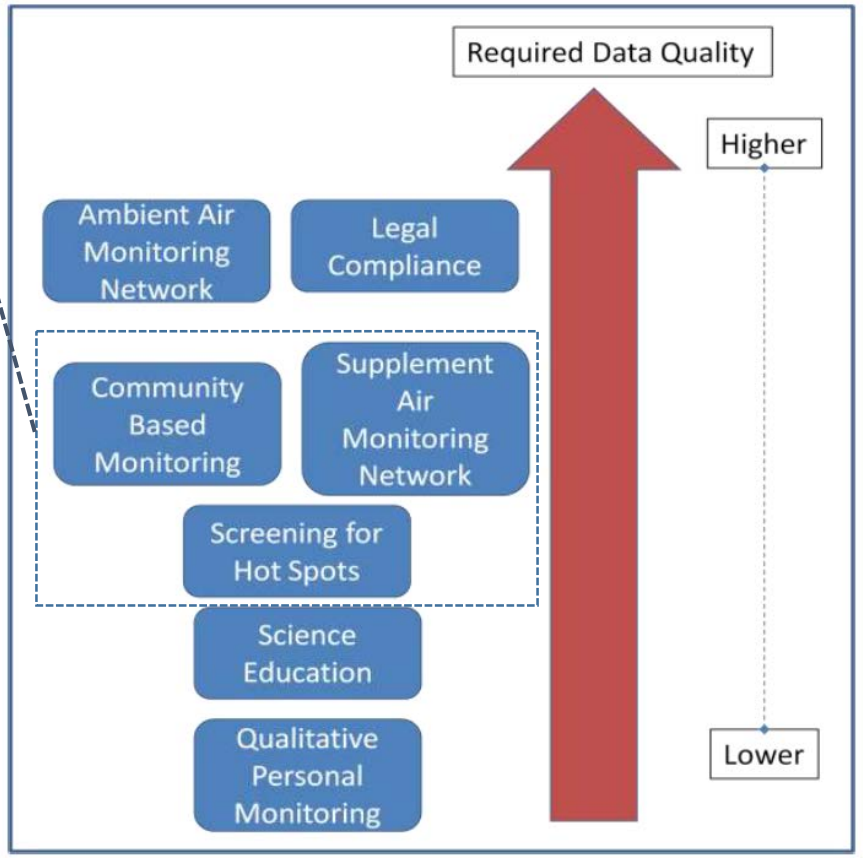
- Very expensive to implement correctly
  - Multiple field testing locations across the Nation
  - Multiple laboratory testing facilities
  - Extended testing time

Sensor Applications

- Categorize sensors based on performance
- Identify application(s) based on sensor capabilities

Several interesting applications

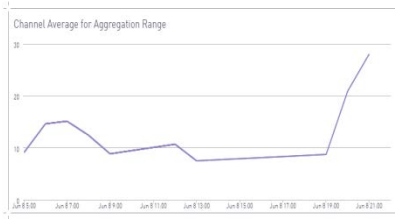
- Characterize spatial variations
  - Wide area coverage
- Improve network design
  - Set-up monitors in high concentration areas
- Permitting
  - Monitoring before and after construction
- Fence-line Monitoring
  - Large refineries and emission sources
- Community concerns
  - Local impact of freeways, airports, refineries, etc.



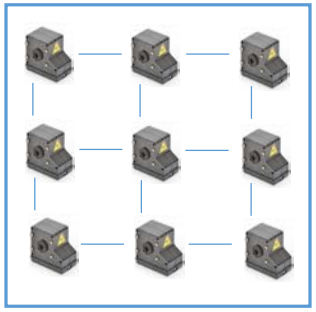
EPA's "*DRAFT Roadmap for Next Generation Air Monitoring*"

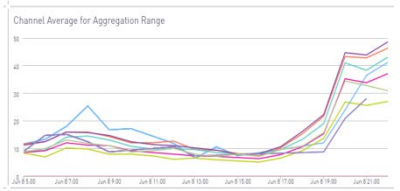
Low-cost Sensors / High-cost Networks

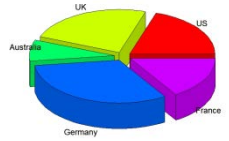
- Single user (e.g. 1 sensor)
  - Cost: $
    - Hardware
    - Minimal maintenance



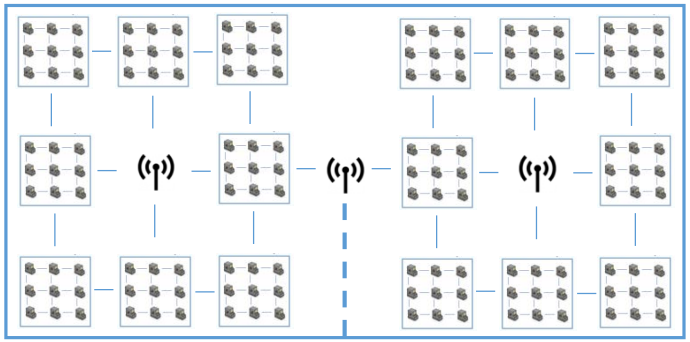
- Small sensor network (e.g. 9 sensors)
  - Cost: $$
    - Hardware
    - Maintenance & calibration
    - Sensor connectivity
    - Data logging and management
    - Data validation and analysis
    - Visualization and reporting

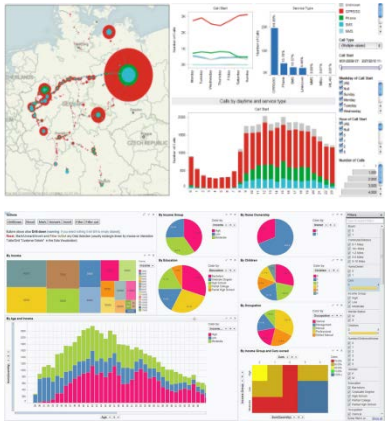






- Large sensor network (e.g. > 100 sensors)
  - Cost: $$$$
    - Hardware
    - Maintenance & calibration
    - Sensor connectivity
    - Data logging and management
    - Data validation and analysis
    - Visualization and reporting



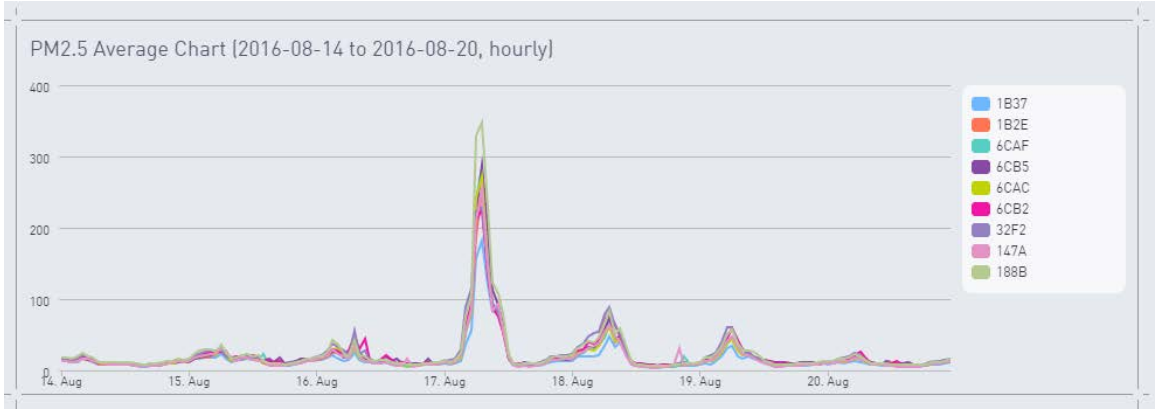


AQ-SPEC – Current Activities
Fenceline Monitoring: Waste Disposal Facility

- Monitor fugitive emissions from a Waste Disposal facility in Southern California
- 9 sensor nodes deployed at facility fenceline on June 2016
- Wireless network / remote server
- Real-time PM_1, $PM_{2.5}$ and PM_{10} monitoring

AQ-SPEC – Current Activities
Fenceline Monitoring: Waste Disposal Facility

- Dedicated website
  - www.aqmd.meshify.com
  - *Real-time data logging, display, and mapping*
  - *Data analytics*
  - *Email and/or text alerts*
- Project benefits
  - *Correlate PM measurements w/ on-site activities*
  - *Measure PM levels before and after facility upgrades*



AQ-SPEC – Current Activities
Fenceline Monitoring: Refinery
(EPA Community Scale Grant)

- Use “SPODs” to:
  - *Monitor VOC emissions from refineries in real-time*
  - *Assess potential impacts on nearby communities*
  - *Study temporal and spatial dispersion of VOCs*

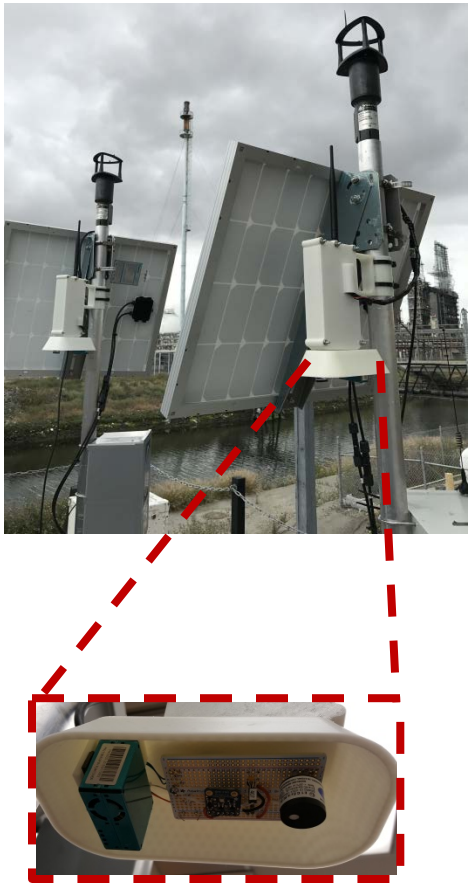
  (Technology: PID sensor + 2D anemometer)

- Use of Optical Remote Sensing (ORS) methods to:
  - *Validate “SPOD” data*
  - *Estimate annual refinery (VOC) emissions*

  (Technology: SOF/DOAS/FTIR)

AQ-SPEC – Current Activities
Fenceline Monitoring: Refinery
(EPA Community Scale Grant)

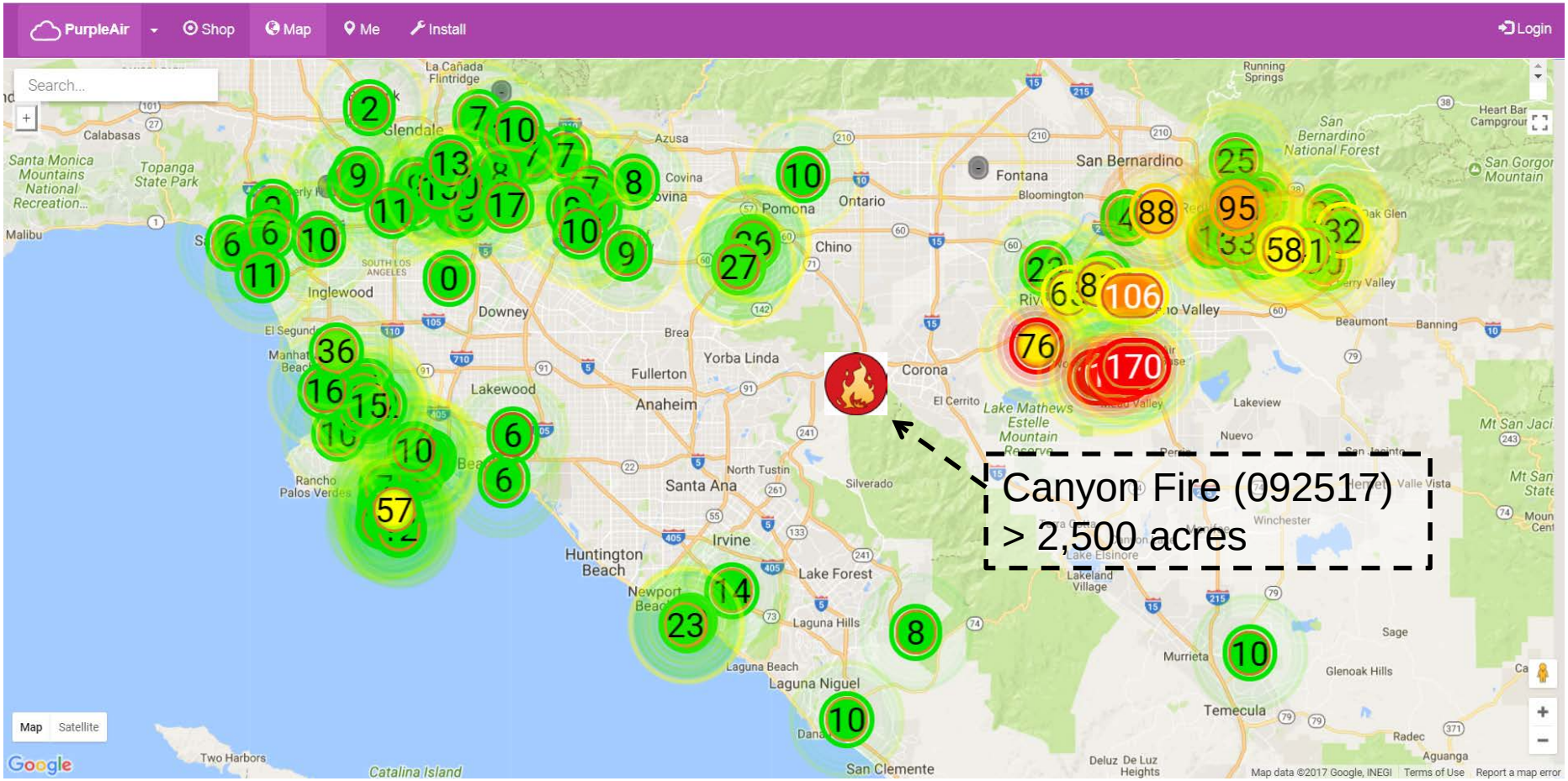
- Mobile ORS: *quarterly surveys of emission measurements and concentrations mapping*
- "Low-cost" sensors network: *long-term monitoring of VOC and PM2.5 at facility fenceline and inside communities*



Example of benzene concertation mapping

AQ-SPEC – Current Activities
Fenceline Monitoring: Refinery
(EPA Community Scale Grant)

AQ-SPEC – Current Activities
PM Sensor Network



Note: Values are reported as AQI units

AQ-SPEC – Current Activities

U.S. EPA Science To Achieve Results (STAR) project

Engage, educate, and empower California communities on the use and applications of "low-cost" air monitoring sensors

- Provide communities with the knowledge necessary to select, use and maintain low-cost sensors and to correctly interpret the collected data
- Three year study:
  - SCAQMD (PI)
  - University of California Los Angeles (UCLA; Co-PI)
  - Sonoma Technology Inc. (STI; Co-PI)
  - BAAQMD
  - Santa Barbara County APCD
  - Other CAPCOA agencies
  - Community Groups
  - Leisure World (Seal Beach, CA)
  - Weather Underground
  - University of Auckland (New Zealand)

South Coast AQMD

UCLA

STI Sonoma Technology, Inc.

AQ-SPEC – Current Activities

U.S. EPA Science To Achieve Results (STAR) project

Engage, educate, and empower California communities on the use and applications of "low-cost" air monitoring sensors

- Four specific aims:
  1. Develop educational material for communities
  2. Evaluate / identify candidate sensors for deployment
  3. Deploy selected sensors in California communities
  4. Communicate the lessons learned to the public

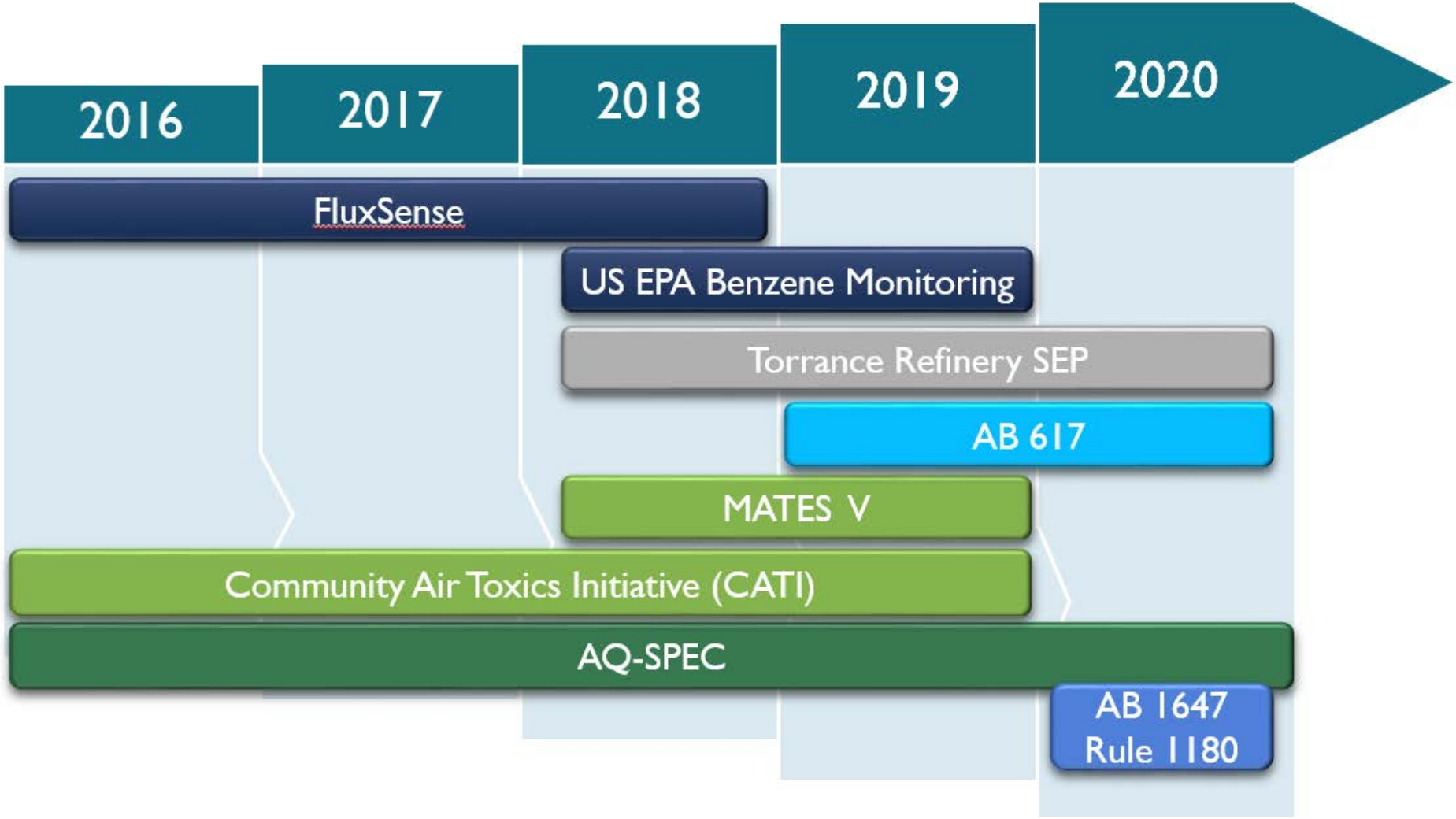
- On-going activities:
  - Wide Spread Sensor Deployment across California
    - ~450 PM sensors
    - 100 Aeroqual nodes (i.e., PM, O_3, NOx)
  - Cloud Based Platform Development
    - Data ingestion and storage
    - Data visualization and mapping
    - Data dissemination

South Coast AQMD

UCLA

STi Sonoma Technology, Inc.

Current and Upcoming Air Toxic Initiatives



Thanks!

The AQ-SPEC Team

- *Dr. Andrea Polidori*
- *Dr. Vasileios Papapostolou*
- *Brandon Feenstra*
- *Dr. Hang Zhang*
- *Berj Der Boghossian*
- *Dr. Olga Pikelnaya*