Research on Availablity/Reliability Low-cost Air Quality Monitors
4.15.21

The Albuquerque-Bernalillo County Joint Air Quality Program (AQP), administered by the City of Albuquerque's Environmental Health Department, is authorized to implement and enforce clean air laws within the boundaries of the City of Albuquerque and Bernalillo County.

This research was conducted by AQP staff to clearly present to the public what affordable air quality monitors are available and reliable. This is a working document, so if you know of a sensor AQP should research, please let us know by emailing: mburstein@cabq.gov.

How "Low-cost" Sensors Can be Used:

"Low-cost" air quality sensors provide a means for environmental groups and individuals to independently evaluate air quality. They can show a general trend in air pollution and alert citizens about the kinds of pollution in their neighborhoods. The advantages of utilizing sensor technologies include:

- Complement conventional monitoring networks
- Raise awareness in local communities

Low-cost Sensor Limitations:

Recently, U.S. Environmental Protection Agency (EPA) summarized the current status of small air quality sensors:

> Despite the opportunities low-cost sensors provide to better understand local air quality conditions, there are many uncertainties about the technology's operating and performance capabilities. Studies by EPA and others have shown that results from air sensors do not always compare well to high-quality regulatory monitors, which are used to implement the nation's air quality standards. These more expensive reference monitors have undergone rigorous independent scientific evaluation and testing.[1]

A major disadvantage of sensors is that they cannot be used for compliance with the National Ambient Air Quality Standards (NAAQS) unless they meet the requirements in 40 CFR Part 50, 53, and 58.

Low-cost air quality sensors are better developed for monitoring criteria pollutants than hazardous air pollutants (HAPS), and the latter are not yet sophisticated enough for regulatory monitoring. A few small air quality sensors can detect a few HAPs, but they are not sufficiently reliable for assessing the concentrations and health effects of HAPs. The EPA nor the South Coast Air Quality Management District (SCAQMD) in California have not tested any HAPS sensors to date, and therefore these monitors are not included in the follow research.

[1] Study Assesses Long Term Capabilities of Air Sensors (June 18, 2019) available at: https://www.epa.gov/sciencematters/study-assesses-long-term-capabilities-air-sensors

Sensor Evaluation Criteria:

Various agencies have conducted field studies regarding the effectiveness of "low-cost" criteria pollutant sensors. The two main agencies are EPA and SCAQMD.

The sensors are evaluated and a coefficient of determination, R^2, is calculated. R^2 is a statistical term that represents how well a sensor performs in comparison to a reference monitor. A value of $R^2 = 1$ would mean the sensor has perfect correlation to the reference monitor, and $R^2 = 0$, means no correlation to the monitor. Another important consideration is how the data is stored and reported. At this time, AQP does not have the capability to Quality Assure or host the data derived from the sensors. The sensors for this project will have hosted websites for data reporting. Our research to date has shown that low-cost air toxics sensors are not widely available and those currently on the market are not reliable or accurate. According to EPA, reliable, low cost air toxic sensor technology is about 10 years down the road.

The SCAQMD evaluates the performance of various sensor technologies under ambient (field) and controlled (laboratory) conditions. The tables below summarize the SCAQMD evaluation data for both gaseous and particulate sensors and which sensors meet AQP's criteria detailed above.

SCAQMD Evaluation Data:

Particulate Sensors				**AQP Criteria**	
Make (Model)	**Est. Cost (USD)**	**Pollutant(s)**	***Field R2**	**R2 >.80, Sensor less than $2,500**	**Comment**
Aeroqual (AQY v1.0)	$ 4,000.00	$PM_{2.5}$	0.76 to 0.81	No	Cost does not meet criteria
		PM_{10}	0.56 to 0.68	No	Cost does not meet criteria and R2 <.80
Aeroqual (S500-PM)	$ 1,490.00	$PM_{2.5}$	0.46 to 0.67	No	R2<.80
		PM_{10}	0.15 to 0.24	No	R2<.80
AethLabs (microAeth)	$ 6,500.00	BC (Black Carbon)	0.79 to 0.94	No	Cost does not meet criteria
Air Quality Egg (2018 Model)	$ 249.00	$PM_{1.0}$	0.86 to 0.88	Yes	
		$PM_{2.5}$	0.84 to 0.85	Yes	
		PM_{10}	0.12 to 0.13	No	R2<.80
Air Quality Egg (Version 1)	$ 200.00	PM	~ 0.0	No	R2<.80
Air Quality Egg (Version 2)	$ 240.00	$PM_{2.5}$	0.79 to 0.85	Yes	
		PM_{10}	0.31 to 0.40	No	R2<.80
AirThinx (IAQ)	$ 1,000.00	$PM_{1.0}$	0.68 to 0.70	No	R2<.80
		$PM_{2.5}$	0.54 to 0.57	No	R2<.80
		PM_{10}	0.03 to 0.05	No	R2<.80
Airviz Inc. (Speck)	$ 150.00	$PM_{2.5}$	0.32	No	R2<.80
Alphasense (OPC-N2)	$ 310.00	$PM_{1.0}$	0.63 to 0.82	Yes	
		$PM_{2.5}$	0.65 to 0.80	No	
		PM_{10}	0.45 to 0.57	No	R2<.80
Alphasense (OPC-N3)	$ 338.00	$PM_{1.0}$	0.78 to 0.82	Yes	
		$PM_{2.5}$	0.52 to 0.67	No	R2<.80
		PM_{10}	0.45 to 0.52	No	R2<.80

AQMesh (v3.0)	$ 7,800.00	$PM_{1.0}$	0.55 to 0.73	No	Cost does not meet criteria and R2 <.80
		$PM_{2.5}$	0.47 to 0.79	No	Cost does not meet criteria and R2 <.80
		PM_{10}	0.24 to 0.58	No	Cost does not meet criteria and R2 <.80
AS-LUNG (Air Quality Station)	$ 2,000.00	$PM_{1.0}$	0.42 to 0.88	No	Cost does not meet criteria
		$PM_{2.5}$	0.59 to 0.81	No	Cost does not meet criteria and R2 <.80
		PM_{10}	0.15 to 0.23	No	Cost does not meet criteria and R2 <.80
AS-LUNG (Portable)	$ 1,000.00	$PM_{1.0}$	0.86	Yes	
		$PM_{2.5}$	0.78	No	R2<.80
		PM_{10}	0.11 to 0.14	No	R2<.80
Atmotube (Pro)	$ 189.00 $ 189.00	$PM_{1.0}$	0.91 to 0.93	Yes	
		$PM_{2.5}$	0.88	Yes	
		PM_{10}	0.22	No	R2<.80
Cair	$ 200.00	$PM_{(1-2)}$	0.43 to 0.51	No	R2<.80
		$PM_{(3-10)}$	0.39 to 0.51	No	R2<.80
Clarity (Node)	$ 1,300.00	$PM_{2.5}$	0.73 to 0.76	No	R2<.80
Dylos (DC1100 Pro)	$ 300.00	$PM_{(0.5-2.5)}$	0.65 to 0.85	Yes	
Dylos (DC1700-PM)	$ 475.00	$PM_{2.5}$	0.58 to 0.68	No	R2<.80
		PM_{10}	0.15 to 0.18	No	R2<.80
Ecowitt (WH415B)	$ 100.00	$PM_{2.5}$	0.35 to 0.47	No	R2<.80
Edimax (AirBox)	$ 249.00	$PM_{2.5}$	0.61 to 0.87	Yes	
Edimax (Edigreen Home)	$ 299.00	$PM_{2.5}$	0.82 to 0.83	Yes	
Elitech (Temtop LKC-1000S+)	$ 140.00	$PM_{2.5}$	0.91 to 0.92	Yes	
		PM_{10}	0.31 to 0.35	No	R2<.80
Elitech (Temtop M2000 2nd Generation)	$ 100.00	$PM_{2.5}$	0.77 to 0.82	Yes	
		PM_{10}	0.17 to 0.28	No	R2<.80
Elitech (Temtop P20)	$ 70.00	$PM_{2.5}$	0.42 to 0.87	No	
FabLab (Smart Citizen Kit V2.1)	$ 119.00	$PM_{1.0}$	0.94	Yes	
		$PM_{2.5}$	0.76 to 77	No	R2<.80
		PM_{10}	0.06 to 0.09	No	R2<.80
Foobot	$ 200.00	$PM_{2.5}$	0.55	No	R2<.80
HabitatMap (AirBeam)	$ 200.00	$PM_{2.5}$	0.65 to 0.70	No	R2<.80
HabitatMap (AirBeam2)	$ 250.00	PM1.0	0.71 to 0.74	No	R2<.80
		$PM_{2.5}$	0.63 to 0.75	No	R2<.80
		PM_{10}	~ 0.0	No	R2<.80
Hanvon (Hanvon N1)	$ 200.00	$PM_{2.5}$	0.52 to 0.79	No	R2<.80
Igienair (Zaack AQI)	$ 3,000.00	$PM_{1.0}$	0.78 to 0.83	No	Cost does not meet criteria
		$PM_{2.5}$	0.80 to 0.82	No	Cost does not meet criteria

		PM_{10}	0.69 to 0.71	No	Cost does not meet criteria and R2 <.80
IQAir (AirVisual Pro)	$ 270.00	$PM_{2.5}$	0.69 to 0.73	No	R2<.80
		PM_{10}	0.24 to 0.41	No	R2<.80
IQAir (AirVisual Pro FW1.1683)	$ 270.00	$PM_{2.5}$	0.63 to 0.81	Yes	
Kaiterra (Laser Egg 2+)	$ 199.00	$PM_{2.5}$	0.81 to 0.85	Yes	
		$PM_{1.0}$	0.17 to 0.25	No	R2<.80
Kunak (Air A10)	$ 3,000.00	$PM_{1.0}$	-	No	Cost does not meet criteria and R2 <.80
		$PM_{2.5}$	0.69 to 0.75	No	Cost does not meet criteria and R2 <.80
		PM_{10}	0.60 to 0.68	No	Cost does not meet criteria and R2 <.80
Lunar Outpost (Canary-S)	$ 1,070.00	$PM_{2.5}$	0.83	Yes	
		PM_{10}	0.14	No	R2<.80
Magnasci SRL (uRADMonitor A3 HW105)	~$500	$PM_{1.0}$	0.81 to 0.85	Yes	
		$PM_{2.5}$	0.72 to 0.81	Yes	
		PM_{10}	0.15 to 0.38	No	R2<.80
Magnasci SRL (uRADMonitor INDUSTRIAL HW103)	~$1,300	$PM_{1.0}$	0.74 to 0.83	Yes	
		$PM_{2.5}$	0.70 to 0.78	No	R2<.80
		PM_{10}	0.13 to 0.34	No	R2<.80
Magnasci SRL (uRADMonitor SMOGGIE-PM v1.101)	$ 110.00	$PM_{1.0}$	0.84 to 0.86	Yes	
		$PM_{2.5}$	0.60 to 0.81	Yes	
		PM_{10}	0.03 to 0.06	No	R2<.80
Met One (E-Sampler)	$ 5,500.00				
		$PM_{2.5}$	0.55 to 0.62	No	Cost does not meet criteria and R2 <.80
Met One (Neighborhood Monitor)	$ 1,900.00	$PM_{2.5}$	0.53 to 0.67	No	R2<.80
Moji China (Airnut)	$ 150.00	$PM_{2.5}$	0.81 to 0.88	Yes	
Naneos (Partector)	$ 7,000.00	PM (LDSA: Lung-Deposited Surface Area)	PM1.0: R2 ~ 0.1 PM2.5: R2 ~ 0.2	No	Cost does not meet criteria and R2 <.80
Origins (Laser Egg)	$ 200.00	$PM_{2.5}$	0.58	No	R2<.80
		PM_{10}	~ 0.0	No	R2<.80
Perkin Elmer (ELM)	$ 5,200.00	PM	~ 0.0	No	Cost does not meet criteria and R2 <.80
Plume Labs (Flow 2)	$ 199.00	$PM_{1.0}$	0.01 to 0.14	No	R2<.80
		$PM_{2.5}$	0.01 to 0.13	No	R2<.80
		PM_{10}	0 to 0.04	No	R2<.80
PurpleAir (PA-I)	$ 150.00	$PM_{1.0}$	0.93 to 0.95	Yes	
		$PM_{2.5}$	0.90 to 0.92	Yes	
		PM_{10}	0.32 to 0.44	No	R2<.80
PurpleAir (PA-I-Indoor)	$ 180.00	$PM_{1.0}$	-		
		$PM_{2.5}$	0.75	No	R2<.80
		PM_{10}	0.36 to 0.46	No	R2<.80

PurpleAir (PA-II)	$ 200.00	$PM_{1.0}$	0.96 to 0.98	Yes	
		$PM_{2.5}$	0.93 to 0.97	Yes	
		PM_{10}	0.66 to 0.70	No	R2<.80
Redspira	$ 180.00	$PM_{2.5}$	0.57 to 0.69	No	R2<.80
		PM_{10}	0.25 to 0.29	No	R2<.80
RTI (MicroPEM)	$ 2,000.00	$PM_{2.5}$	0.65 to 0.90	No	Cost does not meet criteria
SainSmart (Pure Morning P3)	$ 170.00	$PM_{2.5}$	0.71 to 0.74	No	R2<.80
Samyoung S&C (SY-DS-DK3)	$ 100.00	$PM_{2.5}$	0.60 to 0.62	No	R2<.80
Sensirion	$ 2,000.00	$PM_{1.0}$	0.96	No	Cost does not meet criteria
(Nubo)	$ 2,000.00	$PM_{2.5}$	0.91	No	Cost does not meet criteria
Sensirion (SPS30)	$ 100.00	$PM_{1.0}$	0.91	Yes	
		$PM_{2.5}$	0.80 to 0.83	Yes	
		PM_{10}	0.07 to 0.20	No	R2<.80
Shinyei (PM Evaluation Kit)	$ 1,000.00	$PM_{2.5}$	0.80 to 0.89	Yes	
TSI (AirAssure)	$ 1,500.00	$PM_{2.5}$	0.81 to 0.83	Yes	
TSI (BlueSky)	$ 400.00	$PM_{2.5}$	0.65 to 0.76	No	R2<.80
		PM_{10}	0.09 to 0.21	No	R2<.80
uHoo	$ 300.00	$PM_{2.5}$	~ 0.0	No	R2<.80

Gas-Phase Sensors					**AQP Criteria**	
Make (Model)	**Est. Cost(USD)**	**Type**	**Meas.**	***Field R^2**	**R^2 >.80, Sensor less than $2,500**	**Comment**
2B Technologies (POM)	$4,500	UV absorption (FEM Method)	O_3	1.00	No	Cost does not meet criteria
Aeroqual (AQY v1.0)	$4,000	Electrochem	NO_2	0.60 to 0.77	No	Cost does not meet criteria and R^2 <.80
		Metal Oxide	O_3	0.96 to 0.97	No	Cost does not meet criteria
Aeroqual (S-500)	$500	Metal Oxide	O_3	0.85	Yes	
Air Quality Egg Ver. 1	$200	Metal Oxide	CO	0.0	No	R^2<.80
			NO_2	0.40	No	R^2<.80
			O_3	0.85		
Air Quality Egg Ver. 2	$240	Electrochem	CO	0.0		
			NO_2	0.0	No	R^2<.80
Air Quality Egg Ver. 2	$240	Electrochem	O_3	0.0 to 0.20	No	R^2<.80
			SO_2	n/a	No	R^2<.80
APIS	$4,995	Electrochem	CO	0.87 to 0.90	No	Cost does not meet criteria
			NO	0.87 to 0.97	No	Cost does not meet criteria

			NO_2	0.30 to 0.44	No	Cost does not meet criteria and R^2 <.80
			O_3	0.73 to 0.83	No	Cost does not meet criteria
AQMesh V5.1	$7,800	Electrochem	CO	0.74 to 0.79	No	Cost does not meet criteria and R^2 <.80
			NO	0.007 to 0.01	No	Cost does not meet criteria and R^2 <.80
			NO_2	0.21 to 0.35	No	Cost does not meet criteria and R^2 <.80
			NO_x	0.01 to 0.02	No	Cost does not meet criteria and R^2 <.80
			O_3	0.88 to 0.90	No	Cost does not meet criteria
			SO_2	n/a	N/A	N/A
CairPol Cairsens (CO)	$1,243	Electrochem	CO	0.93 to 0.94		
CairPol Cairsens (NO2)	$1,198		NO_2	0.0 to 0.12	No	R^2<.80
Igienair (Zaack AQI)	$3,000	Electrochem	CO	0.84 to 0.87	No	Cost does not meet criteria
			NO_2	0.53 to 0.58	No	Cost does not meet criteria and R^2 <.80
			O_3	0.0	No	Cost does not meet criteria and R^2 <.80
Kunak (Air A10)	~$5,000	Electrochem	CO	0.55 to 0.60	No	Cost does not meet criteria and R^2 <.80
			NO	0.78 to 0.93	No	Cost does not meet criteria
			NO_2	0.24 to 0.32	No	Cost does not meet criteria and R^2 <.80
			O_3	0.86 to 0.88	No	Cost does not meet criteria
Magnasci SRL (uRADMonitor) Industrial HW103	~$1,300	Electrochem	CO	0.00 to 0.07	No	R^2<.80
			NO_2	0.00 to 0.05	No	R^2<.80
			O_3	0.00 to 0.08	No	R^2<.80
Perken Elmer (ELM)	$5,200	Metal Oxide	NO	n/a	No	Cost does not meet criteria and R^2 <.80
			NO_2	0.0	No	Cost does not meet criteria and R^2 <.80

			O_3	0.89 to 0.96	No	Cost does not meet criteria
Plume Labs (Flow 2)	$199	Metal Oxide	NO_2	0.04 to 0.14	No	R^2<.80
Smart Citizen Kit	$200	Metal Oxide	CO	0.50 to 0.85	Yes	
			NO_2	0.0	No	R^2<.80
Spec Sensors	$500	Electrochem	CO	0.84 to 0.90	Yes	
			NO_2	0.0 to 0.16	No	R^2<.80
			O_3	0.0 to 0.24	No	R^2<.80
uHoo	$300	Metal Oxide	CO	0.0	No	R^2<.80
			O_3	0.43 to 0.72	No	R^2<.80
UNITEC SENS-IT (CO)	$2,200	Metal Oxide	CO	0.33 to 0.43	No	Cost does not meet criteria and R^2 <.80
UNITEC SENS-IT (NO2)			NO2	0.57 to 0.62	No	Cost does not meet criteria and R^2 <.80
UNITEC SENS-IT O3	$2,200	Metal Oxide	O_3	0.72 to 0.83	No	Cost does not meet criteria
Vaisala (AQT410) Ver. 1.11	$3,700		CO	0.28 to 0.31	No	Cost does not meet criteria and R^2 <.80
		Electrochem	NO_2	0.0	No	Cost does not meet criteria and R^2 <.80
			O_3	0.40 to 0.58	No	Cost does not meet criteria and R^2 <.80
			SO_2	n/a	N/A	
Vaisala (AQT410) Ver.1.15	$3,700	Electrochem	CO	0.80 to 0.83	No	Cost does not meet criteria
			NO_2	0.43 to 0.61	No	Cost does not meet criteria and R^2 <.80
			O_3	0.66 to 0.82	No	Cost does not meet criteria
			SO_2	n/a	N/A	

The comprehensive evaluation reports can be viewed at http://www.aqmd.gov/aq-spec/home.

The EPA Air Sensor Toolbox website provides the latest information on the performance, operation, and use of air sensor monitoring systems. The EPA works to advance air sensor technology including by evaluating of sensor devices and identifying best practices for effectively using sensors. Below is a summary of the evaluation results.

EPA Evaluation Data:

Particulate Matter (PM) Sensors					AQP Criteria:	
Sensor Model:	**Price:**	**Detection Approach:**	**Pollutant**	**Field R2**	**R^2 >.80, Sensor less than $2,500**	**Comment**
Alphasense	Not Available	Optical Particle Counting	PM2.5	.007	No	**R^2 >.80**
			PM10	.01	No	**R^2 >.80**
Shinyei	<$2,500	Volume Scattering	PM2.5	0.45 to 0.60	No	**R^2 >.80**
Dylos	<$2,500	Optical Particle Counting	PM2.5	0.63 to 0.67	No	**R^2 >.80**
Airbeam	<$2,500	Volume Scattering	PM2.5	0.65 to 0.66	No	**R^2 >.80**
MetOne	<$2,500	Optical Particle Counting	PM2.5	0.32 to 0.41	No	**R^2 >.80**
Air Quality Egg	<$2,500	Volume Scattering	PM2.5	-.06 to 0.40	No	**R^2 >.80**
CairPol CairClip PM prototype	Not Available	Volume Scattering	PM2.5	.06	No	**R^2 >.80**
Airviz Speck v2	<$2,500	Volume Scattering	PM2.5	.01	No	**R^2 >.80**
Dylos	$300	Optical Particle Scattering	PM2.5	.55a	No	**R^2 >.80**
MetOne Model 831	$2,050	Optical Particle Scattering	PM2.5	.77b	No	**R^2 >.80**
RTI MicroPEM	$2,000	Volume Scattering	PM2.5	0.72	No	**R^2 >.80**
Shinyei PMS-SYS-1	$1,000	Volume Scattering	PM2.5	.15	No	**R^2 >.80**
Perkin-Elmer Elm	Not Available					

Gas Phase Sensors					AQP Criteria	
Sensor Model:	**Price:**	**Detection Approach:**	**Pollutant**	**Field R2**	**R^2 >.80, Sensor less than $2,500**	**Comment**
AQMesh	<$2,500	All gases are detected by air passing over electrochemical cells	Ozone	0.39 to 0.45	No	**R^2 >.80**
CairClip	<$2,500	All gases are detected by air passing over electrochemical cells	Ozone	0.82 to 0.94	Yes	
Aeroqual SM50	<$2,500	Gas-sensitive semiconductor	Ozone	0.91 to 0.97	Yes	
CairClip	<$2,500	All gases are detected by air passing over electrochemical cells	Nitrogen Dioxide	0.42 to 0.76	No	**R^2 >.80**
AQMesh	<$2,500	All gases are detected by air passing over electrochemical cells	Nitrogen Dioxide	0.14 to 0.32	No	**R^2 >.80**
Air Quality Egg	<$2,500	The sensor device passes air over an internal metal oxide sensor.	Nitrogen Dioxide	-0.25 to -0.22	No	**R^2 >.80**
WT-SU1 Dynamo	<$1,000	Ozone is detected via a metal oxide semiconductor	Ozone	0.95	Yes	
Cairclip NO2/O3 USB Version	<$1,000	All gases are detected by air passing over electrochemical cells	Ozone	0.98	Yes	
Air Casting	<$1,000	Ozone is detected via a metal oxide semiconductor	Ozone	1.0	Yes	
			Nitrogen Dioxide	1.0	Yes	
Platypus	<$1,000	Nitrogen dioxide is detected using a thin film liquid crystal mounted to a metal strip.	Nitrogen Dioxide	0.80	No	**R^2 >.80**

Additional evaluation information can be found at https://www.epa.gov/air-sensor-toolbox/evaluation-emerging-air-sensor-performance.