Community Air Monitoring Project (CAMP)

EPA Air Quality Monitoring
Quality Assurance Project Plan (QAPP)

Supporting an Air Health Community Health Project
in South Philadelphia, Pennsylvania

February 01, 2023, through July 31, 2026

Grant: EPA Grant # - [redacted]

Revision 5.0 July 16, 2025

Prepared for the U.S. EPA Region 3
1600 JFK Blvd., Philadelphia, PA 19103-2029

Prepared by A SMART Collaboration LLC
[redacted]

Date:	July 16, 2025
To:	[redacted], EPA Grant Project Officer [redacted] EPA Quality Assurance Reviewer
From:	[redacted], Pennsylvania Director, Clean Water Fund [redacted], Clean Water Fund, Eastern Pennsylvania Director [redacted] A SMART Collaboration LLC, Project Manager
Title:	*Community Air Monitoring Project (CAMP)* Quality Assurance Project Plan Identification and Approval Plan Philadelphia, PA from 9 February 2024 through 31 July 2026
Subject:	Quality Assurance Project Plan
Title:	EPA Grant # [redacted] Tax # - [redacted]

The attached QAPP is hereby recommended for approval and commits the Community Air Monitoring Project (CAMP) of the Clean Water Fund (CWF) implemented by A SMART Collaboration LLC (ASC), to follow the elements revised within.

[redacted]
Clean Water Fund Eastern Pennsylvania Director
[redacted]

[redacted]
A Smart Collaboration LLC, Project Manager

[redacted]

[redacted]
Quality Assurance Manager

[redacted]
EPA Grant Project Officer

[redacted]
EPA Quality Assurance Reviewer

A3. Document Format, Document Control, and Table of Contents,

Document Format

This Quality Assurance Project Plan (QAPP) was developed in accordance with the EPA Quality Assurance Project Plan Standard 2023. The order of the elements in this QAPP follows the Standard, as seen in the Table of Contents. The QAPP also follows the guidance and recommendations of the EPA Region 3 Quality Management Plan reference, DCN R3QMP001-20200601.

This document features illustrations, diagrams, tables, and maps. Our design intention was to prepare our QAPP content in a form that would be accessible to both professionals in the disciplines associated with quality assurance planning and also to the general public, including members of our community and others interested in civic engagement, public health, and air quality monitoring. We welcome questions and comments about this final approved version of CAMP QAPP. Please contact [redacted] at [redacted] as needed.

This table shows changes to this controlled document over time. Table 1: QAPP Versions

DCN Version	Changes	Effective Date
DCN OX-95313101.0	Original Document	12/20/2024
DCN OX-95313101.1	Version 2 - Update and reformat to EPA QAPP Template 2017.	01/28/2025
DCN OX-95313101.2	Version 3 - Update and reformat to EPA QAPP Template 2023 Standard	04/22/2025
DCN OX-95313101.3	Version 4 - Update and reformat to EPA QAPP Template 2023 Standard	06/23/2025
DCN OX-95313101.4	Version 5 - Update and reformat to EPA QAPP Template 2023 Standard	07/14/2025

Statement of Commitment to Quality Assurance and Quality Control

This *CAMP Quality Assurance Project Plan* explains and illustrates our methodology for ensuring quality control throughout this project. We acknowledge and express our gratitude to the EPA, its Grant Project Officers, and the EPA Quality Assurance Reviewer for their guidance and support.

Data quality is crucial, particularly when it comes to monitoring air quality. Our goal for this QAPP is to ensure that we employ best practices in gathering and managing quality-assured data through quality control planning and implementation.

The Quality Assurance Manager (QAM) and Project Manager (PM) will oversee the implementation of the quality assurance procedures outlined in this plan. Everyone involved in this project is committed to excellence in quality management, from planning and implementation to oversight and review.

Table of Contents

Group B. Implementing Environmental Operations

Group C. Assessment, Response Actions, and Oversight

Group D. Environmental Information Review and Useability Determination

List of Tables:

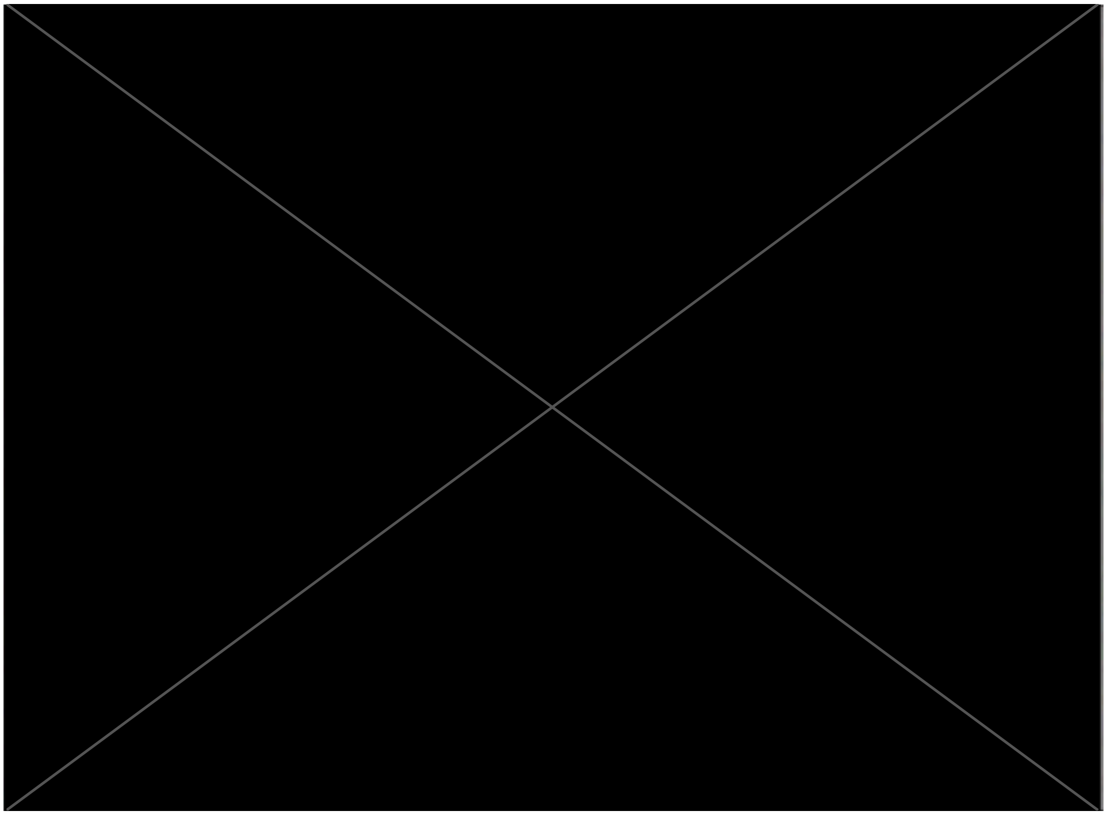
List of Figures:

References:

Note: Appendix References are provided in a second document for this QAPP.

A4. Project Purpose, Problem Definition, and Background

Purpose and Problem Definition



Members of Philly Thrive Organization in our Community Reference
Image Source: Philly Thrive

The mission of the Community Air Monitoring Project (CAMP) is to empower community members to collaboratively locate, install, and maintain air quality sensors that measure local air quality conditions. The purpose of the project is to enhance the community's understanding of such conditions and its capacity to advocate for improvement in the health of their neighborhood environment. This project will recruit individuals who live in the neighborhood to be AQ Stewards and AQ Tech Team members. Our project will provide them with education about air quality and train them in the AQM installation and maintenance procedures. Our project team will also enlist members for the AQ Council and educate them concerning air quality, public health issues, and environmental justice.

The distinctions between AQ Stewards and AQ Council include geographical focus (immediate neighborhood for AQ Stewards, overall community for AQ Council members) and engagement activities. An individual may serve as both an AQ Steward and a member of the AQ Council. Collectively, the AQ Stewards and AQ Council will serve as community representatives. They will educate their community about air and airborne health and support efforts to improve and sustain air quality conditions.

The ASC Team, in collaboration with CWF, will implement methodologies and practices to ensure data integrity, as outlined in this Quality Assurance Project Plan (QAPP). We affirm that our CAMP initiative is built upon a network of community member relationships to enhance the well-being and public health of all those who call these neighborhoods their home, workplace, or destination.

Problem Definition

Our environmental justice project serves the residents of Grays Ferry and adjacent South Philadelphia neighborhoods, which are located in environmental justice census tracts. The neighborhood's topography is densely populated with many place-based commercial air hazards, including adjacency to the fenceline of a former 150-year-old industrial refinery site. Residents of our community have suffered from some of the highest rates of air-related respiratory illness in the region.

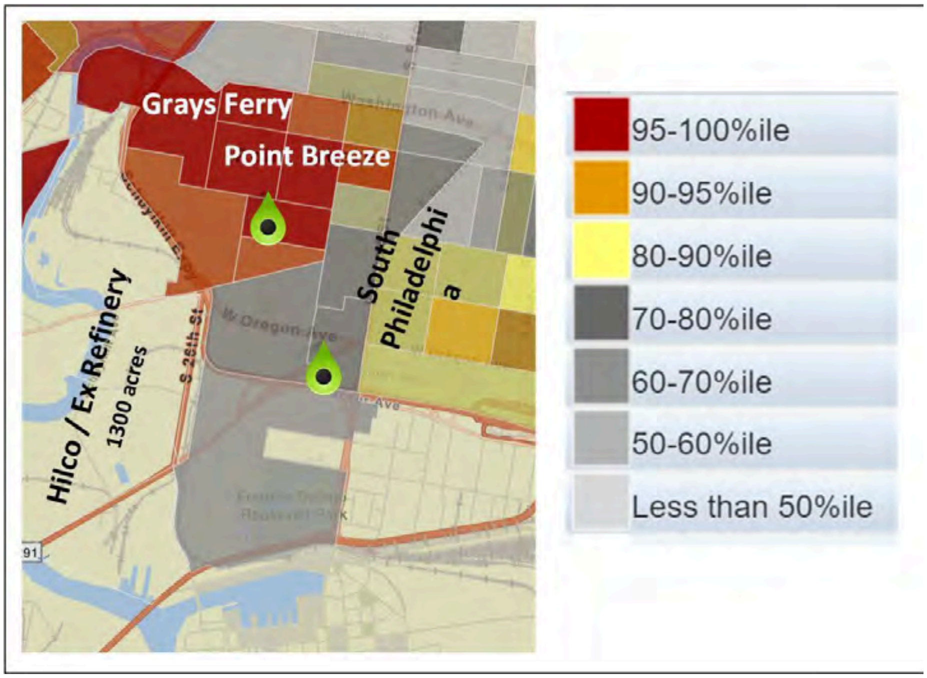


Diagram of the sum of the percentiles of the highest asthma rates and the lowest life expectancy rates compared to national averages in the Grays Ferry neighborhoods.
Image Source: Environmental Justice Screening and Mapping Tool:
https://ejscreen.epa.gov/mapper

The landscape features a brownfield, an industrial food processing plant, tire storage facilities, auto repair shops, and contaminated vacant lots resulting from previous polluting business activities. The neighborhood is situated near the Lower Schuylkill River, downwind from the Philadelphia International Airport and upwind from the Packer Avenue Marine Terminal of Philaport, contiguous to CSX and Norfolk Southern rail yards, and adjacent to the Schuylkill Expressway with high volume, 24/7 traffic.

Sites reporting to EPA within defined area:

Superfund	0
Hazardous Waste, Treatment, Storage, and Disposal Facilities	3
Water Dischargers	26
Air Pollution	20
Brownfields	1
Toxic Release Inventory	4

Image Source: Environmental Justice Screening and Mapping Tool:
https://ejscreen.epa.gov/mapper

Based on surveys conducted by CAMP partner Philly Thrive, our Grays Ferry Environmental Justice (EJ) community feels that they have not been well-informed or well-served regarding the condition of their air quality or the health risks associated with air pollution. Residents of our community lack trust in the current, publicly available air monitoring data, in their ability to interpret such data, and in the recommendations provided by public agencies, those responsible for environmental remediation, or the new private owners of the refinery property.

SELECTED VARIABLES	VALUE	STATE AVERAGE	PERCENTILE IN STATE
ENVIRONMENTAL BURDEN INDICATORS			
Particulate Matter 2.5 ($\mu g/m^3$)	8.16	8.13	42
Ozone (ppb)	62.6	59.9	68
Nitrogen Dioxide (NO_2) (ppbv)	12	6.8	96
Diesel Particulate Matter ($\mu g/m^3$)	0.299	0.171	93
Toxic Releases to Air (toxicity-weighted concentration)	2,300	4,000	65
Traffic Proximity (daily traffic count/distance to road)	4,900,000	1,400,000	94

Image Source: Environmental Justice Screening and Mapping Tool:
https://ejscreen.epa.gov/mapper

These are the categories of activities that this project will focus on:

Three Core Air Quality Problems in our Community:

1. Lack of quality-assured and trusted local air quality measurements.
2. Lack of quality-assured and accessible local air quality data information from the measurements.
3. Lack of quality assured and meaningful education about the measurements.

Three Core Air Quality Goals for our project:

1. The goal is to increase air quality, safety, public health, and environmental justice in our community.
2. The goal is to engage community members and organizations in using the air quality measurements from this project to document environmental health and safety conditions in Grays Ferry.
3. The goal is to ensure that air health measurements and their interpretation will be available in real-time and recorded via mobile and online access.

FOUR CORE UTILIZATIONS and BENEFITS for our AQ DATA:

1. Data will be used to document the local air health conditions for public access.
2. Data will be used to identify unhealthy sources and patterns of air contamination.
3. Data will support further environmental health research to benefit our community.
4. Data will contribute to the EPA air health initiatives.

Background

Our community is situated adjacent to the 1,300-acre contaminated industrial site, which was formerly the largest and oldest petroleum refinery complex on the East Coast of North America. Continuing trauma and health effects attributed to proximity to the refinery have been reported to us by community residents. Our environmental justice (EJ) community has experienced higher rates of cancer, heart disease, and respiratory illness than non-EJ sections of Philadelphia, especially among children and the elderly. Our Grays Ferry community has lower life expectancy rates and higher asthma rates than the national averages. Students enrolled in local schools are 90% African American or Latinx, and 80% of their families live below the poverty line. The tree canopy for this area is minimal, and the summer heat index is one of the highest in the region. Demographic data from the Statistical Atlas of the Grays Ferry neighborhoods.
https://statisticalatlas.com/neighborhood/Pennsylvania/Philadelphia/Grays-Ferry/Population

Beginning in 1866, this petrochemical refinery and heavy industry enterprise operated for over 150 years until activity ceased in 2019 following a devastating explosion and fire. The highly contaminated landscape will undergo decades of remediation to address the soil, water, and air pollution.

The HRP Group (Hilco Redevelopment Partners) acquired the former refinery property out of Chapter 11 bankruptcy for commercial development in 2020. It is the largest parcel of private property in Philadelphia. The site's industrial infrastructure has been decommissioned and demolished. Construction has already begun on The Bellwether District, featuring a 25-year plan for a massive, multi-tenant logistics hub and life science campus. Residents in the adjacent communities distrust the site owners' goodwill and feel threatened by health risks from multiple hazardous sources that have compromised their well-being for decades.

A desire to address the deleterious health effects of air pollution and the ongoing environmental injustice caused by environmental hazards has motivated local residents to organize for effective collective action. These community members value the empowerment derived from collecting and understanding the data obtained through our participatory science activities, which measure and document the air quality where they work, play, and live.

A5. Project Task Description

Our quality assurance data collection process is a comprehensive cycle of activities that includes engaging the community, selecting equipment, configuring, calibrating, installing, recording, maintaining, documenting, storing, accessing, analyzing, publishing, and continually improving our methodology. The five subsections below provide project descriptions for our planned quality assurance activities. The five activity descriptions are detailed in the next sections of the QAPP.

1. **ENGAGING our COMMUNITY**: Civic engagement and empowerment for monitoring local air quality conditions, improving air-related health, and expanding environmental justice.
2. **MEASURING THE PROBLEM**: Quality-assured measurement of local air quality problems.
3. **RECORDING & ARCHIVING**: Quality-assured recording and archiving of local AQ measurements.
4. **ACCESSING**: Providing community-informed, public access to the air quality data from AQ measurements.
5. **LEARNING & SHARING**: Community education and sharing about what the data measurements teach us.

A5-1. Engaging Our Community:

Our core community engagement mission is to empower and support local environmental justice community members in advocating for improved air quality and health using data resources from our project's documented air quality monitoring. The local grass-roots organization *Philly Thrive* is a core advocate of our mission to promote healthy air and environmental justice. Their mission statement is *We will continue to build people-power until everyone has a right to breathe, free from pollution, oppression, and a violent economy*.

Key personnel of our project team are long-term, active members of *Philly Thrive*. Our existing beneficial relationships with Thrive members provide a primary foundation for engaging local residents, businesses, and civic organizations in our *EPA Environmental Justice and Air Health Project*. Our community engagement processes include the following:

- Our community programming includes multiple open community meetings to engage residents, businesses, and civic organizations in the direction and coordination of this project. We are a community-led organization. Community members guide the strategic goals of this project and participate in multiple activities to define, design, implement, and evaluate all phases of our Community Air Quality initiative.

- Establishing and supporting a community-based team of AQ (Air Quality) Stewards who live in and/or work in our neighborhood. They will be the core coordinating team for local community engagement. They confirm methodologies for air quality (AQ) monitoring, lead the selection of AQ installation locations, recommend strategies for effective AQ data communication with the public, guide educational programming about AQ environmental justice (EJ) in their neighborhood, and advocate for community participation in this project.

- The AQ Stewards provide local air quality and environmental justice expertise for their extended family, friends, neighbors, and other community members. We welcome the opportunity to enhance air health and air monitoring capabilities and to foster a commitment in our community to *care for the air we share collectively*.

- Establishing and supporting a community-based AQ Tech Team that lives/works in our neighborhood. They will be the core coordinating team for configuring, installing, monitoring, and maintaining the AQM instruments, including the Clarity Node-S, Wind Module, Atmotube PRO, and Community Sensing Stations. The AQ Tech Team will receive training to work as "participatory scientists," with core knowledge about air health, air quality monitoring, and expanding environmental justice in their community.

- Our community engagement includes air quality educational programming at local schools, neighborhood civic organizations, and health centers, and enhancing online access to air health-related learning and training sessions. We seek collaboration with the Philadelphia School District, the Philadelphia Department of Public Health, the Philadelphia Office of Sustainability, the Philadelphia Department of Children and Families, local social service agencies, and faith-based organizations.

A5-2. Measuring the Problem:

The well-known adage, “Measure what you treasure," motivates us. We treasure community health, specifically healthy air. We have identified a set of primary air gases, masses, and motions to measure for our air quality monitoring project via public meetings, in-depth research, and the guidance of our community and air consultants' expertise.

Our community’s air quality concerns directly result from its immediate proximity to hazardous air from the toxic legacy of the adjacent former petrochemical refinery, current demolition contamination, additional pollution from local industrial construction, and increased commercial road traffic.

Particulate matter and nitrogen dioxide measurements are essential to document air health from multiple sources. Measuring hyper-local wind direction and speed will increase our ability to identify potential sources of air pollution and toxicity. Measuring hyper-local weather conditions, including temperature, humidity, and barometric pressure, will enhance our ability to correlate air quality with local ground pollution effects.

Since air quality is determined by multiple factors, including air chemistry, particulate matter composition, air movements, and weather, our participatory science methodology will incorporate these multiple-factor measurements into our air quality monitoring and recordings.

The following are the air properties that our community has selected for air measurement and recording:

- Particulate matter: $PM_{2.5}$
- Nitrogen Dioxide NO_2
- Benzene
- Ambient air wind speed and wind direction
- Ambient air temperature, humidity, and atmospheric pressure

Our deployment of air quality measurement stations includes the following:

- 20 Clarity Node-S AQM instruments
- 10 Clarity Wind Modules
- 6 Benzene Air Sampling Stations
- 30 Atmotube PRO Mobile AQM instruments

A5-3. Recording & Archiving the Measurements:

The data measurements from our air quality monitoring instruments are recorded and archived in the following locations for access and quality assurance.

- Our AQM partners provide data storage, including Clarity Movement, Atmotube PRO, and the Air Science Laboratory at Lewis & Clark State College.
- Duplicate AQM storage at JustAir facilities.
- Duplicate storage at ASC CAMP facilities.
- Duplicate storage at OpenAQ.

A5-4. Accessing & Analyzing the Measurements:

A core virtue of air quality monitoring is the capability to record AQM data, which facilitates the identification of usually invisible patterns, processes, and sources of ambient air health and contamination. In fact, the invention of air quality monitors and the development of the telescope and microscope are paradigm-shifting scientific instruments. With AQM instruments, “we can see the invisible air we share.”

Our goal in measuring air quality is to learn from the measurements what they can teach us so that we can improve our community's health and justice. AQM instruments are “observational tools,” and they function best when combined with "pattern illustration and pattern recognition tools.”

By utilizing various methods of processing numeric air measurement data, we can visualize ambient air patterns through charts, graphs, maps, dashboards, animations, and other visual representations. These “data visualizations" quantify, transform, and verify living environmental processes, affirming another adage, “seeing is believing.”

We are exploring the efficacy of using various data visualization methods to inform participant-science learning about local community air among community members. Thus far, community feedback affirms three categories of local AQM information that are most valuable.

The following are additional details about local community data access. We have organized this information into three subject areas. Each category includes a project description of the core activities associated with this subject.

1. Access & Interpretation of Current Local AQ Status
2. Access to and Interpretation of Local AQ Patterns
3. Notifications of Urgency & Emergency AQ Conditions

A5-4-1. Access & Interpretation of Current Local AQ Status:

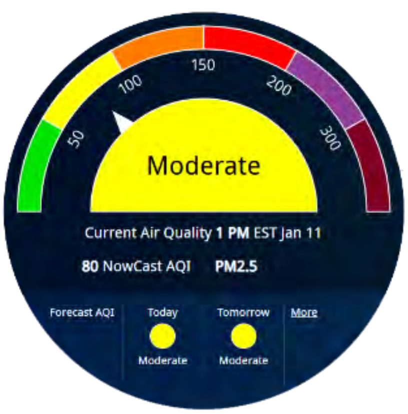


Image Source: PA AirNow:
https://www.airnow.gov

An online digital display is a common method for providing the public with current air quality information. An example is the online color-coded dial display on the EPA AirNow website. The AirNow format may be useful; however, our community wants more hyperlocal information than AirNow provides.

Our technology partner for the *Community AQ Dashboard* is *JustAir*. The following is an example of a hyper-local display of the current AQ status from a specific AQM monitor location. We intend to use a version of this type of current AQ data status display for community access for all 20 of our stationary Clarity AQM monitors.

Below are two examples of interactive mobile air quality monitoring dashboards for direct community access. This application will be integrated with the JustAir public access platform. The local air quality information from our Clarity AQ Instruments will be immediately and freely available to community members. The information is displayed graphically for quick and easy comprehension. This AQ educational platform has proven high-quality performance and ease of use. Working with our community, we will tailor this dashboard to meet the specific information and educational needs of our community.

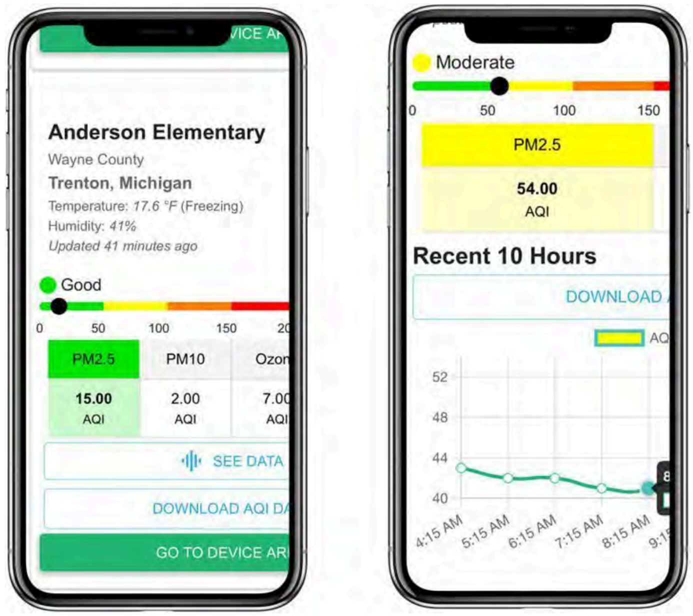


Image Source: Graphic Design by Interpret Green and JustAir

5-4-2. Access to and Interpretation of Local AQ Patterns:

We will develop a *Community Air Quality (AQ) Dashboard* in partnership with JustAir. The sample image below is an example of a hyper-local, interactive dashboard display for a specific AQM monitor location, accompanied by an interpretation of the data. We intend to use a version of this type of dashboard with all 20 of our stationary Clarity AQM monitors.

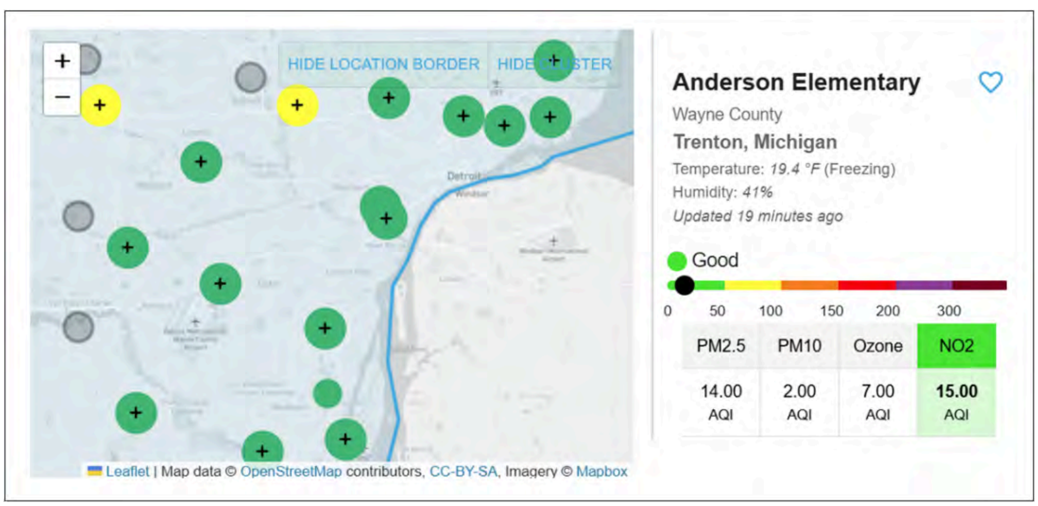


Image Source: Graphic Design by Interpret Green and JustAir

A5-4-3. Notifications of Urgency & Emergency AQ Conditions:

Our community members and advisors have inquired whether our project could include methods for developing a communication system to alert residents and businesses to potential or actual air quality emergencies. Our community members' ongoing experience of not receiving trustworthy information about the local air quality remains a persistent cause of concern.

A near-catastrophe occurred at the refinery on June 21, 2019, after failed equipment caused a tremendous explosion, fire, and release of lethal hydrogen fluoride gas. Public information about this potentially deadly air quality emergency was sparse for communities, including our Grays Ferry neighborhoods, during and after the disaster. This air quality emergency was a major reason for the permanent closure of the refinery operations.

The recent Refinery explosion and its aftermath increased the already high level of community concern about their ambient air quality conditions. To appreciate the severity of this event, please use the web link below to view an animated demonstration of the explosion. The Federal U.S. Chemical Safety Board prepared this visual documentation to explain the severity of the explosion, fire, and release of airborne toxins. You can click the web link below to view the video.

Click the URL to view video: https://www.youtube.com/watch?v=gc8qXTh6tTY&ab_channel=USCSB

Developing an effective air quality emergency alert and communication system is beyond the scope of our project. However, the measurements from our AQM sensing system could provide helpful AQ data for local government agencies and commercial enterprises.

We acknowledge the benefits of local "participation science" air quality monitoring, for example, during the Canadian Wildfire Air Pollution events in the Summer of 2023. We anticipate that our local AQM project will provide local access to reliable air quality measurements.

A5-5. What the Measurements Can Teach Us:

One of the most valuable opportunities of our CAMP project is to share with our community the emerging insights generated from the air quality data measured by our Air Quality Monitors (AQMs). We will collaborate with our air expert partner, JustAir, to develop educational programming on local air quality and air health. We have established trusting relationships with our local schools, health centers, environmental justice organizations, and civic associations to learn from the insights our air data quality can provide. We will host air education workshops and advocate for expanding local knowledge and skills about the "air we share." Our outdoor air monitoring locations will feature educational and instructional signage about our community air quality project, as well as real-time AQ data accessible via mobile phones and online, including graphs, charts, and other visualizations of local, current, and historical air quality measurements.

The Atmotube Pro provides hands-on experience in viewing and interpreting the correlations between air quality changes and external factors, including air pollution, weather conditions, and seasonal allergies. These insights can be beneficial for community members with respiratory and other related health conditions. The Atmotube PRO is an excellent tool for learning about local air quality monitoring in our community.

A6. Information/Data Quality Objectives and Performance & Acceptance Criteria

The following references are provided to define the quality of the sensing data acquired by our air monitoring initiative. Please note that our AQM methodology is determined by the quality and specificity of the data we aim to measure. Per the EPA guidelines, the value of the data we measure is defined by the parameters of the *Data Quality Indicators*. Our goal is to ensure that the data quality supports the verifiable scientific criteria.

For this project, we are using the definition of *Data Quality Objectives* published in the *Handbook for Air Pollution Measurement Systems Volume II, Ambient Air Quality Monitoring Program*.
https://www.epa.gov/sites/default/files/2020-10/documents/final_handbook_document_1_17.pdf Page 34.

> *Data Quality Objectives are qualitative and quantitative statements derived from the DQO Planning Process that clarify the purpose of the study, define the most appropriate type of information to collect, determine the most appropriate conditions from which to collect that information, and specify tolerable levels of potential decision errors.*

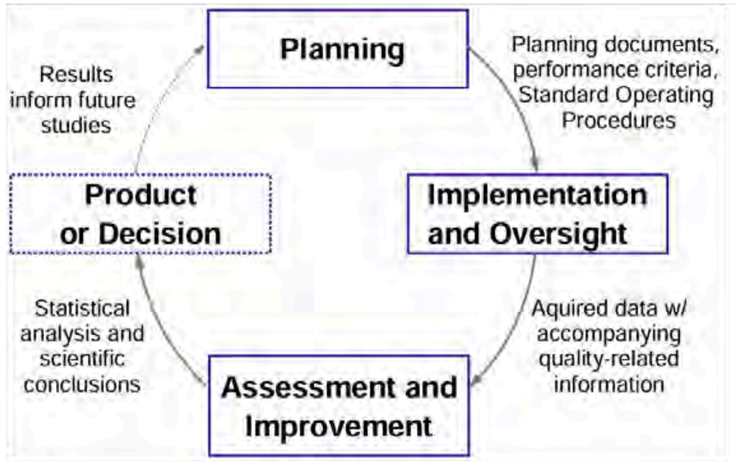
We have used the following additional references to guide our understanding and methodology for our data quality objectives planning process:

- *EPA Handbook for Citizen Science Quality Assurance and Documentation* Guidelines
  https://www.epa.gov/sites/default/files/2019-03/documents/508_csqapphandbook_3_5_19_mmedits.pdf

- *OEPA Guidance for Quality Assurance Project Plans*
  https://www.epa.gov/participatory-science/quality-assurance-handbook-and-toolkit-participatory-science-projects

- *Quality Assurance Handbook for Air Pollution Measurement Systems Volume II Ambient Air Quality Monitoring Program*
  https://www.epa.gov/sites/default/files/2020-10/documents/final_handbook_document_1_17.pdf

The diagram below illustrates four categories of activities for an iterative process that supports Quality Systems for Environmental Data and Technology per EPA references.



https://www.epa.gov/sites/default/files/2015-08/documents/overview-final.pdf
Image Source: Diagram from: Overview of the EPA Quality System for Environmental Data and Technology, page 13.

Data Quality Objectives

Data Quality Objectives for our project include both the (1) data quality of the field measurements for air pollution via our AQ sensor systems and (2) the quality objectives to which these measurements are compared with EPA guidelines and regulations for air pollution. Thus, knowing the Federal quality and quantity standards for measuring air pollution is helpful, if not essential, for documenting and communicating our air pollution data and educational information within our community.

The EPA published the following National Ambient Air Quality Standards (NAAQS) for PM (particulate matter) on February 7, 2024: *EPA strengthened the National Ambient Air Quality Standards for Particulate Matter (PM NAAQS) to protect millions of Americans from harmful and costly health impacts, such as heart attacks and premature death. Particle or soot pollution is one of the most dangerous forms of air pollution, and an extensive body of science links it to a range of serious and sometimes deadly illnesses. EPA is setting the level of the primary (health-based) annual PM2.5 standard at 9.0 micrograms per cubic meter to provide increased public health protection, consistent with the available health science.*
https://www.federalregister.gov/documents/2024/03/06/2024-02637/reconsideration-of-the-national-ambient-air-quality-standards-for-particulate-matter

Implementing the Final Rule to Strengthen the National Air Quality Health Standard for Particulate Matter – Clean Air Act Permitting, Air Quality Designations, and State Planning Requirements
https://www.epa.gov/system/files/documents/2024-02/pm-naaqs-implementation-fact-sheet.pdf

Air Monitoring for Fine Particle Pollution (PM2.5) Fact Sheet
https://www.epa.gov/system/files/documents/2024-02/pm-naaqs-monitoring-fact-sheet.pdf

EPA Online Guide to: Particulate Matter (PM) Pollution
https://www.epa.gov/pm-pollution

Final Updates to the Air Quality Index (AQI) for Particulate Matter Fact Sheet and Common Questions for the NAAQS 2024 guidelines:
https://www.epa.gov/system/files/documents/2024-02/pm-naaqs-air-quality-index-fact-sheet.pdf

On March 12, 2025, this press release was issued from the EPA Press Office: *Trump EPA Announces Path Forward on National Air Quality Standards for Particulate Matter (PM2.5) to Aid Manufacturing, Small Businesses* https://www.epa.gov/newsreleases/trump-epa-announces-path-forward-national-air-quality-standards-particulate-matter

> *WASHINGTON – U.S. Environmental Protection Agency (EPA) Administrator Lee Zeldin announced the agency is revisiting the Biden PM2.5 National Ambient Air Quality Standards (NAAQS), which has raised serious concerns from states across the country and served as a major obstacle to permitting.*
> *"All Americans deserve to breathe clean air while pursuing the American dream. Under President Trump, we will ensure air quality standards for particulate matter are protective of human health and the environment while we unleash the Golden Age of American prosperity," said EPA Administrator Zeldin.*
>
> *National Ambient Air Quality Standard for Particulate Matter (PM NAAQS) Powering the Great American Comeback Fact Sheet*
> [*https://www.epa.gov/system/files/documents/2025-03/pm-naaqs_powering-the-great-american-comeback_fact-sheet.pdf*](https://www.epa.gov/system/files/documents/2025-03/pm-naaqs_powering-the-great-american-comeback_fact-sheet.pdf)

Our CAMP Project acknowledges that Federal Agencies may soon revise air pollution monitoring standards and associated Data Quality Objectives and Data Quality Indicators. Per the planning methodology for our QAPP, we will continue to implement the EPA 2024 AQ Standards for the objectives and activities of our CAMP Project. We affirm that the mission of our project is *to empower members of our community to collaboratively locate, install, and maintain air quality sensors whose measurements can identify and improve the health of their local air quality conditions.*

Data Quality Indicators

Our QAPP document categorizes the Data Quality Indicators into six measurements, which can be grouped into two categories: Programmatic Data Quality Indicators (DQIs) and Derived Data Quality Indicators (DQIs). The DQIs for our project are precision, accuracy (bias), completeness, representativeness, comparability, and sensitivity. Note that the EPA also refers to the six standard DQIs via the acronym PARCCS,

1. **Programmatic DQIs** related to the Project Quality Objectives listed in the above Section A7.1. These include **Precision, Accuracy (Bias), Completeness**

2. **Derived DQIs** are qualitative in nature. They are used to describe data quality rather than assess its quality. These include **Representativeness, Sensitivity, and Comparability.** Derived DQIs are calculations of Programmatic DQIs.

We are using the following definitional guidelines for the DQI from the *Quality Assurance Project Plan Standard - EPA 8.21.2023.* They are published on pages 11 and 12. A copy of the text is below.. https://www.epa.gov/system/files/documents/2024-04/quality_assurance_project_plan_standard.pdf

Programmatic DQIs:

- **Precision** is the measure of agreement among repeated measurements of the same property under identical or substantially similar conditions. (Note: Precision is often referred to as "repeatability." Precision is measured by QC checks such as Co-location Calibration and Global Calibration of particulate matter monitors.)

- **Accuracy (Bias)** measures the overall agreement of a measurement to a known value. (Note: Accuracy is the confidence range in measurements corresponding to actual values. Usually, the measurement is +/- % of the actual value.)

- **Completeness** measures the proportion of valid data obtained from a measurement system, expressed as a percentage of the number of valid measurements that were actually collected.

Derived DQIs:

- **Representativeness** is the measure of the degree to which data accurately and precisely represent a population characteristic, parameter variations at a sampling point, a process condition, or an environmental condition.

- **Comparability** is a qualitative term that expresses confidence in the ability of two or more data sets to contribute to a common analysis. Before pooling data, the comparability of data sets generated at different times or by different organizations must be evaluated to determine whether two data sets can be considered equivalent in terms of measuring a specific variable or a group of variables.

- **Sensitivity** is the capability of a method or instrument to discriminate between measurement responses representing different levels of the variable of interest. The term "detection limit" is closely related to sensitivity and is often used synonymously. The scope of our project primarily involves examining aggregate properties and patterns in our specific area of study. Therefore, the measure of sensitivity is not essential for the sensing data. Note: “Detection Limit” is a means of communicating sensitivity and is defined as the lowest concentration or amount of the target pollutant that can be determined to be different from zero by a single measurement at a stated probability level. It is typically expressed as the Method Detection Limit (MDL). Reference: [Code of Federal Regulations: Appendix A to Part 58—Quality Assurance Requirements for Monitors used in Evaluations of National Ambient Air Quality Standards:

  Title 40 Chapter I Subchapter C Part 58 Appendix A to Part 58 - 1.0 General Information - Section 1.3 Definitions.]
  https://www.ecfr.gov/current/title-40/chapter-I/subchapter-C/part-58/appendix-Appendix%20A%20to%20Part%2058

The following table identifies the features of our *Data Quality Objectives* that support the public health and engagement goals of our project.

References: *Region 3 Quality Assurance Project Plan (QAPP) Template*, pages 15 to 19.

Parameter	Field QA Method	Averaging Time	Accuracy	Precision:	Completeness
Clarity Node-S $PM_{2.5}$ (µg/m^3)	Solar-powered, cellular-connected, real-time $PM_{2.5}$ concentrations based on calibrated laser sensors. 24/7 for 12 months at a data recording rate of one measurement per 5 minutes. https://click.clarity.io/knowledge/clarity-data-quality-assurance-process (See QAAP Appendix pages 64-68)	30 Minutes	±25%	Precision: Standard Deviation (SD) = ≤ 5 µg/m3 Coefficient of Variation≤ = 30%	75%
Clarity Node-S $N0_2$	Solar-powered, cellular-connected, real-time N02 concentrations based on a calibrated chemiluminescence continuous analyzer. 24/7 for 12 months at a data recording rate of one measurement per 5 minutes. https://click.clarity.io/knowledge/clarity-data-quality-assurance-process (See QAPP Appendix pages 64-68)	30 Minutes	±25%	±25% for detects above the limit of quantitation	75%
Sorbent Tube Benzene (µg/m^3)	Lab analysis and field blanks collected weekly, lab blanks are collected weekly. (See QAPP Appendix page 114)	1 week	Uncertainty rate: +/- 10%	Calibration with known standards is conducted each time of analysis. % accuracy and % precision are obtained from these procedures.	80%

Clarity Wind/Weather Module: - Wind Speed - Wind Direction	Solar-powered, cellular-connected, continuous measurement of wind speed and wind direction, 24/7 for 12 months at a data recording rate of one measurement per 5 minutes. https://click.clarity.io/knowledge/clarity-data-quality-assurance-process (See QAAP Appendix pages 64-68)	30 Minutes	Wind speed = ±2% (at 12m/s) Wind direcction = ±3% (at 12m/s)	NA	75%
Clarity Wind/Weather Module: - Temperature - Humidity - Atmospheric pressure	Solar-powered, cellular-connected, continuous measurement of - Temperature, Humidity, and Atmospheric pressure, 24/7 for 12 months at a data recording rate of one measurement per 5 minutes.) https://click.clarity.io/knowledge/clarity-data-quality-assurance-process (See QAAP Appendix pages 64-68)	30 Minutes	Temperature = ±0.5 degrees C) Humidity = ±0.2% RH (at 25 degrees C) Atmo Pressure = ±0.12% hPa	NA	75%
Atmotube PRO Mobile AQM: PM_1, $PM_{2.5}$, PM_{10} ($\mu g/m^3$) VOCs ($\mu g/m^3$) - Temperature - Humidity - Atmospheric pressure	The Atmotube Pro AQMs offer community members a mobile air quality monitoring solution for educational purposes. These instruments measure air conditions with sufficient accuracy to learn about and identify potential hazardous air conditions.	NA	Atmotube Pro: Educational Particulate Matter: Resolution: 0 to 100 µg/m3 ±10 % - 100 to 1000 µg/m3 ±10 % VOCs: = 15% of measured value	NA	75%

A7. Distribution List

The following table identifies our core project team, partners, and collaborators. All members of the distribution list below will receive a copy of this Quality Assurance and Performance Plan (QAPP).

Name	Position	Division / Affiliation	Address / Location
[redacted]	EPA Grant Officer	U.S. EPA Region 3	[redacted]
[redacted]	EPA Quality Assurance Reviewer	U.S. EPA Region 3	[redacted]
[redacted]	Director Southeastern Pennsylvania	Southeastern Pennsylvania Clean Water Fund	[redacted]
[redacted]	Project Manager	A SMART Collaboration LLC	[redacted]
[redacted]	Director of Design and Communications	Interpret Green. LLC	[redacted]
[redacted]	Quality Assurance Manager	Independent	[redacted]
[redacted]	Air Science and Community Engagement	Independent Advisor	[redacted]
[redacted]	Director Community Outreach and Core (COEC)	U Penn Center for Excellence in Environmental Toxicology, CAMP AQ Advisory Committee	[redacted]

[redacted]	Program Coordinator Community Outreach and Core (COEC)	UPenn Center for Excellence in Environmental Toxicology, CAMP AQ Advisory Committee	[redacted]
[redacted]	Executive Director Lexicomm for Language Translation	Lexicomm International	[redacted]
[redacted]	Vice President of Business Development and Partnerships	Clarity Movement, CAMP AQ Advisory Committee	[redacted]
[redacted]	Projects Team Lead at Clarity	Clarity Movement, CAMP AQ Advisory Committee	[redacted]
[redacted]	Co-founder and CEO	JustAir, CAMP AQ Advisory Committee	[redacted]
[redacted]	Head of Partnerships	JustAir, CAMP AQ Advisory Committee	[redacted]
[redacted]	Director of Air Science Laboratory	Lewis & Clark State College LC State Atmospheric Chemistry Lab	[redacted]
[redacted]	Air Quality Consultant	Drexel University Dornsife School of Public Health	[redacted]

There will be three locations for the official, controlled, and protected version of this QAPP.

- A digital copy is publicly available on the project's website. https://www.asmartcollaboration.com/CAMP//QAPP
- Stored digital filing system at the A SMART Collaboration LLC headquarters,
- A digital copy in the CAMP Team's Google Drive [ASC Google Drive > AIR QUALITY > CAMP > Quality Assurance Project Plan] as well as in our external hard drive for CAMP

A8. Project Organization

Our project organization reflects our mission, which is to empower community members to collaboratively monitor air quality measurements that can identify and help improve local air health quality conditions. Thus, this project will recruit AQ Stewards and AQ Tech Team members who reside in the neighborhood, provide them with education on air quality monitoring, and train them in AQM installation and maintenance procedures. Our project team will also enlist members for the AQ Council and educate them on air quality and public health issues.

The Clean Water Fund (CWF) is the grantee for the EPA's Community Air Monitoring Project (CAMP). A SMART Collaboration LLC (ASC) is the contractor for CWF to develop and implement the CAMP initiative. [redacted] ASC president, is the Project Manager for CAMP. [redacted] is assisted by a CAMP cadre consisting of [redacted] (Director for Air Quality Science), [redacted], Founder and Director of Interpret Green, LLC (Project Communications Director), [redacted] (Quality Assurance Manager) and [redacted] (Project Engagement Coordinator).

[redacted], PA State DIrector, Project DIrector, CWF

[redacted] is the project director for this initiative. He has served as the Pennsylvania State Director of Clean Water Fund since 2007. He has worked as an organizational leader and community organizer for over 25 years with various neighborhood, environmental, and social justice organizations in Pittsburgh, Philadelphia, and Chester, PA. The project director has the authority to halt and restart work after a stoppage. [redacted]

[redacted], Project Supervisor, CWF

[redacted] serves as the project supervisor for this initiative on behalf of The Clean Water Fund of Southeastern Pennsylvania. He is responsible for the administrative, operational, and financial management activities of this grant. The supervisor has the authority to halt and restart work after a stoppage. [redacted]

[redacted] Project Manager, ASC

The Project Manager is responsible for implementing the administrative, operational, and financial management activities of this CAMP. He oversees QAPP development and updates. He distributes and ensures that the latest QAPP and SOPs are available in the three locations specified in this document and that older QAPP versions are archived in the ASC digital file archive. As the project manager, he is responsible for overseeing data collection and training activities. He and the project supervisor will be responsible for overseeing the contractors and approving deliverables. The project manager is responsible for authorizing purchases and has the authority to halt or resume work after a stoppage. [redacted]

[redacted] Communications Director, IG

The Communications Director is responsible for developing, designing, and producing media and project communications for this project. Internal communications activities include recruitment, training, and education. External public-facing media activity includes videos, websites, and social media related to community engagement, education initiatives, and progress reporting.

[redacted]

[redacted], Director for Air Quality Science

The Director of Air Quality Science provides strategic project direction, develops proposals, and offers technical consulting services. [redacted] has over 13 years of experience in environmental exposure science and community-engaged research. She previously managed a research laboratory at Drexel University's Dornsife School of Public Health, where she co-designed a community-based air toxics study with Philly Thrive from 2022 to 2024. [redacted]

[redacted] Quality Assurance Manager

The Quality Assurance Manager provides an outside reviewer, independent of project operations, to help identify any shortcomings or departures from this Quality Assurance Plan and to suggest corrective actions that should be taken or improvements that should be made. She will consult with the Project Manager on a monthly basis, reviewing checklists, logbooks, reports, and other project documentation, and monitoring any limitations on the use of the collected data. [redacted]

[redacted] Director for Benzene Monitoring

[redacted] received an M.S. and Ph.D. from the University of California, Irvine. She has been a professor teaching chemistry and science for over 20 years. [redacted] leads an atmospheric chemistry and instrumentation laboratory at Lewis & Clark State College. She will supervise all laboratory activities related to benzene analysis and provide consultation on sampling methodology. [redacted] collaborated with members of a prior 2-year study of Benzene in our study area. [redacted]

[redacted] Local Air Quality Consultant for Benzene Monitoring

[redacted] is a current doctoral candidate at Drexel University Dornsife School of Public Health. They received a Master's in Public Health from Harvard TH Chan School of Public Health. [redacted] was engaged in AQM training, data collection, analysis, and reporting for the NIH-funded AQM project in Grays Ferry that was the predecessor to the CAMP project. They are very familiar with the community and the AQM technology for monitoring Benzene. [redacted] also built and maintained the public access ThriveAir website for the NIH study, providing support for local community engagement.

[redacted], Community Engagement Coordinator,

The Project Community Engagement Coordinator is a resident of the community. Under the direction of the Project Manager, she is responsible for recruiting, supporting, and coordinating the AQ Stewards and AQ Council members. She will help CAMP develop and deliver workshops, events, and programs that educate and discuss air quality issues. [redacted]

AQ Stewards

Project staff, designated "AQ Stewards," will be recruited, enrolled in training, and will provide operational air quality monitoring, maintenance, and assessment. Community focus is on the Grays Ferry neighborhood of South Philadelphia. Educational programs will include air health and remediation activities designed to reduce air pollution. They will table at events in Philadelphia to raise awareness and enable community members to interact with the data in real time. AQ Stewards will be assigned schedules for periodic AQM tasks. AQ Stewards will be compensated for their services in the form of gift cards.

AQ Council Members

ASC will convene an AQ Council to provide CAMP clear channels of communication across the community to identify and convey information about air quality conditions and issues. Participating Council members will include leadership from local faith congregations, environmental justice organizations, registered community organizations (RCOs), community improvement groups, schools, and other organizations concerned about air quality and related issues. The AQ Council will be asked to meet periodically, and members will be compensated for their services in the form of gift cards.

A9. Project Quality Assurance Manager Independence

Our Project Quality Assurance Manager (QAM) for this project brings the necessary knowledge and experience to this crucial role, ensuring high standards for project quality assurance. We affirm that our Quality Assurance Manager operates independently from the environmental information team. In this role, the manager will not be involved in collecting data or doing fieldwork. This separation ensures that the manager’s oversight remains objective and unbiased.

Our Quality Assurance Manager ensures that all data is collected in strict accordance with our Quality Assurance Project Plan (QAPP) and Quality Management Plan (QMP). Our QAM has the authority to monitor all aspects of the project's progress and evaluate whether the project is meeting the defined quality assurance standards outlined in the project's QAPP.

A10. Project Organization Chart and Communications Project Organization Chart

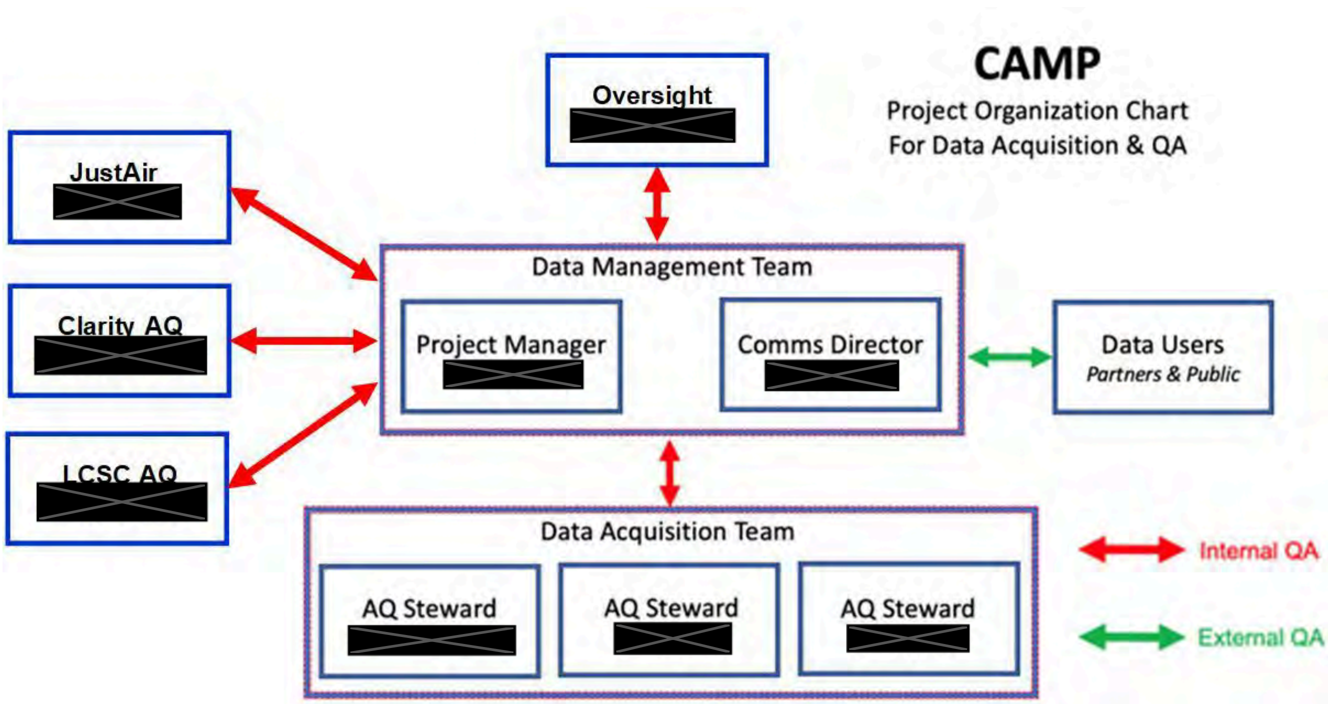


Image Source: Diagram Artwork by Interpret Green

Communication Pathways:

Communication Driver	Responsible Entity	Procedure (timing, Pathway, etc.)
Communication with the EPA Region 3 Project Officer about strategic Quality Assurance and Quality Control, issues, reports, and documentation.	[redacted], Project Director, CWF, or [redacted], Project Supervisor	The CWF Team maintains communications with the EPA Region 3 Project Manager about strategic updates, required reports, and progress reports. Follow-up can include additional emails, phone calls, Zoom meetings, and in-person meetings on a scheduled or as-needed basis with 24 hours of notice..
Communication with the EPA Region 3 Project Officer about Quality Assurance and Quality Control status and questions regarding the implementation of QAPP-defined activities.	[redacted] Project Manager, ASC, or [redacted], Project Supervisor, and [redacted], Quality Assurance Manager	The Project Manager, Project Supervisor, and Quality Assurance Manager maintain communication with the EPA Region 3 Project Manager regarding the status of Quality Assurance and Quality Control, as well as questions related to the implementation of QAPP-defined activities. Follow-up can include additional emails, phone calls, Zoom meetings, and in-person meetings, scheduled or as needed, with at least 24 hours' notice.
Need to communicate with the internal team to address status, reports, issues, anomalies, and discrepancies within the project team.	[redacted] Project Manager, ASC, or [redacted], Project Supervisor	The Project Manager or Project Supervisor maintains communication with the EPA Region 3 Project Manager and the internal project staff to confirm plans, monitor progress, and resolve anomalies and discrepancies within the project team. Follow-up can include additional emails, phone calls, Zoom meetings, and in-person meetings, scheduled or as needed, with at least 24 hours' notice.
Need to communicate with contractors or subcontractors to address status reports, issues, anomalies, and discrepancies.	[redacted] Project Manager,	The Project Manager maintains communication with the EPA Region 3 Project Manager, contractors, and subcontractors to address status reports, issues, anomalies, and discrepancies. Follow-up can include additional emails, phone calls, Zoom meetings, and in-person meetings on a scheduled or as-needed basis with 24 hours of notice..
Need to communicate issues about digital AQM operations or data.	[redacted] Project Manager, or [redacted], Communications Director	The Project Manager and Communications Director maintain communications with the EPA Region 3 Project Manager and Clarity or JustAir to address status reports, issues, anomalies, and discrepancies. Follow-up can include additional emails, phone calls, and in-person meetings on a scheduled or as-needed basis, with 24 hours' notice.

Need to communicate issues regarding benzene sampling or data.	[redacted] Director for Air Quality Science, [redacted], Director for Benzene Monitoring, [redacted], Air Quality Consultant	The Benzene monitoring team maintains communications with the EPA Region 3 Project Manager and the Benzene Lab and field team to address status reports, issues, anomalies, and discrepancies. Follow-up can include additional emails, phone calls, and in-person meetings, scheduled or as needed, with 24 hours' notice.
Need to communicate issues about the Benzene Lab data.	[redacted] Director for Air Quality Science, [redacted] Director for Benzene Monitoring, [redacted], Air Quality Consultant	The Benzene monitoring team maintains communications with the EPA Region 3 Project Manager and the Benzene Lab to address status reports, issues, anomalies, and discrepancies. Follow-up can include additional emails, phone calls, and in-person meetings on a scheduled or as-needed basis, with 24 hours' notice.
Need to communicate issues about the Atmotube PRO educational devices.	[redacted] Project Manager, or [redacted], Communications Director	The Atmotube PRO educational devices are periodically tested for functionality, but the data is not included in our Data Quality Control or documented for scientific reference.
Need to communicate issues with private property owners or public property owners for property access or AQM installations.	[redacted] Project Manager, or [redacted], Communications Director	The Project Manager and Communications Director will communicate with the EPA Region 3 Project Manager for support in interacting with private property owners or public property owners regarding property access or AQM installations. Follow-up can include additional emails, phone calls, and in-person meetings
Need to communicate corrective actions for QA and QC activities and data analysis	[redacted] Project and [redacted], Quality Assurance Manager	The Project Manager and Quality Assurance Manager maintain communication with the EPA Region 3 Project Manager regarding Quality Assurance and Quality Control corrective actions and provide update reports of the efficacy of resolving issues.

A11. Personnel Training/Certification

Our CAMP project will install the stationary Clarity AQM equipment in multiple locations throughout the Grays Ferry and adjacent neighborhoods of Philadelphia. Local community members will be trained to handle multiple procedures and processes, ensuring the quality assurance and quality control of our Quality Assurance Project Plan (QAPP) implementation. Our technical partners, Clarity Movement and JustAir, will train two *Community Technical Team Members* and a technical supervisor from Interpret Green. The instructional reference guides, instructional videos, and in-depth online reference sources from the Clarity Knowledge Base and the Clarity Learning Center will support training. JustAir will lead user training for the CAMP AQM Digital Dashboards, which support the AQ and QC processes related to data management, equipment monitoring, and maintenance of the CAMP AQM digital network.

Certificates will be provided to staff and volunteers upon successful completion of the training programs. Upon certification of knowledge and skills, CAMP staff and volunteers will be authorized to provide air quality equipment assembly, technical configuration, performance testing, installation, operational monitoring, maintenance, and repairs. The CAMP QAM is responsible for ensuring that the required training, skills, and knowledge testing and demonstration competency is completed.

CAMP staff who have completed the training and skills testing will be certified to implement CAMP Technical Services. Training sessions will be scheduled to ensure that local residents can participate. Training materials include equipment manuals, maintenance procedure manuals, and diagnostic and repair procedure manuals. Online access to training videos and technical documentation will support quality-controlled data collection and data management.

Clarity Learning Center:

Clarity Movement provides instructional training for operational training and skills acquisition. The following is a sample weblink to three of their training programs:
https://click.clarity.io/learning-center

Clarity Air Quality Sensor Bootcamp

https://www.clarity.io/air-sensor-bootcamp/enroll

Clarity Knowledge Base

https://click.clarity.io/knowledge

Clarity Educational Videos

https://www.clarity.io/videos

Sample Instructional Program: Device Collocation and Calibration for Improved Data Quality
The following is a sample Clarity Course outline and overview for Device Collocation and Calibration for Improved Data Quality. The following is the web link to access the sample Clarity instructional training program.
https://click.clarity.io/device-collocation?lesson=lesson-1-types-of-air-monitors
https://click.clarity.io/device-collocation

Device Collocation and Calibration for Improved Data Quality Training

Lesson 1: Types of air monitors

Lesson 2: What are calibration and collocation?

Lesson 3: How do I find a reference site?

Lesson 4: Clarity Node-S Deployment for Collocation

Lesson 5: Collocation and calibration checklist

Lesson 6: Complete the questionnaire

A12. Documents and Records

According to our understanding, the most recent EPA-published and authorized summary for “Documents and Records,” referenced in the EPA QAPP, is provided in the Region 3 Quality Assurance Project Plan (QAPP) Template, pages 30-32.

https://www.epa.gov/system/files/documents/2024-07/region-3-qapp_standard-template-final.docx
There are also definitions for reference in the 8.21.2023 *Environmental Information Quality Policy.* pages 10 and 11.
www.epa.gov/system/files/documents/2024-03/enviornmental_information_quality_policy.pdf

We are using the following comprehension definition of "data measurements" from both the 8.21.2023 EPA QAPP and QMP reference documents. *Environmental Measurement—A subgroup of Environmental Information that includes or produces values derived from tools, instruments, observational results, laboratory operations on environmental samples, or other sampling and testing equipment. It is any data collection activity or investigation involving the assessment of chemical, physical, or biological factors in the environment that affect human health and the environment.*

Please note that the data records and documents for our project are in digital format. With the exception of the sorbent tubes, our AQM field instruments generate this data via automated technical processes co-supervised by CAMP and our technical partners, Clarity Movement and JustAir. Multiple quality control methods are integrated into our system to ensure data accuracy and integrity through all phases of the data pipeline protocol. This encompasses the sequential stages of AQ sensor operations, including measurements, data networking, data processing, data analysis, data storage, data archiving, and data access. Our AQ digital sensors continuously measure and record air quality. The recorded data is distributed and stored at multiple locations, including CAMP, Clarity Movement, and JustAir data repositories. A permanent archive of the AQM data for our project is maintained through the global AQM data repository, which is managed by the notable non-profit organization OpenAir. www.openair.org.

> *OpenAQ is an environmental tech nonprofit. We aggregate and harmonize open-air quality data from across the globe onto an open-source, open-access data platform so that anyone concerned about air quality has unfettered access to the data they need to analyze, communicate, and advocate for clean air. By providing universal access to air quality data, OpenAQ empowers a global community of changemakers to solve air inequality–the unequal access to clean air.*
>
> *Anyone can explore the data via OpenAQ Explorer, https://explore.openaq.org/#1.2/20/40 an interactive web application. For programmatic access via the API or to create custom lists on OpenAQ Explorer, user registration is required. See also our AQI Hub, a first-of-its-kind website to navigate air quality indexes across the world.*

Copies of the QAPP, sensor and sample collection SOPs, Clarity Node-S sensor user manuals, sorbent tube sample collection processes, and other procedures/protocol will be kept as electronic copies in the CAMP Google Drive [CAMP Drive > AIR QUALITY > CAMP > Technical Specifications (and/or) Standard Operating Procedures]. Up-to-date hard copies will also be kept in the CAMP offices. Additionally, external hard drive backups will be performed on a weekly basis. Copies of relevant SOPs are attached to this QAPP as Appendices.

Calibration and maintenance records for the sensors will be maintained in the CAMP Google Drive (CAMP Drive > AIR QUALITY > CAMP > Equipment Logs), on the external hard drive, and in the offices. Since data is automatically recorded to the Clarity website, there is no field data notebook for Clarity Node-S air quality monitoring activities.

CAMP program reports will be prepared quarterly, with a comprehensive final report prepared at the end of the grant cycle. These reports will include data generated from the Clarity sensors, benzene passive samplers, and local wind plus weather conditions. The final report will consist of a narrative describing how our activities met or did not meet our objectives, what was accomplished during the reporting period, and the anticipated next steps for this initiative based on the data gathered at that stage.

The organization, maintenance, and storage schedules for CAMP project records will follow the guidelines outlined in the “Records Schedule and Disposition” table, presented on pages 32 and 33 of https://www.epa.gov/system/files/documents/2024-07/region-3-qapp_standard-template-final.docx.

B. Implementing Environmental Operations

B1. Identification of Project Environmental Information Operations

The design for our stationary installations for the air quality sampling project began with defining the core air quality (AQ) measurements that can best serve our community. After our collective research and review of options for air monitoring, the recommendations from our community members and technology team support included air quality sampling of PM2.5 particulates, NO2, and Benzene. They also support the monitoring of air conditions, including wind speed, wind direction, temperature, humidity, and barometric pressure. And, there was consensus support for integrating the use of mobile and instructional air quality monitors for community education.

The following are specific features and functions for Air Quality Monitoring equipment that are required to meet the Quality Assurance and Quality Control for the CAMP Project:

- The AQM system is built on autonomous, solar-powered, and cellular-connected AQM operations to ensure self-sufficient electrical power and wireless network connectivity. Our technical configurations minimize hardware, software, and network complexities, eliminating external dependencies on local Wi-Fi and electrical services. This significantly increases options for successful location installations.

- The AQM technical platform excels in providing real-time monitoring of multiple air quality parameters with high precision and accuracy. Measurements include PM2.5 particulate matter and NO2 gas, which our community recognized as the primary air quality measure parameters for their community..

- The digital data infrastructure provides robust access to data, data analytics, and data management. Advanced data analytics identify trends, patterns, and potential pollution sources. Secure data storage and sharing functions enable seamless integration with third-party data management applications, including the JustAir interface, which facilitates the visualization and interpretation of air quality data.

The following are the design features and functions that our teams recommended for the technical specification of our stationary Community AQM system:

- High precision $PM_{2.5}$ and NO_2 air quality sensing.
- Integration of wind and weather sensor measurements
- Pre-calibration with *Standard Global Calibration*

- Custom collocation-based calibration
- Solar-powered and cellular network-connected operations
- Sampling frequency rates are adjustable
- 99+% % operational uptime
- Noteworthy and successful large-scale AQM deployments
- Weekly evaluation and performance reports
- Cloud data management & visualization
- Easily adaptable for public access to the local air quality dashboard
- Easily adaptable for public access to data via the Internet and mobile devices
- Demonstrated expert air quality project support

Stationary Sampling Methods with Clarity Node-S AQMs for $PM_{2.5}$ and NO_2

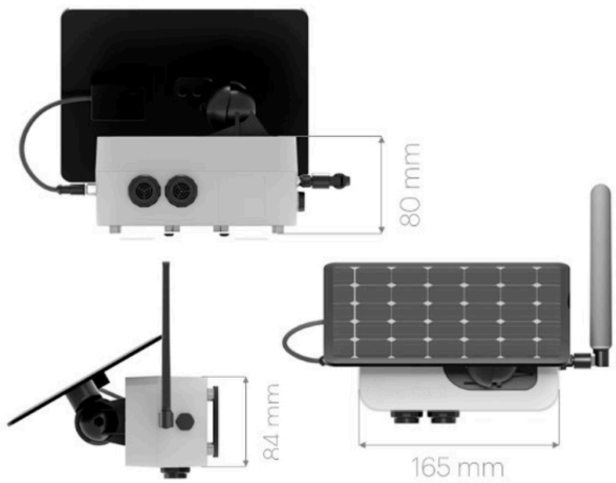


Image Source: : Clarity Movement

Our core sampling methodology utilizes unattended and automated AQM monitoring, which is operated by solar-powered instruments and managed remotely via cellular-connected devices. After researching options, we confirmed that the Clarity Node-S was the optimum instrument for our sampling program. We have designed our AQ sampling system for this project as a distributed network of 20 Clarity Node-S AQM instruments, which operate continuously to measure local air quantity conditions, including PM2.5 and NO2 air composition.

Our method for AQ sampling involves recording AQ measurements along with a digital time and date stamp, location stamp, and technical ID of the sample. The sample data recording is distributed over a digital communication network for immediate digital data archival storage and future data archival retrieval.

Our AQ data management system processes data in real-time via online data analytics, which can identify both current and predictive AQ patterns and trends. The analytic data processing also identifies when air quality conditions are healthy or if they require urgent or emergency public notifications or alerts.

Our method of AQ data archiving ensures perpetual, open-source public access to all AQ measurements. Our project partners and data are shared with the non-profit OpenAQ for the archiving of our community air quality data measurements in perpetuity. https://openaq.org/about/

Stationary Wind and Weather Monitoring via Clarity Node-S Wind Module:

The wind module technology is integrated, powered, and data processed within the Node-S device system. In addition to air particulates and gases, we are documenting the winds and atmospheric conditions that contribute to air quality. Clarity offers a Wind Module that provides highly accurate monitoring of meteorological parameters, including the following: Image Source: Clarity Movement

- Wind Speed
- Wind Direction
- Atmospheric Pressure
- Ambient Temperature
- Ambient Relative Humidity

Stationary Benzene Monitoring Station

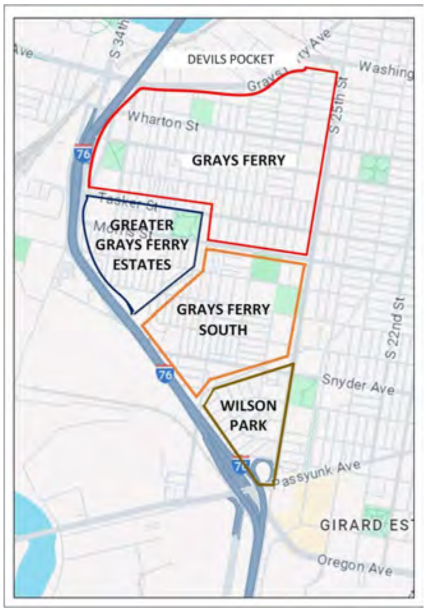
The presence of Benzene has been identified as a current potential pollution hazard resulting from decades of industrial use of Benzene at the Refinery adjacent to our Grays Ferry community. Our method for monitoring Benzene uses Sorbent Tubes installed inside a protective enclosure. Our Tech Team and Dr Nancy Johnston will manage the field procedures. The Sorbent Tubes will be analyzed at Dr. Johnson's laboratory facilities, and the quality-assured data will be shared with the CAMP technical review team. Lisa Frueh, the local CAMP consultant for Benzene monitoring, will provide the overview of the Benzene procedures and report documentation. This NIH-funded study laid the groundwork for our ongoing benzene assessment within the geographical context of the study area. Our project benefits from the previous work selecting locations for Benzene sampling. Image Source: Markes International Ltd

Mobile AQM Educational Monitoring with Atmotube PRO Equipment

The Atmotube PRO is a portable, mobile AQM ideal for public engagement and educational programming about community Air Quality Monitoring. These small and economical instruments will support our local CAMP participatory science activities for this project. These devices will not be used as precision AQM sensors for AQ data collection, archiving, or auditing.

Image Source: Atmotech, Inc.

Stationary Sampling Locations



Multiple factors guide the selection of air quality monitor locations for this project, with the intent of maximizing the representativeness and usefulness of the collected data. Our Grays Ferry community comprises four self-identifying neighborhoods, which include row housing, townhouses, single-family public housing, and multi-family and public housing towers.

The adjacent map illustrates the boundaries of the four neighborhoods that comprise the core area of our project study community, with townhouses and single-family homes.

Image Source: Artwork by Interpret Green with Google Earth Base-map.

The weblink below provides an interactive geographic view of our Grays Ferry community:
https://www.google.com/maps/@39.9269095,-75.2035737,13.08z?entry=ttu&g_ep=EgoyMDI1MDEyMi4wIKXMDSoASAFQAw%3D%3D

Statistical Atlas Weblink below provides demographic reference data about our Grays Ferry community:
https://statisticalatlas.com/neighborhood/Pennsylvania/Philadelphia/Grays-Ferry/Population

The following are the primary considerations and selection criteria to determine our AQM location selection for stationary sensing instruments: .

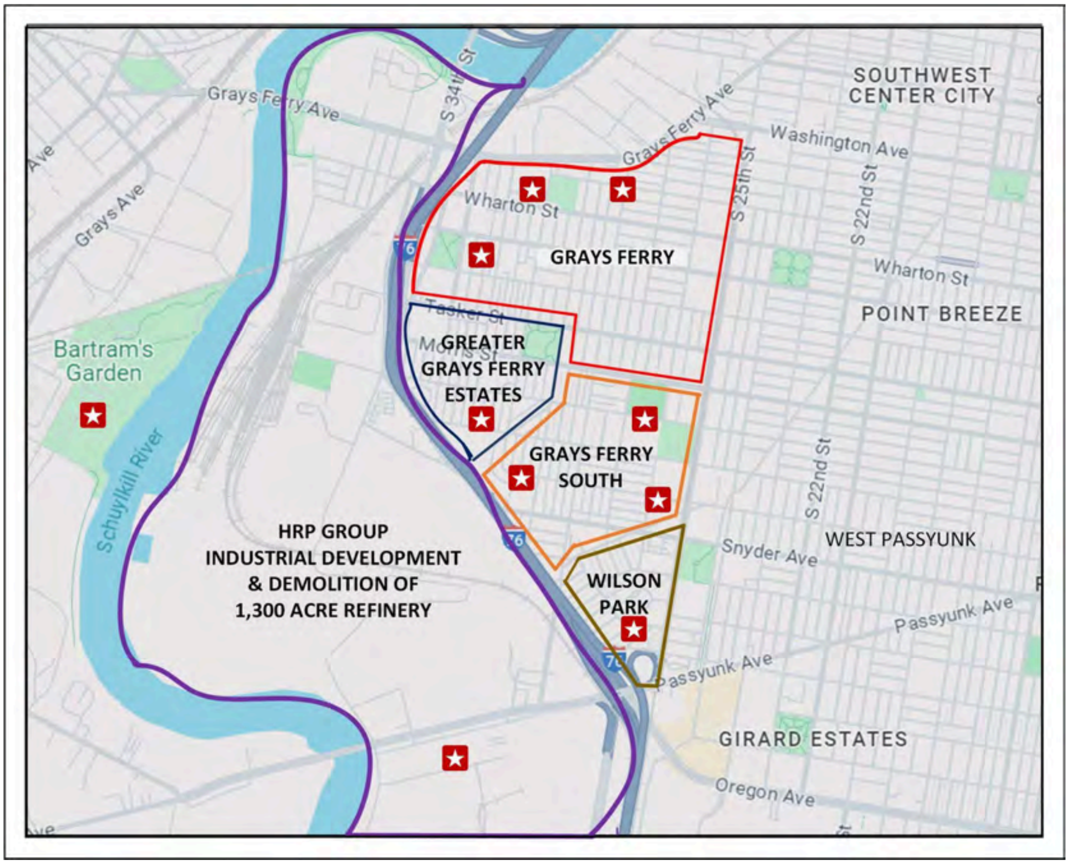
- **Population Diversity:** Select locations in areas with populations with higher-risk sensitivities to respiratory health, including children and the elderly. Examples of these types of potential installation locations include schools, playgrounds, daycare centers, senior housing facilities, medical centers, and high-traffic retail areas.

- **Proximity to Pollution Sources:** Select locations near known or suspected pollution sources in Grays Ferry. These include known industrial sites, such as the refinery, commercial areas with dense parking, high-traffic arteries, power plants, commercial waste disposal areas, and abandoned sites contaminated with toxic waste.

- **Influence of Meteorological Conditions**: Select locations influenced by local wind and weather patterns that affect the dispersion and concentration of air pollutants.

- Our location selection process involves considering infrastructure access for the installation and maintenance of monitoring equipment, as well as the level of cooperation from potential site owners or managers in participating in this project.

In collaboration with community members, the following locations have been selected for the initial installation of Community Sensing Stations, which will measure $PM_{2.5}$ particulates and NO_2.



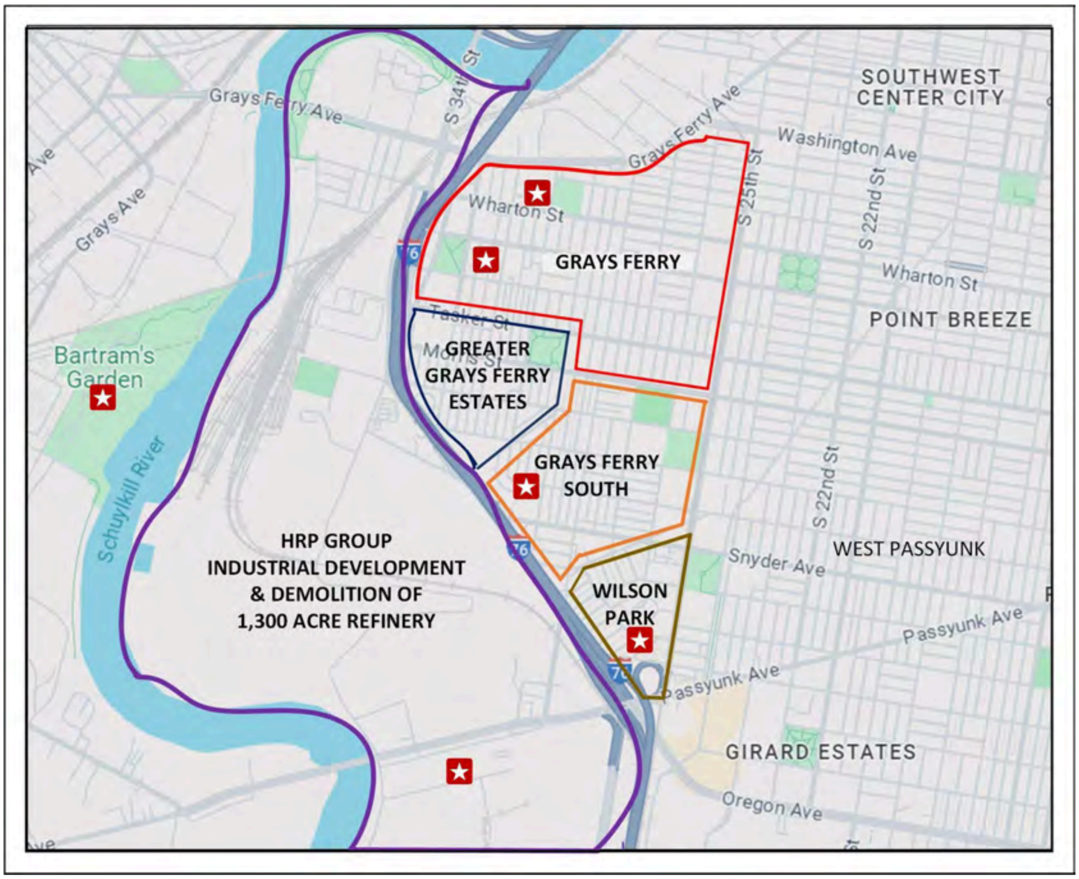
Stars indicate initial locations for Community Sensing Stations

Image Source: Artwork by Interpret Green with Google Earth Base-map

- Bartram's Garden (South Plaza), [redacted]
- Bellwether District, [redacted]
- [redacted]
- Finnegan Playground, [redacted]
- Lanier Park, [redacted]
- Overbrook Environmental Education Center. [redacted]
- Philly Thrive Headquarters, [redacted]
- Stinger Square Park, [redacted]
- Universal Audenried Charter School, [redacted]
- Universal Vare Charter School, [redacted]

Benzene Monitoring Locations:

Optimal locations for passive Benzene air quality sampling have been previously identified through a community-engaged program involving local public health stakeholders for fence-line residents along the east perimeter of the refinery. Our Benzene monitoring effort included scientists from Drexel University, Philly Thrive, and residents of Grays Ferry. The guidance from our experts and community members was to co-locate the Benzene monitors with the Clarity Node-S monitors on the Community Sensing Station (CSS) installation mounts. Five Benzene monitors will be installed at five CSS locations across our AQM installation network.



Stars are Locations for Community Sensing Stations with Benzene Monitoring

Image Source: Artwork by Interpret Green with Google Earth Base-map

- Bartram's Garden (South Plaza), 3000 South 56th Street, Philadelphia, PA, 19143
- Bellwether District, Lanier Avenue, Philadelphia, PA 19145
- Carol White, 2334 Bambrey Terrace, Philadelphia, PA 19145
- Philly Thrive Headquarters, 1101 South 27th Street, Philadelphia, PA 19146
- Stinger Square Park, 3200 Dickinson Street, Philadelphia, PA 19146
- Universal Audenried Charter School, 3301 Tasker Street, Philadelphia, PA, 19145

B2. Methods for Environmental Information Acquisition

The table below outlines the environmental information acquisition operations of our project, which aim to achieve the performance and acceptance criteria described in Section A of this Quality Assurance Project Plan (QAPP).

Environmental Information Operations and DQO

Environmental Information Operation	Frequency	Description of how the EIO will satisfy the project purpose	Description of how the EIO will satisfy the data quality objectives
$PM_{2.5}$	Continuous for the length of the study period.	A distributed network of 20 calibrated, high-performance $PM_{2.5}$ sensors will operate continuously, 24/7, for a period of one year. The quality-assured data from this AQM network will provide detailed empirical data to document the concentration and locations of $PM_{2.5}$ particulate matter in our community. This data will help achieve the goals of community information and engagement regarding particulate pollution concentrations and distribution in our study neighborhoods.	Our data quality-based technology is supported by our partners Clarity and JustAir. Our EIO implements a data quality process methodology for $PM_{2.5}$ monitoring that has been pre-qualified in other similar projects, which have achieved very high data quality performance.
NO_2	Continuous for the length of the study period.	A distributed network of 20 calibrated, high-performance NO_2 sensors will operate continuously, 24/7, for a period of one year. The quality-assured data from this AQM network will provide detailed empirical data to document the concentration and locations of NO_2 particulate matter in our community. This data will help achieve the goals of community information and engagement regarding particulate pollution concentrations and distribution in our study neighborhoods.	Our data quality-based technology is supported by our partners Clarity and JustAir. Our EIO implements a data quality process methodology for NO_2 monitoring that has been pre-qualified in other similar projects, which have achieved very high data quality performance.

Wind Motion	Continuous for the length of the study period.	A distributed network of 10 calibrated, high-performance Wind speed and wind direction sensors will operate continuously, 24/7, for a period of one year. The quality-assured data from this wind information network will provide detailed empirical data to document the attributes, patterns, and potential source locations of $PM_{2.5,}$ $NO_{2,}$ and other air pollutants. This data will help achieve the goals of community information and engagement, as well as identify air pollution patterns and sources in our study neighborhoods.	Our data quality-based technology is supported by our partners Clarity and JustAir. Our EIO implements a data quality process methodology for wind motion monitoring, which has been pre-qualified in other similar projects that have achieved very high data quality performance.
Environmental Weather Conditions	Continuous for the length of the study period.	A distributed network of 10 calibrated, high-performance Environmental Weather Conditions sensors will operate continuously, 24/7, for a period of one year. The quality-assured data from this weather information network will provide detailed empirical data to document the attributes, patterns, and potential source locations of Benzene air pollution. This data will help achieve the goals of community information and engagement and identify air pollution patterns and sources in our study neighborhoods.	Our data quality-based technology is supported by our partners Clarity and JustAir. Our EIO implements a data quality process methodology for monitoring environmental weather conditions, which has been pre-qualified in other similar projects that have achieved very high data quality performance.
Benzene	Five Sorbent tube sites are refreshed every 7 days.	The continuous, 7-day cycle of Benzene Sorbent tube monitoring will provide empirical data to document the concentration and to help identify the locations of Benzene in our study area. The quality-assured data from this Benzene monitoring will provide detailed empirical data to document the patterns and environmental conditions. This data	Our data quality-based technology is supported by our partners at the Lewis & Clark State College, LC State Atmospheric Chemistry Lab, directed by Dr. Nancy Johnston. Our EIO implements a data quality process

		will help achieve the goals of community information and engagement, as well as identify air pollution patterns and sources in our study neighborhoods.	methodology for Benzene monitoring that has been pre-qualified in other similar projects, which have achieved very high data quality performance.
$PM_{2.5}$, VOC, and weather for educational engagement.	On a variable, rotating schedule with community-participatory scientists.	The use of the educational AQM from Atmotube PRO will be shared on a rotational basis throughout our project. The usual period for a community member or family to use the Atmotube is three weeks. The data from this participatory science engagement accelerates the understanding of various features and functions of air quality monitoring and air health, a significant objective of our CAMP program.	Our partner, Atmotube PRO, supports our data quality-based technology. Our EIO implements a data quality process methodology for educational air monitoring that has been pre-qualified in other similar projects, which have achieved very high data quality performance.

The following table provides references for summaries of the episodic sampling methods and *the Standard Operating Procedure* (SOP) for our project.

Air Property to be Measured	Method of Measurement	Collection/ Analysis	Procedures	Technical Partner and/or Laboratory
$PM_{2.5}$	Node-S AQM	Continuous Digital Monitoring	(See Appendix pages 6 to 17)	Clarity Motion, LLC.
NO_2.	Node-S AQM	Continuous Digital Monitoring	(See Appendix pages 6 to 17)	Clarity Motion, LLC
Wind Motion	Node-S AQM Wind Module	Continuous Digital Monitoring	(See Appendix pages 18 to 25)	Clarity Motion, LLC

Benzene	Sorbent Tube	Collection and Lab Analysis	(See Appendix page 18 to 25)	Dr. Nancy Johnston Lewis & Clark State College LC State Atmospheric Chemistry Lab
$PM_{2.5}$, VOC, and weather for educational engagement.	Atmotube Pro	Continuous Digital Monitoring	(See Appendix page 71 to 88) Note: that the Atmotube Pro is being used for educational purposes. The data from this device will not be included in or data archive references.	. Atmotech, Inc.

Field and Laboratory Quality Control for Benzene

Passive Benzene monitoring will be performed using Markes thermal desorption tubes (TDT). Markes axial Tenax®TA sorbent tubes (3.5 inches/89 mm length and ¼ inch/6.4 mm OD and 5 mm ID stainless steel inert coated, pre-packed) collect air diffusively, providing the raw amount (calibrated in nL or ng) of compounds of interest adsorbed over the sampling duration (7 days).

Sorbent Tube System with pole mount installation

Sorbent Tube with hand for scale

Image Source: ThriveAir Philadelphia Sorbent Tube outdoor Installations

Tubes will be deployed and retrieved at the same locations once a week, on Wednesdays, to maintain consistency with previously collected THRIVEair VOC tubes and current HRP benzene sampling. Samples will be used to calculate a one-week average concentration of benzene.

Analytical Method (Benzene)

Samples will be analyzed using TD-GC-MS to determine the mass or volume of analytes adsorbed and their respective concentrations. A Markes Unity 2 thermal desorption unit (He flow of 25 mL/min during desorb with 50°C/200°C heating onto a 30 °C Markes sulfur cold trap) is coupled with an Agilent 7820 GC/5977 MS (DB-624 UI, 60m x 320µm x 1.8 µm column and electron ionization MSD in scan and trace ion detection modes).

The TD injects the sample with He flow of 1.5 mL/min (no split) into the GC/MS and the GC temperature starts at 40 °C for 2 min, then ramp of 10 °C/min until 195 °C, holding there for 12.5 min, total run time of 30 minutes in the GC. Quality control is ensured by comprehensive 5-point calibration for VOC compounds including routine standard checks using gas (Airgas TO-15/17 62 component VOC mix and PAMS 57 component mix) and liquid (AccuStandard® VOC 60 component Mix M-502, SPEXertificate® CAN-TERP-MIX2 terpenes) standards; and the use of periodic duplicates, method and field blanks.

The following are sample *Data Quality Charts*. They are examples of the data management procedural documentation for Benzene that will be employed in our field and laboratory quality control. Project partner [redacted] provided this chart.

	A	B	C	D	E	F	G
1	Ground Site	START DATE (Local)	START TIME (Local)	END DATE (Local)	END TIME (Local)	Duration (min	Benzene
2	Boise	6/25/2019	11:58	7/2/2019	11:00	10022	0.089
3	Boise	7/2/2019	11:08	7/9/2019	10:25	10037	0.076
4	Boise	7/9/2019	10:30	7/16/2019	12:05	10175	0.084
5	Boise	7/16/2019	12:14	7/23/2019	11:05	10011	0.094
6	Boise	7/16/2019	12:14	7/23/2019	11:05	10011	0.093
7	Boise	7/23/2019	11:08	7/30/2019	10:20	10032	0.103
8	Boise	7/30/2019	10:23	8/6/2019	9:40	10037	0.149
9	Boise	8/13/2019	13:46	8/21/2019	8:45	11219	0.183
10	Boise	8/21/2019	8:46	8/27/2019	12:55	8889	0.088
11	Lewiston	6/18/2019	18:08	6/25/2019	16:31	9983	0.067
12	Lewiston	6/25/2019	16:31	7/2/2019	9:41	9670	0.060
13	Lewiston	6/25/2019	16:50	7/2/2019	9:52	9662	0.066
14	Lewiston	7/2/2019	9:52	7/9/2019	12:48	10256	0.047
15	Lewiston	7/2/2019	9:41	7/9/2019	12:35	10254	0.044
16	Lewiston	7/9/2019	12:51	7/16/2019	11:07	9976	0.066
17	Lewiston	7/16/2019	11:10	7/23/2019	13:43	10233	0.079
18	Lewiston	7/23/2019	13:45	7/30/2019	7:47	9722	0.061
19	Lewiston	7/30/2019	7:49	8/6/2019	9:53	10204	0.088
20	Lewiston	8/6/2019	9:57	8/13/2019	11:35	10178	0.101

B3. Integrity of Environmental Information

Sample Handling and Custody (Benzene)

[redacted] prepares the TDT Tubes. The CAMP team inspects the tubes on arrival for any issues, including missing caps. Markes tubes are shipped from [redacted] lab every 3 weeks and stored in a cool, dry location until use. After the tubes are retrieved, they are placed in a Styrofoam rack, wrapped in aluminum foil, and stored in the CAMP refrigerator (between 34°F and 40°F). Every two weeks, tubes are shipped back to [redacted] lab using overnight shipping and analyzed via GC-MS.

The electronic log is a Google Sheet file that [redacted] and the CAMP team have online access to and will be stored in the CAMP Google Drive. A paper copy of this log is printed for each weekly sampling session, and then the data is input into the electronic log. Field log Instructions are as follows:

Box number	Tube number	INDENT FACING DOWN, ARROW POINTIN G UP?	Location Reference number or code	LOCATION (DESCRIPTION)	Sample Type	START DATE	START TIME military	User name (set up)	END DATE	END TIME military	User name (take down)	COMMENTS	Date return shipped to ID
20	P726601												
20	P726602												
20	P726603												
20	P726604												

The following identifies the data fields for this report:

Box number:	This number corresponds to the shipping box number for the tube.
Tube number:	This is the number *on the tube* by the barcode.
Box number:	This number corresponds to the shipping box number for the tube.
Affirm indent facing down, arrow pointing up:	Write “yes” once you double-check that the correct end of the tube was uncapped.
Location reference number or code:	A one-digit number corresponding to each site
Location (description):	The name of the site (such as “Bartram’s”)
Sample type: This can be one of four types:	1. “Sample” = Most of the time, this will be what you select 2. “Duplicate” = if this is the second tube mounted into the same housing (we also call this a “co-lo”, short for “co-located”) 3. “Field blank” = if this is the field blank. Every week, we designate one tube to be the field blank and open it briefly at our last sampling site. 4. “Lab blank” = once every two weeks, we designate a tube as the lab blank before shipping tubes to Idaho. The lab blank never leaves the lab.

Start date:	The date the tube went up
Start time:	The time of day that the tube went up (in 24-hour / military time)
User name (set up):	Initials of the person who put the tube up
End date:	The date the tube came down
End time:	The time of day the tube came down (in 24-hour / military time)
User name (take down):	Initials of the person who took the tube down
Comments:	Add comments. You may notice a strong smell in the air, such as wildfire smoke or other factors that could affect measurements at that site.
Date return shipped to ID:	Date of shipment

Equipment Installation and Retrieval (Benzene)

The following is the TDT tube sampling protocol that we will be using for Benzene sampling:

Set up:

1. Obtain tubes from storage or shipping, as well as CAP tools and wrenches (9/16” and 1/2”). Work with clean hands. Do not touch the tube ends directly with your hands.
2. Allow the tube to equilibrate with the outside temperature for 15-30 minutes, if possible (usually while in the car en route to the sampling site). Note: The working temperature range is from 0 to 40 °C.
3. Mount the weather housing onto a telephone pole using zip ties. If the pole is large, you might have to use two strings together.
4. In the FIELD LOG, note the site ID/location, VOC tube ID, and date.
5. Uncap the side of the tube with the small indentation using tools or a wrench. Store the gold cap.
6. Replace the cap with a diffusion cap by sliding it into the tube in a slight twisting motion until it is firmly in place. The arrow should point up, away from the diffusion cap, with the diffusion cap pointing down (see image).
7. Note the start time in the field log. The start time is when you remove the cap from the tube.
8. Clip the VOC tube into the weather housing with the arrow pointing up in the housing.
9. Record comments in the field log.

Take down:

10. Record comments in the field log.
11. Remove the tube from the weather housing.
12. Remove the diffusion cap by gently sliding it off the tube while twisting. Replace it with an end cap. Hand-tighten, then turn 1/8 turn with a wrench or tool. Check for tightness by pulling on both ends. The caps should stay on. Also, ensure that the caps extend up to the indent and the barcode; otherwise, they may not be slid down far enough.
13. Record the location, tube number, end time (the moment you put the gold cap back on), day, user, and comments.

14. Once back in the lab, pack the tube in foil, place it back in the original packaging or container for shipping, and store it in the refrigerator if it is not being shipped until the following week.
15. If shipping that week, mail the mailer in the next 1-3 days. Keep in a cool place while waiting, or refrigerate.

Note: If directed, replace it with a new tube. Repeat steps 1-8 until it is time to take it down.

Note: Lab and field blanks are collected for each sampling period, and we also co-locate two samples at one site each sampling session.

Upon returning to the office, the scientists scan and submit the datasheets to the Project Manager every week, which are then reviewed and inspected. Hard copies of the original data sheets are kept on file in the Project Manager's office. Data generated by the Laboratory is emailed to the Project Manager. As needed, the Project Manager will provide the field and/or laboratory data to the scientists for digital data entry.

Microsoft Access is used to record and organize all data. Once all the data is entered, the Program Manager inspects the data for accuracy. Any entry errors are corrected, including the cross-checking with calibration and QC logs to confirm successful sampling and data management.

All data entry and error correction activities are recorded in a set of documents before and immediately after any data management activity. Queries have been set up within Access to facilitate data analysis without altering the master dataset. These queries will be used to compare current data with existing historical data from the sites.

B4. Quality Control

The following table provides a relational summary of the key Quality Control tasks, activities, identifications, and evaluations for each type of air quality operational monitoring.

QC Operational Monitoring	QC Frequency	QC Assessment Management Team	QC Assessment Responses	Identifying and Implementing Corrective Action	QC Evaluating Effectiveness of Corrective Action
$PM_{2.5}$ monitoring for calibration prior to installations	Continuous QC calibration monitoring at a rate of once per 5 minutes for a minimum of 14 days	Calibration by Clarity, who are the systems integrators and technical device managers, with field support from the CAMP Tech Team	Real-time continuous monitoring to ensure instruments operate within OC Objectives	In the event data sensing performance is over or under the margin of ± 10% for $PM_{2.5}$ of the measured approved QC Objectives values, Clarity will notify the CAMP Tech Team and collaborate to resolve the issue. All issues will be resolved by corrective action or replacement of the $PM_{2.5}$ instrument. All issues will be resolved by corrective action or replacement of the	All technical anomalies that have generated a "trouble ticket" remain active until resolved by the CAMP, Clarity, and JustAir technical teams. Corrective action will be re-evaluated to ensure the instrument, software, network, or other causes of errors have been successfully corrected. A list of unresolved issues is emailed to all teams on a weekly basis.

				instrument.	
$PM_{2.5}$ Monitoring for field operations	Continuous monitoring at a rate of once per 5 minutes	Real-time continuous assessment monitoring by Clarity and JustAir	The automated real-time $PM_{2.5}$ digital assessment systems from Clarity and JustAir provide the CAMP Team with status reports of any operational monitoring anomalies and initiate the remediation protocol.	If the data sensing performance exceeds or falls below the margin of ± 10% for $PM_{2.5}$ compared to the measured approved QC Objectives values, Clarity and JustAir will collaborate with the CAMP Tech Team to resolve the issue. All issues will be resolved by corrective action or replacement of the $PM_{2.5}$ instrument. All issues will be resolved by corrective action or replacement of the instrument.	All technical anomalies that have generated a "trouble ticket" remain active until resolved by the CAMP, Clarity and JustAir technical teams. Corrective action will be re-evaluated to ensure the instrument, software, network, or other causes of errors have been successfully corrected. A list of unresolved issues is emailed weekly to all teams.
NO_2 Monitoring for field operations	Continuous monitoring at a rate of once per 5 minutes	Real-time continuous assessment monitoring by Clarity and JustAir	The automated, real-time NO_2 digital assessment systems from Clarity and JustAir provide the CAMP Team with status reports of any operational monitoring anomalies, allowing them to initiate the remediation protocol.	If data accuracy exceeds or falls below the NO2 margin of ±15 % of the measured approved QC Objectives values, Clarity and JustAir will collaborate with the CAMP Tech Team to resolve the issue. All issues will be resolved by corrective action or replacement of the instrument.	All technical anomalies that have generated a "trouble ticket" remain active until resolved by the CAMP, Clarity, and JustAir technical teams. Corrective action will be re-evaluated to ensure the instrument, software, network or other cause of errors has been successfully corrected. A list of unresolved issues is emailed weekly to all teams.
Wind Monitoring for field operations	Continuous monitoring at a rate of once per 5 minutes	Real-time continuous assessment monitoring by Clarity and JustAir	The automated, real-time NO_2 digital assessment systems from Clarity and JustAir provide the CAMP Team with status reports of any operational monitoring anomalies, allowing them to initiate the remediation protocol.	In the event that the data sensing performance exceeds or falls short of the approved QC Objectives values, which are ±2 % at 12m/s for wind speed and ±3 % at 12m/s for wind direction, Clarity and JustAir will collaborate with the CAMP Tech Team to resolve the issue. All issues will be resolved	All technical anomalies that have generated a "trouble ticket" remain active until resolved by the CAMP, Clarity, and JustAir technical teams. Corrective action will be re-evaluated to ensure that the instrument, software, network, or other causes of errors have been successfully corrected. A list of unresolved issues is emailed weekly to all

				by corrective action or replacement of the instrument.	teams.
Environmental Weather Conditions Monitoring for field operations	Continuous monitoring at a rate of once per 5 minutes	Real-time continuous assessment monitoring by Clarity and JustAir	The automated, real-time NO_2 digital assessment systems from Clarity and JustAir provide the CAMP Team with status reports of any operational monitoring anomalies and proceed to initiate the remediation protocol.	If the data sensing performance is over or under the approved QC Objectives values, Clarity and JustAir will collaborate with the CAMP Tech Team to resolve the issue. All issues will be resolved by corrective action or replacement of the instrument.	All technical anomalies that have generated a "trouble ticket" remain active until resolved by the CAMP, Clarity, and JustAir technical teams. Corrective action will be re-evaluated to ensure the instrument, software, network, or other cause of errors has been successfully corrected. A list of unresolved issues is emailed to all teams on a weekly basis.
Benzene Monitoring for field operations		Our Tech Team and [redacted] will manage the field procedures, data usability, and accuracy.	Lab and field blanks are collected for each sampling period. We also co-locate two samples at one site during each sampling session. Calibration with known standards is conducted each time of analysis. Accuracy and precision are obtained from these procedures. Each sample undergoes inspection of raw data to confirm the presence or absence of each compound via retention time and mass spectra.	If data usability or accuracy issues are identified, the associated data will be reported to our team and [redacted] for further review. For raw data, values below the detection limit but above zero are retained and labeled as LOD (limit of detection). Values of zero are replaced with the limit of detection /2 and labeled non-detect (ND). Values above the upper level of detection are replaced with the upper limit and labeled (LOD). Average values of lab and field blanks are subtracted from the raw data. We convert the raw amount (in volume) to parts per billion or µg/m3	All technical anomalies that have generated a "trouble ticket" remain active until resolved by our CAMP Team in collaboration with [redacted] and her team. Corrective action will be re-evaluated to ensure that the sampling process and equipment, as well as any other causes of errors, have been successfully corrected. A list of unresolved issues is emailed to all teams on a weekly basis.
Mobile AQM. $PM_{2.5}$, VOC, and	Continuous monitoring at	The CAMP Tech Team provides	Accuracy will not be evaluated for	The operational status of the Atmotube PRO	All technical anomalies that have generated a

environmental monitoring for educational engagement.	a rate of once per 5 minutes	real-time and recorded data monitoring of the operational status of the Atmotube PRO educational AQM devices.	the Atmotube PRO AQM instruments, as they are used primarily as community education tools.	instruments will be periodically evaluated to ensure that they can provide meaningful educational opportunities for users, particularly if operational status indicates potentially malfunctioning errors.	"trouble ticket" remain active until resolved by our CAMP Team. Corrective action will be re-evaluated to ensure the Atmotube PRO errors have been successfully corrected. A list of unresolved issues is emailed weekly to all teams.

Reference for Quality Control for the EPA Guidelines for low-cost PM sensors Guidelines

Our technology partner, Clarity Movement, Inc., provides the following quality control information for PM2.5 particulate monitoring. Clarity provides the hardware and data management for measuring, recording, archiving, and accessing particulate matter and nitrogen dioxide. The following table from Clarity affirms the EPA data quality objectives for low-cost PM sensors Guidelines:

https://click.clarity.io/hubfs/Marketing%20Assets%20-%20PDFs/White%20Papers/Guide%20to%20Accurate%20Particulate%20Matter%20Measurements%20-%20How%20to%20Meet%20USEPA%2c%20EU%2c%20and%20Other%20Performance%20Standards%20for%20Air%20Sensors.pdf

EPA data quality objectives for low-cost PM sensors	Guidelines*
Daily average data completeness; USEPA deployment averages are based on 24-hour averages for PM2.5 concentrations over a 30-day period.	>75%
Precision: Standard Deviation (SD)	≤ 5 µg/m3
Precision: Coefficient of Variation (CV)	≤ 30%
Bias: Slope (m) of y=mx+b - Sensor PM2.5 measurements are the dependent variable (y) with FRM/FEM PM2.5 measurements as the independent variable (x).	1.0 ± 0.35
Bias: Intercept (b) of y=mx+b - Sensor PM2.5 measurements are the dependent variable (y), with FRM/FEM PM2.5 measurements as the independent variable (x).	-5 ≤ b ≤ 5 µg/m3
Linearity: Coefficient of Determination (R2) - Sensor PM2.5 measurements are the dependent variable (y), with FRM/FEM PM2.5 measurements as the independent variable (x).	≥ 0.70
Error: Root Mean Square Error (RMSE)	≤ 7 µg/m3
Error: Normalized Root Mean Square Error (NRMSE) - The USEPA notes that this metric is especially important when PM levels are significantly higher than the general US levels (e.g., during wildfires).	≤ 30%

** USEPA 2021 - deployment averages are based on 24-hour averages for PM2.5 concentrations over a 30-day period.*

Data Quality Accuracy, Precision, and Completeness Guidelines:

Data Quality Measurements & Indicators: Clarity Node-S for Stationary Installations

Data Quality	Description for Clarity Node-S PM2.5 and NO2 DQ Monitoring
General References	The Clarity Note-S instrument was selected because of its industry-recognized high performance, accuracy, and reliability. Our technology partners' data analytical hardware and software provide the DQ measurements and operational monitoring. (Appendix: pages 2 to 5) The measurement period is 24/7 for 12 months at a data recording rate of one measurement every 5 minutes. Clarity "performance management tools" are core to helping ensure high quality assurance of the day-to-day operations and identifying anomalous and potentially 'imprecise" data that does not meet our AQM performance standards. Fundamental to our operational methodology is our partnerships with Clarity and JustAir technical teams to resolve all issues related to Clarity Node-S and Weather Modules operations, data recording, and data storage. Web link to technical reference below: https://click.clarity.io/hubfs/Marketing%20Assets%20-%20PDFs/Product%20and%20Specification%20Sheets/Node-S%20Specifications%20Sheet.pdf?_ga=2.245600129.420374346.1691424738-1677394860.1683761900 Clarity Movement and JustAir provide us with an online dashboard that shows graphs of both raw data and data calibrated to a regulatory reference monitor or to the Global Reference Calibration. The Clarity website dashboards for our project also list the standard deviation in both absolute and relative terms of AQ Data Quality Indicators. Our CAMP Tech Team receives weekly emails from Clarity about operational performance. The online Clarity Dashboard Digest displays the performance status of each AQM Node-S
Precision (quantitative)	The Precision of each Clarity Node-S is measured both by Clarity prior to shipment and locally by the CAMP technology team. The recommended testing period for PM2.5 and NO2 is a 30-day Global Calibration procedure. The data from this measurement process ensures that the instrument operates with the established operational parameters published by the EPA Daily average data completeness for USEPA deployment averages are based on 24-hour averages for PM2.5 concentrations over a 30-day period is >75% Precision: Standard Deviation (SD) ≤ 5 µg/m3 Precision: Coefficient of Variation (CV) ≤ 30% Sensor PM2.5 measurements are the dependent variable (y) with FRM/FEM PM2.5 measurements as the independent variable (x). 1.0 ± 0.35
Accuracy	The Clarity Technical Specification Document provides the following information: https://click.clarity.io/hubfs/Marketing%20Assets%20-%20PDFs/Product%20and%20Specification%20Sheets/Node-S%20Specifications%20Sheet.pdf Performance after calibration for PM2.5 [µg/m3]: Accuracy: < 100 µg/m3: ± 10 µg/m3 ; ≥ 100 µg/m3: within ± 10% of measured value Correlation (R2) with US EPA FEM instrument > 0.8

	If data accuracy falls outside the margin of error (± 10% for PM2.5 and ± 15% for NO2) of the measured value as calibrated with regulatory sensors, the CAMP Tech Team will resolve the issue with the assistance of the Clarity technical support team as needed. For NO2: Clarity monitors the accuracy of Node-S NO_2 sensors in real-time. If 25% or more of the readings in the last 3-hour period fall outside the range of -500 to 500 ppb, Clarity will automatically flag the sensor for further troubleshooting and post a service alert for further investigation.
Bias	Bias is determined here using the slope and intercept of the linear regression. The following calculations are used by Clarity for automated monitoring bias. Bias: Slope (m) of y=mx+b EPA Recommends = 1.0 ± 0.35 Bias: Intercept (b) of y=mx+b EPA Recommends = -5 ≤ b ≤ 5 µg/m3 Linearity: Coefficient of Determination (R2) EPA Recommends = ≥ 0.70 Error: Root Mean Square Error (RMSE) EPA Recommends ≤ 7 µg/m3 Error: Normalized Root Mean Square Error (NRMSE) EPA Recommends = ≤ 30%
Comparability	All twenty Clarity Node-S air sensors for our project use the same technical sensor components, the same methods for ambient air sampling, and the same data recording and storage methodology. All air quality instruments are installed on identical mounts and with the same methodologies. Thus, all our PM2.5 stationary AQM instruments and their operation-engineered functions are as identical as technically possible. In addition, the Precision of all Clarity instruments is calibrated to ensure maximum comparability. The Clarity data center continuously monitors the operational precision of each instrument, and automated data processing can then identify any instrument that fails to maintain accuracy in compatibility with other instruments in the network.
Completeness	The Clarity Dashboard Data website for our project reports the completeness of the data for the stationary sensors. I can be calculated as % Completeness = [(# of valid results)/ (# of potential samples)] x 100. Hourly measurements of averaged data completeness will represent the diurnal and seasonal characteristics of air quality. If the completeness of data falls below 75%, the cause will be investigated, and the CAMP Tech Team will resolve the issue with assistance from the Clarity technical support team as needed. Data completeness is calculated as the percentage of data that is both collected and usable. PM2.5: EPA Completeness Goal Standards for $PM_{2.5}$ = 45 minutes of recording per 1 hour and 18 hours per 24-hour day. NO2: EPA Completeness Goal Standards for PM2.5 = 45 minutes of recording per 1 hour and 75% of hourly values per quarter. Reference: *EPA Completeness Goal Standards per 40 CFR Part 50 - QA Handbook Vol II, Section 6.0 Revision No: 0 Date: 01/17 Page 13 to 15.* https://www.epa.gov/sites/default/files/2020-10/documents/final_handbook_document_1_17.pdf Clarity and JustAir automated data processing will check new data for hourly completeness (i.e., sensors collecting and transmitting data). They will verify the reported data for usability (i.e., sensor

	malfunctions). and check the data stream for anomalous data incidents or data errors.
Sensitivity	$PM_{2.5}$ 1 µg/m3 resolution within ± 10% of measured value Correlation (R2) with US EPA FEM instrument > 0.8 Measurement Range: 0-1000 µg/m3; NO_2 Resolution: 1 ppb Measurement Range: 0-3000 ppb

Data Quality Indicators for Clarity Wind Modules

Data Quality Indicators Wind Modules	DQI Description for Clarity Wind Measurements and Environmental Weather Conditions
General References	See general references for the Clarity Wind Module and the EPA wind measurement guidelines. can be accessed via the online Web links below: https://click.clarity.io/hubfs/Marketing%20Assets%20-%20PDFs/Product%20and%20Specification%20Sheets/Wind%20Module%20Specifications%20(October%202021).pdf Quality Assurance Handbook for Air Pollution Measurement Systems Volume IV: Meteorological Measurements Version 2.0 (Final) www.epa.gov/sites/default/files/2020-10/documents/volume_iv_meteorological_measurements.pdf Wind measure references: Quality Assurance Handbook for Air Pollution Measurement Systems Volume IV: Meteorological Measurements Version 2.0 (Final) Page 60-61 www.epa.gov/sites/default/files/2020-10/documents/volume_iv_meteorological_measurements.pdf **Meteorology i**s considered when determining not only the geographical location of a monitoring site, but also factors such as height, direction, and extension of sampling probes. The following meteorological factors can greatly influence the dispersion of pollutants: **Wind speed** affects the travel time from the pollutant source to the receptor and the dilution of polluted air in the downwind direction. The concentrations of air pollutants are inversely proportional to the wind speed. **Wind direction** influences the general movements of pollutants in the atmosphere. A review of available data can indicate the mean wind direction in the vicinity of the major sources of emissions. **Wind variability** refers to the random motions in the wind's horizontal and vertical velocity components. These random motions can be considered atmospheric turbulence, which is either mechanical (caused by structures and changes in terrain) or thermal (caused by heating and cooling of land masses or bodies of water).

Data Quality Indicators for Wind & Weather by Clarity Specifications.

Sensor Parameter	Range	Performance
Wind Speed	Range: 0 to 60.00 m/s Resolution: 0.01 m/s	Accuracy: ± 2% (at 12m/s)
Wind Direction	Range: 0 to 359.9° Resolution: 0.1°	Accuracy: ± 3° (at 12m/s)
Atmospheric Pressure	300 to 1100 hPa Resolution: 0.02 hPa	Accuracy: ± 0.12 hPa
Ambient Temperature	Range: - 20° C to 75° C Resolution: 0.1° C	Accuracy: ± 0.5° C
Ambient Relative Humidity	10% to 99.9% RH Resolution: 0.1% RH	Accuracy: ± 2% RH (at 25° C)

Data Quality Indicators: Benzene Monitoring

Benzene DQI	Benzene DQI Description for Benzene Monitoring
Precision (quantitative)	Co-located samples will be deployed and retrieved at one site for each sampling period. This site will rotate each sampling period (one week). Benzene concentrations from co-located sites will be compared, and if a difference greater than 20% is found, the data will be flagged with this information.
Accuracy	Lab and field blanks are collected for each sampling period. We also co-locate two samples at one site during each sampling session. Calibration with known standards is conducted each time of analysis. Accuracy and precision are obtained from these procedures. Each sample undergoes inspection of raw data to confirm the presence or absence of each compound via retention time and mass spectra. Our Tech Team and [redacted] will manage the field procedures and data usability/accuracy. If data usability or accuracy issues are identified, the associated data will be reported to our team and [redacted] for further review. For raw data, values below the detection limit but above zero are retained and labeled as LOD (limit of detection). Values of zero are replaced with the limit of detection /2 and labeled non-detect (ND). Values above the upper level of detection are replaced with the upper limit and labeled (LOD). Average values of lab and field blanks are subtracted from the raw data. We convert the raw amount (in volume) to parts per billion or µg/m3
Comparability	We have chosen this method of monitoring Benzene because it is comparable to publicly available benzene data previously monitored by Drexel University and Lewis and Clark College within the CAMP sampling domain. To our knowledge, the only Benzene monitoring currently being conducted in our study domain is by Philadelphia Air Management Services at the Riter St AQS regulatory monitoring site. This is a canister sample for a 24-hour period taken once every 6 days, so it is not directly comparable to the benzene data collected in CAMP.
Completeness	We have a completeness goal of 80% sample retention for each project quarter.

Sensitivity	Method Detection Limit: .01 ppb Uncertainty rate: +/- 10%

Data Quality Indicators: Atmotube PRO for PM2.5, VOCs, and weather conditions.

Data Quality Indicators	DQI Description for Atmotube PRO AQM
General References	The sensor data from the Atmotube PRO educational AQM devices will not be archived for data retention purposes. The Atmotube PRO will not be included in our "reference level" data documentation. The Atmotube PRO AQM sensing is for instructional purposes only. **Atmotube Pro: Educational Particulate Matter:** Range: PM1,PM2.5, PM10 Resolution: 0 to 100 µg/m3 ±10 % - 100 to 1000 µg/m3 ±10 % **Atmotube Pro: Educational: VOCs:** Range 0-60 ppm. 0.2 % of the measured value; Accuracy: 15% of the measured value

B5. Instrument/Equipment Calibration, Testing, Inspection, & Maintenance

Operational Performance Monitoring: (Clarity Stationary AQ)

Our Clarity Node-S Stationary Monitors undergo performance testing twice for functionality and calibration before being installed in the field. This includes testing for network connectivity, data recording efficacy, and operational functions of data. For additional references about our pre-installation calibration testing, see the section *Stationary AQM Equipment Calibration* of this document.

Our *Community Tech Team* will manage and implement the setup, installation, and operational certification for all installations. Because the Clarity Node-S Stationary Monitors are solar-powered and cellular-connected, they can be installed and operational on-site quickly with quality-assured performance and reliable network functionality. Our pre-assembled mounting pole ensures consistency and dependability for all hardware devices and interpretive panel information.

Our Tech Partner, JustAir, provides the administrative software to manage the deployment and quality-assured performance of AQM instruments and the AQM Network.

Note that the JustAir Administrative Dashboard includes the following functions:

- Full operational performance management of all AQ instruments and the AQ Network.
- Integrated data quality assurance monitoring and quality system checks to implement Quality Assurance Project Plans
- Real-time operational status displays and online alerts when pre-set functional thresholds are exceeded or unmet.
- Generation of air quality reports and data analysis assessments with project teams and partner organizations

Once an AQM instrument's operational functions exceed predetermined performance limits or the AQM goes offline, Clarity and JustAir will send automated email and text alerts to the project Camp Tech Team for investigation. If data patterns appear operationally suspect, the CAMP Tech Team is notified to initiate remediation. Corrective action includes online diagnostics and on-site technical visits within 24 hours.

JustAir conducts weekly audits through a dedicated network manager, who analyzes data gaps between the core and current monitoring sites. These audits ensure data integrity is maintained throughout the transmission process. Additionally, JustAir has implemented an automated system to trigger alerts in the event of data transmission failure.

Additional technical information about the JustAir Operational Performance Monitoring functions and services is documented in the Appendix, pages 89 to 103.

On-site Inspection: (Clarity Stationary AQ)

The performance monitoring process during active operation includes the following activities:

- Note that the Clarity Node-S instrument is designed to operate continuously with no required preventive maintenance, except for visual inspections of the Station System and cleaning of the air inlet once every quarter.
- Each *Environmental Sensing Station* will be inspected monthly for the first three months. This initial monthly inspection frequency will help ensure quality assurance for new installations.
- The monthly site visits to each AQM location by the Community Tech Team include connecting with the local community liaisons who provide regular periodic reviews of the *Environmental Sensing Station.* These are our "frontline" Community Air Quality Stewards. Their regular observations of the equipment help to ensure and protect the *Stations*. Additionally, they serve as an early warning system for potential malfunctions or vandalism. The AQ Stewards received a monthly stipend for their services after training. They also become a local advocate for local air quality health.

Equipment (Clarity Stationary AQ)

Our AQM technology partner is Clarity Movement. Clarity was selected to ensure a high level of quality assurance technical support. This includes the procurement, installation, and operation of excellent sensing instruments. https://www.clarity.io/

We will be using two types of Clarity Instruments for our project. The Clarity-Node instruments will provide measurements of $PM_{2.5}$ and NO_2. Additionally, the Clarity Wind Module measures the 2-dimensional horizontal components of wind speed and direction, and ambient measurements of air temperature, humidity, and barometric pressure, and calculates the heat index.

The following AQM instruments have been selected for the stationary AQM measurements. Detailed technical specifications, references, and deployment instructions for the Clarity Wind Module are located in the appendix. The image illustrates the configuration of the Node-S and Wind Module instruments.

Image Source: Clarity Movement Node-S AQM and integrated Wind Module:

Sampling Frequency: (Clarity Stationary AQM)

A benefit of selecting Clarity as our technology partner and their Node-S as our AQM instrument is that their AQM system provides functions to adjust the air sampling frequency. Thus, we can increase or decrease the sampling rates depending on our progressive operational assessment of the level of data measurement detail required at a location.

The default sampling rate is once every 15 minutes. The minimum rate is once every 5 minutes. Our technical partners recommend that we begin the frequency for our Clarity Node-S instruments at an initial sampling rate of once every 5 minutes. Then, as we analyze our AQ data, we can adjust the sampling frequency to expand or contract the temporal resolution of our data acquisition, thereby improving the representation of actual pollution patterns at each AQM recording location.

Calibration: (Clarity Stationary AQ)

Setting performance goals for low-cost air quality sensors is a continuous effort involving governments and academics. This comes with challenges. Different use cases require different sensor performance. While calibration helps, there's a balance between enhancing accuracy and managing operational costs. Sensors also work differently under different environmental conditions. Comparing sensor performance is challenging due to differences in testing protocols and scenarios. Clarity tackles this by implementing a performance metric-based decision framework, leveraging our understanding of typical performance on the field. This ensures reliable data for real situations.

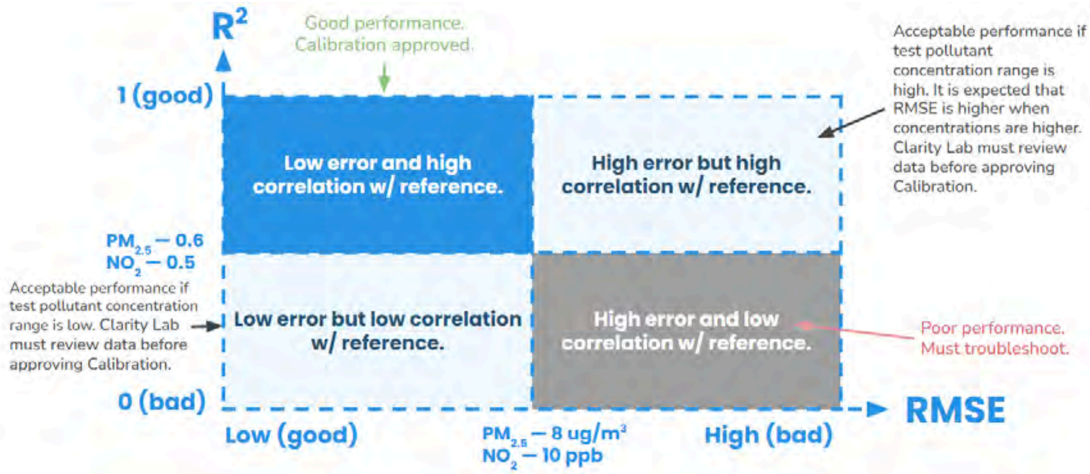


Image: performance metric-based decision framework
Image Source: Clarity Movement
https://click.clarity.io/knowledge/clarity-data-quality-assurance-process

All Clarity Node-S instruments come equipped with preset, factory-confirmed calibration. This pre-shipment calibration process significantly enhances measurement accuracy beyond the raw sensor data, thereby increasing quality assurance when co-location is not possible. Our CAMP Tech Team also recalibrates these instruments for two weeks before field installation. This double calibration helps ensure that our AQMs meet or exceed the required quality-assured performance we have established for our air quality monitoring. Our Tech Teams will monitor any performance alerts or alarms. They recheck the operations of our AQMs on a monthly schedule. If there is elevated performance drift beyond specification, our Team in, collaboration with Clarity, will respond rapidly with remediation.

We are employing a thorough two-phase quality assurance methodology for accurate and reliable instrument calibration. The local calibration utilizes the Global Calibration process recommended and monitored by the AQM manufacturer, Clarity Movement. All Clarity Node-S instruments come equipped with preset, factory-confirmed calibration. This pre-shipment calibration process significantly enhances measurement accuracy beyond the raw sensor data, thereby increasing quality assurance when co-location is not possible.

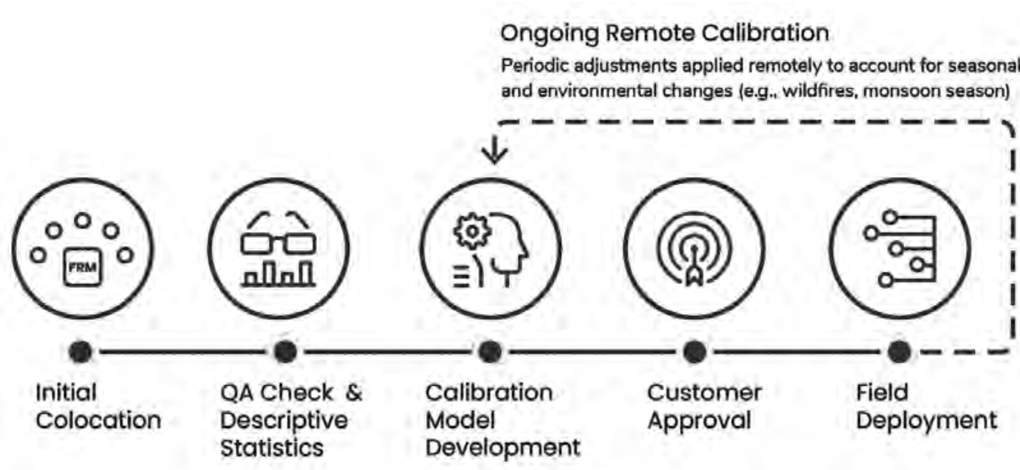


Image Source: Clarity Movement

Image Source: Clarity Movement

Co-location testing, conducted before field installation, further enhances the accuracy of our AQM instruments' quality assurance. Our technical team will co-locate each Clarity Node-S Monitor with a standard reference monitor for two weeks, or via Clarity's *Global Calibration* reference methods. Note that if the results of the local co-location evaluation affirm that an AQM instrument meets or exceeds our specifications, then the AQM will be installed in our community. If the two-week calibration testing identifies any anomaly, Clarity will be contacted to remediate the instrument. Remediation can include retesting the calibration of an AQM or returning the instrument to Clarity for repair or replacement.

Community Sensing Station Installation.

Our technical design and engineering team has been installing outdoor air quality monitors since the summer of 2016. These initial environmental educational installations were funded and supported as STEM learning programs for the School District of Philadelphia. Our multiple field experiences with our AQM installations on school grounds, parks, and other public venues have guided our refinement of our installation technical and device mounting methodology. The following guidelines can best ensure quality-assured installations that are protected from malfunction or vandalism.

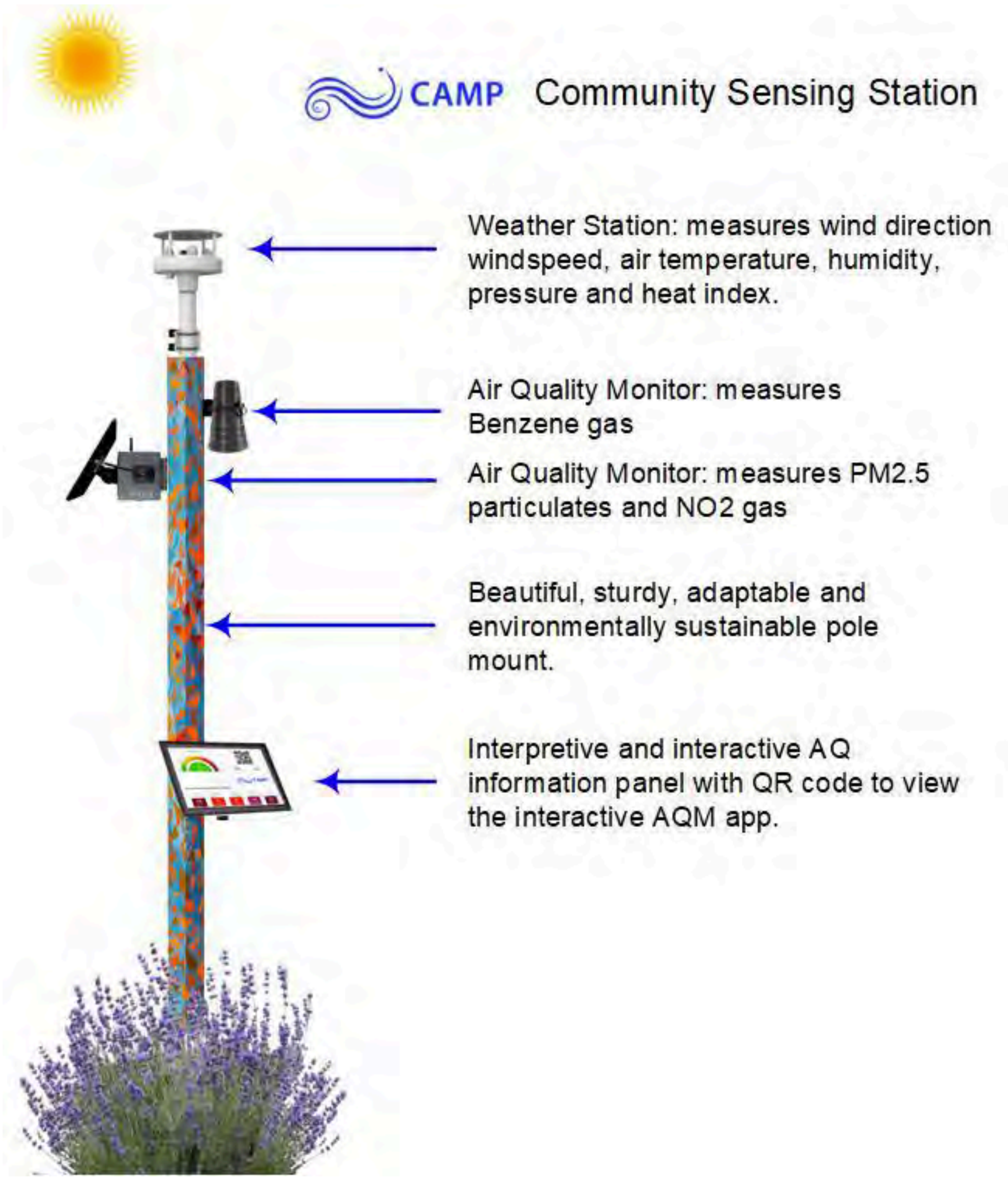


Image Source: Design and Artwork Rendering by Interpret Green

Design Considerations for the Community Sensing Station

- Whenever possible, use AQM mounting on free-standing, self-sufficient poles that can be securely mounted in the ground, specifically for the intended use of technical environmental monitoring. This will ensure both the effectiveness and safety of installed monitoring devices.
- Given our experience with the logistics and practicalities of AQM installations, we do not

recommend mounting AQM outdoor equipment on public or private utility poles, or on homes, or on commercial buildings or on trees or on fences, or on any outdoor structure that is not explicitly intended for the installation of environmental monitoring devices.

- Use 4x4 wood mounting poles with protective vinyl sleeves. This will maximize sturdiness and longevity. These pole mounts are also relocatable.
- Apply a beautiful, graphic wrap around the vinyl sleeve. This greatly reduces vandalism and minimizes the potential of theft. Community members will design the artwork. Thus, the installation becomes a community asset that the community will help protect.
- Use interpretive signage on the pole with beautiful graphics to communicate to the community the purpose and value of the AQM installation for the health of their community. Include signage, QR Codes, and other web + phone access information so that visitors to the installation can access the air quality measurements at the installation site or elsewhere. Included in the messaging are health-related air information that is easily viewable via mobile phone, tablet, or computer. The drawing below illustrates the Air Quality Community Sensing Station, identifying its primary components.

Illustration of neighborhood *Community Sensing Station* Installation
Image Source: Design and Artwork Rendering by Interpret Green

Equipment Calibration, Installation, and Inspection: (Atmotube PRO Educational)

Image Source: Atmotech, Ltd

The Atmotube Pro comes pre-calibrated by the manufacturer. Atmotube PRO provides all performance testing and calibration adjustments before shipment.

Setting Up Alerts and Notifications (Atmotube PRO Education)

Atmotube PRO enables you to set up custom alerts and notifications, allowing you to stay informed about your air quality in real-time. Within the app, navigate to the settings or alerts section. Here, you can configure notifications for various parameters based on your preferences and health needs. For example, you may want to be alerted when $PM_{2.5}$ levels exceed a specific threshold or when VOC levels suddenly increase.

You can typically set different alert levels for each parameter, allowing for a personalized monitoring experience. Some users prefer to set conservative thresholds for more frequent updates, while others may only want alerts for significant air quality events. Additionally, you can often customize notification types, choosing between push notifications, in-app alerts, or even email notifications for critical events.

We will check the Atmotube Pro sensors monthly to evaluate sensor drift, or more frequently if preset alarms are activated due to increased sensor drift beyond predetermined limits.

B6. Inspection/Acceptance of Supplies and Services

Our CAMP Project has a formal protocol for managing the specification, procurement, shipping, receiving, configuration, performance testing, and deployment of equipment and associated supplies. Our Project Manager, [redacted] has extensive experience in administration and project management for technical and cultural programs.. He supervises all purchasing and accounting for our CAMP Project. [redacted] manages the operations of the CAMP Project in collaboration with the CWF management and accounting team to ensure accurate supervision and quality control of the labor, services, and supplies.

Sample Installation and Inspection Sequence: Example Stationary AQM

The following outlines our operational methodology to ensure the quality assurance of installations supporting the Stationary Clarity Node-S AQM, Weather Module, and Interpretive Panel.

- Procurement of the calibrated Clarity devices that can include the Node-S and Weather Modules
- Technically configure Node-S and Weather Modules for online connectivity and operational performance.
- Two-week co-location calibration performance assessment and remediation if necessary.
- Procurement and assembly of pole mount components, including structural wood pole, vinyl sleeve with artwork, and mounting brackets for devices.
- Procurement of installation equipment and supplies, including a post hole digger, field tools, and Quikcrete to secure the pole in the ground.
- Field installation with technical equipment, mounting components, installing equipment, and installing supplies.
- Field testing for quality assurance confirms that the technical equipment is operating to specifications.
- Site documentation, including GPS location, reference photos, and the launch of a technical equipment maintenance protocol.
- Our community-based CAMP Tech Team will implement and manage the installation tasks outlined above.

B7. Environmental Information Management

Our Clarity Node-S Stationary Monitors will be monitored via *JustAir Operational Services,* and the data is accessible via the *JustAir Administration Dashboard*. The JustAir staff and their analytical software will remotely manage the day-to-day technical operations of our digital air monitoring systems, including identifying, responding to, and resolving technical anomalies.

JustAir conducts weekly audits through a dedicated network manager, who analyzes data gaps between the core monitoring site data and the expected range of data values. These audits ensure that data quality and data integrity are maintained throughout the transmission and storage processes.
JustAir operates an automated system for our data processes that triggers alerts in the event of data transmission failure.

Should any data gaps be identified in the historical data, the JustAir platform automatically issues a data fill job to correct and fill these gaps, ensuring that the transmitted data is both complete and accurate. These ongoing checks and the automated correction data systems are designed to ensure continuous data accuracy for all transmitted data from the sensor devices to the public-facing website and mobile app. This system has been developed and is managed by our technology partner, JustAir, for our project.

The Clarity and JustAir Teams will process the AQ data to identify spatial and temporal patterns that reveal normal, potential, or hazardous conditions of local air pollution. To ensure the quality assurance of the data and the precision of the AQ sensors, we will compare AQ data with data from regulatory instruments and historical regional data patterns. This systematic approach helps ensure data quality assurance with our QAPP objective standards.

If questionable or suspect data is detected, the Clarity and the JustAir team will properly assign EPA Air Quality System (AQS) codes to the potential device anomaly and contact the CAMP Tech Team to discuss options for remediation.

Data Quality Indicator (DQI) Monitoring & Management

JustAir operates as an independent data quality management system, ensuring that $PM_{2.5}$ measurements meet project-specific data quality objectives (DQOs). The JustAir Data Management Platform and Dashboard offer real-time QA/QC tracking, automated anomaly detection, and validation workflows to ensure the maintenance of high-quality air monitoring data.

The table below outlines how JustAir monitors each Data Quality Indicator (DQI), followed by details on the review and validation process for these indicators.

JustAir DQI Monitoring & Management

Data Quality Indicator (DQI)	Dashboard Functions
Precision	- Displays real-time and historical sensor variability - Flags sensors with excessive deviation from expected performance
Bias	- Records calibration offsets - Automatically flags deviations from expected bias thresholds
Completeness	- Displays completeness based on the manufacturer's measurement frequency and provides alerts for missing data
Representativeness	- Shows sensor siting metadata - Maps pollution sources vs. sensor readings
Comparability	- All quality control checks are documented and followed per the manufacturer's SOPs, data export in uniform formats, and measurements
Sensitivity	- Shows detection limits and measurement thresholds - Alerts for sudden pollutant spikes

Data Review, Verification, and Validation

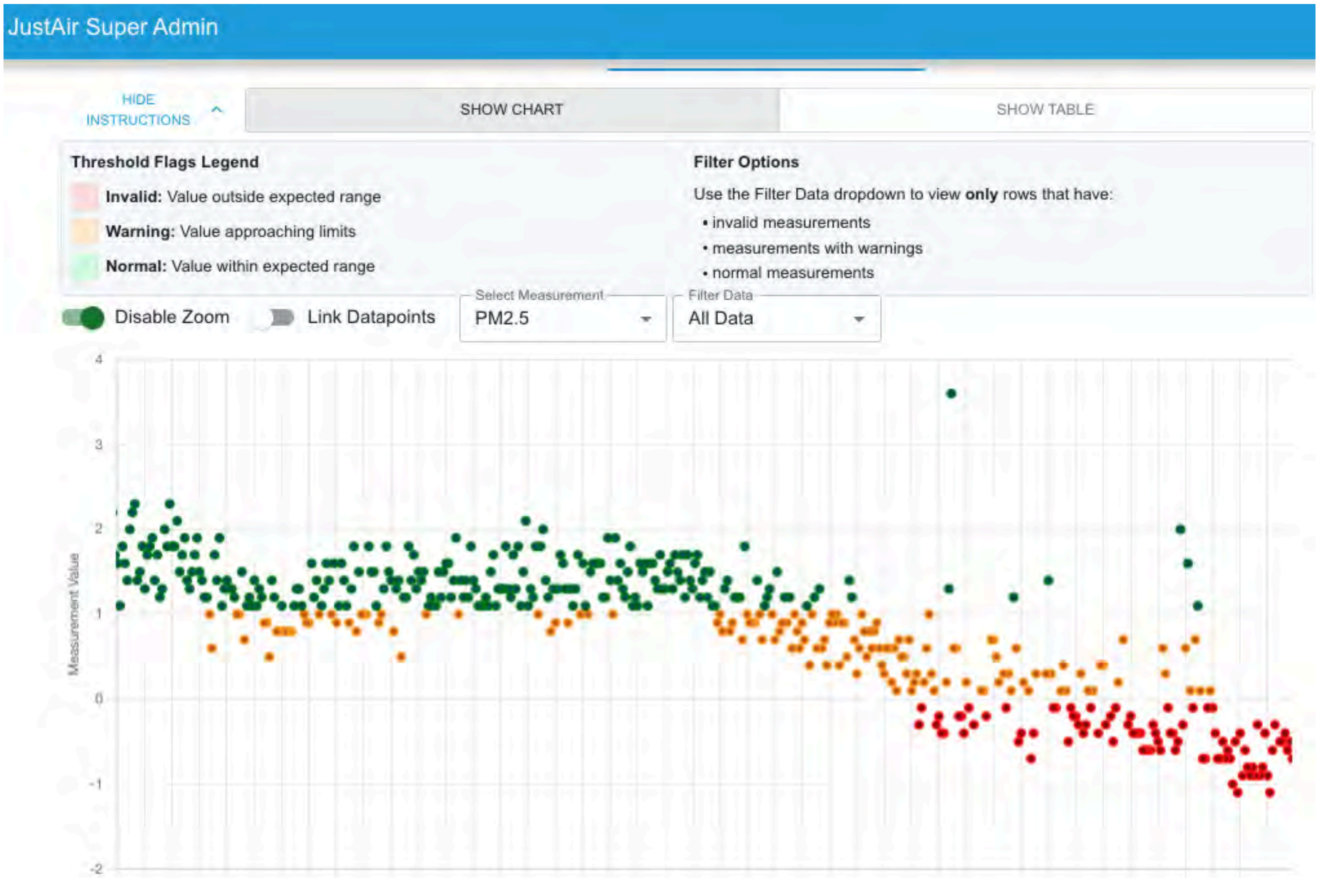
To ensure ongoing compliance and reliability, JustAir performs a three-tiered data review process, following the EPA's Best Practices for Review and Validation of Ambient Air Monitoring Data. This supports continuous QA/QC monitoring and guarantees high-confidence, decision-ready data.

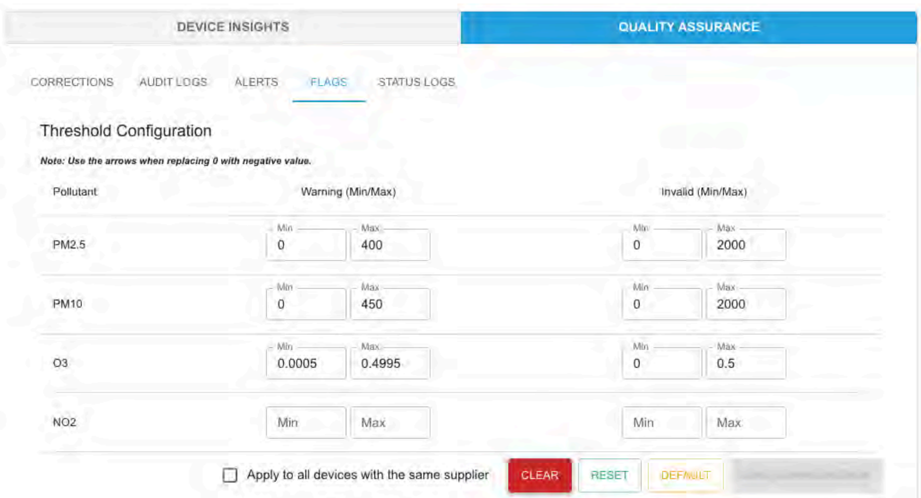
Level 0/1 – Automated and Manual Data Review
Level 0: Automated Data Quality Checks

JustAir's data management system performs real-time automated quality control (QC) checks to flag potential data issues as they occur. These automated checks trigger alerts that notify the Data Manager and Field Technicians when data irregularities require investigation.

Level 0 Automated Data Checks and Associated Level 1 Review

Automated Check	Description	Associated Level 1 Review
Offline Sensor Alert	The $PM_{2.5}$ monitor has been offline for over 2 hours, indicating a potential power, communication, or hardware failure.	The Data Analyst reviews sensor connectivity logs and determines if the data loss is intermittent or persistent. If unresolved, Field Technicians are deployed for troubleshooting.
High Data Flag (Severe)	5-minute $PM_{2.5}$ readings exceed the 50% threshold compared to previous readings, potentially indicating sensor error or an extreme pollution event.	The Data Analyst cross-references historical trends, meteorological conditions, and regulatory monitoring data to determine if the values are valid extreme pollution events or sensor anomalies.
Negative Data (Severe)	$PM_{2.5}$ readings fall below 0 µg/m³, which is physically impossible, suggesting sensor drift or hardware malfunction.	The Data Analyst examines recent calibration logs and flow sensor diagnostics to determine if the issue is caused by sensor malfunction or firmware error.
High Data (Suspect)	Hourly $PM_{2.5}$ data falls within a suspect 25% range compared to similar AQM devices in the local area, but does not meet the severe data flag threshold.	The Data Analyst reviews seasonal patterns, time-of-day trends, and nearby air quality monitors to determine if the values are expected or should be flagged for review.
Negative Data (Minor)	Small negative values appear due to instrument noise or sensor drift over time. These may not always be invalid.	The Data Analyst examines whether the values are consistent with past performance or if they are increasing in frequency. Adjustments may be required.
Flatline Data Flag	$PM_{2.5}$ readings remain unchanged for 24 hours, suggesting a sensor freeze or data transmission issue.	The Data Analyst reviews past data behavior and determines if the issue is caused by real-world pollution stability or a monitor malfunction.





Example Flagging View and Threshold Settings Configuration

Action: If an issue is confirmed, the Data Manager and Field Technicians determine corrective actions, such as on-site calibration, firmware updates, or sensor replacements.

Level 2 – Data Verification

The Data Manager verifies that all Level 0/1 automated checks were correctly reviewed and documented. Quarterly verification ensures that manual QA/QC checks are followed consistently and that any sensor errors, calibration drift, or transmission issues are addressed.

Key Verification Activities

- Ensuring sensor downtime alerts were investigated and resolved.
- Reviewing logged data corrections and anomaly flags.
- Cross-referencing calibration history with recent sensor performance.
- Validating that the suspect PM2.5 data was correctly identified and adjusted.
- Confirm that sensor replacement or maintenance logs align with the flagged issues.
- Verify that the monitor is in maintenance mode for the public

Action: If any discrepancies are found, the Data Manager provides corrective feedback to the Data Analyst and Field Team to improve the efficiency and accuracy of Level 0/1 reviews.

Level 3 – Data Validation

Data validation ensures that PM2.5 monitoring results meet project and regulatory quality objectives before being finalized for reporting and analysis. The Data Analyst, under the QA Officer's supervision, conducts quarterly validation reviews to assess overall data quality.

Validation Procedures

1. **Bias Evaluation:**
   If a systematic offset is found, JustAir applies correction factors in the final dataset.
2. **Completeness Assessment:**
   At least 75% of the expected PM2.5 data points must be recorded and validated within each reporting period. If completeness falls below the threshold, gaps are identified and documented, and the usability of the data is assessed.
3. **Comparability Review:**
   Monitors are checked for consistency in accordance with the manufacturer's guidelines and standard operating procedures (SOPs).
4. **Sensitivity & Representativeness Assessment:**
   The dataset is analyzed for unexpected variations caused by site conditions. If a site consistently has unreliable data, the field team may relocate or adjust the sensor deployment.
5. **Final QA Sign-Off:**
   The Data Manager and QA Officer confirm that all validation procedures were completed, documented, and met QAPP objectives before the data is included in any reports, dashboards, or regulatory submissions.

Data Usability and Presentation

Data is considered usable and reportable if it meets:

- >75% completeness for valid hourly and daily PM2.5 measurements.
- Comparability with reference monitors (e.g., R^2 value of at least 0.55 for bias correction).
- No significant unresolved data flags related to drift, calibration failure, or power loss.
- Quality assurance checks verify accuracy, precision, and representativeness.

Once validated, $PM_{2.5}$ datasets are:

- Published in real-time via the JustAir dashboard
- Formatted to align with EPA/state data systems.
- Included in quarterly and annual reports detailing trends, air quality impacts, and data reliability.

If a site repeatedly fails to meet usability criteria, JustAir flags the dataset and recommends corrective actions, such as replacing sensors, recalibrating, or adjusting deployment locations.

C. Assessment, Response Actions, and Oversight

C1. Assessments and Response Actions

All the air quality data for this project will be tracked and reported to the U.S. Environmental Protection Agency (EPA) through quarterly reports. A final report will be prepared, distributed to the EPA, and made publicly accessible via the project website. Real-time air quality data will be available to residents through the Clairty and JustAir-managed Air Quality Monitoring mobile and online digital applications.

Our technology partners, Clarity and JustAir, will collaborate to manage and distribute the recorded data for archival storage and data access. The AQ measurements, location, date, and time data will be verified using diagnostic software. Clarity and JustAir's algorithmic and automated data processing software will identify anomalous data and facilitate the evaluation of data verification and subsequent validation. Our technology partners' quality assurance data protocols are designed to meet EPA Quality Assurance compliance requirements. The following is a list of the features and functions for data verification and subsequent validation.

Quality Control and Quality Assurance

- Standardized deployment checklists
- Audit trails, reporting
- Documentation & compliance tracking for QAPPs

Incident & Anomaly Detection

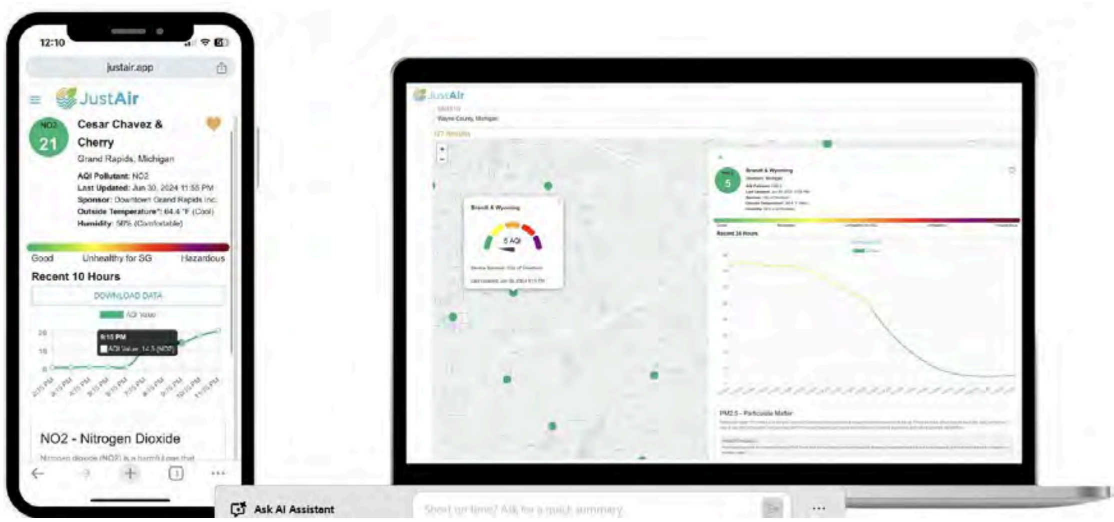
- Real-time monitoring & alerts
- Automated device status update
- Anomaly detection algorithms
- Threshold-based notifications

Incident logging & tracking

- Recovery & Reporting

- Incident tracking system
- Detailed resolution documentation
- Action log, notes, and timeline
- Resolution verification & validation

Data content for real-time reporting of air quality data will be displayed on our local mobile and online public air quality dashboard. The data assessment functions employ EPA EPA-approved standard method computation. The public-facing JustAir Dashboard will generate weekly summary reports on the air quality status for the preceding week. A monthly summary report will also be generated, summarizing any air quality events, health alerts, safety tips, and other key statistics. AQI Calculations will be made in accordance with USEPA.

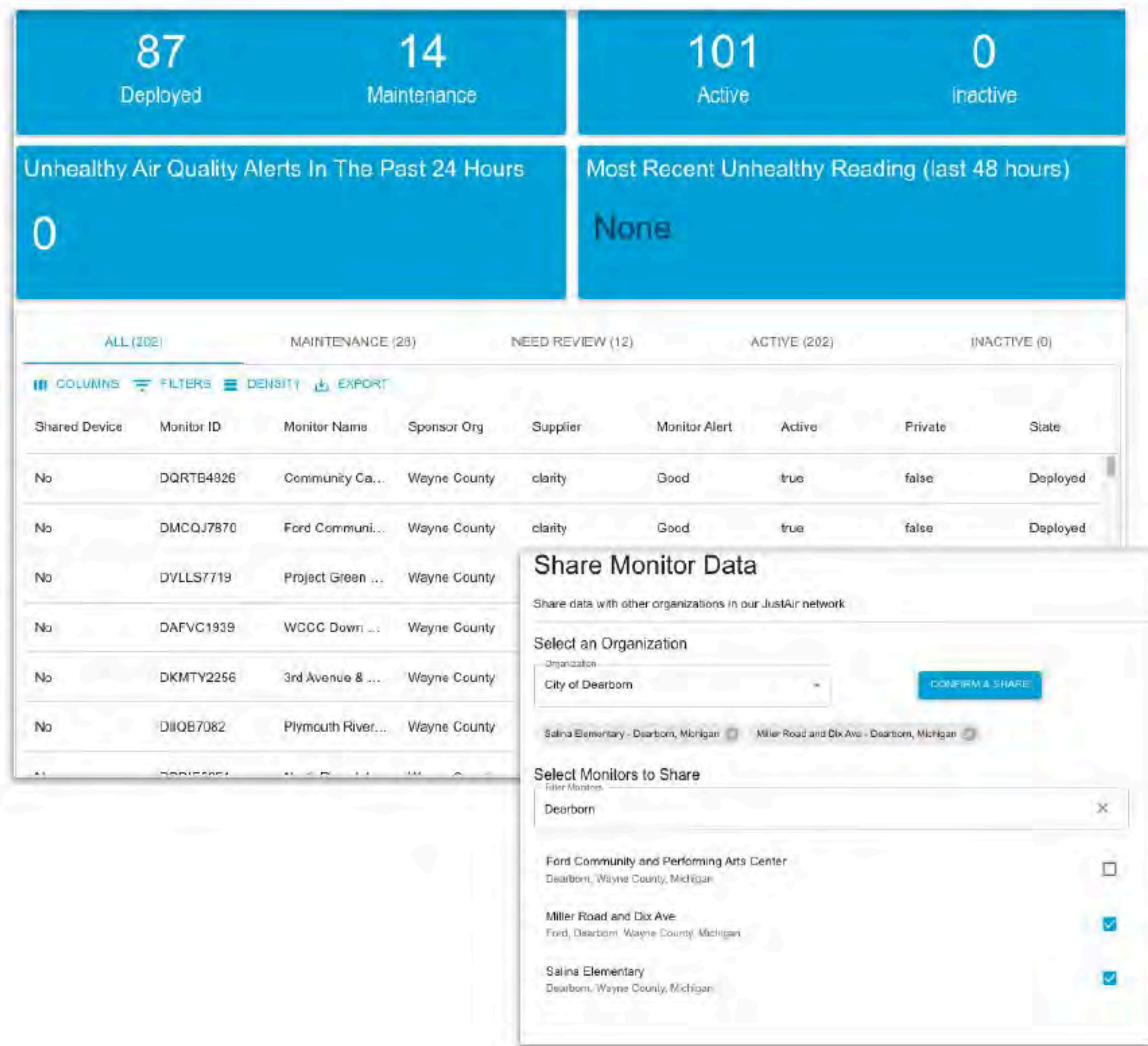


Real-time QAPP data visualizations via JustAir AQM Admin Dashboard

C2. Oversight and Reports to Management

On a monthly basis, the project manager and CWF Southeastern Pennsylvania director will meet to review the collected and reported data. Data that is outside the standard threshold ranges will be evaluated to identify potential sources. Considerations will be given to potential equipment malfunctions, data processing errors, or other operational casualties. Remediation plans to address anomalies will be initiated in collaboration with the CAMP Tech Team, Clarity, and JustAir. On an annual basis, the CAMP staff will review the project plans and activities to ensure that the guidelines of the QAPP are being successfully implemented and that the required quality objectives and quality assurance measures are being met. And, as needed, to develop and apply remediation procedures.

The operational management software from our JustAir and Clarity partners generates detailed reports on the status of all hardware, networks, error notifications, remediation activities, and data-related applications, covering periods ranging from weekends to quarters. These reports are delivered to the CAMP Project Manager and Quality Assurance Manager for final review, revision, approval, and distribution.



Examples of a JustAir AQM Admin Dashboard Display of AQ monitoring reports

D1. Environmental Information Review and Useability Determination

Verification of AQ data received from the Clarity Movement Node-S and Wind Module instruments will be processed by the Clarity Movement AQ Software Application Diagnostics. The algorithms in Clarity software identify potential data anomalies that may indicate inaccurate data measurements or technical issues, which can lead to data errors.

Clarity will perform verification diagnostics to assess whether any data system or subsystem is non-compliant with the defined operating specifications. These assessments will be communicated to the CAMP Tech Team for review and remediation if required.

Given the high level of technical methodology and operational performance of our partners, Clarity Movement and JustAir, we have a high level of confidence that our project will achieve a high level of data verification. This certifiable AQ data verification is the core for us to achieve the usability goals of quality certifiable air quality measurements. We are guided by the phrase “measure what you treasure.” We consider our air to be one of our most precious treasures.

The Quality Assurance Manager provides an outside reviewer, independent of project operations, to help identify any shortcomings or departures from this Quality Assurance Plan and to suggest corrective actions or improvements that should be made. She will consult with the Project Manager on a monthly basis, reviewing checklists, logbooks, reports, and other project documentation, and monitoring any limitations on the use of the collected data.

D2. Usability Determination

The concluding core activities of our CAMP project include assessing the usability of the quality-assured data that our project has documented. The project leadership for this data usability determination consists of the Project Manager and the Quality Assurance Manager. Our methodology for determining data usability begins with the EPA's definition of *Data Usability*.

> *DATA Usability is the process of determining and ensuring that the quality of the data produced meets the intended use of the data and the criteria set forth in the QAPP.*
> EPA Glossary Updates 8,1,2024: https://www.epa.gov/esam/glossary

Our Data Usability Determination methodology will be managed via a collaboration among the key personnel of our project, which includes the following:

- Project Manager
- Quality Assurance Manager
- Directors of Air Science
- Director of Air Quality Science
- Director of Benzene Monitoring
- Community Engagement Coordinator
- Communications Director
- Manager for Projects Lead at Clarity
- Manager for Projects Lead at Just Air

The assessment process for the determination of data usability includes multiple activities:

- Reviewing weekly, monthly, and quarterly operational performance reports for hardware, software, digital networks, field logs, and other documentation to determine the level of data quality and data usability.
- Reviewing error, maintenance, and remediation reports associated with both data and equipment to determine the level of deviations from expected performance that significantly impacted or impaired the usability of data.
- Correlating via multifactor analysis of the distributions and chronology of particulate matter data, air chemistry data, wind data, weather data, sensor locations data, local geography data, and pollution proximity data to determine relationship patterns that can provide environmental health insights that can improve local air quality in our community.
- Preparing a final report that documents our assessment of data usability.

Project:	Air Quality Monitoring Quality Assurance Project Plan (QAPP)
Content	Appendix: Table of Contents for References
Notes	The following are references associated with the: Community Air Monitoring Project (CAMP) EPA Air Quality Monitoring Quality Assurance Project Plan (QAPP) Grant: EPA Grant # - CWF ARP OX-95313101

Table of Contents for References:

Accurate PM and NO2 measurements, anywhere you need them

Clarity's flagship particulate matter (PM) and nitrogen dioxide (NO_2) sensor is self-powered, FCC/CE-certified, MCERTS-certified, UV-resistant, and weatherproof.

A self-sufficient IoT air quality monitoring device with solar harvesting, an internal battery, and global cellular connectivity, the Clarity Node-S requires minimal maintenance and operates seamlessly even in remote locations. We're so confident in the Node-S's ability to amaze, our solution comes with free hardware replacements.

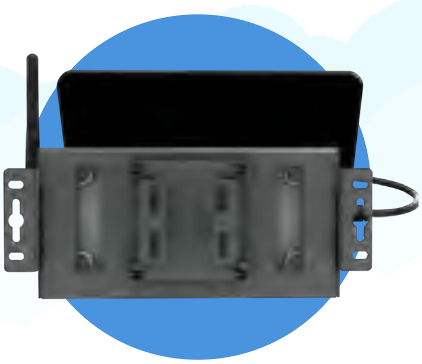
SOLAR-POWERED & CELLULAR-CONNECTED

Pre-configured with integrated solar power harvesting, batteries, and global cellular connectivity to get up and running quickly without external infrastructure.

CSA MC230425/00

MCERTS-CERTIFIED FOR ACCURACY

Complies with MCERTS Performance Standards for Indicative Ambient Particulate Monitors (CSA MC230425/00) for both PM2.5 and PM10.



WARRANTIED, ROBUST & WEATHERPROOF

Rugged, weatherproof devices for seamless operation and minimal maintenance even in remote locations, with free servicing and replacement of equipment under warranty.

clarity

Node-S Technical Specifications

CSA MC230425/00

AIR QUALITY MEASUREMENTS

PERFORMANCE BY CALIBRATION TYPE*

PARAMETER	TECHNOLOGY	RANGE	PRE-CALIBRATED [1]	CUSTOM COLLOCATION
Particulate Matter $PM_{2.5}$ [$\mu g/m^3$] **MCERTS-Certified** **CSA MC230425/00**	Laser Light Scattering with Remote Calibration	• 0-1000 $\mu g/m^3$ • 1 $\mu g/m^3$ resolution	R^2 { Optimal Conditions: 0.97 Typical Conditions: > 0.7 RMSE { Optimal Conditions: 1.4 Typical Conditions: < 4	R^2 { Optimal Conditions: 0.94 Typical Conditions: > 0.7 RMSE { Optimal Conditions: 1.3 Typical Conditions: < 3
Nitrogen Dioxide NO_2 [ppb]	Electrochemical Cell with Remote Calibration	• 0-3000 ppb • 1 ppb resolution	R^2 { Optimal Conditions: 0.83 Typical Conditions: > 0.5 RMSE { Optimal Conditions: 3.8 Typical Conditions: < 8	R^2 { Optimal Conditions: 0.86 Typical Conditions: > 0.6 RMSE { Optimal Conditions: 2.4 Typical Conditions: < 6

*** About Performance Specifications:** Calculated from Clarity's dataset of > 6,000,000 measurements. **Optimal** refers to the 95th percentile of performance Clarity has observed under ideal or favorable conditions. **Typical** refers to common performance under various conditions. For more information on Clarity Node performance and why we don't cherry-pick performance results, see our calibration explainer here.

Additional Node-S Parameters: $PM_{2.5}$ Number Concentration [#/cm³] | PM_1 Mass Concentration [$\mu g/m^3$] | PM_1 Number Concentration [#/cm³] PM_{10} Mass Concentration [$\mu g/m^3$] | PM_{10} Number Concentration [#/cm³] | Internal Temperature [°C] | Internal Relative Humidity [%]

Additional Parameters with Add-On Modules: Wind Speed | Wind Direction | Ambient Temperature | Ambient Relative Humidity Atmospheric Pressure | FEM-Grade Ozone Concentration | Black Carbon Concentration

DATA FLOW

Measurement Frequency (Adjustable)	Default: Once every 15 minutes Minimum: Once every 3 minutes
Data Retrieval from Cloud	Clarity Dashboard (Web App) RESTful APIs (Programmatic Access) OpenMap (Public Data Sharing)
Device to Cloud Communication	Global cellular 2G/ 3G/ 4G SIM card and service included

POWER[2]

Current Consumption	28 mA (sensing) | 30 mA (transmission) <300 uA (sleeping)
Input Voltage	15 V
Battery Capacity	6400 mAh capacity | 5-hour charge time 10.8 V nominal voltage
Solar Panel	6 W (max power) | 21.6 V (open circuit voltage) | 350 mA (short circuit current)
Battery Life [3]	30 days (without solar power harvesting) >5 years (with solar power harvesting)[3]

OPERATING CONDITIONS

Weatherproof Rating	IPX3
Operating temperature[4]	-10° to 55° C
Absolute temperature rating	-40° to 70° C
Operating humidity	10% to 98% RH
UV Exposure	UV-resistant

DIMENSIONS

Node (no antenna, shield or solar panel)	188 mm (W) x 98 mm (H) x 128 mm (D) Weight: 2.00 lb / 0.91 kg
Solar Panel	233 mm (W) x 176 mm (H) x 4 mm (D) Weight: 1.03 lb / 0.47 kg
Solar Shield [5] (not including solar panel)	232 mm (W) x 100 mm (H) x 162 mm (D) Weight: 0.60 lb / 0.27 kg
Weight	Total assembled: 3.64 lb / 1.65 kg

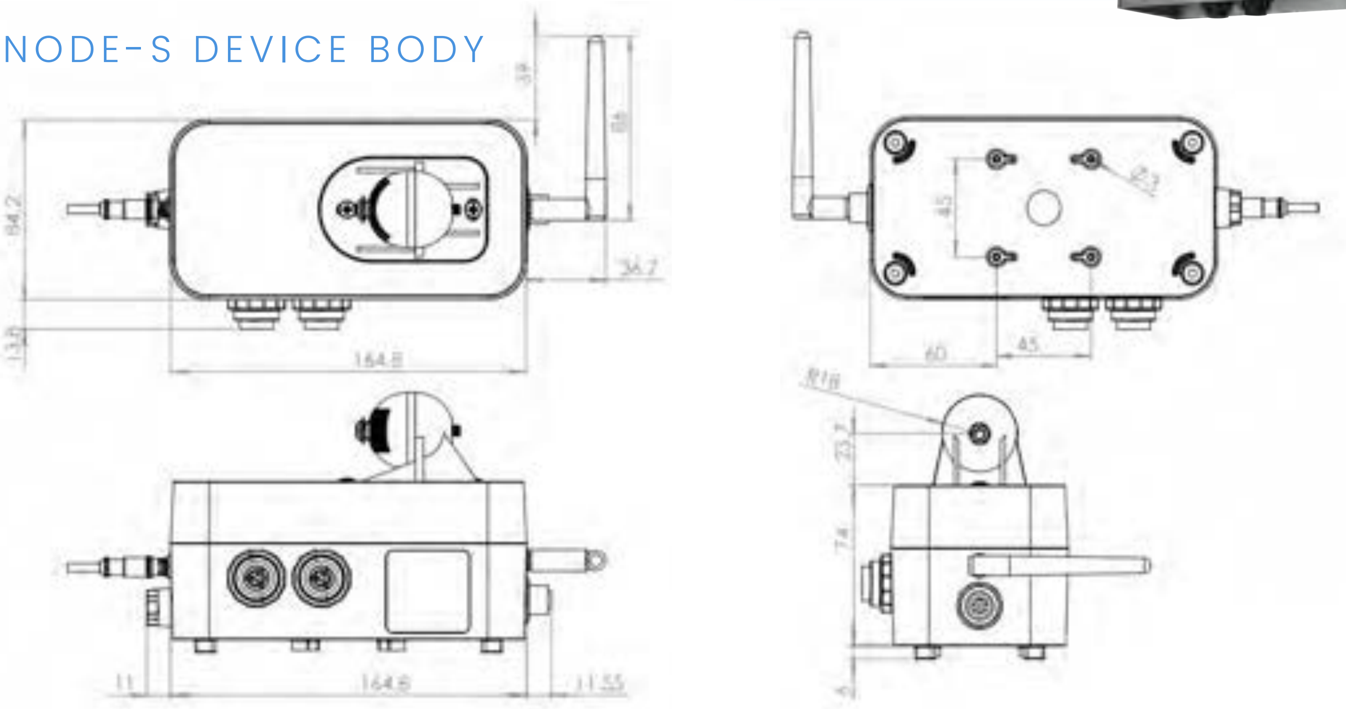
[1] Please note that our Global pre-calibration for NO2 can only be applied when temperatures are between 0 - 40° C.
[2] The Node-S can be used as a solar-powered or externally-powered device. External power required for operation below 0° C.
[3] Varies by deployment site location, solar panel orientation, and sampling frequency.
[4] Assuming default measurement frequency and exposure to an average of one hour of full sunlight per day over a 15-day rolling window.
[5] Solar shield provides protection against direct heat radiation.

clarity

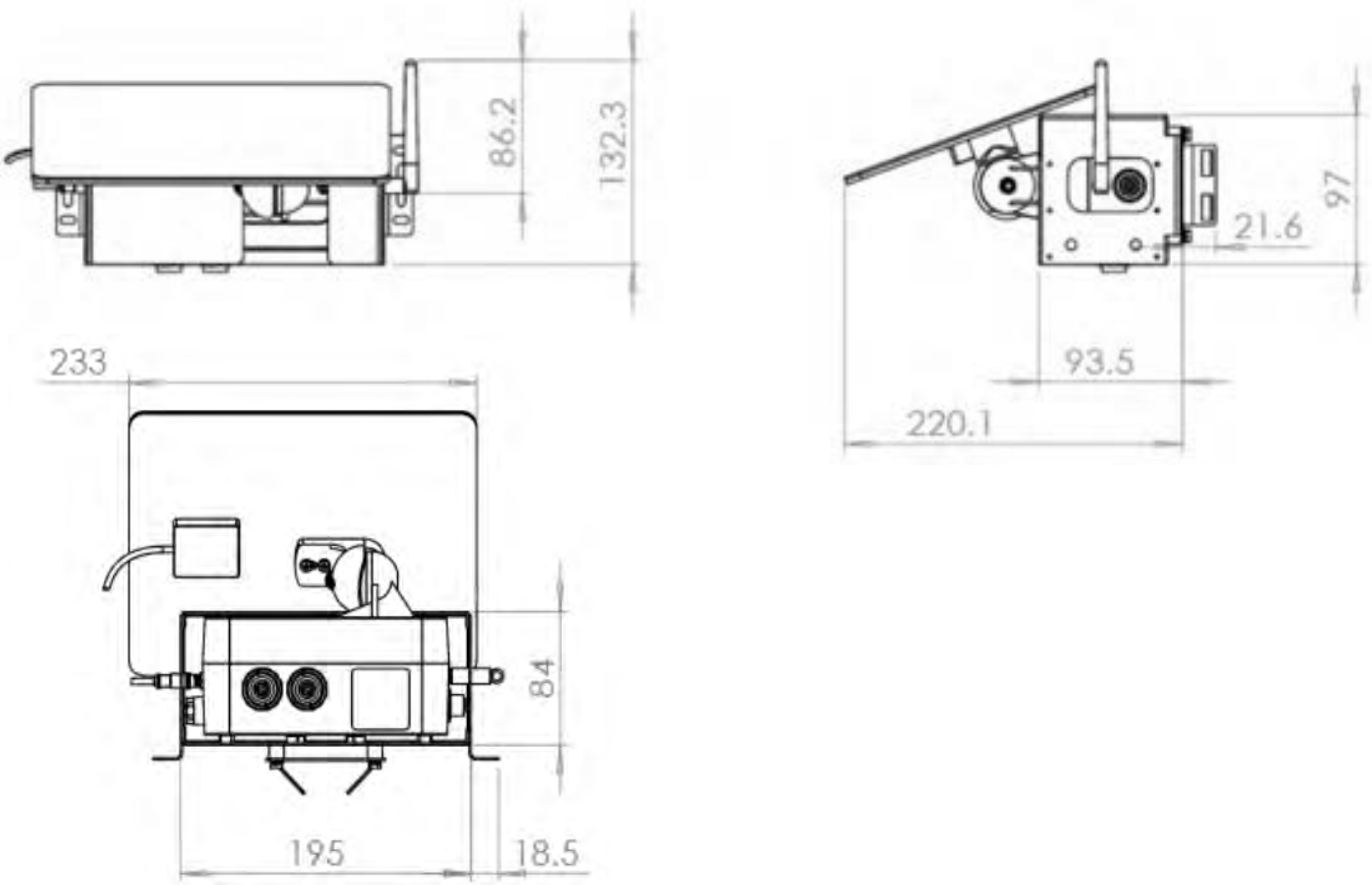
Node-S Technical Drawings[1]

CSA MC230425/00

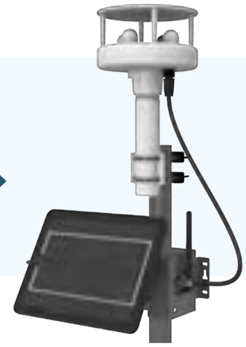
NODE-S DEVICE BODY



NODE-S DEVICE WITH SHIELD + SOLAR PANEL



Wind Module Technical Specifications



AIR QUALITY MEASUREMENTS

PARAMETER	TECHNOLOGY	RANGE	PERFORMANCE
Wind Speed	Solid-state 2-axis ultrasonic wind sensor	Range: 0 to 60.00 m/s Resolution: 0.01 m/s	Accuracy: ± 2% (at 12m/s)
Wind Direction	Solid-state 2-axis ultrasonic wind sensor	Range: 0 to 359.9° Resolution: 0.1°	Accuracy: ± 3° (at 12m/s)
Atmospheric Pressure	–	300 to 1100 hPa Resolution: 0.02 hPa	Relative Accuracy: ± 0.12 hPa
Ambient Temperature	–	Range: - 20° C to 75° C Resolution: 0.1° C	Accuracy: ± 0.5° C
Ambient Relative Humidity	–	10% to 99.9% RH Resolution: 0.1% RH	Accuracy: ± 2% RH (at 25° C)

DATA FLOW

Measurement Frequency (Adjustable)	- Default: Once every 15 minutes - Sampling synchronized with Node-S to occur simultaneously with air pollutant measurements; **see Node-S specifications for details**
Data Retrieval from Cloud	- Clarity Dashboard (Web App) - RESTful APIs (Programmatic Access)
Device to Cloud Communication	Connectivity provided by Clarity Node-S (SIM card and service included)

POWER[1]

Solar-Powered via Clarity Node-S	Wind Module self-powered via solar panel of companion Node-S device[1]

MOUNTING & DEPLOYMENT

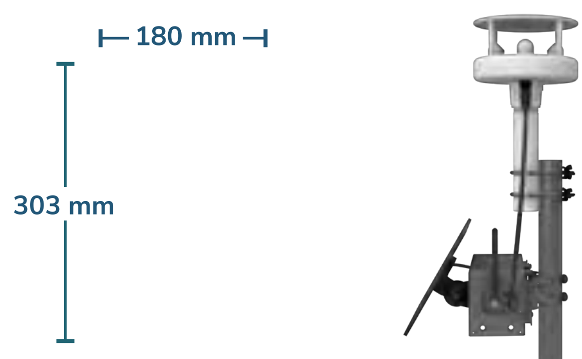
Connect to Node-S	Plug module into Clarity Node; Node will reset and automatically recognize the module
Sensor Siting	- Install sensor in an open area with unobstructed air flow - Align to true north
Mounting	Use the manufacturer-provided mounting bracket to affix to a pole or another secure foundation

OPERATING CONDITIONS

Weatherproof Rating	IP65
UV Exposure	UV-stabilised ABS plastic
Absolute temperature	-40° to 80° C
Operating temperature	**See Node-S specifications**
Operating humidity	**See Node-S specifications**

DIMENSIONS

Total (Assembled)	180 mm (Diameter) x 303 mm (H)
Sensor	180 mm (Diameter) x 146 mm (H)
Mount Shaft	40mm (Diameter) x 158 mm (H)
Total Weight	< .5 kg / 1.10 lb



[1] The Node-S can support Wind Module power requirements with a natively-integrated solar panel at default sampling rate.

Back to home

Deploying your Clarity Node-S

How to configure and set up a Clarity Node-S in the field.

IMPORTANT:

- Node-S devices must be **charged for a full 24 hours prior to deployment**. Devices are shipped partially charged for safety reasons. Devices that are not charged before configuration may not complete configuration when deployed and only will configure once there is sufficient battery charge. The device will slowly charge up via solar but the time required to do so is variable by device, so we highly recommend charging the device fully before deployment. Without a full charge, follow up visits to the deployment site may be required.
- The Node-S devices must be oriented correctly to be weatherproof. The air inlet/outlet should point straight down to the ground. **Incorrect deployment may allow moisture to enter the device and void the warranty.**

Reminders:

- Your Clarity device comes with a SIM card pre-installed.
- Your Clarity device comes with a power adapter with plugs for US, EU, UK, and Australia sockets. Other sockets will require additional adapters that will need

to be sourced separately.

- Please use this guide to set up your Clarity Node-S first before setting up any add-on modules. If you have already set up your Node-S device, please proceed to deployment instructions for the module.
- If you have any questions about deployment, please contact **support@clarity.io.**

In the Box

1 (one) Solar Panel	
1 (one) Clarity Node-S body with 1 solar shield attached	
1 (one) power adapter with adapters for US, EU, UK, and Australia sockets	

1 (one) antenna	
1 (one) mounting bracket	
4 (four) screws with washers for mounting bracket	

For deployment, you will also need the following equipment (not included):

- A Phillips head screwdriver
- Stainless steel zip ties, hose clamps, binding straps, or screws for mounting that are appropriate for your site(s)

Assemble the device

- Attach the mounting bracket to the Node-S body.
    - **If you have a generation 2 Node-S device with the aluminum solar shield:** Your device includes an additional mounting bracket and four (4) screws that allows for using hose clamps to secure to railings or poles:

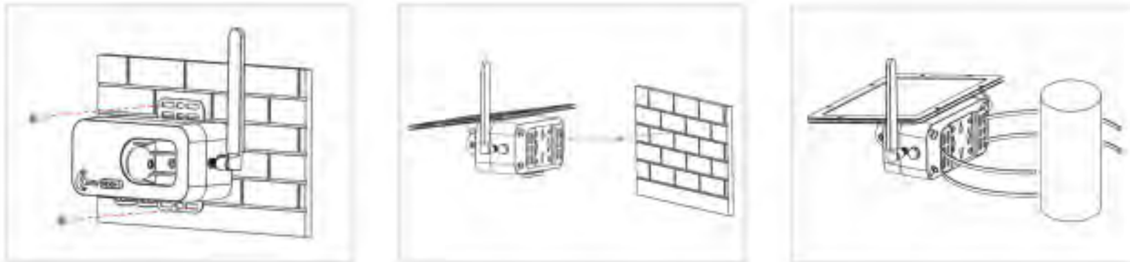
      
      

      The optional bracket can be rotated and secured to the Node body using the screws depending on the direction of the railing or pole. Examples:

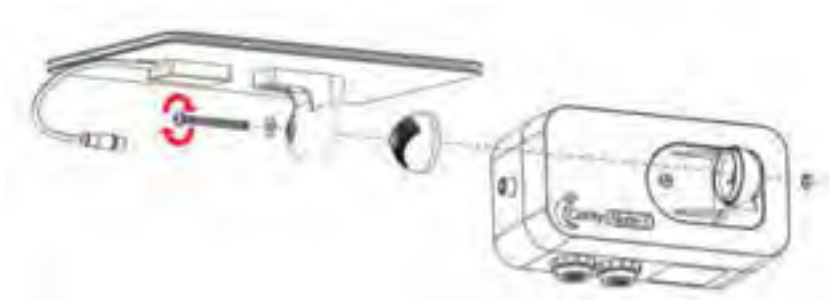
      
      

      If you are mounting the Node-S to a wall or panel, do not use the additional mounting bracket. Instead, rely on the flaps on the sides of the shield.
    - **If you have a generation 1 Node-S device without the aluminum solar shield:** Attach the mounting bracket to the device body with the mounting screws. The bracket

can be screwed in vertically or horizontally depending on the infrastructure at the site.



- Attach the solar panel to the device. Do not plug in the solar panel cable to the device body.



- Attach the antenna to the device body and orient upright.

Charge the device

> **IMPORTANT:**
>
> Node-S devices must be charged for a full 24 hours prior to deployment. Devices that are not charged before configuration may not complete configuration when deployed.

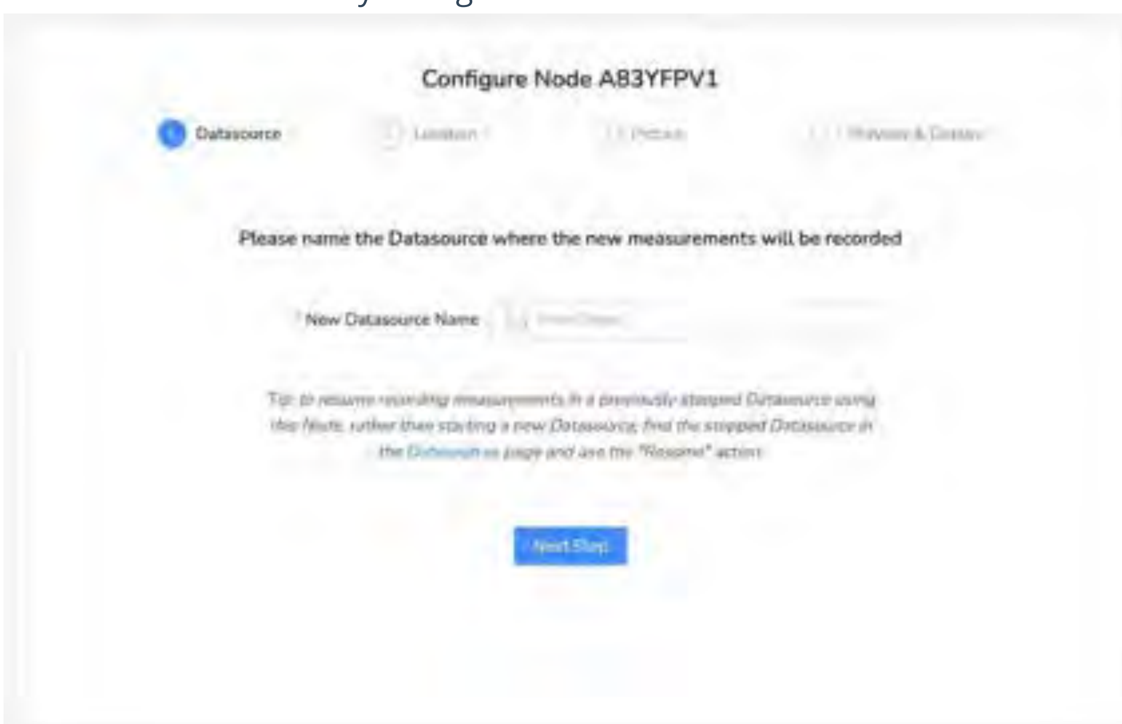
- Plug the device into an outlet with the provided power adapter. The device will play the Power On sound (*single beep*). Disregard any subsequent sounds for now.

- Charge for 24 hours. After fully charging or to store the device, please disconnect the external power adaptor or solar panel cable from the device body. Keeping the cable connected will keep the device on and continue consuming the battery.

Configure the Node on Dashboard

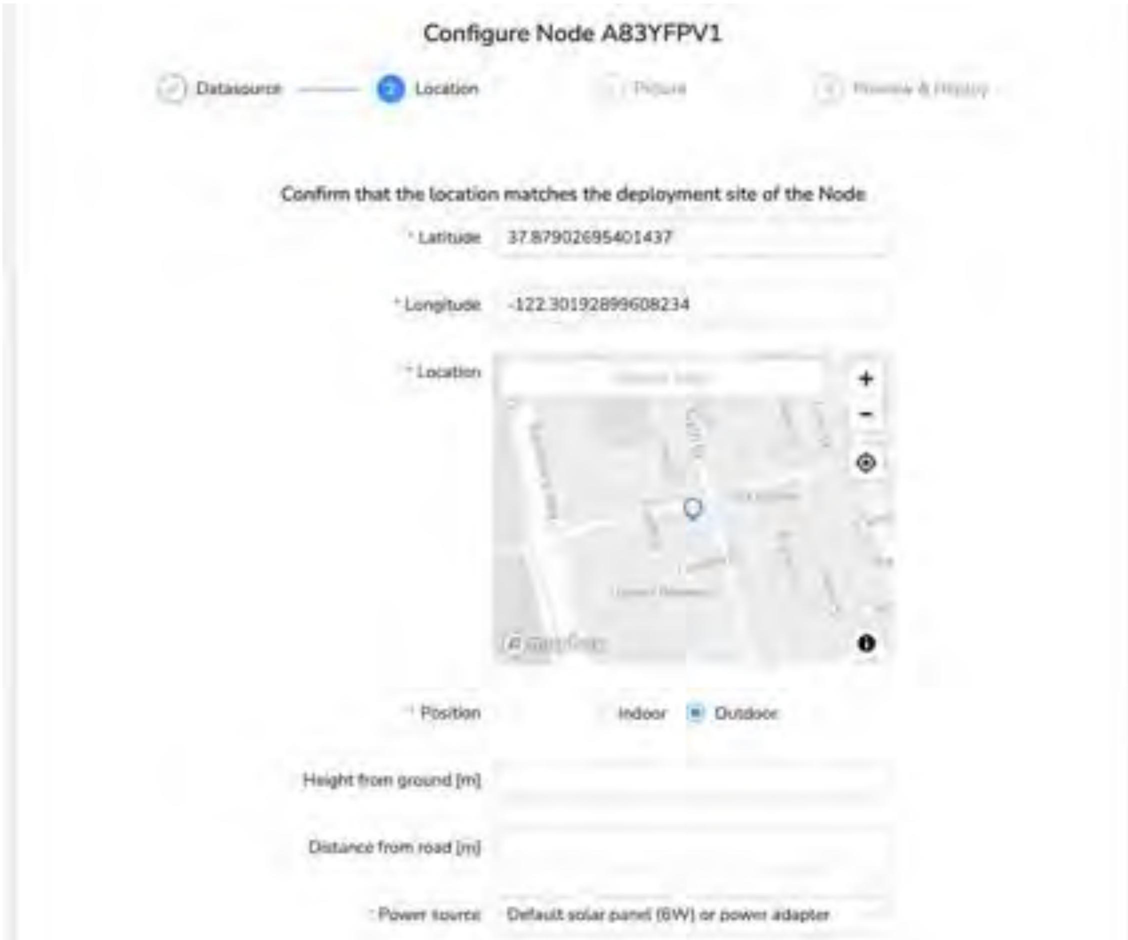
Configuration on Dashboard is a key step in deploying your Node-S. This process assigns a location to your Node, initiates a new Datasource for measurement streaming, and establishes secure communication with Clarity Cloud.

- Scan the QR code on the bottom of the Node or log in to the Clarity Dashboard and navigate to the Devices / Nodes page.
- Find the Node in the Inventory table and click on Configure.
- Follow the configuration steps:
    - Step 1: Choose a name for the new Datasource that the Node will record measurements to. Tip: For field deployments, use names that refer to the location you are deploying at such as “Main Street”. For collocations use descriptive names such as “Collocation at Laney College for A20DDFG4”.

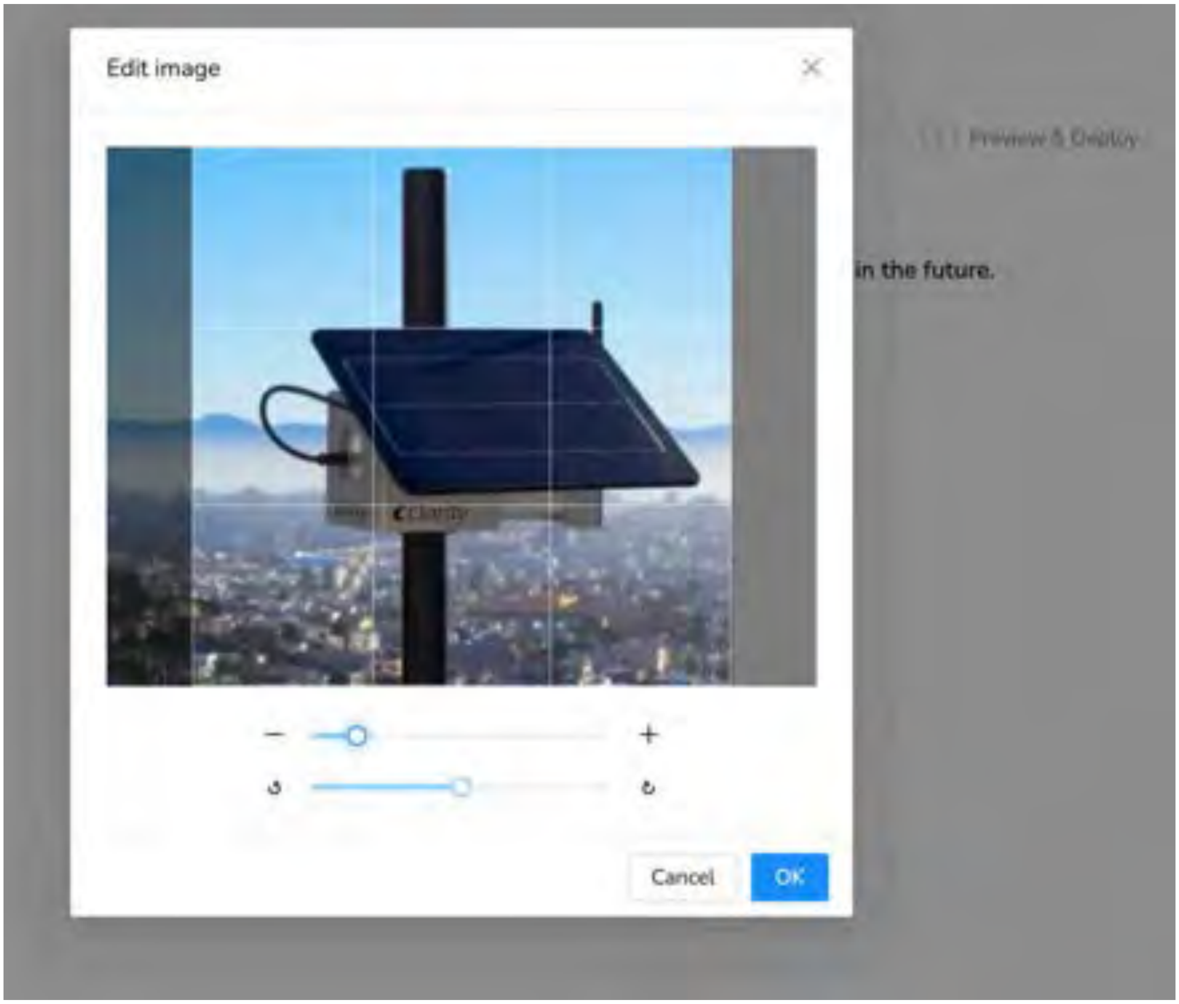


    - Step 2:
        - Enter the Node's location using latitude and longitude. You can manually input these, use a map, or use your device's location feature.

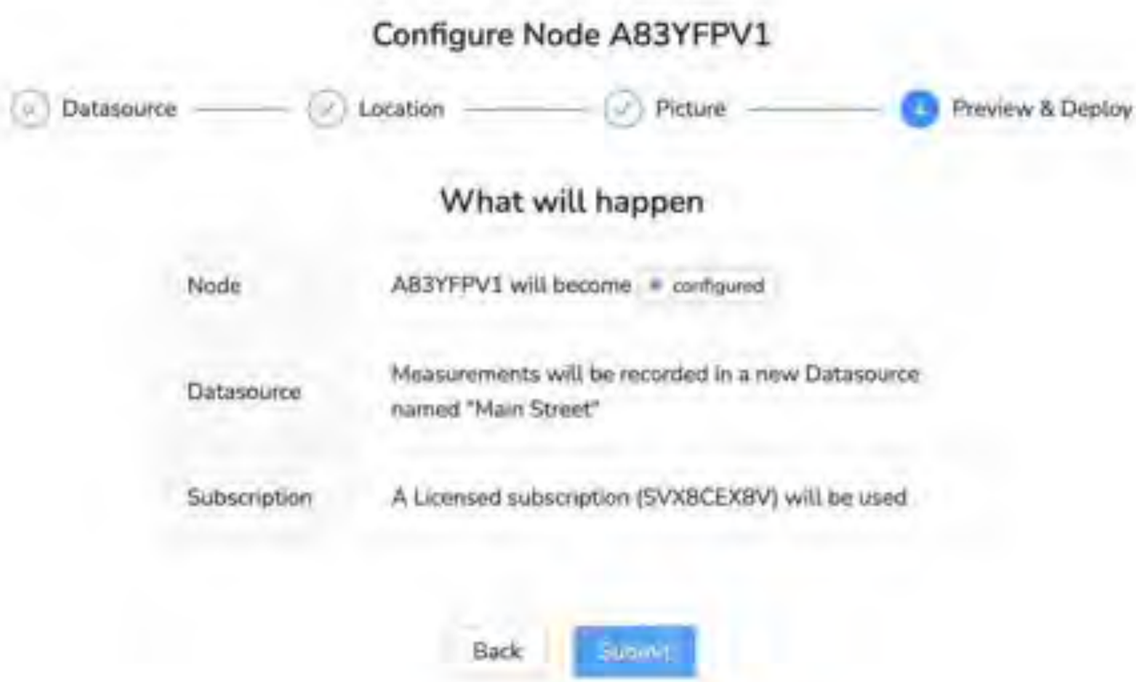
- Specify if the Node is indoor or outdoor, and provide the mounting height and distance from the nearest road if applicable.
- Indicate how you are powering the node: with the provided solar panel or power adapter, or with Clarity's External Solar System, used in combination with certain add-on Modules.



- Step 3: Add photos of the deployment site (optional).



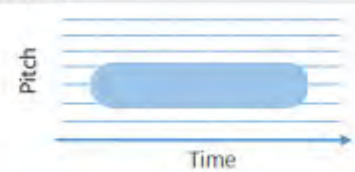
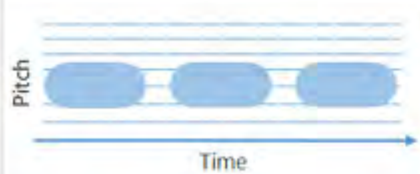
- Step 4: Review the information you entered and click Submit



> Here are links to more detail guides on [Node management]() and [Datasource management]() on Dashboard.

Pre-deployment tests

- At the deployment site, plug the solar panel cable or mains-power connector into the device. The device will play the **Power On sound** and attempt to connect to Clarity Cloud.
    - If the Connection Failure sound (*beep beep beep*) plays, please confirm the device has been configured on the Dashboard first. If this doesn't resolve the issue, please contact us **support@clarity.io.**
    - If you hear a **Low Battery sound**, please charge the device for at least 24 hours before proceeding.
    - If the **Connection Successful sound** plays, proceed to deploy the device.

Sound	Profile	Description
Power On (1 long beep)		Plays when the power adapter or the solar panel cable is plugged into the device. Indicates device is now powered.
Connection Successful (2 beeps, increasing in pitch)		Plays when the device connects to Clarity Cloud successfully. Indicates correct configuration.
Connection Fail (3 short beeps)		Plays when the device fails to connect to Clarity Cloud. Indicates connectivity issues or incorrect configuration.
Low battery (2 beeps, decreasing in pitch)		Plays when the battery level of device is low. Use the power adapter to charge the device for 24 hours.

- After successful connection, please wait for the first data point to upload to the Cloud and to appear on the Dashboard, which may take anywhere from 2 to 20 minutes depending on cellular connectivity strength. This can be checked by looking at the 'Last Reading Received' column on the **Nodes** page.

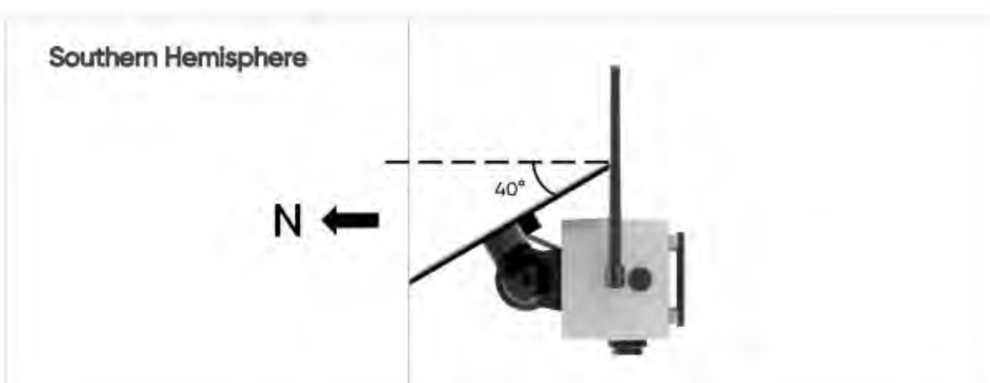
Deploy the device

- Mount the device to a pole, wall, or panel using stainless steel zip ties, hose clamps, binding straps, or screws that are appropriate for your site (not provided). Ensure the inlet and outlet are facing downwards and unobstructed. Make sure there is at least 250 mm/10 in clearance below the device inlets.

> **Note:** When deploying devices with the solar shield, mounting devices to a pole is recommended. Mounting to a wall or other flat surface may not be possible or require additional equipment.

- Orient the solar panel south (northern hemisphere) or north (southern hemisphere) with the optimum angle. Please find the optimum angle for your site here.

> **Note:** The optimum angle for the solar panel will vary during the winter and summer months if not near the equator. You may need to adjust the solar panel as the seasons and sun patterns change to maximize sunlight exposure in some locations. If accessing the device is difficult and the solar panel can't be adjusted, we recommend using the more conservative winter angle as long as during the summer months, there will be plenty of direct sun exposure.



Congratulations! The device is online and uploading data.

To ccess the d t , ple se chec out "How to a ess the data from your Clarity devices."

If you have Clarity modules to deploy, please continue deployment using the following guides below:

- Link to Wind Module deployment guide
- Link to Ozone Module deployment guide
- Link to Black Carbon Module deployment guide

Was this article helpful? Yes No

Related articles

Clarity Node-S Siting Guide

Node-S maintenance

Troubleshooting the alarm when NO_2 readings are out of expected range

Troubleshooting Accessory Module Alarms

Troubleshooting a Weak Signal Alarm

Guide to Accurate Particulate Matter Measurements

How to Meet USEPA, EU, and Other Performance Targets for Air Quality Sensors

clarity

Table of Contents

Low-cost air sensors are becoming the standard for non-regulatory supplemental and informational monitoring

For decades, forward-looking air quality managers and researchers have recognized the potential of low-cost sensors (LCS) to democratize air pollution measurement. However, a lack of consensus regarding how to ensure data quality from LCS meant they were relegated to use primarily by community groups and citizen scientists.

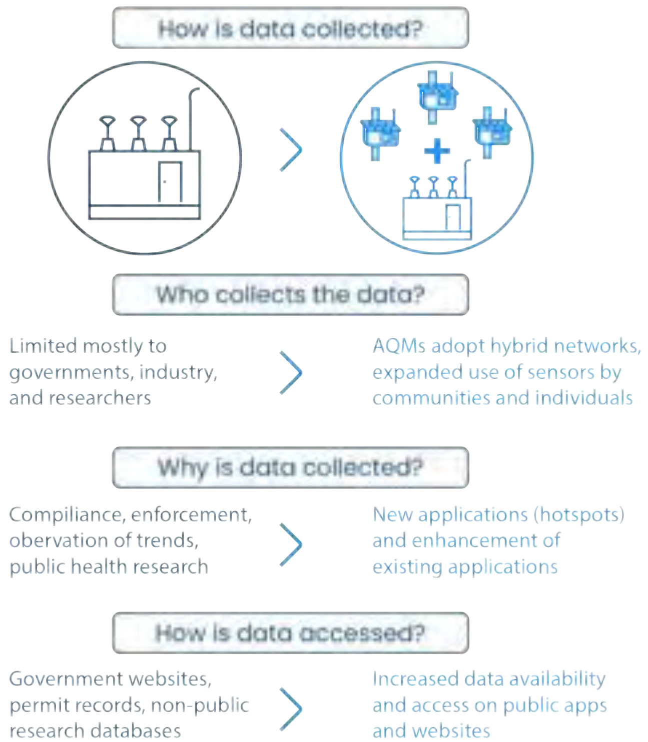
Until recently, it has been rare to see data from low-cost sensors used to support policy or operational decisions due to strict performance requirements for the accuracy, precision, and completeness of air quality data[1]. Policymakers have also expressed concern that uncalibrated data from LCS could be misinterpreted by the public, potentially complicating the already-complex debate around air quality policy.

The adoption of LCS at scale by cities like London demonstrates that a paradigm shift is underway. LCS are now seen as a valuable part of an air quality manager's toolkit for a wide range of non-regulatory supplemental and informational monitoring (NSIM) applications.

As technological advances in low-cost sensing technology and the calibration techniques used to ensure data accuracy progress, regulators have been working in tandem to establish standards that would validate the use of LCS for official purposes and enable the reporting of high spatiotemporal resolution air quality data in near-real-time.

With the recent publication of performance targets and testing protocols for air sensors by the United States Environmental Protection Agency (USEPA)[2], there is now a standard by which air sensor technologies can be evaluated for "fitness for use" for a wide range of NSIM applications.

The changing paradigm of air quality measurement



The USEPA's and other performance evaluation protocols for LCS will serve to legitimize data coming from "hybrid networks", which leverage the strengths of both LCS and monitoring technologies in compliance with the Federal Reference or Federal Equivalent Methods (FRM/FEM).

In this paper, we examine the USEPA's recommendations, compare them with other performance standards for low-cost sensors, and explain the steps you can take to evaluate the performance of LCS against these standards. Finally, we outline how to ensure the data from your LCS comply with USEPA and other performance targets for LCS, with a focus on particulate matter.

Toward the adoption of performance standards for low-cost air sensors

The USEPA's performance standards are the culmination of many years of expertise-building across academia and the public and private sectors. The timeline below highlights some of the significant milestones in the development of performance standards for LCS in recent years.

While not as robust as the USEPA certification program for FRM/FEM applications*, the publication of standardized performance targets and testing protocols for LCS represents a huge step toward a broader understanding and more effective use of these technologies.

To contextualize the significance of the USEPA's performance standards for air sensors, it is important to understand the limitations of low-cost sensing technology as compared to FRM/FEM technology.

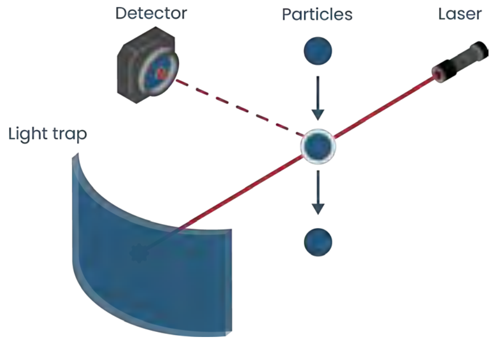
* It is important to recall that FRM and FEM designation require a rigorous testing process. Instruments with this designation are typically at least an order of magnitude more expensive than an LCS instrument.

Why are performance standards for low-cost sensors needed?

There are a number of reasons why LCS are less accurate than reference monitoring equipment. The exact nature of these limitations depends on the pollutant being measured and the specific technology being used to do so, but for illustrative purposes, we'll take particulate matter sensors as an example here.

Solid or liquid matter suspended in air, known as particulate matter (PM), is an air pollutant included in the USEPA's National Ambient Air Quality Standards[3] and causes a wide array of negative health impacts.

LCS typically measure PM with optical sensors that use light scattering to measure the particle number and size distribution of materials suspended in the air[4]. These optical particle counter (OPC) sensors are typically laser-based and measure the scattering properties of particles in the air stream, which serves as a proxy for the measurement of the actual particles. Common OPC sensors include those manufactured by Plantower and Sensirion (SPS30 was patented by Clarity and licensed to Sensirion in 2016).[5]



Challenges associated with low-cost PM sensors

- **Assumptions required to output mass concentration**—Because laser-based sensors count particles visually and not by weight, a density assumption is required (typically applied at the factory with calibration aerosol). This "density" is a function of particle composition and varies both locally and seasonally.
- **Inconsistent sensitivity across particle sizes**—Light-scattering based instruments can fail to detect very small particles (varies by sensor model but typically, <300 nm)[6] due to the low-power and long wavelength (red) of the low-cost laser diodes they employ, and/or larger particles (>PM_{10}) due to sampling bias (larger particles often present in a small number per unit volume).
- **Dependency on environmental conditions (cross-sensitivities)**—LCS measurements can be impacted by cross-sensitivities between pollutants as well as factors like temperature (T), relative humidity (RH), and wind speed and direction.
- **Mechanical issues**—If the air intake or other mechanical elements of the sensor are obstructed (e.g., by insects or pollen) this reduces accuracy.
- **No insight into particle composition**—PM composition can be complex, including both liquid and solid materials such as organic compounds, elemental carbon and soot, inorganic salts, metals, and a range of minerals.
- **Inconsistency between brand/manufacturer**—Accuracy can vary significantly between different LCS manufacturers; the USEPA found a wide range of R^2 values[7] for uncalibrated data from different manufacturers.
- **Unit-to-unit precision**—Not all LCS manufacturers can guarantee good unit-to-unit precision for a given sensor.*
- **Durability concerns**—Depending on quality of construction, some LCS may see degrading performance over time.*
- **Need for calibration specific to local and seasonal particle composition and environmental factors**—Due to the number of factors that can influence LCS measurements, there is a need to actively monitor and manage the calibration processes used for LCS networks to ensure consistency with local FRM & FEM instruments.

Fortunately, many of these issues can be addressed with proper calibration techniques. By establishing standard criteria for measurements from LCS, the USEPA is taking an important first step to ensuring that only high-quality data are collected, reported, and used for decision-making. Let's take a closer look at existing performance standards.

* Clarity uses the Plantower PMS6003 for best-in-class unit-to-unit precision, with a dual laser for an extended lifetime in the field.

What performance standards exist for PM air sensors?

In February 2021, the USEPA released Air Sensor Performance Targets and Testing Protocols[8] for ozone and $PM_{2.5}$ to help government agencies, community groups, citizen scientists, and academia identify LCS that would be best suited for their NSIM application. By establishing a consistent set of protocols for the standardized testing and reporting of sensor performance, these standards will help better characterize the performance of commercially available LCS in a clear and standardized way.

To date, the USEPA's performance targets are the first standards published that specifically target the evaluation of LCS for NSIM applications. With that said, standards in the EU and UK have also established air quality data performance targets that serve as requirements for all classes of monitoring equipment used for indicative monitoring.

Existing data quality objectives for low-cost PM sensors	USEPA*	EU**	UK MCERTS**
Daily average data completeness	>75%	>90%	>90%
Precision: Standard Deviation (SD)	≤ 5 µg/m³	-	≤ 5 µg/m³
Precision: Coefficient of Variation (CV)	≤ 30%	-	-
Bias***: Slope (m) of y=mx+b	1.0 ± 0.35	-	-
Bias***: Intercept (b) of y=mx+b	-5 ≤ b ≤ 5 µg/m³	-	-
Linearity***: Coefficient of Determination (R^2)	≥ 0.70	-	-
Error: Root Mean Square Error (RMSE)	≤ 7 µg/m³	-	-
Error: Normalized Root Mean Square Error (NRMSE)****	≤ 30%	-	-
Uncertainty*****	-	≤ 50%	≤ 50%

* USEPA deployment averages are based on 24-hour averages for $PM_{2.5}$ concentrations over a 30-day period.

** EU and UK averages are based on 24-hour averages for PM_{10} or $PM_{2.5}$ concentrations over a 40-day period.

*** Sensor $PM_{2.5}$ measurements are the dependent variable (y) with FRM/FEM $PM_{2.5}$ measurements as the independent variable (x).

**** USEPA notes that this metric is especially important when PM levels are much higher than general US levels (e.g., wildfires).

***** While the USEPA standards provide more criteria, both the EU and the UK employ an "Uncertainty" metric that includes many of these criteria.[9]

All three methods take a reference instrument as the "gold standard", but importantly, while the USEPA method treats the reference instrument as error-free, the EU & UK methods allow for uncertainty in the reference instrument's measurements. This helps to ensure that the LCS being evaluated are not unfairly penalized for uncertainty in the reference instrument's measurements. Further, while the USEPA recommends issuing two separate reports for raw and calibrated sensor data, the uncertainty metric is defined as the residual uncertainty after any calibrations are applied.

Future LCS performance standards will likely look to these existing protocols for guidance on the most appropriate criteria and target values for sensor performance evaluation.

Third-party validation of sensor performance

Before conducting a full evaluation of LCS per the USEPA protocol, you may wish to research how certain LCS models have performed under various testing protocols. One of the best ways to research the quality of measurements provided by a certain brand or model of LCS is by looking at third-party evaluations. Several research centers conduct standardized testing on LCS with the objective of providing a neutral, quantitative evaluation of sensor performance for commercially available LCS.

Who conducts third-party sensor evaluations?

Air Quality Sensor Performance Evaluation Center (AQ-SPEC)

AQ-SPEC conducts field and laboratory performance evaluations on commercially available low-cost air sensors. Detailed reports and condensed summaries are made public on the SCAQMD website.

USEPA Air Sensor Toolbox Program

EPA researchers perform colocations with reference-grade equipment to evaluate low-cost air sensors on accuracy and reliability. Sensor Evaluation Tables with sensor performance results are available.

European Commission Joint Research Center (JRC) Publications

The European Commission JRC publications repository includes field and laboratory performance evaluations of air sensors. Protocols on evaluating and calibrating air pollution sensors are also available.

AIRLAB Microsensors Challenge

Airparif's Airlab conducts a periodic evaluation campaign of commercially available air sensors called the Microsensors Challenge. Test protocols and testing results are available online.

These early testing protocols were not flawless, but their efforts have contributed significantly to the development of the USEPA's and other standards. While all of these research centers use slightly different methods in their evaluations, results from various third-party evaluations can be compared to arrive at a reasonably neutral and objective understanding of LCS performance.

Unfortunately, these protocols are heterogeneous—AirLab, for example, uses an entirely different accuracy metric than SCAQMD and the USEPA—and are not nearly as comprehensive as the USEPA's. While most testing centers report R^2, this statistic does not provide the full picture of sensor performance when considered in isolation without RMSE, bias, and offset.

While results from these testing centers can serve as useful references, we recommend using the USEPA's method to arrive at a complete and objective understanding of LCS performance.

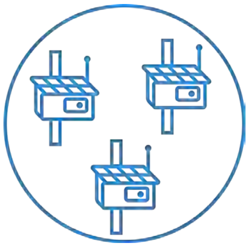
How to conduct a sensor performance evaluation

In addition to performance targets, the USEPA has also provided guidance on recommended protocols for setting up and running your own evaluation testing, should you wish to do so for a certain make and model of air sensor. This can provide valuable information about how a sensor will perform given the climatic conditions and pollutant profile specific to your region—as well as valuable inputs for a future, regionally-tailored calibration model!

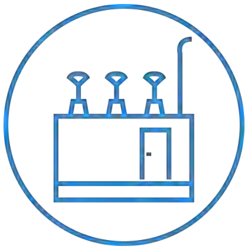
The EPA differentiates between two categories of testing: field testing (or "Base Testing") and laboratory testing (or "Enhanced Testing"). While laboratory testing allows sensors to be evaluated across a wider range of conditions than might be possible in the field, we will focus on field testing here as it is more accessible for the majority of people that do not have access to a laboratory. Field testing also provides more insight into how a sensor will perform under local conditions.

For both field and laboratory testing, the EPA recommends testing at least three identical sensors (of the same make, model, and firmware version) simultaneously. $PM_{2.5}$ air sensors should be colocated with FRM/FEM monitors for a minimum of 30 days each, at a minimum of two testing sites* in different climatic regions.

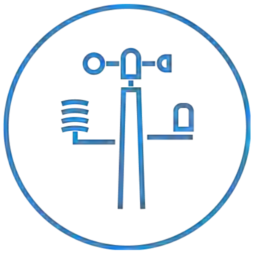
Equipment you'll need to perform testing per USEPA protocols



Three or more $PM_{2.5}$ air sensors



Calibrated $PM_{2.5}$ FRM/FEM monitor*



Calibrated RH & T monitors

USEPA Guidance on Air Sensor Setup at Testing Site[2]

Recommendations

- Mount sensors within 20 meters horizontal of the FRM/FEM monitor
- Mount sensors in a location where they are exposed to unrestricted airflow
- Ensure the air sampling inlet for the sensors are within a height of ± 1 meter vertically of the air sampling inlet of the FRM/FEM monitor
- Mount sensors ~1 meter apart from each other
- If necessary, install sensors within a weather-protective shelter/enclosure that maintains ample airflow around the sensor (as recommended by the manufacturer)

Cautions

- Do not place sensors near structures/objects that can affect airflow to the sensor OR block the sensor air intake (e.g., against a wall, near a vent, or on the ground blocking the inlet)
- Do not place sensors near structures/objects that can alter T or RH near the sensor (e.g., vents, exhausts)
- Do not place sensors near sources/sinks that can alter pollutant concentrations (e.g., idling cars, smoking)
- Do not place sensors in locations with risk of vibration, electrical shock, or other potential hazards

clarity

* If high $PM_{2.5}$ concentrations are expected (e.g., wildfire smoke applications), the USEPA recommends conducting testing in more than two locations and including sites impacted by wildfire smoke and higher $PM_{2.5}$ concentrations.

USEPA sensor performance evaluation checklist*

Select your test sites

- ☐ **Consider sites where reference monitoring equipment is already available:** Testers may wish to avoid procuring FRM/FEM equipment by developing relationships with state, local, or tribal air quality agencies to colocate sensors near FRM/FEM monitors at existing air quality monitoring sites.
- ☐ **Choose at least two sites in different climatic regions:** Select at least two sites located in climate regions that are not adjacent for the greatest possible variation in $PM_{2.5}$ variables.
- ☐ **Target at least one day with a 24-hour average $PM_{2.5}$ concentration of ≥ 25 μg/m³:** Target sites with adequate $PM_{2.5}$ exposure to ensure statistics are comparable across sites and that a low R^2 does not occur due solely to low $PM_{2.5}$ concentration ranges.

Perform technical setup

- ☐ **Establish reference monitors:** If not already set up at a test site, install the FRM/FEM, T, and RH monitors at the test site. Reference monitors should be 2 to 15 meters from the ground, more than 1 meter from supporting structures, and a minimum of 10 meters from trees and roadways
- ☐ **Time zone settings:** Adjust all instrument times to a common standard clock (e.g. NIST time).
- ☐ **Configure all devices for consistent sampling interval:** Consider whether data from any instrument reports an average; if so, understand if the data average is 'time ending' or 'time beginning'.
- ☐ **Connectivity:** For testing purposes, the USEPA recommends that measurements be logged internally on each instrument or through a central data acquisition system. If an internet or cellular connection is needed to operate the sensor, this information should be reported.
- ☐ **Understand if any calibration will be applied by the sensors**: If data from the sensors will typically be calibrated before use by end-users, the USEPA recommends issuing a secondary report using calibrated data. Primary performance testing should be based on raw (uncalibrated) data outputs.
- ☐ **Conduct a one-point flow rate verification check on FRM/FEM monitor:** Record the date of the check.

Install your air sensors

- ☐ **Install LCS at the test site:** Use sensors in the same condition as received from the manufacturer.
- ☐ **Take photographs of the equipment setup:** Include these in your documentation.
- ☐ **Record information about the equipment and set-up, including:**
  - ☐ **Parameters measured** (e.g., pollutant(s) and units)
  - ☐ **Sampling time interval** (e.g., 15-minute, 1-hour, 24-hour)
  - ☐ **Data storage and transmission method(s)** (e.g. where data are stored/transmitted, the form of data stored—raw and/or corrected/cleaned data)
  - ☐ **Data analysis/data correction scripts** (e.g., Jupyter Notebook, R Markdown)
  - ☐ **Location of final reported data and its format** (e.g., website shows raw data and corrected data on the user interface, data provided as .csv, expanded definitions of data headers)
  - ☐ **Data correction approach (if applicable) including:**
    - ☐ **How the data are corrected** (e.g., manufacturer derived multilinear correction)
    - ☐ **Variables used to correct the data** (e.g., RH, T)
    - ☐ **Where the correction variable(s) comes from** (e.g., onboard RH sensor)
    - ☐ **How the data are validated or calibrated** (e.g., RH sensor calibrated by manufacturer)

Conduct field testing

- ☐ **Verify that all equipment is reporting measurements.**
- ☐ **Allow all equipment to run for at least 30 consecutive days:** All equipment should be running during the same time period to allow for comparable results
- ☐ **Follow manufacturer maintenance recommendations for all equipment throughout testing:** Record and report all maintenance or troubleshooting performed, including dates/times
- ☐ **Record and report the rationale for missing or invalidated data:** Target at least 75% uptime for all instruments (i.e. all equipment reporting at least 23 valid 24-hour pairs of time-matched data points)
- ☐ **Generate a field testing report for each deployment:** Each deployment should have a separate report
- ☐ **Generate a secondary report for calibrated data, if this is how the sensors will be operated.**

* Note that the above is a summarized version of the testing protocols provided by USEPA. For the full protocols, please refer to the USEPA Performance Testing Protocols Metrics and Target Values for Fine Particulate Matter Air Sensors (February 2021).

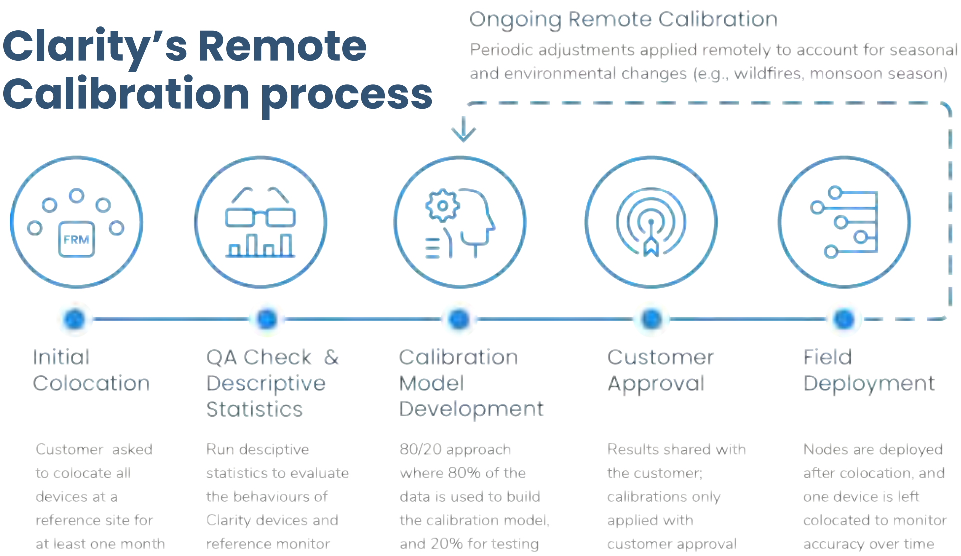
How proper calibration helps to ensure that data meet performance standards

When thinking about LCS performance, it is important to consider that data accuracy can be assessed at multiple levels. When using low-cost sensors for NSIM purposes, most users will be looking to deploy a **network** of LCS. If the manufacturer also includes services such as calibration, the final dataset produced by the **solution** may be very different from what is output by the network of sensors themselves.

Sensor	Network	Solution
The device that delivers data to the network system.	The sensor locations and their connected arrangement.	Value-added services such as maintenance and calibration.

Even when LCS are factory calibrated, a calibration model should be applied to further optimize for local conditions and pollutant profiles to obtain the most accurate measurements. Researchers have found that the main challenge for a large majority of LCS air quality monitoring projects is developing appropriate calibration models to ensure data quality[1]—that's why Clarity performs Remote Calibration for all customers as part of our Sensing-as-a-Service model.

Clarity's Remote Calibration process



For particulate matter, calibration is especially important because particulate profiles (i.e., particle composition and size distribution) vary significantly based on pollutant sources and environmental conditions. Accuracy can be improved to meet the targets recommended by the USEPA through additional data processing that takes localized calibration models into account. Our Air Quality experts create customized calibration models to ensure data is continuously adjusted to be as accurate as possible for local conditions.

The benefits of Remote Calibration

- ✓ **Improves accuracy** of Clarity devices by adapting to local environmental conditions
- ✓ **Reduces operational costs** as Remote Calibration is included in Clarity's service solution
- ✓ **Allows for ongoing & remote calibration** throughout project duration
- ✓ **Streamlines the traditional low-cost sensor calibration process**

How calibrated data from low-cost sensors perform against EPA performance standards

To demonstrate the importance of calibration to meeting the performance targets recommended by the USEPA, the following two pages include the results from several example calibrations of our Clarity Node-S sensors.

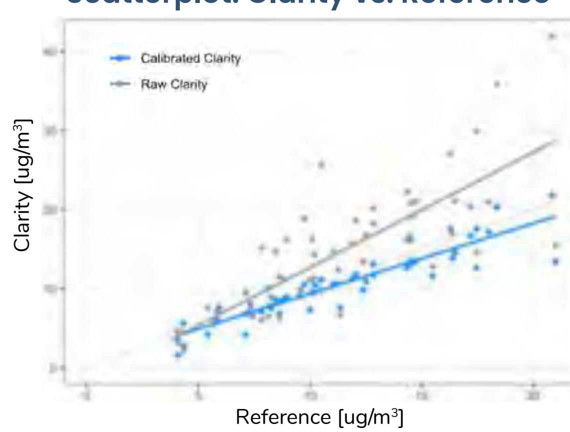
The dataset used for these plots is from a Clarity device located in Los Angeles, CA, with data collected from mid-February 2021 to mid-April 2021. The daily $PM_{2.5}$ average concentrations observed by the reference monitors range from 2.95 to 26.38 µg/m^3. This calibration did not precisely follow the EPA's recommendations for performance testing given that three sensors were not colocated, but demonstrates how calibration can improve performance for an extended period of time (60 days).

While the raw data met only two out of five of the USEPA's recommended performance targets, the **calibrated data was improved significantly for all specified metrics and met all five performance targets**. This performance improvement is typical when comparing calibrated LCS data to uncalibrated data for the same period.

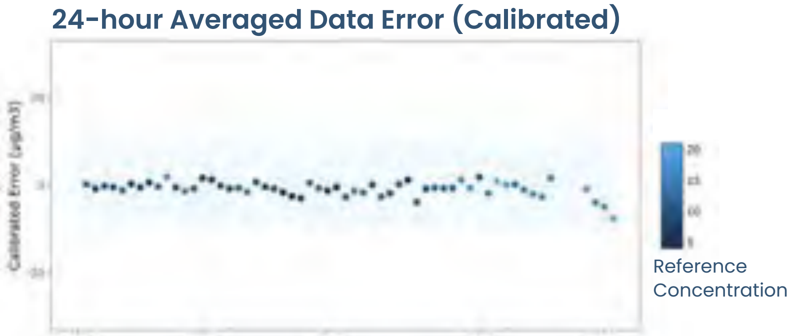
	EPA Recommendations	Raw Clarity Data	Calibrated Clarity Data
Bias: Slope (m) of y=mx+b	1.0 ± 0.35	1.46	0.89
Bias: Intercept (b) of y=mx+b	-5 ≤ b ≤ 5 µg/m^3	-1.90	0.47
Linearity: Coefficient of Determination (R^2)	≥ 0.70	0.64	0.85
Error: Root Mean Square Error (RMSE)	≤ 7 µg/m^3	5.97	1.86
Error: Normalized Root Mean Square Error (NRMSE)**	≤ 30%	73%	20%

24-hour Averaged Time Series

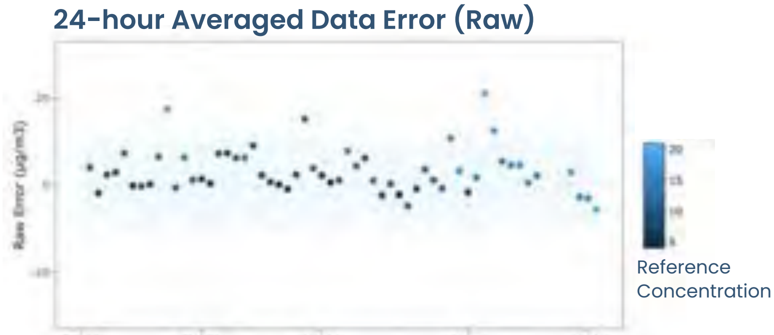
Scatterplot: Clarity vs. Reference



24-hour Averaged Data Error (Calibrated)



24-hour Averaged Data Error (Raw)



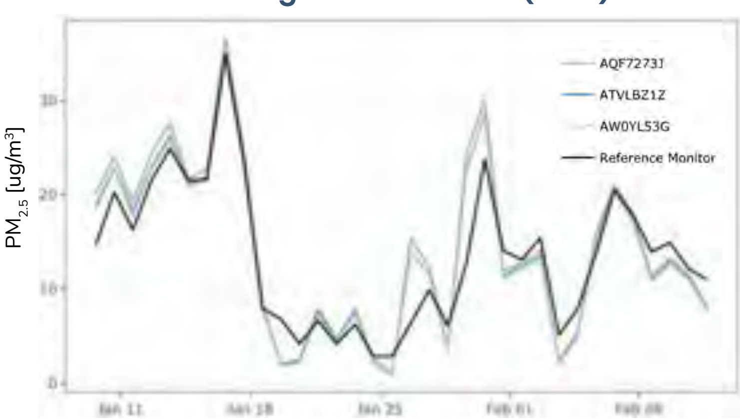
How calibrated data from low-cost sensors perform against EPA performance standards

The USEPA recommends performing field testing in two different climatic regions. To provide an additional example that is more closely aligned with the testing protocols recommended by the USEPA, we have included the results from a calibration of three of our Clarity Node-S sensors located in Phoenix, Arizona, here.

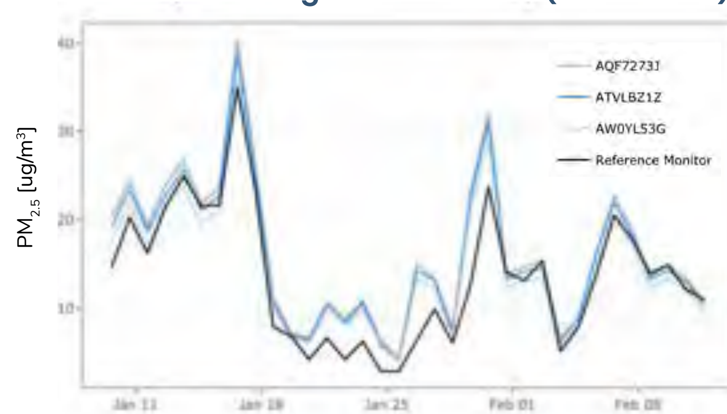
The dataset used for these plots is from three Clarity devices located in Phoenix, Arizona, with data collected from January 9, 2021, to February 11, 2021. The daily average concentrations observed by the reference monitors range from 2.86 to 35.02 µg/m³. Calibrations were applied January 8th, 2021.

		Raw			Calibrated		
	EPA Recommendations	AW0YL53G	AQF7273J	ATVLBZ1Z	AW0YL53G	AQF7273J	ATVLBZ1Z
Slope (m) of y=mx+b	1.0 ± 0.35	1.00	1.05	1.01	.85	.96	.92
Intercept (b) of y=mx+b	$-5 \le b \le 5$ µg/m³	1.00	0.43	0.29	3.32	3.51	3.44
R^2	≥ 0.70	0.82	0.81	0.83	.85	.85	.85
RMSE	≤ 7 µg/m³	3.60	4.10	**3.62**	3.31	4.30	3.86
NRMSE	≤ 30%	16%	18%	16%	23%	24%	29%

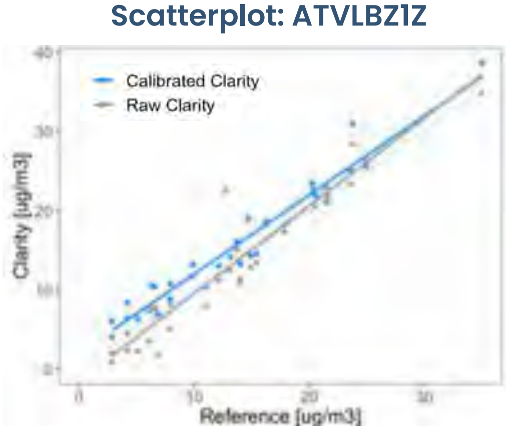
24-hour Averaged Time Series (Raw)



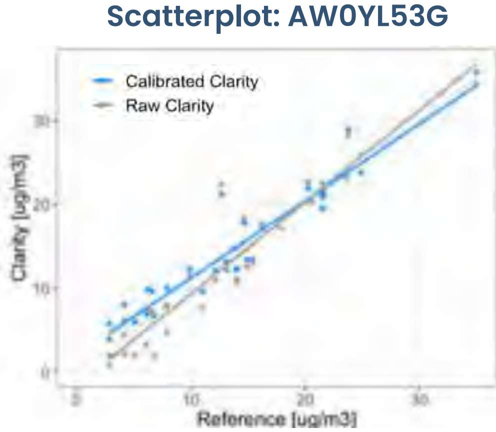
24-hour Averaged Time Series (Calibrated)



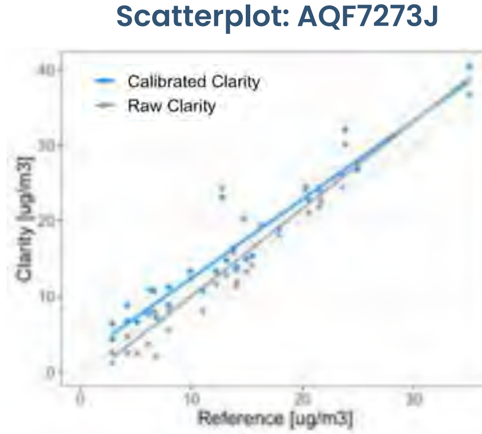
Scatterplot: ATVLBZ1Z



Scatterplot: AW0YL53G



Scatterplot: AQF7273J



How to ensure data from your low-cost air sensors meet official performance standards

Low-cost air sensors are still a new technology that will continue to see improvements in accuracy as they see wider adoption by governments, communities, and businesses. The USEPA's publication of performance standards for low-cost sensors represents a significant step toward the appropriate use of LCS technology for a wide range of applications.

The result will be better availability of high spatiotemporal resolution air quality data in near-real time for air quality managers, researchers, and the general public. The availability of this data will help governments and communities to better understand—and take action to reduce—air pollution around the world.

The availability of performance targets in no way guarantees that all commercially available LCS will meet those standards. At Clarity, we provide the only air quality monitoring solution which comes complete with self-reliant hardware, scalable cloud software, and expert calibration services to help ensure the data from your networks meet USEPA, EU, and MCERTS data quality standards.

It is of course possible to apply calibrations to your sensor network manually—but this process requires a lot of overhead (not to mention technical expertise).

With Remote Calibration, our customers partner with Clarity's Air Quality Experts to develop the best calibration model for their project, with significantly less input or technical expertise required on their end. Once the calibrations have been applied, Clarity customers have access to both raw and calibrated data at all times in the Clarity Cloud.

The USEPA's performance targets and testing protocols provide the first standardized, comprehensive benchmark for LCS performance, and represent a significant step toward the development of a standard for LCS data accuracy. These standards will serve to further legitimize LCS for official uses and advance the availability of high spatiotemporal resolution air quality data around the world.

Want to learn more about Clarity's Remote Calibration?

We have provided Remote Calibration for our customers with NSIM sensor networks in 50+ countries around the world. Contact us to speak with an Air Quality Expert and learn more about our calibration process and results:

- ✓ Learn about best practices for colocation and calibration
- ✓ Review sensor performance results from colocations around the world
- ✓ Get recommendations for the implementation of NSIM sensor networks

GET IN TOUCH

References

1 Williams, R., D. Nash, G. Hagler, K. Benedict, I. MacGregor, B. Seay, M. Lawrence, AND T. Dye. Peer Review and Supporting Literature Review of Air Sensor Technology Performance Targets. U.S. Environmental Protection Agency, Washington, DC, EPA/600/R-18/324, 2018. Retrieved from https://cfpub.epa.gov/si/si_public_record_Report.cfm?dirEntryId=342652&Lab=NERL

2 Duvall, R., A. Clements, G. Hagler, A. Kamal, Vasu Kilaru, L. Goodman, S. Frederick, K. Johnson Barkjohn, I. VonWald, D. Greene, AND T. Dye. Performance Testing Protocols, Metrics, and Target Values for Fine Particulate Matter Air Sensors: Use in Ambient, Outdoor, Fixed Site, Non-Regulatory Supplemental and Informational Monitoring Applications. U.S. EPA Office of Research and Development, Washington, DC, EPA/600/R-20/280, 2021. Retrieved from https://cfpub.epa.gov/si/si_public_record_Report.cfm?dirEntryId=350785&Lab=CEMM

3 United States Environmental Protection Agency. (2021, March 22). Criteria Air Pollutants. Retrieved from https://www.epa.gov/criteria-air-pollutants

4 Alfano, B., Barretta, L., Del Giudice, A., De Vito, S., Di Francia, G., Esposito, E., Formisano, F., et al. (2020). A Review of Low-Cost Particulate Matter Sensors from the Developers' Perspectives. Sensors, 20(23), 6819. MDPI AG. Retrieved from http://dx.doi.org/10.3390/s20236819

5 Sensirion. (2016, October 12). Sensirion and Clarity Collaborate on PM2.5 Sensor Technology [Press release]. https://www.sensirion.com/en/about-us/newsroom/news-and-press-releases/detail/news/sensirion-and-clarity-collaborate-on-pm25-sensor-technology/

6 Kuula, J., Mäkelä, T., Aurela, M., Teinilä, K., Varjonen, S., González, Ó., and Timonen, H.: Laboratory evaluation of particle-size selectivity of optical low-cost particulate matter sensors, Atmos. Meas. Tech., 13, 2413–2423, https://doi.org/10.5194/amt-13-2413-2020, 2020. Retrieved from https://amt.copernicus.org/articles/13/2413/2020/

7 United States Environmental Protection Agency. (2020, December 22). Evaluation of Emerging Air Sensor Performance. Retrieved from https://www.epa.gov/air-sensor-toolbox/evaluation-emerging-air-sensor-performance

8 United States Environmental Protection Agency. (2021b, April 5). Air Sensor Performance Targets and Testing Protocols. Retrieved from https://www.epa.gov/air-sensor-toolbox/air-sensor-performance-targets-and-testing-protocols

9 European Commission Working Group 15 (2010, January). Guidance for the Demonstration of Equivalence of Ambient Air Monitoring Methods. Retrieved from https://ec.europa.eu/jrc/sites/jrcsh/files/aquila-guide_equivalence.pdf

Wind Module Technical Specifications

AIR QUALITY MEASUREMENTS

PARAMETER	TECHNOLOGY	RANGE	PERFORMANCE
Wind Speed	Solid-state 2-axis ultrasonic wind sensor	Range: 0 to 60.00 m/s Resolution: 0.01 m/s	Accuracy: ± 2% (at 12m/s)
Wind Direction	Solid-state 2-axis ultrasonic wind sensor	Range: 0 to 359.9° Resolution: 0.1°	Accuracy: ± 3° (at 12m/s)
Atmospheric Pressure	–	300 to 1100 hPa Resolution: 0.02 hPa	Relative Accuracy: ± 0.12 hPa
Ambient Temperature	–	Range: - 20° C to 75° C Resolution: 0.1° C	Accuracy: ± 0.5° C
Ambient Relative Humidity	–	10% to 99.9% RH Resolution: 0.1% RH	Accuracy: ± 2% RH (at 25° C)

DATA FLOW

Measurement Frequency (Adjustable)	- Default: Once every 15 minutes - Sampling synchronized with Node-S to occur simultaneously with air pollutant measurements; **see Node-S specifications for details**
Data Retrieval from Cloud	- Clarity Dashboard (Web App) - RESTful APIs (Programmatic Access)
Device to Cloud Communication	Connectivity provided by Clarity Node-S (SIM card and service included)

POWER[1]

Solar-Powered via Clarity Node-S	Wind Module self-powered via solar panel of companion Node-S device[1]

MOUNTING & DEPLOYMENT

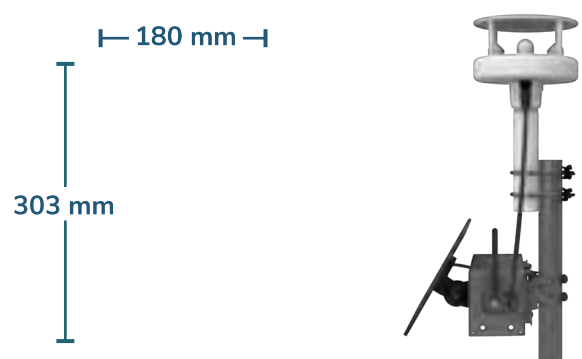
Connect to Node-S	Plug module into Clarity Node; Node will reset and automatically recognize the module
Sensor Siting	- Install sensor in an open area with unobstructed air flow - Align to true north
Mounting	Use the manufacturer-provided mounting bracket to affix to a pole or another secure foundation

OPERATING CONDITIONS

Weatherproof Rating	IP65
UV Exposure	UV-stabilised ABS plastic
Absolute temperature	-40° to 80° C
Operating temperature	**See Node-S specifications**
Operating humidity	**See Node-S specifications**

DIMENSIONS

Total (Assembled)	180 mm (Diameter) x 303 mm (H)
Sensor	180 mm (Diameter) x 146 mm (H)
Mount Shaft	40mm (Diameter) x 158 mm (H)
Total Weight	< .5 kg / 1.10 lb



[1] The Node-S can support Wind Module power requirements with a natively-integrated solar panel at default sampling rate.

Deploying your Clarity Wind Module

How to pair and set up a Clarity Wind Module with a Node-S in the field.

IMPORTANT:

- You must first charge, assemble, and configure the Clarity Node-S devices before connecting the wind module. If you have not yet configured the Node-S, please find instructions here before proceeding with the instructions below.
- Not all versions of the Clarity Node-S can be paired with the Wind module. Please check with Clarity support (support@clarity.io) if you need device IDs that can be paired.
- When not in use, please store the wind module in the **original manufacturer-provided packaging**.
- If a return to Clarity is needed, please return the module in the **original manufacturer-provided packaging** to prevent damage to the units.

Contents

- Assemble the Module
- Connect the Module to the Clarity Node-S
- Deploy the Node-S + Wind Module in the Field
- Maintenance

In the Box

1 Wind module quick installation manual (provided by ONWA).	
1 Wind Module	
1 cable connecting Wind Module to Clarity Node-S (1.5m length)	

1 mounting pole with outer diameter of 40 mm	
Standard accessories pack: • 2x M6 U-style screw bolts • 2x dog tooth mount • 4 butterfly screws • 1 hex key screwdriver • 2 fuses (not needed when used with the Clarity Node-S)	

For wind module deployment, you will also need the following equipment (not included):

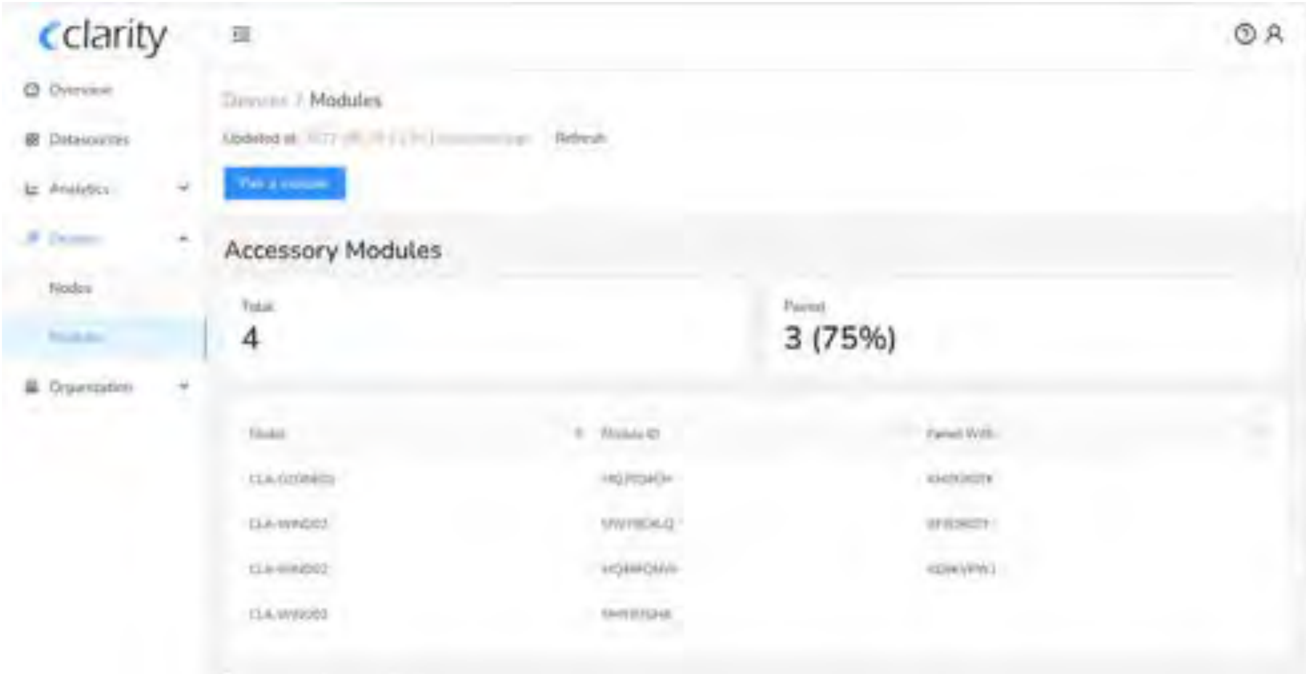
- Deployment pole (maximum outer diameter of 40 mm) or surface to attach the mounting pole of the wind module.
- Additional mounting equipment depending on the surface or pole diameter. The mount included with the wind module will work with poles up to 40mm in outer diameter.
- Compass to determine true north.

Pair the Module in Dashboard

In order to use an accessory module, it needs to be "paired" with a Node-S device. Pairing a module with a Node-S device tells the Clarity system that the two are connected and allows the module to begin sending data to the Clarity cloud.

1. Before beginning your module pairing, make sure your Node-S is configured, review the instructions for configuring your node here.

2. Sign into your Clarity Dashboard and navigate to **Modules** under **Devices**. Click **Pair a module**.

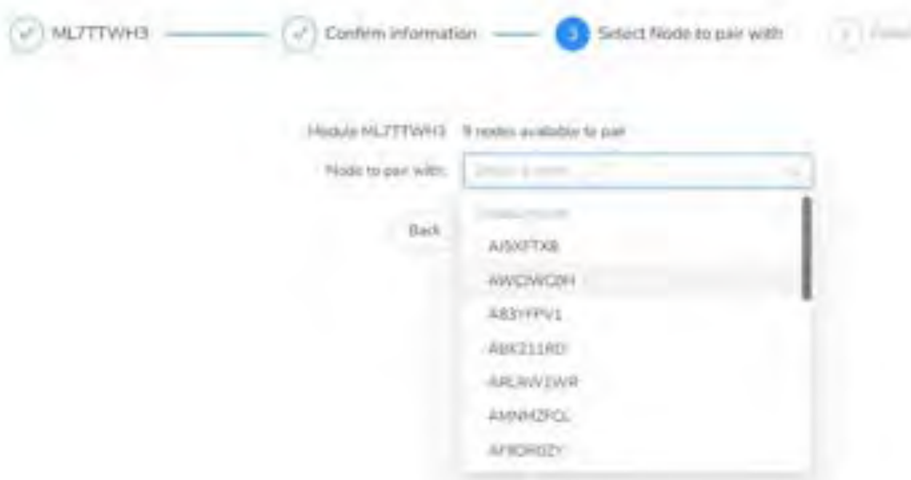


3. Scan the module QR code, manually input the module ID or select the correct ID from the dropdown menu. See the image below for where to find the module ID and QR code. Click "Next Step".

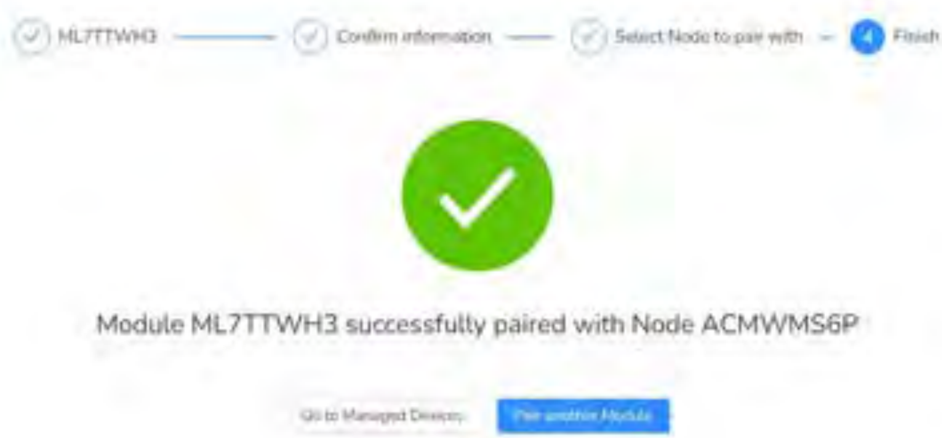
4. Confirm the information on the screen matches what is found on the module ID sticker. Confirm both the Module ID and Type are correct.

5. If a Module has already been paired with a Node, you must unpair it before continuing. To do so, click “Unpair”.

6. Input the ID of the Node-S that you will be pairing the Module with, or select the ID from the drop down menu. This ID can be found on the bottom of the Node-S device. Nodes that are not compatible with the Module, or are already paired are grayed out in the dropdown menu. Click “Pair”.



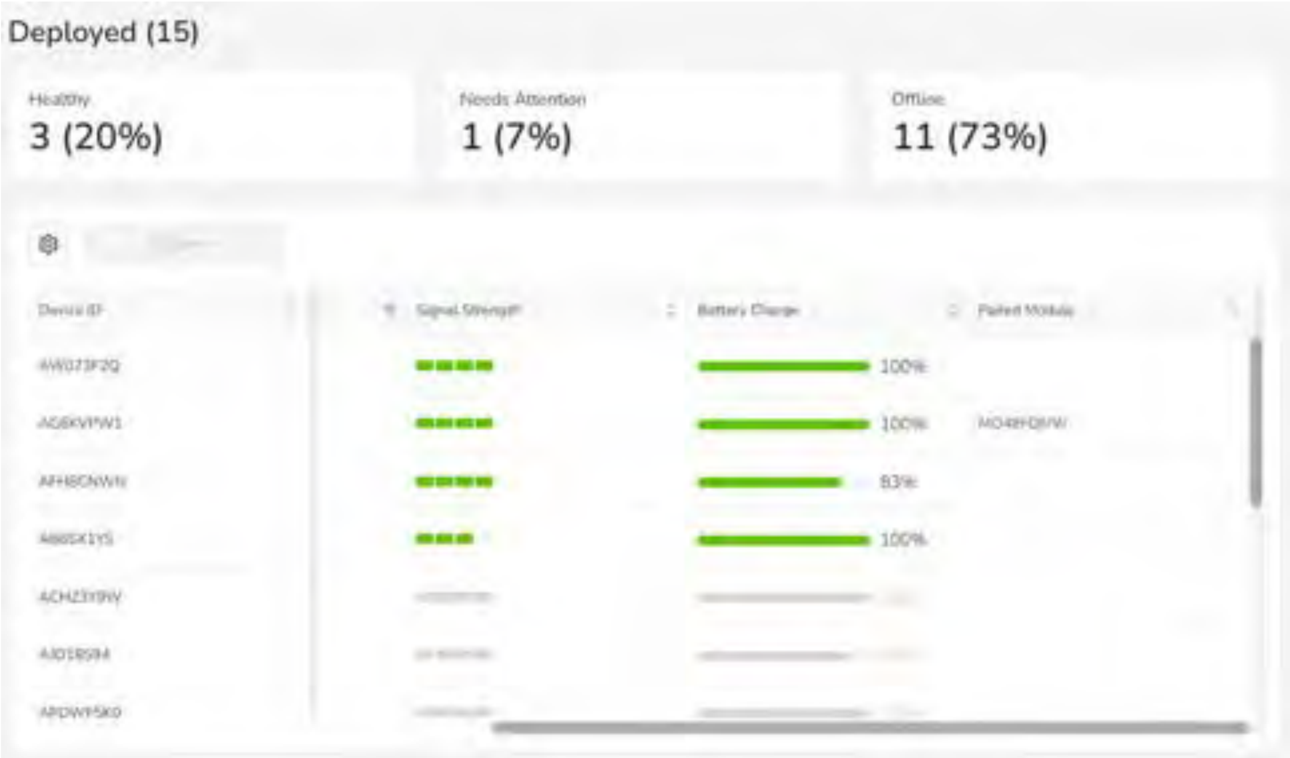
7. You will see a message indicating that device pairing was successful. Continue to assemble and deploy the Module. If you see any errors, contact support@clarity.io for help.



Check Module Status in Dashboard

To check the status of the Module and of the Node that it is paired with, navigate to the **Nodes** page under **Devices**.

Focus your attention on the top table. Here you can search devices by the ID of the Module that it is paired with, you can list all devices paired with a certain Module type, and you can also search a device by its ID and check which Module it is paired with.



Additionally, by selecting a device and clicking **Actions**, you can unpair the device from its Module.

Assemble the Module

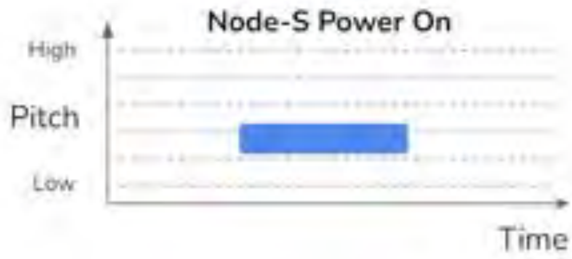
1. Ensure the Clarity Node-S is assembled and configured in Dashboard. If not, please review the Clarity Node-S deployment guide <u>here</u>.
2. Attach the mounting pole to the Wind Module by screwing it into the base of the Module.

3. Tighten the two set screws on either side of the mounting pole using the provided hex screwdriver. Make sure not to overtighten.

4. Plug the cable into the Wind Module and tighten using the knob.

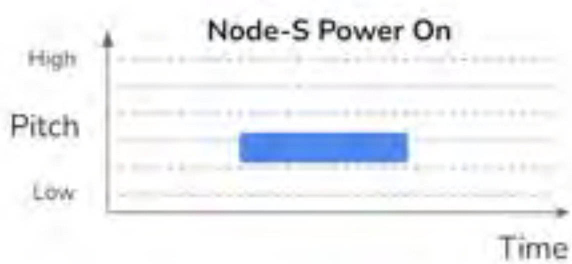
Connect the Module to the Clarity Node-S

1. Ensure the solar panel cable is plugged into the configured Clarity Node-S body. When you plug the cable in, the Node-S will play the Node-S Power On sound and attempt to connect to Clarity Cloud.



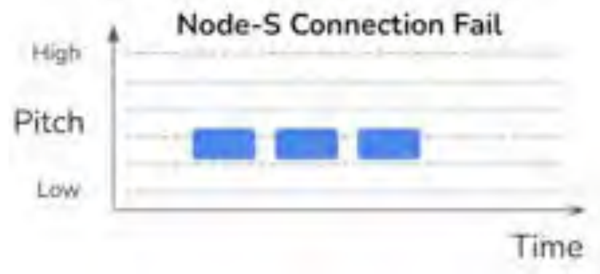
2. Unscrew the cap covering the module port and plug the other end of the Wind Module cable into the Clarity Node-S body by aligning the cable pins and tightening the metal portion of the connector.

3. Once you plug in the Wind Module cable to the Clarity Node-S, you will hear the **Node-S Power On sound** again as the device resets.

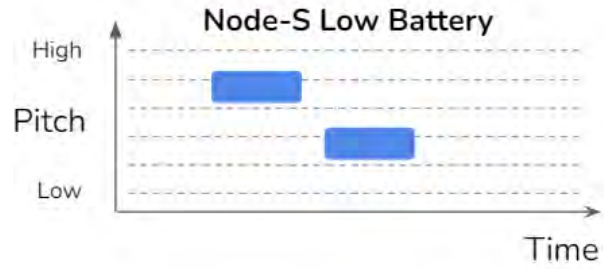


4. Please wait as the Clarity Node-S establishes cellular connection at your site. This may take anywhere from 2-10 minutes depending on signal strength.

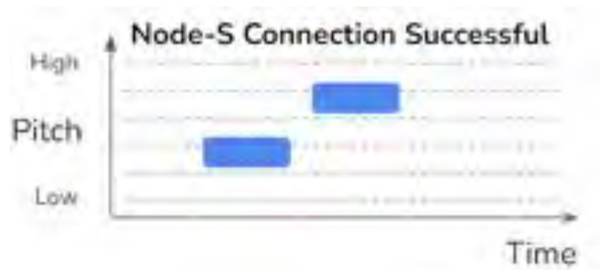
   a. If the node fails to connect, you will hear the Node-S Connection Failure sound. If this happens, please confirm the device has been configured on the Dashboard first. If this doesn't resolve the issue, please contact **support@clarity.io**.



b. If you hear a [Node-S Low Battery sound](), please charge the device for at least 24 hours before proceeding.



c. If the Node-S Connection Successful sound plays, proceed to deploy the device.



After successful connection to Clarity Cloud, the device will attempt to communicate with the module. You will hear one of the following sounds:

a. Successful Module Connection sound, if the module is working properly

b. Failed Module Connection sound, if there are issues communicating with the module. In this case, please check the cable connection between the Clarity Node-S and the Module.

c. Module Configuration Error sound, if Clarity Node-S is not configured properly. Ensure that the module and node are paired in Dashboard, and unplug and replug the Node-S solar panel cable. If this does not resolve the issue, contact support@clarity.io.

Deploy the Node-S + Wind Module in the Field

1. The Clarity Node-S + Wind Module needs to be sited properly to provide valid wind data:

    a. The Wind Module needs to be installed at a site in an open area. It must be clear of obstructions for at least 15m in all directions.

    b. Avoid installing next to trees and tall buildings. Ideally the wind module should be installed as the tallest object in the area, 2m or higher in the air.

    c. Avoid installing next to a high power radar or high power radio transmitter to limit interference.

    d. Ensure the solar panel can receive enough direct sunlight for at least 1 hour a day to keep the device charged.

    e. Additional siting considerations for the Clarity Node-S are available here.

2. After the site has been selected, mount the Clarity Node-S device to the designated pole, wall, or panel.

    a. For making installation easier, you can temporarily detach the wind module cable from the node module port

    b. Use stainless steel zip ties, hose clamps, or screws (not provided).

    c. Ensure the inlet and outlet are facing downwards and unobstructed

    d. Ensure that the cable will be able to reach the Wind Module once it is installed.

    e. More instructions on deploying the Clarity Node-S here.

2. Mount the Wind Module to the designated pole or boom.

    a. If using the provided accessories, align the pole with the mounting pole of the Wind Module

    b. Attach the two U-style screw bolts, and secure each with the provided butterfly screws.

3. **IMPORTANT:** Rotate the wind module to align the triangle mark on its casting to the TRUE NORTH.

    a. The triangle is found on the module's side as shown in the picture below.

    b. The NOAA CrowdMag app (available from Google Play for Android devices or the App Store for iOS devices) provides a quick way to get location-specific declination. While you may also use the CrowdMag app's compass functionality, we recommend only using the app for obtaining the appropriate declination (via either the Compass or WMM tabs at the bottom) and using that declination with a high-precision compass.

2. Reattach the Wind Module cable to the Clarity Node-S body after both devices are securely installed.
3. Listen for the following sounds in succession:

    a. **Node-S Power On sound**

b. Node-S Connection Successful sound

c. Successful Module Connection sound

Wind Module Maintenance

Routine maintenance is minimal as the Wind Module has no moving parts:

- If there is dust on the device, you may use a soft cloth to gently wipe the unit. DO NOT use any cleaning solutions. Avoid scratching the surface of the instrument.
- If ice or snow accumulates, allow the ice or snow to naturally melt. DO NOT use tools to forcibly remove which may damage the unit.

Was this article helpful? Yes No

Related articles

Troubleshooting Accessory Module Alarms

Black Carbon Module maintenance

Ozone Module maintenance

Finding true north to align the Wind Module

Wind Module maintenance

Article

October 19, 2021

Air Quality Measurements Series: Wind Speed and Direction

Air Quality   Air Quality Measurement Series

TL;DR — Data on wind speed and direction are an integral part of understanding the complete picture of air pollution. Wind can move air pollution away from its original source, both locally and on global scales, and accounts for historical patterns of air pollution disparities according to prevailing wind patterns. Understanding wind speed and direction can help pinpoint air pollution sources, allowing for more informed decisions to better protect human and environmental health.

How wind originates and its patterns around the globe

While wind is not an air pollutant, wind speed and direction data are essential measurements to collect when looking to understand air quality dynamics in a given region. Wind plays an important role in the movement and dispersion of air pollution — you can think of wind speed and direction data as a map of the air quality “landscape”, providing information on where air pollution originates and where it is prone to travel.

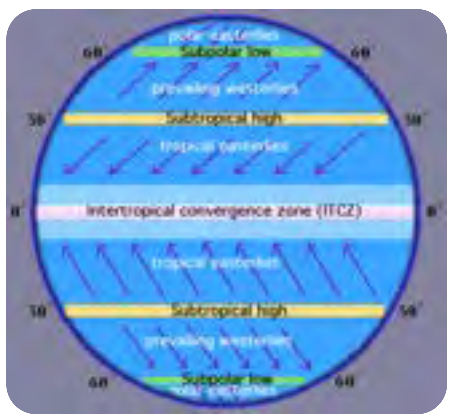
Wind itself is simply the movement of air, arising as a result of climatic and weather patterns that cause differences in air pressure. Pockets of warmer and colder air form as sunlight hits the earth, unevenly warming the air due to various geographical features on Earth’s surface and the varying angles at which the sunlight strikes.

Temperature changes in the air cause pressure differences, as warm air rises and leaves an area of low pressure behind it. In lower pressure areas, gases in the air are less dense. Due to the principle of diffusion, gases move from areas of high pressure to low pressure. The greater the difference in the pressure between two areas, the faster the gases will move, creating wind.

On a larger scale, different wind patterns occur in different environments and geographical regions. Sea breezes commonly occur because inland areas heat up on sunny days, warming the air above the land. The cooler air above the sea then moves inland through diffusion, creating a breeze.

Similar patterns occur on a global scale, creating far-reaching wind patterns such as trade winds. In tropical areas which always remain warm, the air heats up, rises, and spreads north and south high above the land. Lower in the atmosphere, the cooler air from the north and south are pulled in towards the tropics.

Due to the Coriolis effect, moving masses of air tend to curve due to the Earth's rotation, thus causing trade winds. Winds from the northeast in the northern hemisphere and from the southeast in the southern hemisphere converge near the equator.



A variety of wind patterns occur across the globe in different latitudinal zones. These winds include westerlies, tropical easterlies, and polar easterlies, among others. Near the equator, the intertropical convergence zone (ITCZ), where the northeast and southwest trade winds converge from their respective hemispheres, is an area known to have relatively windless weather. (Image source: University of California, San Diego)

The trends of air movement around the globe also cause unevenly distributed wind patterns. Westerlies, one notable wind pattern, occur because surface winds that would otherwise blow towards the poles are bent by the Coriolis effect in the perpendicular direction. The westerlies explain why so many weather events in the United States and other regions at this latitude come from the west. Easterlies prevail at high latitudes where cold winds that would otherwise blow towards the equator are bent by the Coriolis effect, producing polar winds.

Geographic features on the Earth's surface also affect wind and resulting air quality. Coastal areas or regions with few geographic features obstructing air tend to experience more windy weather, and thus, better air quality because the wind carries away much of the air pollution that may have originated in the area.

Other weather conditions also play a role in how wind relates to air quality. In a high-pressure system, air tends to be more still, allowing greater concentrations of air pollutants to build up. In low-pressure systems, wet and windy conditions cause air pollutants to be dispersed or washed out of the atmosphere by rain.

How wind is linked to air pollution

Wind carries air pollutants away from their original source and can disperse them elsewhere, meaning that pollution in one area can affect air quality in an extensive area. During the wildfire season of 2021, smoke from fires in California and Oregon was carried by wind to states as far as New Jersey, New York, and Pennsylvania, creating unhealthy air quality conditions thousands of miles away from the pollution source.

Higher wind speeds generally translate to a greater dispersion of air pollutants, resulting in lower air pollution concentrations in areas with stronger winds. As the ground heats up during the day, the air generally becomes more turbulent, causing air pollutants to disperse in the air. When the air is cooler at night, more stable conditions occur, causing pollutants to tend to disperse less.

Wind disperses the air pollution formed from both natural and anthropogenic activities. Air pollutants that travel higher up into the air can also react to form other types of pollutants. For example, sulfur dioxide and nitrous oxides emitted from upwind sources can undergo chemical reactions in the atmosphere to form particulate matter, and nitrous oxides may also react to form ground-level ozone, or smog. Even though wind may move air pollutants to another geographic location, these pollutants still threaten human and environmental health wherever they settle. (Image source: National Park Service)

TABLE OF CONTENTS

Understanding wind speed and direction helps to pinpoint the sources and forecast the trends of air pollution in a given area. When wind carries air pollution away from its source it can appear that there are lower levels of pollution coming from this source, but this pollution has just been moved elsewhere, affecting air quality in a different location.

One such wind pattern explains why a large number of cities tend to have poorer east ends with greater air pollution. In middle latitudes on Earth — where most of the world's major cities can be found — the wind pattern known as westerlies blows air eastwards. A study shows evidence that these westerlies have tended to blow air pollution eastward, creating eastern sections of cities with greater air pollution, which has been historically tied to sections where individuals with lower socioeconomic status would live.

The way wind can distribute air pollution elsewhere is an important factor when it comes to looking at air pollution levels in a certain city or state. Measured pollutant levels there can reflect not only the pollutants originating there, but also those brought to the area from outside sources by wind, especially when considering whether the location is downwind from a significant pollutant source. Pollutants can travel hundreds of miles, which can make it hard for downwind states to meet standards for pollutants like PM2.5 and ozone — in fact, it is estimated that air pollution carried across the Pacific Ocean from Asia by prevailing westerlies has contributed to as much as 65 percent of an increase in ozone in the Western United States in recent years.

A variety of winds and wind patterns differentiate the way air pollution is moved throughout the world, making wind speed and direction measurement vital to truly understanding the complex dynamics of air pollutant creation and dispersion. To understand the significant human health and environmental impacts that come from pollutants moved by wind, read our recent blogs on particulate matter blog and nitrogen dioxide.

When wind must be measured

Because wind speed and direction provide important information about air pollution concentration and movement, certain operations require that wind be measured. The USEPA requires that regulatory air quality management agencies process certain meteorological data — such as wind speed and direction — in support of regulatory air quality modeling as specified in the Guideline on Air Quality Models.

In addition, many industrial operations such as power plants and mining facilities use anemometer technology to ensure that they can know how air pollution generated from industrial activities will be dispersed.

For example, in the United States, the Mine Safety and Health Administration (MSHA), which operates under the United States Department of Labor, includes an airflow requirement in their safety regulations. MSHA requires mining operations to ensure that wind speed is high enough to provide airflow — especially of harmful air pollutants like carbon monoxide (CO) that can be present — and that wind speed into the mine does not exceed a maximum air velocity of 500 feet per minute, unless the mine ventilation plan can specifically accommodate it.

In other countries, such as Australia, mine airflow has been considered an important factor when looking at how to ensure safety for mining operations. In Queensland, safety legislation requires sufficient ventilation of mining operations to remove air pollutants from the air that workers breathe within the mines.

Whether or not it is required to collect wind speed and direction data from a regulatory standpoint, wind speed and direction are nonetheless important considerations when looking to better understand air quality trends and minimize exposure to harmful air pollution.

How wind speed and direction are measured

The primary device used to measure wind speed and direction is known as an anemometer. The most common design for anemometers involves three or four cups attached to horizontal arms, which are then attached to a vertical rod.

As the wind blows, the cups rotate, making the rod spin and indicating the wind direction. By counting how many rotations occur each time period, the anemometer can be used to calculate wind speed. Anemometers — such as the Clarity Wind Module, pictured below — can also often provide other meteorological measurements such as temperature, humidity, and air pressure.

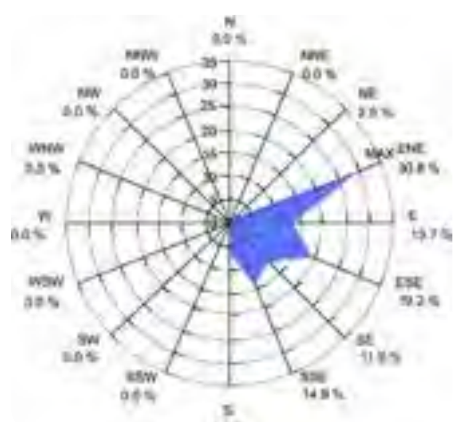
There are variations of anemometer design, such as a windmill type where the rods rotate horizontally, as well as a hot-wire anemometer, where an electrically heated wire is used to determine wind speed by calculating the amount of power needed to keep the wire hot — higher wind speed means more power is needed.

Air pressure can also be measured to determine wind speed. A barometer can be used, while there are also tube anemometers that use air pressure to determine the wind pressure and, thus, speed. By measuring the air pressure inside a glass tube that is closed on one end, and then comparing it to the air pressure outside the tube, wind pressure and speed can be calculated.

Other anemometers may use sound waves or shine laser beams onto particles in the wind to measure the properties of wind. Other types of technology, like wind socks and weather vanes, also exist for this purpose.

Wind speed is generally communicated using either miles per hour (mph), kilometers per hour (kph), or knots, where one knot is the equivalent to one nautical mile per hour, or 1.15 land miles per hour.

Wind direction is reported according to what direction it originates from — for example, a north wind blows from north to south. Winds are usually reported using either cardinal directions, or degrees of direction, and can be visualized using wind roses.



The wind rose above shows wind speed and direction measured as part of a study in Havana City, Cuba. The blue form displays the direction of the wind according and the amount that the blue shape extends from the center relates to its magnitude. (Image source)

The Clarity Dashboard employs wind roses to visualize your wind speed and direction data

Why air quality monitoring networks should collect data on wind speed and direction

Wind speed and direction can be useful measurements in a variety of air quality-related activities. As previously discussed, wind speed and direction can help make sense of where air pollution is moving. If a monitoring station detects high levels of air pollution, air quality managers can look at the wind speed and direction to determine possible pollution sources. Conversely, wind can be used to understand why there may be lower levels of air pollution near a pollutant source if the prevailing wind has carried it elsewhere, such as from a combustion plant.

Anemometers are used frequently in industrial plants and mining operations to measure how air pollution originating from the site is affecting air quality elsewhere, in terms of both the speed and direction that it is being carried away. Air pollution carried from other pollutants sources, such as the particulate matter from large combustion plants, has also been studied in relation to how wind moves the resulting air pollution.

Knowing how air pollution is moving can help drive the appropriate actions to take to protect human and environmental health.

Include wind speed and direction measurements in your Clarity network

Clarity is thrilled to have recently introduced our Wind Module, an ultrasonic anemometer and weather station. This lightweight and durable sensor measures the 2-dimensional horizontal components of wind speed and direction, providing you better insight into where air pollution is coming from — and where it is headed.

The Wind Module also measures atmospheric pressure, ambient temperature, and ambient relative humidity — you can visit the Wind Module product page on our website to download a specification sheet or request a quote.

Datasource Management on Dashboard

How to use Datasources to keep air quality monitoring data organized.

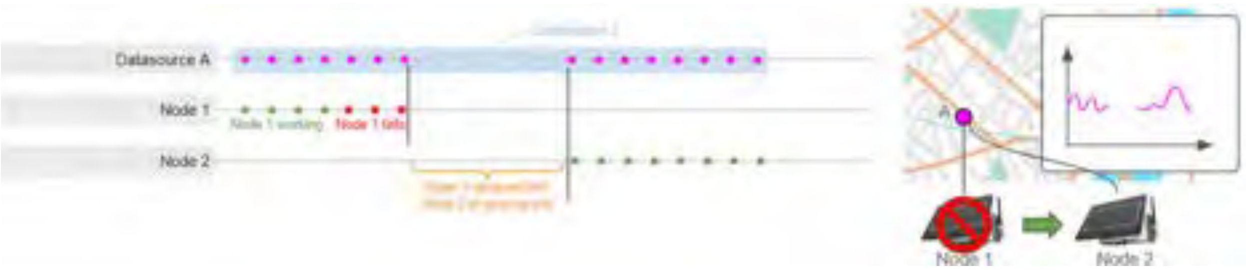
What is a Datasource?

A Datasource is a continuous stream of air quality measurements. It's connected to a source Device - a Clarity Node or a Reference Monitor - which feeds the measurements into the stream. Each Datasource is organized with Annotations - such as names, groups, and tags - to help identify and categorize the data. Accessing this data stream requires a Subscription.

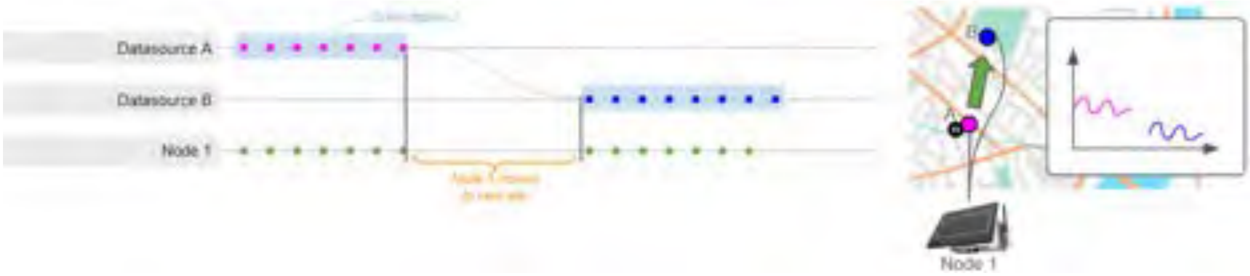
Why are Datasources useful?

Datasources add a layer of flexibility to air quality monitoring by supporting:

- Device Replacement: You can preserve a continuous data stream from a site, even when devices are swapped out due to wear or malfunction. This ensures long-term monitoring data remains unified, regardless of device changes.

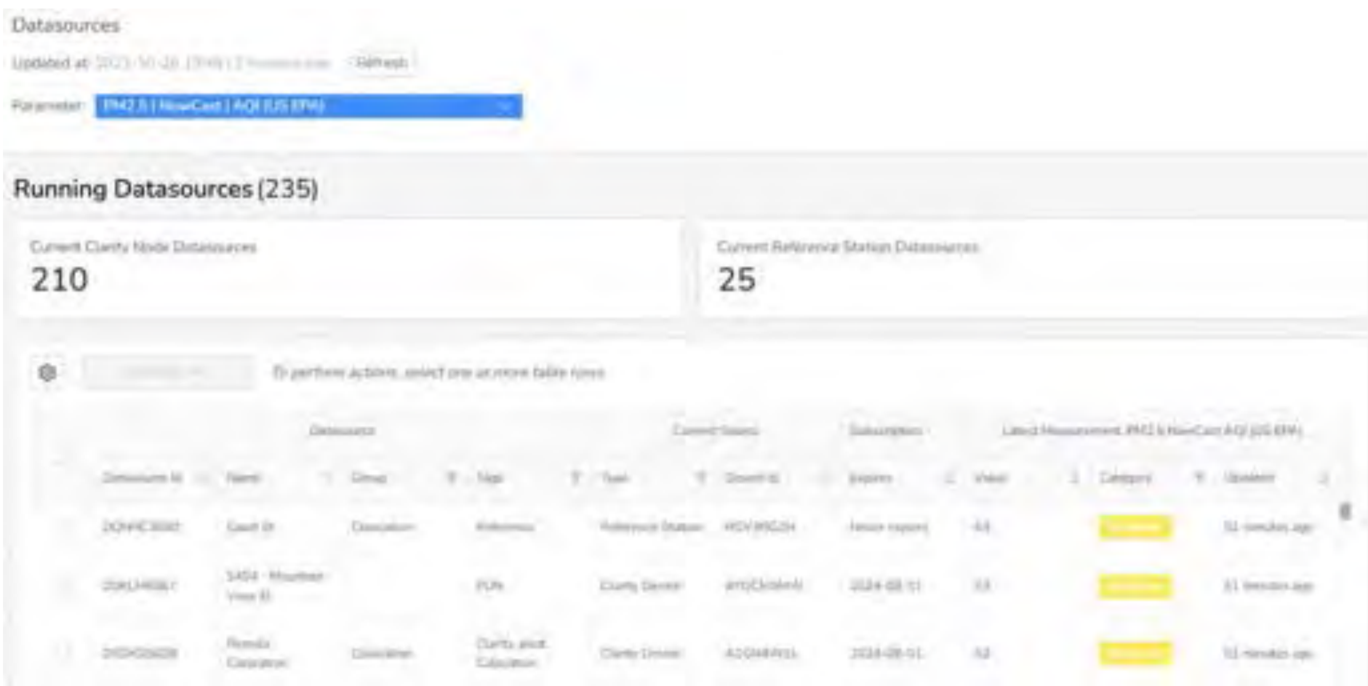


- Device Relocation: When you move a device to a new site, you can choose to either continue feeding data into the existing Datasource or start a new one. This allows you to keep data from different sites separate and organized.



Running Datasources

A Running Datasource is a Datasources with a Node currently streaming measurements to it. Each row in the running Datasources table holds the Datasource ID, its name/group/tags, its current source Device information, the expiration date for the Subscription granting your Organization access to its data, and its latest measurement for the parameter selected at the top of the page.



Stopped Datasources

A stopped Datasource is a Datasource without a Node currently streaming measurements to it. It acts an archive of historical measurements, and can be resumed when desired.

How do I manage my Datasources?

Datasources are managed indirectly, as a consequence of your Node management actions. Here's how to handle different scenarios:

- **Starting a new Datasource:** Configuring a Node from your inventory automatically generates a new Datasource. It appears in the "Running Datasources" table, ready to stream data in real time.
- **Archiving a Datasource:** Performing the "Stop recording data" action on a Node stops its associated Datasource. This Datasource then moves to the "Stopped Datasources" table, where it keeps historical data available for future reference without active monitoring.
- **Moving monitoring to a new site:**
    - **Starting fresh with a new Datasource:** To create a new data stream for a different site perform the following actions:
        - On Dashboard, Stop recording data for the Node you plan to relocate.
        - On the field, retrieve the Node. As you do that, make sure to unplug the solar panel or power adapter to turn off the Node and avoid depleting its battery. If needed, charge the Node battery overnight before relocating it. Finally, install the Node at the new monitoring site.
        - On Dashboard, reconfigure the Node at the new location.

      By performing these actions, the original Datasource moves to the "Stopped Datasources" table, while a new Datasource begins in the "Running Datasources" table, ensuring clear separation of data from different sites.

    - **Continuing with the same Datasource:** If you are tuning a Node's location at the same monitoring site, or if you're relocating a Node but want to maintain the same Datasource, simply edit the Node's configuration. The data stream will continue without interruption in the "Running Datasources" table.

- **Resuming monitoring at a previous site**: To resume monitoring at a previously monitored site, navigate to the “Stopped Datasources” table and select the Datasource corresponding to the site. Click on the "Resume" action, then choose either the original Node or a different one from your inventory for activation. Upon selection, the Datasource will move from "Stopped Datasources" to "Running Datasources," and the chosen Node will become configured and begin streaming fresh data to it automatically.

- **Replacing a Node while continuing monitoring at a site:** To replace a Node due to faults or end of its operational life while maintaining a continuous stream of data, utilize the "Replace Node" action. This procedure ensures that data from the site continues to flow to the same Datasource, seamlessly swapping out the monitoring Node.

- **Reference Monitor Datasources:** Clarity Cloud automatically manages these. When a Reference Monitor near your Node becomes available, its Datasource is integrated into your organization, enhancing your data collection capabilities.

Other Datasource Actions

To perform an action, select a Datasource by clicking on a table row and click on the Blue Actions button. Most of the actions below can also be performed on a batch of Datasources. To do that, just select multiple Datasources in the table by clicking on the checkmarks.

About Datasource

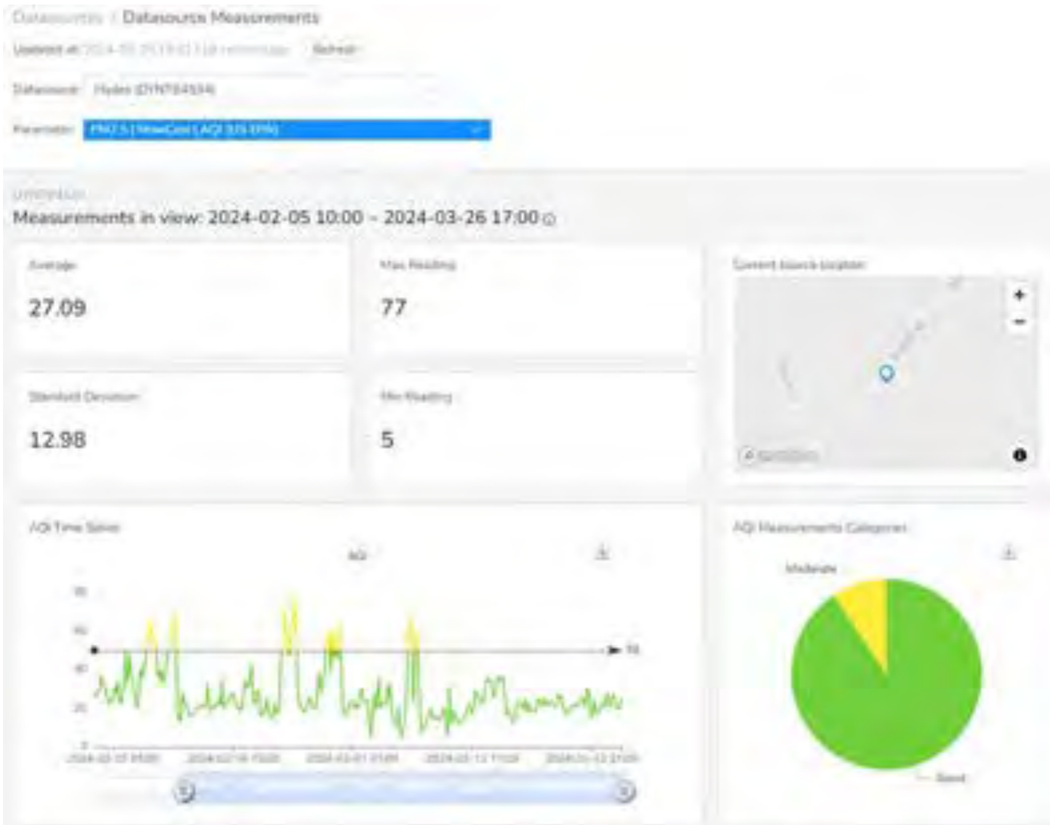
Clicking on About Datasource navigates to a page where you can see everything there is to know about the datasource:

- Licensed indicates that you are the owner of the Subscription
- Shared indicates that another Organization is sharing the data with you
- If a Datasource is shared, you can see who is sharing the data or who you are sharing the data with
- Source of measurements indicates which Clarity Node or Reference Station is currently generating the measurements

- Open data reflects whether the data is visible on OpenMap
- Organization Admins who own the data subscription are able to make the Datasource visible on OpenMap

View Measurements

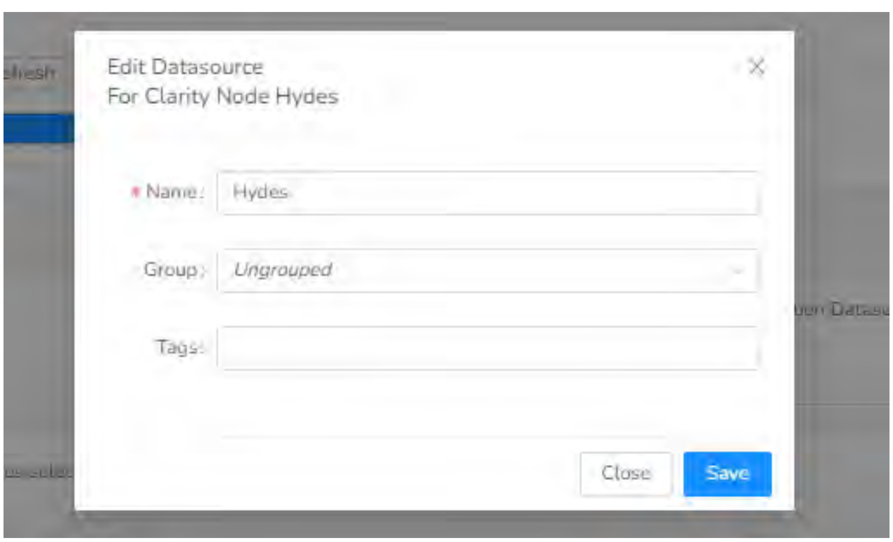
Clicking on View Measurements navigates to a page where you can visualize recent measurements and see some useful statistics.



Edit Name, Group, Tags

Clicking Edit Name, Group, Tags opens a modal that allows you to modify Datasource annotations. Keep annotations up to date to make it easier to search for Datasources across your organization

***Note**: please avoid naming Datasources the ID of the Clarity Node, as it will create confusion in case of Node replacement.*



Download Measurements

Clicking on Download Measurements allows you to download Datasource measurements as described here.

Was this article helpful? Yes No

Related articles

Finding Your API Key on Dashboard

Managing a Guest's access to resources on Dashboard

Managing your Organization's Users

Checking Node-S and Accessory Module compatibility on Dashboard

Clarity Dashboard User roles and permissions walkthrough

Announcement

October 17, 2024

Automated QC Assessment and QC Flags now available for Clarity API and historical reports!

Calibration & QA/QC

Communicating Data

NSIM (Non-regulatory Supplemental and Informational Monitoring)

TABLE OF CONTENTS

We're excited to announce that our Quality Control (QC) Assessment and QC Flags features, previously available on the Clarity Dashboard, are now fully integrated into our Air Monitoring API and historical report downloads in the Clarity Dashboard. This enhancement reinforces Clarity's commitment to delivering not just data, but data you can trust.

Earlier this year we launched automated QC features that identify and flag questionable air quality measurements directly on the Dashboard using red diamonds, making it easy to filter out invalid air quality measurements. This ensures that Clarity users can focus their analyses and data sharing on valid data.

Since then, many users of our air quality measurement equipment have asked when these QC features will be available on our API and Dashboard report downloads — that time has come.

Recap: What are QC Flags and QC assessment?

Back in July, we introduced automated QC tools designed to ensure the integrity and reliability of your air quality data. The QC flags are applied to measurements that meet specific criteria based on our in-depth understanding of air pollution, sensor technology, and known failure modes.

Each flagged measurement is then assessed, and if deemed invalid, it's clearly marked for further review. For our users, this feature provides transparency and control over the data, ensuring you only work with information you can trust. For more information about our QC procedures, visit the Clarity Knowledge Base.

What's new: Access QC information through API and reports

Starting today, QC flags and QC assessments are accessible via the Clarity API and can be included in your downloaded historical reports. This expansion gives you the ability to programmatically retrieve and review the quality status of each data point — so that you can easily exclude invalid data from your offline reports and analyses.

Why is quality control important for your air quality data?

Providing QC information through the API and report downloads allows for a more flexible and comprehensive data experience. You'll now have consistent access to quality-assessed data across all formats.

This ensures that you work with only the most accurate air quality data from your Clarity devices, whether visualizing trends on the Dashboard, pulling historical reports to conduct in-depth analyses in

Python or R, or sharing your air quality measurements publicly via API integration.

How to get started with automated QC control

a. **API Access**: To access QC information via the API, check out our updated API documentation, which includes detailed instructions on querying QC flags and QC assessment for your measurements.

Clarity's Air Monitoring API now includes the ability to query QC flags and QC assessment for your air quality measurements, so you can incorporate Clarity's automated QC features into custom air quality maps, apps and reports.

b. **Historical Reports**: When downloading historical reports from the Clarity Dashboard, you'll now see an option to include QC flags and QC assessment, providing you with comprehensive data quality insights directly in your CSV files.

Historical reports on the Clarity Dashboard now provide the option to include QC assessment and flags, providing you with better visibility of the validity of measurements.

Air quality data you can trust

The integration of QC features into our API and report downloads is a key milestone in our mission to empower users with trustworthy air quality data. By expanding our QC capabilities beyond the Dashboard, we aim to provide better tools to our customer organizations to deliver top-tier air quality information to their community members and stakeholders.

Thank you for your continued feedback and support as we work to enhance our platform. Stay tuned for more updates as we continue to innovate and provide the highest-quality air monitoring solutions in the industry. For more details on how QC flags work, visit the Clarity Knowledge Base.

As always, feel free to reach out to our team if you have any questions or need support navigating these

ATMO® TUBE PRO

Reviewer’s Guide

What is Atmotube Pro?

Atmotube PRO is our most advanced solution for both indoor and outdoor air quality tracking.

Atmotube PRO is a wearable, portable device that continuously monitors air quality in real time and alerts you when it gets unsafe.

Atmotube PRO tracks Volatile Organic Compounds (VOCs), just like Atmotube Plus, but also detects PM1, PM2.5, and PM10 pollutants, such as dust, pollen, soot, and mold.

VOLATILE ORGANIC COMPOUNDS

PARTICULATE MATTER 1µg

PARTICULATE MATTER 2.5µg

PARTICULATE MATTER 10µg

HUMIDITY

TEMPERATURE

ATMOSPHERIC PRESSURE

ALTIMETER

Why care about PM and VOCs in the air?

The average person takes over 20,000 breaths per day. Most of the time, we never think about WHAT we breathe in and how air quality affects our bodies.

Office equipment, paints and lacquers, cleaning supplies, and furnishings often emit Volatile Organic Compounds (VOCs). These gases can have adverse short and long-term health effects on our respiratory systems. Over time, exposure to VOCs has been linked to an increased risk of heart disease, stroke, liver and brain damage, and even cancer.

Particulate matter is a mixture of tiny particles and droplets made up of dirt, dust, soot, smoke, and liquid compounds that pollute the air. The ingredients can vary by season (for example, soot and smoke from wood fires, which are more common in winter, are a source of particulate matter).

When you inhale particle matter, it can harm your lungs, especially if you already have chronic lung disease or asthma. Particulate matter can even cause heart attacks, lung cancer, and low birth weight in babies. Exposure to this type of air pollution often leads to eye and throat irritation.

Particle matter typically consists of nitrates, sulfates, organic chemicals, metals, and soil or dust particles.

With Atmotube PRO, you can easily monitor the air you breathe and and take steps to mitigate dangerous exposure before it's too late.

How do particles affect the human body?

We're sure you have heard about air pollution. It's a major issue worldwide today and is mostly caused by very small particles in the air known as particulate matter (PM)

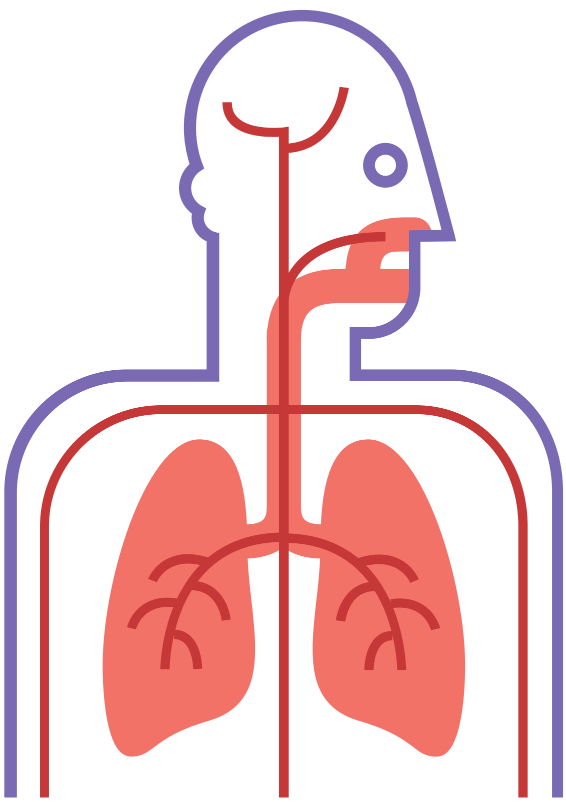
Particulate Matter (PM), also known as soot, is made of microscopic solid particles or liquid droplets that are either emitted directly into the air or formed by pollutants that combine in the atmosphere. PM is usually measured in three size ranges, which are the most harmful to health: PM10, PM2.5, and PM1.

PM10 or coarse dust particles refer to particles with a diameter less than or equal to 10 microns in size. They are about 30 times smaller than the width of a human hair and are small enough to evade our defensive nose hairs and get inhaled into our lungs. Sources of this PM10 include crushing/grinding operations, and dust stirred up by vehicles. Pollen, mold, and plant and insect particles are also considered PM10. Finally, the evaporation of sea spray can also produce large particles in coastal areas.
Dangerous level: 125 µg/m3 (microgram per cubic meter) or more.

PM2.5 or fine particles are 2.5 micrometers in diameter or smaller. Fine particles are produced from all types of combustion, including motor vehicles, power plants, residential wood burning, wildfires, agricultural burning, and some industrial processes. While PM10 ends up in your lungs, PM2.5 is more dangerous as it can transfer from your lungs into your bloodstream. From your bloodstream, it can it end up anywhere in your body, thereby making it **"the invisible killer"**.
Dangerous level: 90 µg/m3 or more.

PM1 – particulate matter with a diameter smaller than 1 micron – is a major subset of PM2.5. These are extremely fine particles that are even more likely to reach deeper into the respiratory system than PM2.5. PM1 is the by-product of emissions from factories, vehicular pollution, construction activities, and road dust. It is not dispersed and stays suspended in the air that you breathe.
Dangerous level: 61 µg/m3 or more.

THE SMALLER THE PARTICLES, THE MORE DANGEROUS THEY ARE



Atmotube: a closer look

CARABINER MOUNT
Elegant and functional solution for carabiner clip

RGB LED
Multicolored LED shows different statuses of Atmotube PRO

BUTTON
The button gives you an opportunity to see current Air Quality Score indication on the LED

AIRFLOW MESH
This is where Atmotube PRO- gets the Air from

On-device notification

The color of Atmotube's LED indicates the current Air Quality Score (AQS), from red (extremely poor) to blue (very clean). Press the button once and the LED will show the current AQS.

- **GOOD**
- **MODERATE**
- **POLLUTED**
- **VERY POLLUTED**
- **SEVERELY POLLUTED**

Setting up Atmotube PRO

1 Connect Atmotube to any USB power source with the supplied USB Type-C cable. The orange LED means Atmotube is turned on and charging.

Atmotube start measuring 4 minutes after it's turned on.

Note: Atmotube is fully charged once the LED changes from orange to green.

2 Install the Atmotube app. It's free on the App Store and the Google Play store. It supports devices running iOS 9+ and Android 4.3+ with Bluetooth LE support.

Download to iOS

Download to Android

How to use Atmotube PRO

3 Once you open the app, press Connect.

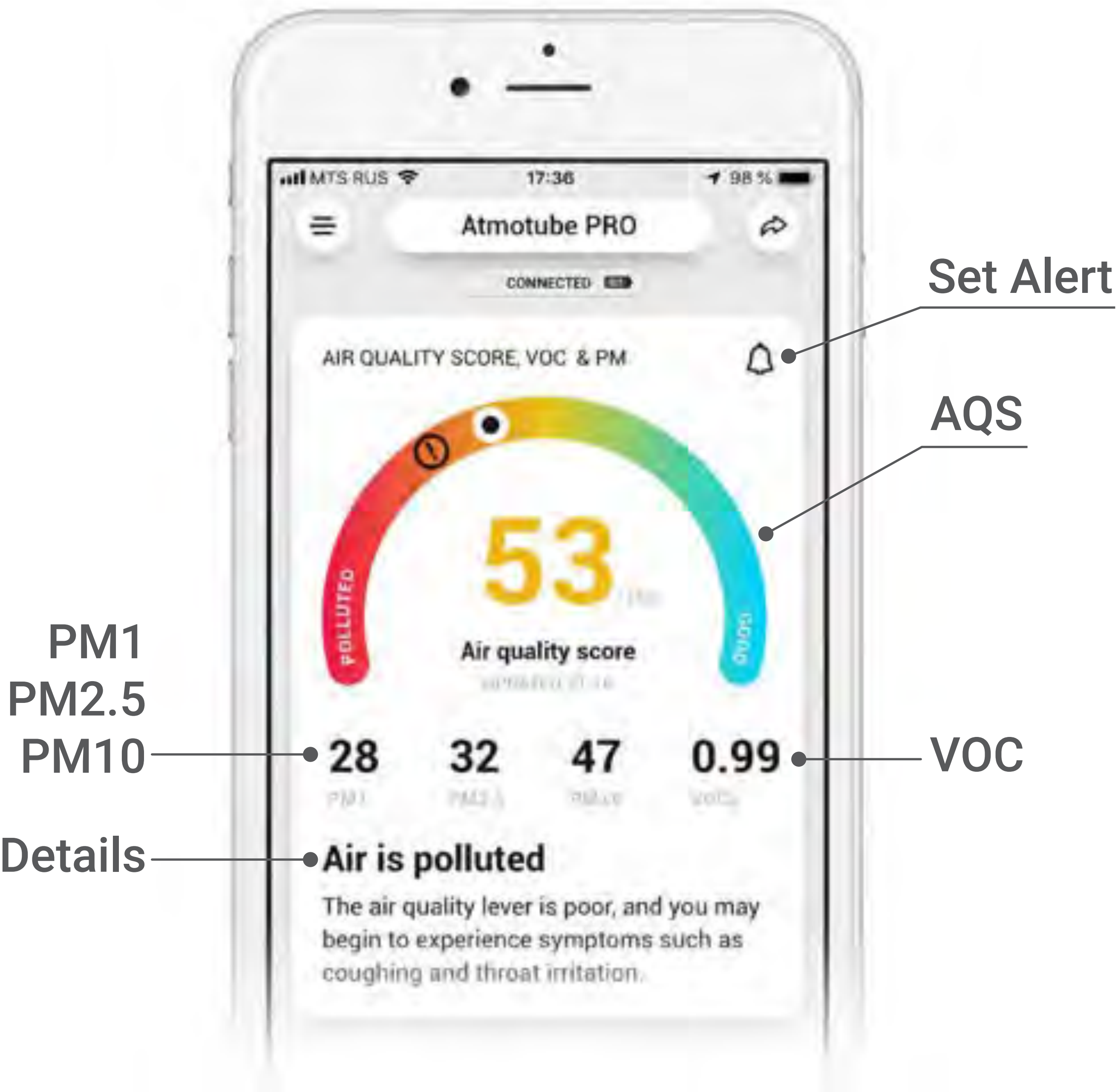
4 Choose your Atmotube from the list of devices and you are all set.

5 Observe the air quality score.

The device starts measuring air quality immediately but will get more accurate after the first 12 hours. Proper calibration takes time.

How to use Atmotube PRO

The Air Quality Score (AQS) is the first thing you see in the app. It provides an instantaneous reading of air quality near the device which combines VOCs and PM. The AQS varies between 0 (extremely poor) to 100 (very clean).



The Atmotube app

Barometer & Altimeter

Atmotube PRO includes a barometric pressure sensor which provides real-time information and alerts for those who are sensitive to weather changes.

Temperature & Humidity

Atmotube lets you monitor real-time the temperature and humidity so you can stay in your comfort zone and feel better.

Measurements History

Atmotube keeps tracking air quality even when your smartphone is disconnected from the device. Once Atmotube reconnects, your smartphone will download the missing data.

Air Quality Map

With our users' permission, we store anonymous, aggregated environmental data in the cloud to update and share a global air quality map that's free to use.

Each Atmotube contributes to global air pollution awareness in addition to being a potential lifesaver for you and your family.

Tech specs

- LED: Multi-color, RGB
- Casing: Polycarbonate plastic + Aluminum holder
- Radios: Bluetooth Low Energy (BLE 5.0)
- Sensors:
    VOC sensor
    PM1/PM2.5/PM10 sensor
    Temperature, Humidity, and Pressure sensor
- Ports: USB Type-C
- Battery: Non-removable, rechargeable
- Li-Polymer (2000 mAh)
- Weight: 105 grams (3.7 oz)
- Dimensions: 86x50x22 mm (3.3x1.9x0.8 inch)

Resources

Website: https://atmotube.com/
Facebook: https://www.facebook.com/atmotube
Instagram: https://www.instagram.com/atmotube/
Twitter: https://twitter.com/atmotube

Technical

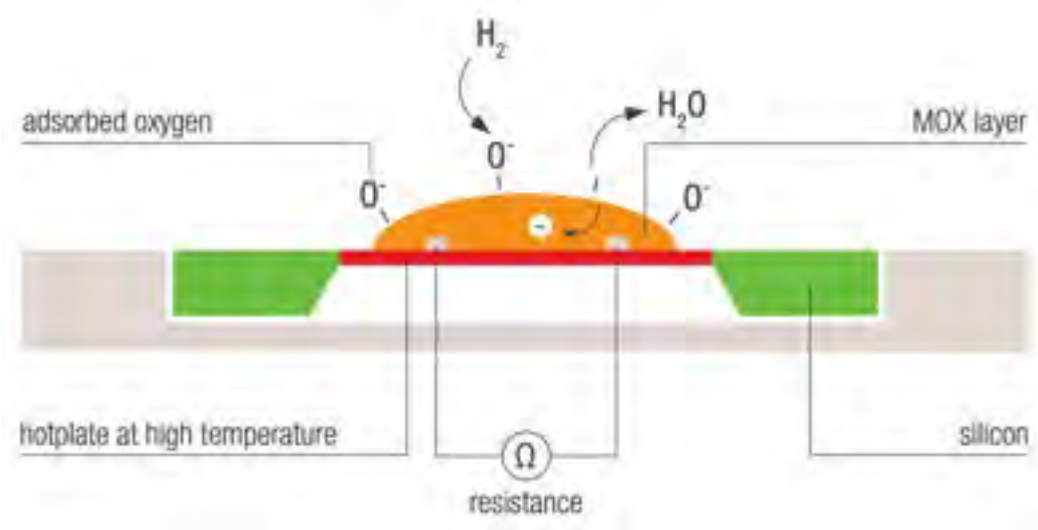
How does Atmotube VOC sensor work?

Atmotube constantly monitors air pollution in real time. We utilize a MOx-based (metal-oxide) VOC sensors in our products, which change conductivity at gas exposure, and these changes can be externally measured and analyzed.

Atmotube Version	VOC sensor model	Type	Manufacturer	Datasheet
Atmotube PLUS	Sensirion SGPC3	Digital	sensirion.com	Download
Atmotube PRO				

Measurement Principle

The sensing principle is based on a heated film of metal-oxide (MOx) nanoparticles. Adsorbed oxygen on the metal-oxide particles reacts with the target gas and thereby releases electrons. This results in a change of the electrical resistance of the metal-oxide layer that is measured by the sensor.



Atmotube VOC gas sensor is responsive to a broad range of volatile organic compounds (VOC) and other gases relevant for indoor air quality, the present gas sensing technology is well suited for monitoring TVOC concentrations and for translating those into IAQ levels. Each Atmotube VOC sensor is production calibrated.

Measurement Range and Accuracy

TVOC output range	0 - 60 ppm
Typical accuracy	15% of measured value
Measurements interval	2 seconds

TVOC Concept

The term total VOC (TVOC) refers to the total concentration of VOCs present simultaneously in the air. The TVOC concept is used as a practical time and cost-effective method of surveying indoor environments for contamination. Global consensus has resulted in the emergence of guidelines for TVOC standards of indoor air quality (IAQ) issued by governmental organizations in different countries (e.g. Australia, Finland, Germany, Hong Kong, Japan).

Recommended TVOC levels of IAQ that are considered acceptable range from 0.6 to 1 mg/m^3.

See "Standards for Indoor Air Quality (IAQ)".

ISO16000-29 Test Gases for VOC Detectors

The ISO norm for indoor air quality IS016000-29 provides standardized test methods for metal oxide based VOC detectors. The norm compares a simulated VOC mixed gas, with more than 40 individual constituents, to three different test gases. Listed test gases for TVOC are toluene, a two kinds of VOC mixed gas (listed in Table below) and six kinds of VOC mixed gas.

VOC group/class	Representative	Mixing ratio
Saturated hydrocarbon Aliphatic hydrocarbon	n-octane	53%
Unsaturated hydrocarbon Aliphatic hydrocarbon	m-xylene	47%

Two kinds of VOC mixed gas is composed of n-octane and m-xylene, representing the two VOC classes of saturated and unsaturated hydrocarbons, respectively.

According to the ISO norm, the difference of indications between the simulated VOC mixed gas (more than 40 individual constituents) and the three different test gases toluene, the two kinds of VOC mixed gas, and the six kinds of VOC mixed gas are -18.1%, -1.6% and -0.46%, respectively. Considering realibility and lower costs of mixed gases with less components, the ISO norm quotes that "the most suitable test gas for metal oxide semiconductor detectors is the two kinds of VOC mix".

> **According to ISO16000-29, the six kinds of VOC mix is based on the idea, that VOC can be classified into seven kinds of groups, i.e. aromatic**

hydrocarbon, aliphatic hydrocarbon, terpene, halide, ester, ketone and aldehyde. Note that aldehyde is omitted due to a poor stability. For each of the other six groups, one representative was chosen, such as toluene, n-decane, αpinene, p-dichlorobenzene, butyl acetate and methyl i-butyl ketone.

Ref.: Indoor air – test methods for VOC detectors, ISO16000-29:2104(E).

Calibration of Atmotube TVOC Sensor

The Sensirion SGP is a broadband VOC detector, which is capable of detecting various VOCs and therefore TVOC. Sensirion's SGP gas sensors are calibrated using ethanol since ethanol serves as a stable, reliable and economical proxy for TVOC. This is verified by linking the SGP sensor response to ethanol with the response to the ISO normed two kinds of VOC mix (see Table above). According to the ISO norm for indoor air quality, this two kinds of VOC mixed gas is a suitable test gas for simulating ambient TVOC concentrations.

Image below illustrates production/calibration, verification and application of SGP TVOC sensors.

SGP sensors are calibrated with ethanol, which serves as a reliable and economical proxy for TVOC. This can be verified by comparison between the reponse of the SGP to ethanol and to an ISO normed two kinds of VOC gas mix that represents TVOC. Within a large target gas concentration range, the SGP reveals a similar gain for both of those target gas compounds (compare similar slopes in Figure below). That allows for calibration and testing with ethanol in production regarding real life TVOC applications.

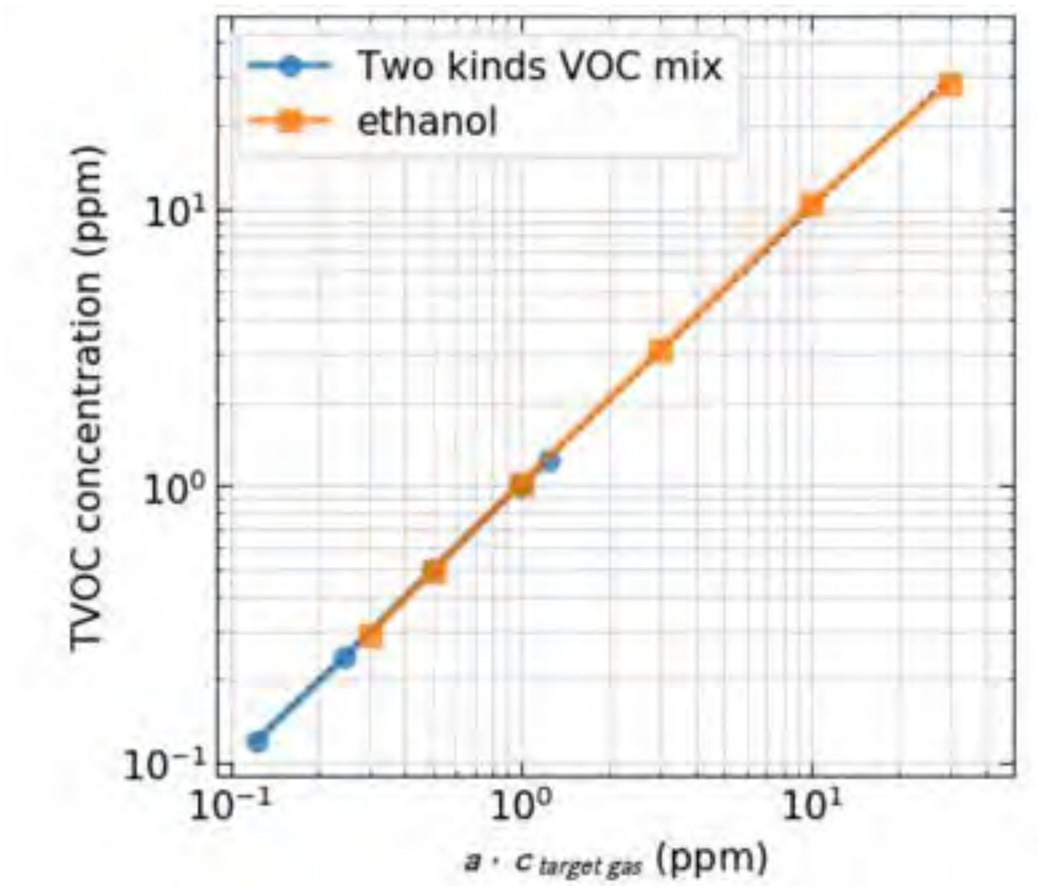


Figure above shows the SGP response for different concentrations of ethanol and of the two kinds VOC gas mix, respectively.

Over a concentration range relevant for indoor air quality the TVOC concentration output of SGP sensors when exposed to different ethanol concentration is directly proportional to the observed response for the two kinds of VOC gas mix of the ISO norm.

Furthermore, this allows for directly converting between concentrations of the different test gases and ambient TVOC concentrations by employing the relative response factors a listed in Table below.

$$c_{TVOC} = a \cdot c_{target\ gas}$$

Target Gas / VOC	Chemical formula	Relative response (a)
TVOC	complex real life mixture	1
Ethanol	C_2H_5OH	0.58
Two kinds VOC mix (n-octane + m-xylene)	$C_8H_{18} + C_8H_{10}$	0.3

Atmotube PRO: VOC sensor

Got more questions? We're here to help!

Please contact us at **info@atmotube.com** or by submitting a support ticket using the form on the following support page:

Do you have customer service and technical support?

You may also use the **ATMO Bot** (usually on the right-hand side of the webpage on desktop, bottom-left for mobile) for a quick answer or leave your email address so that we may get in touch.

Air Quality Sensor Performance Evaluation Center

Sensor Description

Manufacturer/Model:
Atmotube/
Pro

Pollutants:
$PM_{1.0}$, $PM_{2.5}$ and PM_{10}
mass concentration

Time Resolution:
1-min

Type: Optical

Additional Information

Field evaluation report:
http://www.aqmd.gov/aq-spec/evaluations/field

Lab evaluation report:
http://www.aqmd.gov/aq-spec/evaluations/laboratory

AQ-SPEC website:
http://www.aqmd.gov/aq-spec

Evaluation Summary

- Overall, the accuracy of the Atmotube Pro sensors fairly constant (84% to 98% and 86% to 98%) over the range of $PM_{1.0}$ and $PM_{2.5}$ mass concentration tested, respectively. Overall, the Atmotube Pro sensors overestimated GRIMM $PM_{1.0}$ measurements when $PM_{1.0}$ mass concentrations were > 100 µg/m³ and overestimated $PM_{2.5}$ measurements from GRIMM in the laboratory experiments at 20 °C and 40% RH.
- The Atmotube Pro sensors exhibited high precision for all T/RH combinations and all PM concentrations.
- The Atmotube Pro sensors (IDs: E7E0, 05AB and 6C77) showed low to moderate intra-model variability for both the field and laboratory evaluations.
- Data recovery was ~94% and 100% from all units in the field and laboratory evaluations, respectively.
- For $PM_{1.0}$, the Atmotube Pro sensors showed very strong correlations with the corresponding GRIMM data; and showed strong correlations with the ref. instruments from the field for $PM_{2.5}$ ($0.79 < R^2 < 0.90$) and very strong correlations with GRIMM in the laboratory evaluations ($R^2 > 0.99$ for $PM_{1.0}$ and $PM_{2.5}$). For PM_{10}, the sensors showed very weak correlations with the corresponding GRIMM and FEM BAM data ($0.18 < R^2 < 0.26$).
- The same three Atmotube Pro units were tested both in the field (1st stage of testing) and in the laboratory (2nd stage of testing).

Field Evaluation Highlights

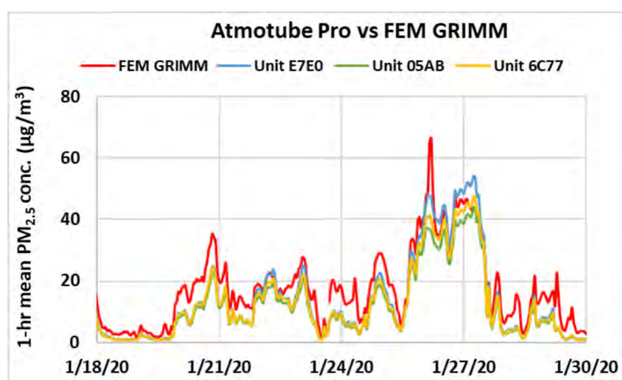
- Deployment period 01/07/2020 - 03/11/2020: the three Atmotube Pro sensors showed very strong, strong and very weak correlations with the corresponding ref. data for $PM_{1.0}$, $PM_{2.5}$ and PM_{10} mass concentrations, respectively.
- The units showed low intra-model variability and data recovery was ~ 94%.

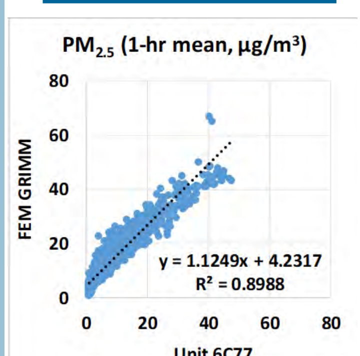
1-hr mean, all ref. inst.

$PM_{1.0}$: ~ 0.92

$PM_{2.5}$: $0.79 < R^2 < 0.90$

PM_{10}: $0.18 < R^2 < 0.26$





Coefficient of Determination (R^2) quantifies how the three sensors followed the $PM_{2.5}$ concentration change by the reference instruments.

An R^2 approaching the value of 1 reflects a near perfect agreement, whereas a value of 0 indicates a complete lack of correlation.

Laboratory Evaluation Highlights

Accuracy ($PM_{2.5}$)

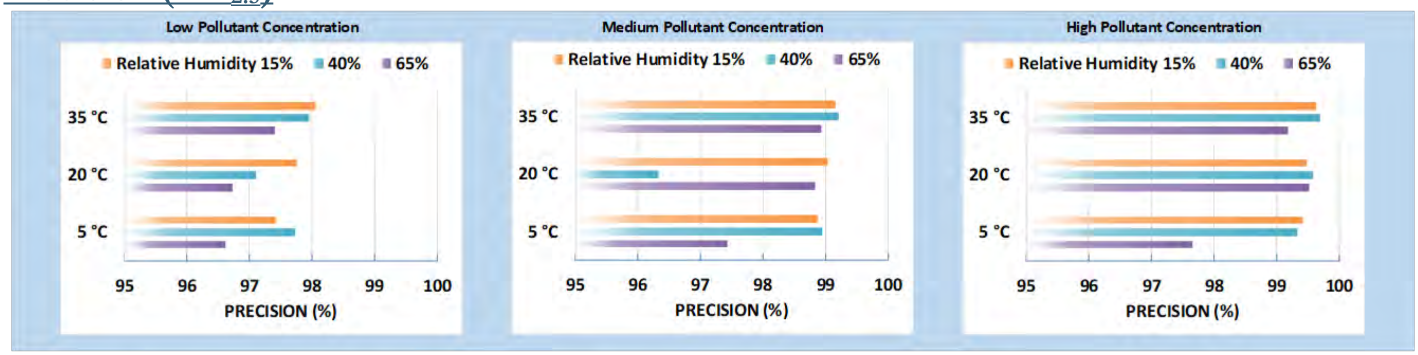
$$A(\%) = 100 - \frac{|\bar{X}-\bar{R}|}{\bar{R}} * 100$$

Steady state #	Sensor Mean (µg/m³)	FEM GRIMM (µg/m³)	Accuracy (%)
1	9.0	8.4	93.3
2	15.6	13.7	86.1
3	47.8	45.3	94.3
4	120.1	117.7	98.0
5	282.8	261.5	91.9

Accuracy was evaluated by a concentration ramping experiment at 20 °C and 40%. The sensor's readings at each ramping steady state are compared to the reference instrument.

A negative % means sensors' overestimation by more than two fold. The higher the positive value (close to 100%), the higher the sensor's accuracy.

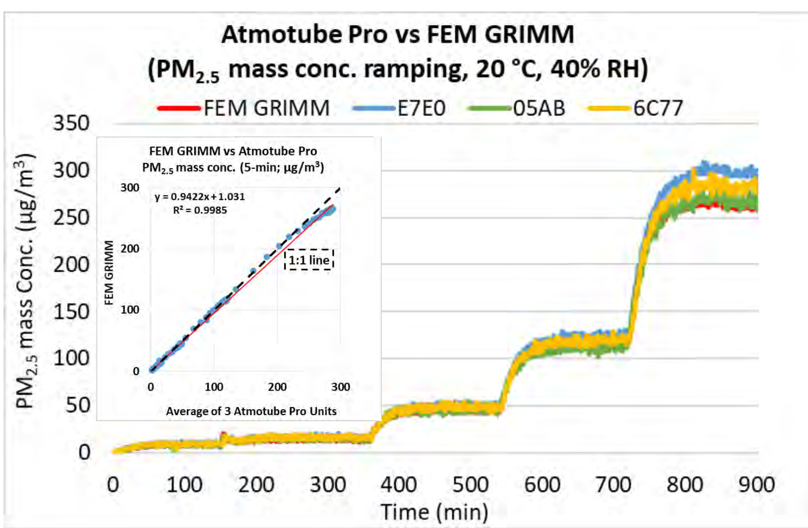
Precision ($PM_{2.5}$)



100% represents high precision.

Sensor's ability to generate precise measurements of $PM_{2.5}$ concentration at low, medium, and high pollutant levels were evaluated under 9 combinations of T and RH, including extreme weather conditions like cold and dry (5 °C and 15%) cold and humid (5 °C and 65%), hot and humid (35 °C and 65%), or hot and dry (35 °C and 15%).

Coefficient of Determination



The Atmotube Pro sensors showed very strong correlations with the corresponding FEM $PM_{2.5}$ data ($R^2 > 0.99$) at 20 °C/40% RH.
For conc. ramping experiments of $PM_{1.0}$, please see the lab report.

Climate Susceptibility

From the laboratory studies, temperature and relative humidity had minimal effect on the Atmotube Pro sensors' precision. At the set-points of RH changes, the sensors reported spiked conc. changes for all PM levels at 5 °C and significant variation in concentration for all PM levels at 5 °C/65% RH.

Observed Interferents

N/A

Detroit residents and community leaders pose next to a public art statue depicting the crown of an African queen in May 2024. The statue is affixed with a light that changes color based on air quality data collected from a nearby sensor.

Engaging Communities in Environmental Justice:

Lessons from Deploying 100 Monitors in Wayne County, MI

by Darren Riley and Sarah Craft

The authors highlight some of the community work that their organization has performed in Wayne County, Michigan, and stress the correlation between increased exposure to environmental harms and health impacts.

In Detroit's 48217 zip code, residents often keep their windows sealed year-round. They frequently find their houses and cars covered in soot, report strange smells, and say that it seems like everyone has asthma and everyone knows someone who has died from cancer.[1] These daily realities reflect a broader pattern: air pollution disproportionately impacts communities of color and low-income neighborhoods, where decades of industrial zoning and infrastructure decisions have concentrated emissions sources. Research published in *JAMA Internal Medicine* quantifies these disparities, finding that communities with higher proportions of minority residents consistently face greater exposure to air pollutants, leading to elevated rates of asthma, cardiovascular disease, and premature death.[2] This systematic inequity demands granular air quality monitoring, community trust-building and targeted interventions to address decades-long environmental health disparities.

Wayne County, MI, exemplifies these challenges. Home to 1.75 million residents across 43 municipalities, the county has a population that is 38% Black, 54% White, and 7% Hispanic or Latino, with 20% of residents living below the poverty line.[3] In Detroit, the county's largest city, where 77% of residents are Black, households have a median income of less than $40,000[4]—half the national average.[5] The county consistently receives an "F" grade in the American Lung Association's Annual State of the Air report.[6] Black residents in Wayne County face asthma hospitalization rates three times higher than white residents,[7] and Detroit ranks as the third worst place to live with asthma, according to the Asthma and Allergy Foundation of America,[8] resulting in frequent emergency room visits and significant health impacts on children.

Justin Littles installs an air quality monitor for the Wayne County project. Littles works for The Green Door Initiative, a Detroit-based nonprofit dedicated to advancing sustainability and environmental stewardship.

Despite widespread air quality concerns, Wayne County historically relied on just a few regional Federal Reference Method (FRM) monitors across its sprawling 673 square miles. FRM monitors are used to determine compliance with U.S. National Ambient Air Quality Standards (NAAQS) and are considered the most accurate measurements for regulatory purposes. However, FRM monitors are expensive to operate and maintain, so they're typically used at select sites rather than for widespread monitoring. This limited network proved insufficient insights at the County's neighborhood level to understand underlying conditions that potentially contribute to poor health outcomes.

To address this gap, in 2023, Wayne County's Department of Health, Human, and Veterans Services partnered with environmental tech company JustAir to develop a comprehensive network of 100 low-cost air quality sensors. Low-cost sensors are easier to manage than FRM monitors and more suitable for dense air quality networks. Although they may need frequent calibration or data correction, low-cost sensors can provide valuable data for relative comparisons and trend analysis that can both empower individuals to make health and safety decisions and policy makers to define targeted intervention strategies.

However, the Wayne County initiative demonstrates that addressing environmental justice through air quality data requires more than just sensor deployment—it demands intentional relationship-building, technical innovation, and sustained community partnership at every stage. The following sections explore how Wayne County and JustAir built trust with environmental justice communities, overcame key implementation challenges, and leveraged early data insights to lay the groundwork for targeted interventions. By examining the project's approach to community expertise, data integrity, and public accessibility, this case study offers valuable lessons for other regions seeking to bridge the gap between air quality monitoring and meaningful environmental justice action.

Building Trust

Wayne County partnered with JustAir for this three-year, multi-million dollar initiative in part due to JustAir's existing community relationships. Based in Detroit, JustAir (https://www.justair.co/) began in 2021 by creating air quality data dashboards for environmental justice leaders and

Screenshot of air quality data recorded at Salina Elementary, a school located in Wayne County's City of Dearborn, as viewed on JustAir.app on February 13, 2025. The school is located in the city's South End, an area that has historically faced EJ challenges due to its proximity to heavy industry.

community organizers. For the Wayne County project, JustAir's leaders implement several key principles to build trust:

1. **Recognition of Community Expertise**—The initiative acknowledges decades of experience from grassroots leaders and residents addressing Wayne County's air quality issues. Local knowledge, cultural insights, and historical perspectives inform the work through direct engagement and bringing leaders to the planning table.
2. **Transparency**—The project team maintains open communication about goals, air quality data, and desired outcomes.
3. **Accessibility**—Air quality information is presented in clear formats (like the U.S. Environmental Protection Agency's [EPA] color-coded Air Quality Index [AQI]) on a public dashboard, while making concentration data available for those interested in deeper analysis.
4. **Collaborative Leadership**—Environmental justice leaders are active partners in project direction, from monitor placement to data interpretation, through committees, online feedback, and one-on-one conversations.
5. **Pride and Ownership**—The project aims for all stakeholders to feel responsibility and ownership in its success. This is achieved through consistent implementation of these core principles throughout the project lifecycle.

Overcoming Implementation Challenges

Historical Skepticism

In Wayne County, years of inattentiveness to environmental health concerns created initial skepticism among longtime environmental justice leaders. To address this, the project team focused on building meaningful partnerships between community leaders and technical experts. Local knowledge proved invaluable in creating a sensor network that serves community needs and concerns.

For example, before purchasing air quality sensors, resident leaders participated in mapping exercises to determine optimal monitor placement in their communities, drawing on their deep understanding of local conditions. Technical experts then sourced appropriate low-cost sensors based on the specific pollutants likely present in these resident-selected locations. Trust began to build as monitors were deployed in community-recommended locations, demonstrating the project's commitment to community input. Even seemingly small efforts contributed to building confidence, such as hosting the Wayne County network launch press event in a neighborhood impacted by poor air quality and ensuring community stakeholders not only attended but spoke at the event.[9] These collaborative approaches have helped transform initial skepticism into active engagement and partnership, creating a strong foundation for the network's long-term success.

Public Accessibility

Many regional monitoring projects lack easy public accessibility—residents often must navigate multiple dashboards to view data from different sensor types or find data buried in municipal websites that only offer near-term information. To address this, the Wayne County project launched a monitor-agnostic and user-friendly public dashboard, accessible at the easy-to-access JustAir.app or the County's Air Quality webpage.[10]

The mobile-responsive dashboard allows everyone to access air quality information through a few clicks, regardless of sensor type. Residents can view hourly AQI data for the last 24 hours or download AQI data for up to 30 days directly from the dashboard. For more extensive data needs, users can submit a data request form to obtain historic and pollutant concentration-level data from specific monitors, ZIP codes, cities, or regions. Community members can also sign up for text alerts from sensors near their homes, schools, or workplaces, enabling informed decisions about daily activities, such as a parent receiving alerts about poor air quality near their asthmatic child's school.[11]

Because of these efforts, community groups have embraced various approaches to raise awareness, from creating signage to distributing flyers and hosting events. In one particularly creative initiative, nonprofit Sidewalk Detroit commissioned an artist to create a sculpture incorporating air quality data—a giant metal crown with lights that change color based on AQI readings from a nearby sensor.[12] These diverse approaches to accessibility and engagement help ensure air quality data reach residents while fostering broader environmental awareness throughout Wayne County.

Data Integrity

Deploying and maintaining 100 air quality sensors presents both physical and technical challenges, making data reliability crucial for maintaining community trust. The project implemented several key processes to enhance data integrity across the Wayne County network noted below.

1. **Multi-Sensor Network Strategy**—The Waye County network incorporates air quality sensors from multiple suppliers, providing both targeted pollutant monitoring capabilities and built-in redundancy. This diversity proved valuable when encountering hardware challenges, from rapid battery drainage during Michigan winters to supplier calibration issues. When problems arise with specific sensors, the network continues functioning while the field team addresses individual hardware concerns. This distributed approach prevents total network failure that could occur in a single-supplier system.
2. **Standardized Installation and Maintenance Procedures**—Project partners collaborated with a local green jobs nonprofit to implement comprehensive installation and maintenance protocols for each sensor type. Custom process forms guide field workers through each step while automatically documenting compliance with Quality Assurance Project Plans. This systematic approach ensures consistent monitor deployment and upkeep across the network.
3. **Issue Detection**—The JustAir software employs a multi-layered approach to data quality. The system continuously analyzes data streams for anomalies and incidents, generating threshold-based alerts for network administrators. This enables the field team to efficiently prioritize maintenance tasks and document troubleshooting efforts. The software supports data recovery through backfilling capabilities, maintains detailed action logs, and includes verification processes to confirm issue resolution.
4. **Public Communication Framework**—While real-time air quality data are valuable for public health decision-making, the project balances immediacy with accuracy. The public dashboard indicates that data are preliminary versus validated, and administrators can quickly display maintenance status for malfunctioning sensors or warning banners when broader quality issues arise. For anticipated air quality events like Fourth of July fireworks or potential system impacts from extreme weather, the team proactively communicates to the public through customized text messages or dashboard banners. Users can also request validated historical data for more detailed analysis. This transparent approach to data quality management helps maintain community confidence in the network's integrity while ensuring the public has access to timely air quality information.

Community leaders and Wayne County partners gather for shared learning and conversation at a 2024 project meeting.

These interconnected systems create a robust framework for ensuring data quality, while keeping stakeholders informed throughout the monitoring process.

Early Analysis

As the Wayne County network approaches its first full year of operation, JustAir has developed quarterly reports that showcase both network-wide trends (including minimum, maximum, mean, and standard deviation of each pollutant) and location-specific areas of concern. The data

Dr. Abdul El-Sayed, Director and Health Officer of Wayne County Health, Human and Veterans Services, speaks alongside environmental justice advocates, community organizers, and Wayne County executives at a press conference commemorating the launch of Wayne County's 100-monitor network in May 2024.

have already revealed concerning patterns. Three Wayne County communities have consistently ranked among the top five cities with the highest daily mean $PM_{2.5}$ in at least two of the three reports. Moreover, monitors at schools, community centers, and parks are consistently among the locations recording the highest daily mean $PM_{2.5}$ levels. This is particularly concerning to Wayne County leaders since children, who frequently use these facilities, are more vulnerable to poor air quality due to their smaller airways, developing lungs, and faster breathing rates.[13]

Early analysis suggests everal factors driving local variations in air quality, including proximity to industrial facilities, high-traffic corridors, and major construction projects. emporal patterns have also emerged in certain locations, such as elevated readings during morning rush hour and afterschool pickup times. After a full year of air quality monitoring, the integration of additional data sets (e.g., land use, wind direction) and further analysis will help the County identify targeted interventions aimed at addressing pollution sources and reducing environmental health inequities.

Conclusion

The Wayne County–JustAir partnership demonstrates that effective environmental monitoring in environmental justice communities requires reimagining traditional approaches to both technology deployment and community engagement.

Rather than treating community input as a one-time check-box, this initiative established a dynamic, ongoing partnership where resident expertise shapes every aspect of the project—from sensor placement to data interpretation. The network's early success in identifying pollution hotspots near schools and tracking temporal patterns of exposure has already provided crucial insights for public health interventions.

This model offers a blueprint for other regions seeking to address environmental justice through air quality monitoring, proving that when technical innovation is guided by community wisdom and supported by transparent data practices, it can build both trust and actionable environmental insights. Most importantly, it shows that with appropriate relationships, leadership, and technical infrastructure, communities can transform decades of environmental monitoring gaps into powerful tools for advocacy and change. **em**

Darren Riley is the co-founder and CEO and **Sarah Craft** is the COO of JustAir, based in Detroit, MI.
Email: **darren@justair.co; sarah@justair.co.**

References

1. Lam, Tina. 48217: Life in Michigan's most polluted ZIP code; *The Detroit Free Press*, 2010. Retrieved from https://web.archive.org/web/20150601160919/http:/www.freep.com/article/20100620/NEWS05/6200555.
2. Patel, V.R.; Jella, T.; Gupta, A. Association of Neighborhood-Level Environmental Injustice With Health Status in the US; *JAMA Internal Medicine* 2023. Retrieved from https://jamanetwork.com/journals/jamainternalmedicine/fullarticle/2808092.
3. Quick Facts: Wayne County, Michigan. U.S. Census Bureau. 2023. Retrieved from https://www.census.gov/quickfacts/fact/table/waynecountymichigan/COM100223.
4. Quick Facts: Detroit, Michigan. U.S. Census Bureau. 2023. Retrieved from https://www.census.gov/quickfacts/fact/table/detroitcitymichigan,waynecounty michigan/COM100223.
5. Income in the United States: 2023. U.S. Census Bureau. 2024. Retrieved from https://www.census.gov/library/publications/2024/demo/p60-282.html#:~:text=Real%20median%20household%20income%20was,median%20household%20income%20since%202019.
6. Detroit Metro Area Ranks 13th Worst in Nation for Annual Particle Pollution, According to the 2024 'State of the Air' Report. American Lung Association. 2024. Retrieved from https://www.lung.org/media/press-releases/detroit-sota-fy23.
7. Kunyangna, Prudence; Anderson, Beth. Detroit: The Current Status of Asthma Burden. Michigan Department of Health and Human Services. 2021. Retrieved from https://www.michigan.gov/-/media/Project/Websites/mdhhs/Folder50/Folder3/Detroit-AsthmaBurden-2021_Update.pdf?rev=187419566778478fa169dfb8bb7791b1.
8. 2024 Asthma Capitals: The Most Challenging Places to Live with Asthma. Asthma and Allergy Foundation of America. 2024. Retrieved from https://aafa.org/wp-content/uploads/2024/09/aafa-2024-asthma-capitals-report.pdf.
9. Golston, Hilary; Nissen, Jack. "Wayne County Air Monitors Installed to Collect Data, Inform Citizens About Poor Air Quality." Fox 2 Detroit. 2024. Retrieved from https://www.fox2detroit.com/news/wayne-county-air-monitors-installed-to-collect-data-inform-citizens-about-poor-quality.
10. Air Quality. Wayne County Health Human & Veterans Services. 2024. Retrieved from https://www.waynecounty.com/departments/hhvs/wellness/air-quality.aspx.
11. Text Alert Sign-up. JustAir. 2024. Retrieved from https://justair.app/signup.
12. Brown, Patricia Leigh. A Crowning Achievement in a Neighborhood's Fight Against Air Pollution; *The New York Times* 2024. Retrieved from https://www.nytimes.com/2024/05/29/arts/design/jordan-weber-crown-sculpture-detroit.html.
13. Who Is Most Affected by Outdoor Pollution? American Lung Association. 2024. Retrieved from https://www.lung.org/clean-air/outdoors/who-is-at-risk#:~:text=Children%20face%20special%20risks%20from,are%20still%20developing%20in%20children.

JustAir at Four: A Reflection on Progress, Purpose & People

JustAir sparked from something personal. I developed asthma as an adult while living in Southwest Detroit, one of the most polluted areas in the country. Then came COVID. And the pandemic made it painfully clear how Black and Brown communities were hit the hardest, largely due to long-standing health disparities, many of which are tied to the air we breathe.

Then I started listening and learning. I spoke with community leaders who had been fighting for clean air for decades. They knew what was happening in their neighborhoods but didn't have data they could rely on.

These experiences opened my eyes to how deeply our environment affects our health and the beginnings of JustAir started to take shape. At first we kept it simple: put a monitor on someone's house and hack together a text alert system to send real-time updates to the homeowner and their neighbors. It wasn't fancy, but it worked — and it was our start.

This month, June 2025, JustAir turns four. We've grown from a simple text alert into a nationwide movement as we strive to prove that cleaner air can happen one community, one breath, and one line of code at a time.

Work from the Heart

The more I listened, the clearer the need became. All of the daytime community conversations and late-night coding sessions slowly turned into something bigger. There wasn't a roadmap. I had to figure out how to secure funding, build a team, learn the science, and create something that could last — all while staying true to [the mission] of protecting the 20,000 breaths we all take every day.

There has been no shortage of setbacks and doubt in this journey. But every time I felt like giving up, I would call on what it feels like to have an asthma attack — how, in that traumatic moment, you don't want anything more than just to breathe again. Then I'd imagine a child or an elder in my community going through the same thing. That reminder grounds me. It brings me back to why this work matters and why I have to keep going.

Being a founder, for me, is about building something that matters, piece by piece, and doing it alongside the very people we're building for.

Team is Everything

One of the most meaningful parts of this journey has been growing our team. Everyone at JustAir shows up with heart, purpose, and their whole, authentic self. We come from different walks of life, but we're united by the simple fact that we care.

Early on, our Head of Engineering, Britney Epps, said something that stuck with all of us: *"Every line of code can be a breath of fresh air."* That mindset has helped shape our culture. Whether we're debugging a dashboard or setting up a sensor in the field, we know the impact is real.

I'm proud that we're building a team that lives by our values in every decision. We support each other, challenge each other, and stay grounded in the belief that this work is bigger than us.

The JustAir team in December 2025. Today we have one more full-time employee - our Product Manager Kelsey Hilbers - plus a few incredible contractors.

The Next Four Years

Four years in, we've moved far beyond that first text message. We're now supporting regions and communities across the country. We're helping governments and grassroots leaders alike respond to air quality challenges with tools that reflect their needs and reality.

Right now we're witnessing a fundamental shift: environmental action is becoming more local, more immediate, and more community-driven. While traditional institutions navigate complexity, mayors are deploying air monitors, public health departments are acting on real-time data, and residents are demanding transparency about the air they breathe. This decentralized movement isn't just more resilient, it's more effective. Technology is democratizing environmental data, equipping local leaders, parents, and agencies to take action that matters.

This is what we're building at JustAir.

Thank you to every community member, partner, team member, and believer who's walked this road with us. Your hope is the reason we believe that clean air will, one day, be a universal standard.

– Darren Riley, Founder & CEO

Monitoring: A Step Toward Cleaner, Healthier Communities

Air pollution is a major global concern, especially in underserved and minority communities. However, the live data and alert systems built into real-time air quality monitoring systems are inspiring change for communities.

Air pollution is a global concern, with nearly 90% of the world's population being exposed to air contaminated by dust, smoke, fumes, and other pollutants. However, we are often unaware that we are breathing polluted air until it's too late, and the associated side effects begin to manifest.

To protect our health and the environment, it’s necessary to measure air quality using real-time air quality monitoring systems. Doing so gives us deep and accurate insights about existing air pollutants and informs decision-making to ensure we take the proper steps to enjoy the cleanest air possible.

What Are Real-Time Air Quality Monitoring Systems?

Real-time air quality monitoring systems are outfitted with sensors capable of detecting specific pollutants in the air like carbon monoxide, nitrous oxide, sulfur dioxides, carbon dioxide, and the level of dust particles. Data from the sensors is automatically transmitted to a central management dashboard in real time for collection and reporting purposes. There, it is analyzed to understand the causes and fluctuations in air pollution. Unlike other types of air monitoring solutions, real-time systems offer more accurate and reliable data since they produce high-resolution measurements within a short period, offering more up-to-date data.

Using real-time air quality monitoring systems enables you to accurately identify patterns and causes of air pollution in a given area. In addition, the live data and alert systems built into the systems ensure that you can promptly respond to alarming pollution levels and mitigate the issue before it negatively impacts people or the environment.

Air Quality Monitoring In The US

In 1963, The Clean Air Act was introduced as the first federal legislation regarding air pollution control. However, essential and significant amendments were added to it in 1970 and 1990. The landmark Clean Air Act is a comprehensive law aimed at reducing ambient and source-specific air pollution. This has helped the country avoid up to 370,000 premature deaths annually and significantly reduced air pollution levels for over a half-century, especially that of hazardous soot.

Air quality monitoring is a vital tool for helping us understand the dangers of air pollution, and the Clean Air Act serves as the key driver for all air pollution control policies in the US. The Clean Air Act put the National Ambient Air Quality Standards in place and determines how much pollution can be allowed by different industries in different regions. In addition, states are required to monitor the air quality, and the data obtained is used to:

- Measure compliance and progress made toward meeting ambient air quality standards
- Activate emergency control procedures to prevent or alleviate air pollution episodes
- Track pollution trends throughout the country
- Provide a database for research evaluation of the effects of air pollution
- In addition, the Clean Air Act also helped the US develop plans to achieve the set standards. There is an interactive 'air data' map that you can use to view the air quality throughout the US, but it still has some significant drawbacks, like the need for up-to-date information on air quality and limited air monitoring stations.

How Do Real-Time Air Quality Monitoring Systems Work?

Real-time air quality monitoring systems have two main elements: air quality sensors and software. The two elements are integrated to automate data collection and reporting so that experts can concentrate on interpreting and analyzing the findings to improve air quality. To get continuous monitoring reports, wireless sensors are placed at the locations you want to monitor for air quality. All data the sensors collect is transmitted to a gateway that forwards it to a cloud database. The information can then be accessed or shared through a mobile or web-based app. The information picked up by the sensors will vary depending on the type of sensor. For example, some sensors can pick up on just one type of pollutant, while others can pick up multiple pollutants. These systems may also include an alert feature that issues notifications when threshold values of different contaminants are reached.

The Impact of Real-Time Air Quality Monitors on Communities

apartment complexes in front of a park

The data obtained from continuous air quality monitoring is used in different ways to help control and eliminate the dangers associated with air pollution. For example, many communities can benefit from real-time air quality monitoring in the following ways:

Health experts can use the data to ascertain the effects air pollutants have on public health and safety.

Effective air quality monitoring helps address specific sources of pollution and devise measures to stop or control the pollution.

Equipped with timely and accurate data, residents, stakeholders and policymakers can make better and more informed decisions. They can also determine if an area is meeting the required air quality standards and, if not, what is hindering them from doing so. Data reports also form the basis for research which can help show the correlation between pollution and health outcomes, and how improving air quality can improve the quality of life.

Real-time air quality monitoring encourages response to situations that would turn disastrous if left to wait.

Implementing Real-Time Air Quality Monitoring In Underserved Communities

According to WHO, 94% of deaths linked to air pollution occur in low and middle-income areas. This is because these areas often lack air pollution monitoring programs, making it hard to tell if the laws put in place are combating air pollution equally across cities. In addition to the less stringent air pollution regulations in these areas, often-time there are more vehicles in these neighborhoods, a high use of inefficient household fuel, and a disproportionate presence of industrial plants and transport corridors; these are all contributors to increased air pollution.

Many underserved communities lacking proper air quality monitoring programs are often near sources of pollution, like power plants and factories. They may also have a higher concentration of vulnerable populations such as children, the elderly, and low-income individuals. Advocating for changes that can improve the air quality in communities that are not necessarily regulatory can significantly impact air quality. By simply providing the correct information, people can be more motivated to take actions that will help reduce air pollution and create a healthier and safer environment.

Real-Time Air Quality Monitoring In Action

Air pollution is a significant factor affecting the quality of life as it poses a risk to human health and the environment. It is, therefore, essential to implement programs that constantly check the pollution level in the air to know when the levels have exceeded the permissible limit. JustAir helps raise awareness about the risks of air pollution and provides communities with the tools and knowledge to help keep their air clean. By partnering with us, you will learn about the sensors and monitoring networks that collect air quality data for the public and access information on air quality and health disparities within your community.

EAHT

OpenAccess

Vol: 39(2), Article ID: e2024012, 24 pages
https://doi.org/10.5620/eaht.2024012

eISSN: 2233-6567

Systemic Review

Benzene: A critical review on measurement methodology, certified reference material, exposure limits with its impact on human health and mitigation strategies

Poonam Kumari [1, 2], Daya Soni [1, 2, *], and Shankar G Aggarwal [1, 2]

[1] CSIR-National Physical Laboratory, Dr. K.S. Krishnan Marg, New Delhi-110012, India
[2] Academy of Scientific and Innovative Research (AcSIR), Ghaziabad-201002, India
***Correspondence:** dsoni@nplindia.org

Received: November 13, 2023 **Accepted**: February 26, 2024 **Recommended by:** Prof. Jung-Hwan Kwon

Abstract

Benzene is a carcinogenic pollutant with significant emission sources present in the atmosphere. The need for accurate and precise measurement of benzene in the atmosphere has become increasingly evident due to its toxicity and the adverse health effects associated with exposure to different concentrations. Certified reference material (CRM) is essential to establish the traceability of measurement results. The present review compiles the available national and international measurement methods, certified reference materials (CRMs) for benzene and the limit of benzene in fuel composition (v/v) worldwide. Overall, the review indicates the benzene level in the atmosphere and the resulting impacts on the environment and human health, which frequently exceed the exposure limits of different environment regulatory agencies. An extensive literature review was conducted to gather information on monitoring and analysis methods for benzene, revealing that the most preferred method, i.e. Gas Chromatography- Flame Ionization Detector and Mass Spectrometry, is neither cost-effective nor suitable for real-time continuous monitoring. By analysing existing literature and studies, this review will shed light on the understanding of the importance of benzene pollution monitoring in ambient air and its implications for public health. Additionally, it will reflect the mitigation strategies applied by regulators & need for future revisions of air quality guidelines.

Keywords: Benzene, Certified reference materials, Standard measurement methods of benzene, Exposure limits

Introduction

Benzene, Toluene, Ethylbenzene, and Xylenes, collectively known as BTEX, are highly hazardous aromatic group of toxic pollutants among all volatile organic compounds (VOCs). The International Agency for Research on Cancer (IARC) classifies "Benzene" as a known human carcinogen [1-6]. Benzene is also included in the list of 12 pollutants of the National Ambient Air Quality Standard (NAAQS) 2009) [7] that has an annual exposure limit 5 μg/m3. Benzene is a colourless and highly flammable liquid widely used in various industries, including petrochemicals, rubber, and paint manufacturing [8-11]. It is also a component of gasoline and tobacco smoke [12]. Traffic emissions and fuel stations are predominant sources of benzene in urban areas [13-14]. It is a VOC that can evaporate into the air, and exposure can occur through inhalation of ambient air or direct contact with contaminated soil or water. Acute exposure to benzene can cause myeloid leukaemia, dizziness, headaches, nausea, and unconsciousness [15-24]. Long-term exposure to small amounts of benzene can lead to bone marrow damage, reduced red and white blood cell counts and anaemia, development of leukaemia, lymphoma, and other haematological cancers [17,25-26]. Additionally, exposure to benzene during pregnancy can cause birth defects [27]. Due contribution towards the formation of SOA (secondary organic aerosol) [28 -35], and Ozone Formation Potential [36], benzene can have a negative impact on environment. Therefore, in urban air pollution, benzene stands out as a significant characteristic of aromatic hydrocarbons and has become a high-priority target for evaluation in ambient air. Continuous monitoring of toxic pollutants in the environment is necessary for maintaining a clean and safe environment. It also aids in protecting the health of the population and can serve as an executive tool for implementing prevention and control measures [37]. To protect public health, WHO (World Health Organization) and other regulatory agencies have established exposure limits for benzene in ambient air and at workplace. Although occupational exposure limit to benzene levels remains high in some countries and industries, it poses a significant risk to workers. Therefore, monitoring benzene levels in ambient air and other workplaces is essential to protect public health. Various monitoring techniques and technologies have been developed for accurate measurement of benzene discussed in this article. Real-time monitoring, active and passive sampling methods have their advantages and limitations. Their selection depends on the specific monitoring objectives and available resources.

Accurate calibration of benzene measurement instruments is essential to establish the measurement traceability of results obtained [38-40]. Accurate and precise data of benzene in the atmosphere is need of our due to its toxic nature and adverse health issues even exposure to very low concentrations. The accurate and traceable measurement is essential to support high-quality scientific research, regulatory compliance, the protection of human health, risk assessment and environmental policy-making efforts to mitigate benzene pollution and its ecological effects.

This review article will discuss gravimetrically prepared calibration gas mixtures of benzene and their national and international intercomparison of certified reference material (CRM) of benzene, sampling and analysis techniques, exposure limits in air and at different occupational areas. The accurate and reliable measurement of benzene in ambient air is crucial for assessing associated health risks, raising awareness of exposure sources, developing mitigation strategies and implementing effective control regulations to protect the human health.

Materials and Methods

Subheading

Subsubheading

Properties of Benzene

The US Environmental Protection Agency (EPA) has identified 40 HAPs the most risky hazardous pollutants (through Section 112 of CAAA) (the Clean Air Act Amendments 1990). Benzene (C6H6) CAS no. 71432 at room temperature is light -yellow liquid or colourless. The nature of benzene is highly flammable and it has a sweet odour. The density of benzene at 20°C is 0.87 g/cm3 with a melting point of 5.5 °C. It evaporates into the air very quickly even at room temperature due to relatively less B.P 80.1 °C and a high vapour pressure of 9.95 kPa at 20 °C. Benzene may sink in the low area because its vapour is heavier than air. Benzene dissolves only slightly in water. Its solubility is 1.8 g per/litre at 25 °C and is mostly miscible with organic solvents. The stability of benzene in the vapor phase depends on climate change or many factors of pollutants present in the air (Wikipedia). Its Henry's Law constant is 550 Pa.m3 /mol at 25 ° C, which means it has the capability to volatilize into the environments from surface water. Its degradation is mainly due to a reaction with hydroxyl radicals, with a rate constant of 1.2×10^{-12} cm^3 $molecule^{-1}s^{-1}$ at 298 K.

Table 1. Description of benzene

Specification	Nature
Chemical formula	C6H6
Physical form (20°C)	Clear liquid (colourless)
Molecular weight	78.11 g/mol
Nature	Volatile, Colourless, flammable
Vapor pressure (VP)	95.2 mm Hg (25 °C)
Boiling point (BP)	80.1 °C
Melting point (MP)	5.5 °C at 20 °C
Flash Point (0°C)	-11.1 °C
Flammable limits	1.3 - 7.1 %
Conversion factors in gaseous form	1 mg/m^3 = 0.313 ppm
	1 ppm = 3.19 mg/ m^3

Source: - Wikipedia

Sources & Sinks of benzene in air

Around 50 years ago, Haagen-Smit studied in Los Angeles and found that organic compound produced by human activity are significant air pollutant present into atmosphere [41]. Benzene can be found in atmosphere as a result of both natural and anthropogenic. It is considered as the hazardous air pollutant and 60 % of total benzene emissions coming from mobile sources [42]. In 2015, Sahu et al. suggested that benzene source in ambient air are anthropogenic, biogenic and other secondary sources, all contributing to some extent [43]. In 2006, Srivastava et al. conducted a study and found that mobile sources associated with benzene and other volatile organic compounds were uniformly distributed in Mumbai urban area [44]. Tobacco smoke is considered as indoor source of benzene. In United States 50 % exposure to benzene is due to cigarette smoke or second-hand smoke. It has been observed that room with tobacco smoke have many times benzene level higher than normal [45]. The evaporation of solvents used in paints, cleaning products, and degreasers containing benzene can release into the air. There are numerous factors responsible for the exposure of benzene in the atmosphere, which can be mainly categorized as both natural and anthropogenic sources as given in Table 2.

Table 2. Brief description of benzene source in ambient air.

no.	Source	Description of sources
1.	Fuel stations	Petrol pumps, gas station, CNG station
2.	Smoke	Cigarette, Biomass burning
3.	Vehicle exhaust	Transport sector, Aeroplane, Road gasoline vehicles
4.	Paints and fragrances	Paint strippers and coating, Aerosol sprays, cleanser and disinfectants, air fresheners,
5.	Office equipment's	Copier and printer, correction fluids, carbonless paper, permanent markers glues etc
6.	Industries	Chemical industries, crude oil processing, refineries
7.	Natural	Volcanoes and forest fires

Benzene is a major component of gasoline and crude oil. that is released from mobile sources i.e gasoline engines [12]. It is used in gasoline as a component to improve engine performance and acts as an octane booster as well as anti-knock properties [46]. It is released during the fuel combustion in vehicles, making vehicle exhaust an important source of benzene in urban areas [47]. However, due to its toxic or carcinogenic effects on human health, the proportion of benzene in fuel has significantly decreased over the past few decades. It is regulated by Directive 2009/30/EC, which mandates that it must be < 1 % (v/v) [48]. Many industrial processes, such as petroleum refining, chemical manufacturing, and rubber and plastic production emit benzene into the air. National Centre for Biotechnology Information (NCBI) 2021 describes that it is widely used in the United State, its rank within top twenty chemicals for production [49]. During production, substantial amount is released into the atmosphere, since 1988 production continuously increasing reaching 20 million tonnes. In recent time, there has been growing demand for benzene and it is expected to continue grows strongly in the coming years. In 2022, production reached 60.28 million metric tonnes with forecast that benzene market will reach around 76.04 million metric tons by 2030 [50].

Benzene is commonly used for manufacturing several chemicals and solvents such as ethylbenzene, cumene, and aniline plastics, drugs, dyes, detergent and insecticides [51]. Its maximum usage is for production of ethylbenzene, (for styrene) cumene and cyclohexane [52]. The global annual production of benzene market is expected to increase by 3 % yearly. The country which are main consumers is China, USA and Western Europe with almost equal shares of 16-17 % [52]. Natural emission of benzene includes vegetation, oceans, microbial decomposition, wildfires and volcanoes [53-56]. In 2022, Dickinson et al observed benzene level ranging from 0.04 to 25 ppbv. in the wildfire smoke [57]. Bihałowicz et al. 2022 also studied the fire impact on air quality. Non methane volatile organic compounds are emitting from landfills in urban areas. The observed concentration of BTEX pollutants were lower at upwind sites as compared to downwind sites [58]. Benzene is produced during the decomposition of organic material in landfills and can be released into the air. Benzene is also found naturally in petroleum and is released into the air during oil and gas drilling and extraction.

VOCs involvement in physico-chemical processes at the troposphere is important in atmosphere, because these hydrocarbons participate in the formation of O3 and other photochemical activity [59]. In all VOCs, pollutants like BTEX increase the level of photochemical oxidants like ozone which is most harmful to both human beings and environment by making the smog in atmosphere [34,60]. The anthropogenic emission of NOx from industries, power plants burning of fossil fuels react with VOCs, produced secondary organic pollutants. The presence of NOx and VOCs in the environment is contributing to the formation of ozone, as indicated by the reactions in Fig. 1.

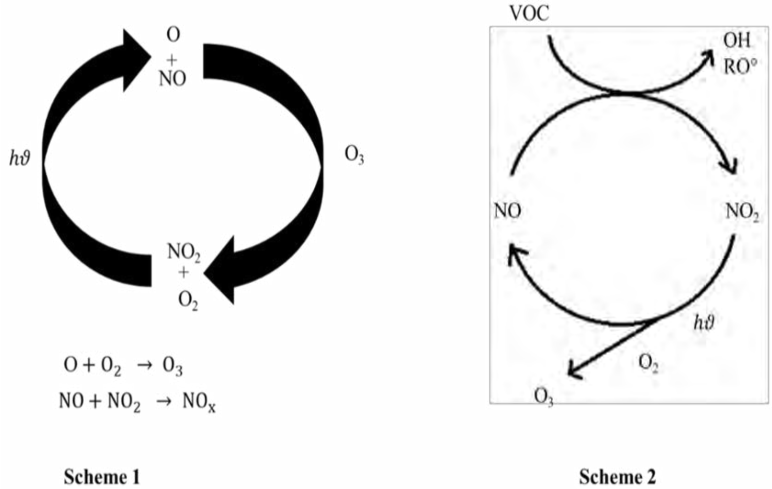


Figure 1. Chemistry of NOx and VOCs towards formation of Ozone in the environment.

Benzene can undergo various chemical reactions, both in the environment and in industrial processes. These reactions can act as "sinks" for benzene, meaning they remove it from the environment. Benzene as a precursor participate in the formation of ozone and other secondary pollutants in ambient air [35]. Benzene and its substitute produced photochemical reactions in the presence of sunlight and hydroxyl radicals (OH), to form SOA and peroxyacetyl nitrate (PAN) [31-32,34].

Benzene can be degraded through reactions with hydroxyl radicals (OH°) produced hydroxy- cyclohexadienyl or OH-aromatic adduct, which is reactive species that help remove pollutants from the air. It can also be removed from water through various treatment processes, such as activated carbon adsorption or biological degradation.

Fuel composition and its limits

The limits for benzene in fuel composition vary by country and region. Here, discussed benzene limits in gasoline for various parts of the world.

Benzene is a highly volatile organic compound (VOC), facilitating its use in gasoline as a component to enhance fuel combustion efficiency through improved vaporization. Benzene also has a high-octane rating, which means it can improve the engine's power and acceleration. However, the use of benzene in fuel has been linked to serious health effects, including an increased risk of cancer and other illnesses. As a result, various countries have implemented regulations to limit the amount of benzene in gasoline, and some have banned its use altogether. The Environmental Protection Agency has set limits of 1 % benzene by volume in gasoline sold in the United States, although some states have stricter limits. Also, the use of alternative fuel additives is made mandatory to reduce the need for benzene. The European Union (EU), China, Japan, Australia has set a limit of 1 % benzene and South Korea has set 0.5 % by volume in gasoline sold in the region.

In India, regulatory bodies of fuel qualities are MOP&NG i.e Ministry of Petroleum and Natural Gas, MoEF i.e Ministry of Environmental and Forest, MoRTH i.e Ministry of Road Transport and Highway and Bureau of Indian Standards (BIS). The benzene limit in gasoline is currently set at 1 % by volume. This limit was introduced by the BIS in 2016, as part of the Indian government's efforts to make better air quality and bring down adverse health effects associated with exposure to toxic pollutants. In 2001, Bharat Stage emission standard (BS II) norms described that benzene limit in gasoline 3 % by volume in metro cities and up to 5 % by volume nationwide. However, the Indian government recognized the need for more stringent regulations to keep safe public health and the atmosphere, particularly in urban areas where air pollution levels are high. BS III, IV and presently BS VI norms described 1 % limit of the benzene in gasoline [61].

It's worth noting that some states like Delhi in India have implemented even stricter limits on benzene in gasoline. Overall, the introduction of the 1 % benzene limit in Indian gasoline represents a positive step towards improving air quality and protecting public health. The Indian government continues to implement additional measures to reduce air pollution, including the promotion of alternative fuels and the introduction of vehicle emission standards. Some countries have lower limits for benzene in gasoline, particularly in regions with high air pollution or where the health risks associated with benzene exposure are well-established. In addition, some countries have implemented incentives or mandates to encourage the use of alternative fuel additives that reduce or eliminate the need for benzene in gasoline.

Health effects of benzene

Loomis D and its group published a report in 2017, to determine the carcinogenicity of benzene. This investigation led to a meeting held in Lyon, France, where 27 scientists from 13 different countries participate at the IARC. During this meeting, they conclusively confirmed the carcinogenic nature of benzene, supported by substantial evidence. In several studies, it has been confirmed that chronic myeloid leukaemia and lung cancer observed with positive association with exposure of benzene [62]. Benzene, one of the most hazardous pollutants among BTEX (Benzene, Toluene, Ethyl benzene, Xylene) has been classified as Group one human carcinogen by both USEPA and IARC [5,63,64]. Ross D et al. 2000 and Snyder R. et al. 2004 studied that Benzene must be metabolized to became toxic or carcinogenic.

In 2010, Martyn T Smith have done detail study on metabolism of benzene and its carcinogenic health effects relevance [17]. Summarized scheme of metabolism of benzene as given in Fig 2.

Here, CYP2E1 denotes cytochrome P450 2E1; GST means glutathione-S-transferase; NQO1 represents NAD(P)H: quinone oxidoreductase 1; MPO means myeloperoxidase; UDPGT means uridine diphosphate glucuronyl transferase; PST denotes phenol sulfotransferase; mEH means microsomal epoxide hydrolase.

Long-term exposure to benzene level in environment has been linked to the development of leukaemia in human. In animals, exposure to benzene has been associated with leukaemia's, lymphomas, various tumor types, delayed bone formation, and low birth weights. Additionally, bone marrow damage during pregnancy and affect biological human organs [17,26].

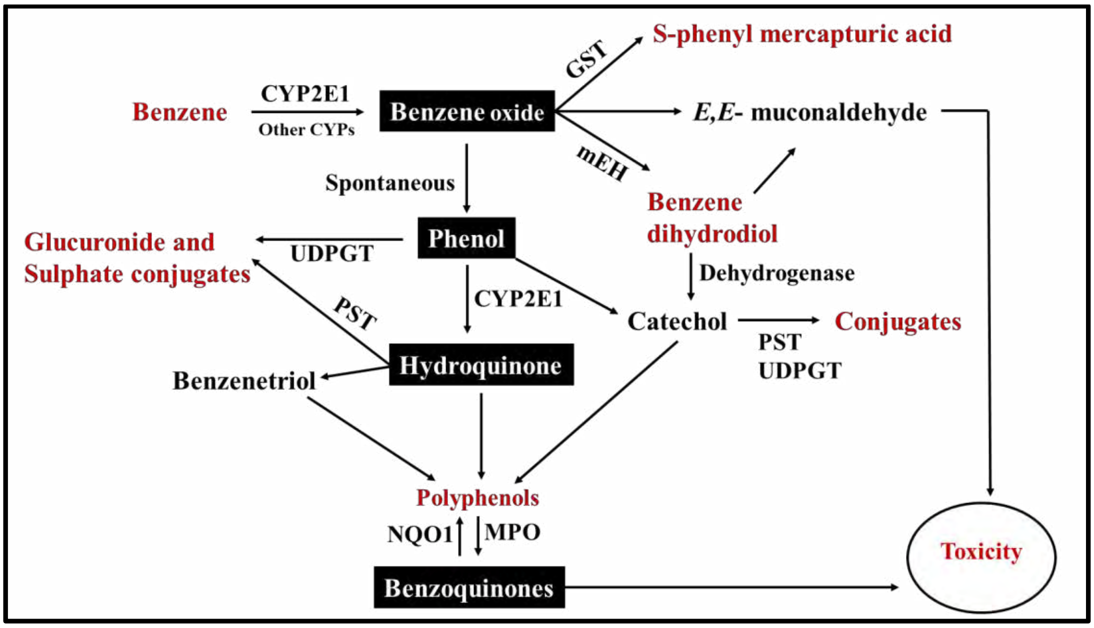


Figure 2. Scheme for metabolism of benzene

A pictorial representation of emission sources and its affected biological organs of human is given, as shown in Fig. 3.

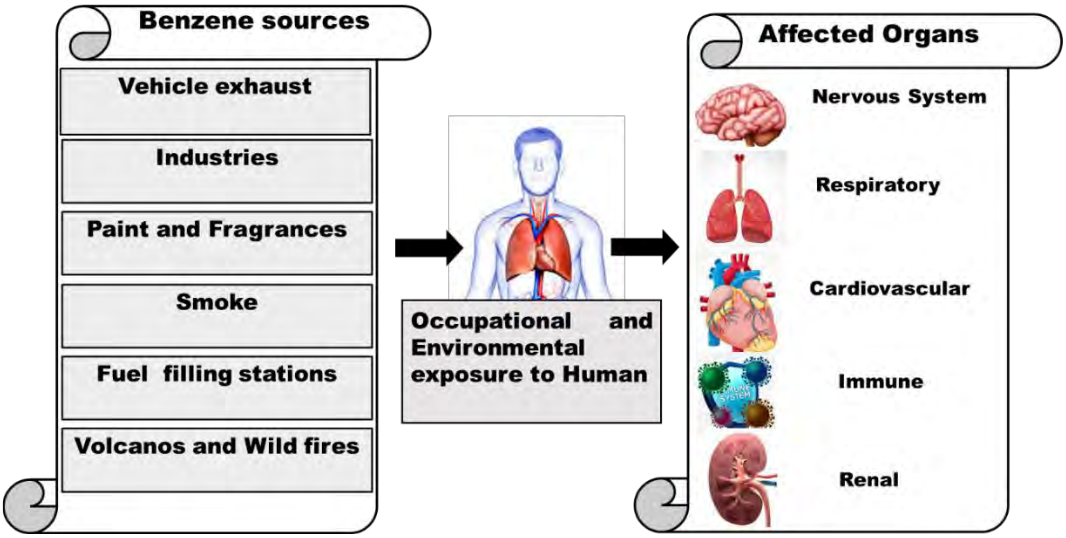


Figure 3. Emission sources of benzene and its biological human health effects.

According to the findings reported by Bahadar et al. (2014), benzene exposure level ranging from 638.8 -5110.8 $\mu g/m^3$ in China, Italy, and Turkey may be linked to childhood leukemia, myeloid leukemia, myelodysplastic syndrome, and Non-Hodgen lymphoma [65-66]. Another study suggested that concentrations below 15.9 $\mu g/m^3$ of benzene, with long-term exposure, may lead to the defeat of hematological parameters [67,68]. In a study done by Lan et al. in 2004, the effects of low amount of benzene exposure on 240 workers were examined, revealing a decrease in platelet and WBC counts among 140 workers due to prolonged exposure to benzene concentration of 3.19 $\mu g/m^3$ [69]. Lupo et al. (2011) found that reproductive and chronic toxic effects were observed in association with benzene emissions, leading to birth defects [70]. Another study revealed pregnant woman exposed to benzene or other organic solvents may face an increased the risk of less birth weight and fetal malformations [71,72]. Furthermore, research has indicated that benzene fumes emitted from traffic-related air pollution may rise up the risk of adverse effects on infant weight growth [25,27]. So above studies concluded that exposure to benzene can lead to serious health issues, highlighting the importance of monitoring and regulating the exposure of benzene to protect public health and environments.

Health risk methodology

A health risk assessment methodology incorporates to evaluate the influence of ambient benzene pollutant. Basic scheme follows to estimate the health risk assessment process as given in Fig 4.

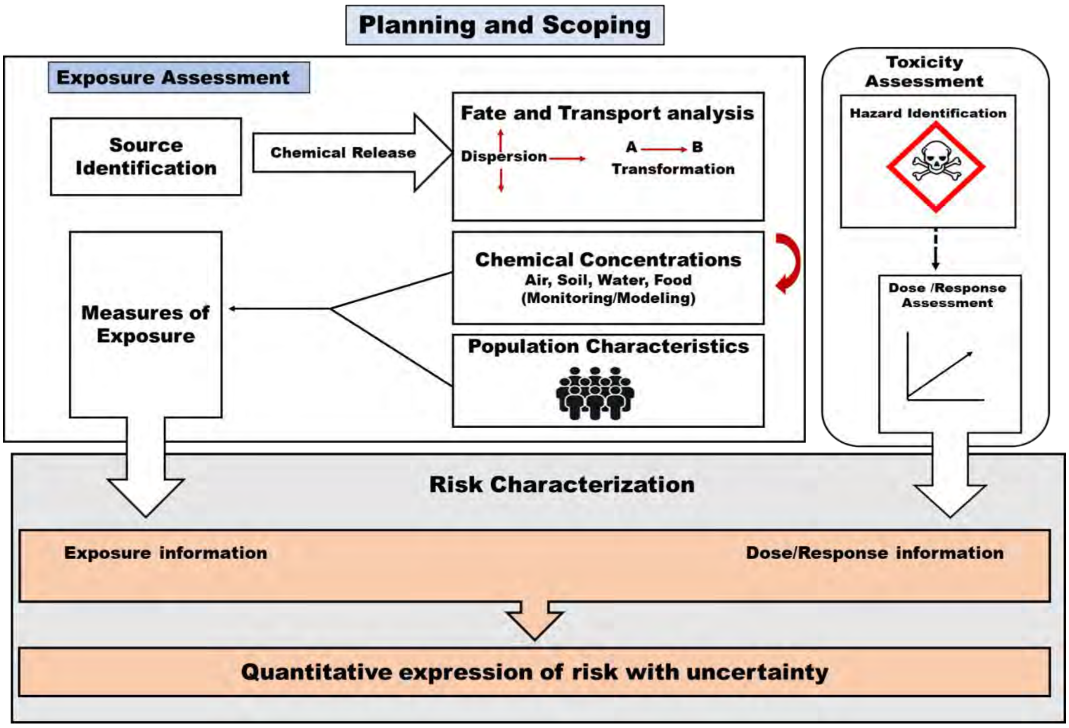


Figure 4. Health risk assessment process

According to the guidelines provided by USEPA, a health risk assessment was conducted to evaluate the inhalation intake of a contaminant present in the air. The assessment was based on the Risk Assessment Guidance for Superfund (RAGS), Part A [73], considering factors such as inhalation rate (IR) and body weight (BW). The risk associated with exposure to benzene in ambient air was estimated using the equations i.e Incremental Lifetime Cancer Risk (ILCR) and Hazard Quotient (HQ). To determine the ILCR value, the Lifetime Average Daily Dose (LADD) was estimated through inhalation pathway using the following Eq. (1)

$$\mathrm{ILCR} = \mathrm{LADD} \times \mathrm{CSF} \tag{1}$$

Where LADD represents the Lifetime Average Daily Dose in milligrams per kilogram per day (mg/kg-day), and CSF stands for the cancer slope factor of benzene, which is 0.0273 mg/kg-day as provided in the Risk Assessment Information System [74].

The LADD for population was calculated using Eq. (2)

$$\mathrm{LADD} = \frac{\mathrm{CA} \times \mathrm{CF} \times \mathrm{IR} \times \mathrm{EF} \times \mathrm{ET} \times \mathrm{ED}}{\mathrm{BW} \times \mathrm{AT}} \tag{2}$$

where,
CA ($\mu g/m^3$) denotes contaminant concentration in air,
CF is the Conversion Factor (1 mg/1000 μg, i.e., 0.001 mg/μg),
IR (m^3/h) represents inhalation rate as per US EPA standard (20 m^3/day, i.e., 0.83 m^3/h)
ET (h/day) signifies exposure time in hours per day,
EF (days/years) represents exposure frequency,
ED (years) represents exposure duration,
BW (kg) denotes body weight (average body weight),
AT (day) represent averaging time (years× days/years)
CSF (mg/kg-day) is inhalation cancer slope factor
Additionally, the non-cancer risk was assessed using the Hazard Quotient (HQ) calculated through Eq. (3)

$$HQ = \frac{LADD}{RfD} \tag{3}$$

Where, the reference dose (RfD) value for benzene is 0.03 mg/kg-day [75].

In 2009, the Environmental Protection Agency (EPA) has adopted a revised approach for assessing human health risks related to inhaling contaminated air, using the Inhalation Dosimetry Methodology [76]. According to this method exposure concentrations (ECs) is calculated for individuals exposed to contaminants through inhalation, following EPA guidelines. The cancer and non-cancer risks associated with benzene pollutant via inhalation pathway are determined by estimating its EC value. In the Inhalation Dosimetry Methodology, the level of contaminants in the air measured in mg/m3 i.e denoted by EC used as exposure metric [76]. This approach contrasts with the method outlined in RAGS, Part A [73], which calculates inhalation intake based on inhalation rate (IR) and body weight (BW). The EC represents a time-weighted average concentration in ambient air over the duration of exposure.

Cancer risk (CR) due to benzene concentration inhalation is calculated as using Eq. (4)

$$CR = EC \times IUR \tag{4}$$

Here, CR represents the excess cancer risk, and IUR is the inhalation unit risk of benzene, given as 0.0000078 ($\mu g/m^3$)-1 in the Risk Assessment Information System (RAIS) [74].

The EC of population is calculated using Eq. (5)

$$EC = \frac{CA \times ET \times EF \times ED}{AT} \tag{5}$$

Where,

EC ($\mu g/m^3$) denotes exposure concentration,

CA ($\mu g/m^3$) denotes contaminant concentration in air,

ET (h/day) represent exposure time,

EF (days/week) is exposure frequency,

ED (weeks/exposure period) indicates exposure duration,

AT (hours/exposure period) represent averaging time,

IUR (µg/m3)-1 signifies inhalation unit risk,

Hazard Quotient (HQ) is for non-cancer risk calculated using Eq. (6)

$$HQ = \frac{EC}{RfC \times 1000\ \mu g/mg} \tag{6}$$

Where, RfC is the inhalation toxicity value for benzene i.e 0.03 mg/m^3. (https://iris.epa.gov/AtoZ/?list_type=alpha)

The value (ILCR and CR) $>1\times10^{-6}$ was considered to have carcinogenic effects of concern, and a value $\leq 10^{-6}$ was considered an acceptable level The value of HQ > 1 indicates adverse non-carcinogenic effects of concern, and the value of HQ ≤1 was considered an acceptable level [77].

Numerous studies have explored the cancer risk associated with benzene concentration in ambient air. Garg et al reported a probability range for benzene- related cancer risk of 0.50 estimated between $1.29\times10^{-6} – 1.80\times10^{-5}$ [78]. Additionally, Tabatabaei et al conducted a health risk assessment for children exposed to hookah smoke indoors. They observed ILCR associated with exposure in smoking and non-smoking households was estimated at 15×10^{-6} and 1.8×10^{-6} respectively [79]. Mostly literature study exceeds the limit of cancer risk i.e 1×10^{-6} given by WHO. In 2023, Poonam et al. estimates the cancer and non-cancer health risk associated due to benzene concentration observed in ambient air and at a fuel station in New Delhi. The average of seven months CR and HQ values of benzene exposure using Tenax sorbent tubes at a fuel station was found to be $9\times10^{-4} \pm 4\times10^{-4}$ and 3.74 respectively. The ILCR value was found with 50% standard deviation due to benzene exposure in ambient [2-3].

Ambient and occupational exposure limits of benzene

Annual exposure limit for benzene in ambient air worldwide as described countrywide. India, Lebanon, Russia, South Korean, New Zealand, North America Botswana, Albania prescribed annual limit as 5 $\mu g/m^3$; Iraq, Japan as 3 $\mu g/m^3$; Scotland, Northern Ireland as 3.25 $\mu g/m^3$; Israel as 1.3 $\mu g/m^3$; Syria as 20 $\mu g/m^3$; Vietnam, Morocco, South Africa, Belarus as 10 $\mu g/m^3$; France 2 $\mu g/m^3$; Malta and Sweden as 2 to 3.5 $\mu g/m^3$. [80]. In 2019, detail study of benzene standard reported by Sekar A.

In India, the CPCB has established a maximum permissible limit for benzene in the NAAQS 2009, which is 5 μg/m^3 specified as annual time weighted average (TWA) [7].

In Directive 2022/431/EU occupational exposure limit value of the European Union specified as 1 ppm (3.25 mg/m^3) over an 8-hour period. OSHA has specified occupational exposure limits for benzene with a Permissible Exposure Limit (PEL) of 5 ppm for short term exposure (STEL) over 15 minutes duration, and Threshold Limit Value (TLV) of 1 ppm as a TWA over an 8-hour period. The National Institute of Occupational Safety and Health (NIOSH) recommends STEL to 1ppm over15 minutes and a TLV-TWA of 0.1 ppm over an 8-hour period [81]. Similarly, American Conference of Governmental and Industrial Hygienists (ACGIH) set limit exposure to benzene as TWA of 0.5 ppm for 8-hour and STEL 2.5 ppm [2, 82]. Worldwide occupational and ambient exposure limits is given in Table 3 and 4.

Table 3. National & International Occupational Exposure limits for Benzene.

Country	TWA 8 h Average (ppm*)	STEL 15 Minute average (ppm*)
India	0.5	2.5
USA-OSHA	1	5
USA-NIOSH	0.1	1
USA-ACGIH	0.5	2.5
Australia	1	-
France	1	-
Germany		-
Ireland	1	-
Israel	0.5	2.5
Romania	1	-
Republic of Korea	1	5
Sweden	0.5	3
Turkey	1	-
United Kingdom	1	-
Spain	1	-
Denmark	0.5	1
Canada – Ontario	0.5	2.5
Belgium	1	-
European Union	1	-
Netherlands	0.2	-

* Conversion factors: Benzene: 1 ppm = 3.19 mg/m^3 [49].

Table 4. Ambient air quality standard limit of benzene country-wise.

Exposure Period	Value (μg/m^3)	Countries
Annual	5	India, Lebanon, Russia, South Korean, New Zealand, North America Botswana, Albania
Annual	3	Iraq, Japan
Annual	3.25	Scotland, Northern Ireland
Annual	20	Syria
Annual	10	Vietnam, Morocco, South Africa, Belarus
Annual	2	France
Annual	2-3.5	Malta and Sweden
Annual	1.3	Israel
24 h	100	Russia
20 min	300	Russia
1 h	22	Vietnam
24 h	3.9	Israel
8 h	5	Albania
24 h	40	Belarus
24 h	1000	N. America Cuba

Source: [80].

National Air quality standard of benzene

For developing countries, managing ambient air quality and minimizing adverse health effects due to air pollution from various sources is imperative. This is achieved through the implementation of "National Ambient Air Quality Standards" which is mandatory. In India, the CPCB initiated the first air quality standards as per Act 1981, Section 16(2) on November 11, 1982. These standards were revised in 1994. To raise awareness of the importance of air quality compliance under the Air (Prevention and Control of Pollution) Act 1981, CPCB established the National Ambient Air Quality Monitoring (NAMP) Network, covering 209 cities and towns across the country. CPCB also holds powers and functions for determining and controlling various air pollutants as per the Air Act 1981. Subsequently, in 1984, CPCB introduced the nationwide program "National Ambient Air Quality Monitoring Programme" (NAAQM), later revised as National Air Quality Monitoring Programme (NAMP). By 2015, the number of monitoring stations had increased to 612, covering almost 254 cities in the nation under the NAAQM scheme (https://www.cpcb.nic.in/). CPCB notified revised NAAQS in 2009 for air quality implementation. This revised NAAQS notification includes 12 major air pollutants, one of which is benzene, a highly hazardous pollutant. The annual limit prescribed by NAAQS (2009) for benzene is 5 μg/m^3, with no short-term standard specified. In India, except for benzene, no guidelines and standards have been defined for monitoring VOC pollutants in ambient air. Two methods for measuring benzene in ambient air mentioned in NAAQS i.e A GC – based continuous analyzer and adsorption followed desorption and then analysis done using GC.

Standard measurement method for benzene in air

There are various methods available for monitoring benzene level in ambient air. These methods involve collecting samples using absorption tubes, canister, passive sampler and subsequently analysing them through gas chromatography with different detector like MS, FID, PID. Additionally, other techniques are employed for sampling and analysis including real-time continuous monitoring systems, portable instruments for direct reading, or other suitable methods depending on the source of pollutants. The selection of monitoring methods for benzene is crucial to ensure accuracy and precision in the results obtained. Each country establishes its own standard limits for exposure and specifies the methods for sampling and analysis. In this section, both national and international standard methods for monitoring of benzene in ambient air has been discussed.

National air quality measurement standard method

The Bureau of Indian Standards described the Indian standard (Part 11), second revision in 2006, i.e., IS 5182 (Part 11): 2006, which outlines methods for measuring air pollution, specifically Part 11 for Benzene, Toluene, and Xylene (BTX). This standard provides three different methods for sampling and analysing BTX pollutants in ambient air. Method 1 involves active sampling using a portable battery-powered pump with a low-flow controller and activated charcoal tubes or other suitable adsorbents (particle size ranging from 60 to 80 mesh). The sampling flow rate should be maintained at 20-100 (±2 percent) ml/min for ambient air, and carbon disulfide (CS_2) is used for desorbing adsorbed pollutants. Analysis is conducted using GC-FID. Method 2 describe the same sampling procedure as Method 1 but employs thermal desorption for desorption, which improves analytical sensitivity. Method 3 utilizes passive diffusive samplers for sampling, with further analysis conducted as described in Method 1 using the GC-FID technique. The detection limit for BTX using GC-FID falls within the sub-ppb range [83].

International air quality measurement standard method

Benzene has been categorized as carcinogenic to human health by IARC since 1979 [80]. Surprisingly, only 27 % of the total 193 United Nations Member States regulate air quality standards for benzene. A worldwide summary of air quality standards for benzene can be found in the published literature by Sekar et al.

The European standard EN 14662 describes the standard method for sampling procedures and the operating conditions of automated chromatographs used to measure ambient benzene levels. The European Union mandates continuous monitoring of ambient benzene due to its toxic nature. Among all hazardous VOCs, benzene is one of the pollutants regulated in European countries, with an annual limit value of 5 μg/m^3 at 293 K and 101.4 kPa. Over the past decades, many countries have successfully reduced the percentage of benzene in fuel compositions. The standard methods for monitoring benzene levels in the atmosphere were established by Directive 2008/50/EC. In 2005, EN 14662 was published, consisting of five parts (CEN, 2005-1, 2, 3, 4, and 5). All parts of this standard are currently active, but Part 3 of EN 14662 was revised in 2015 [84].

BS EN 14662-1:2005 provides general guidance for the sampling and analysis of ambient benzene. Sampling is conducted using a pump and active carbon as an adsorbent, followed by thermal desorption and analysis via GC [85]. In contrast, Part 2 (BS EN 14662-2:2005) differs in the sampling procedure, where desorption is achieved using a solvent. This method utilizes sample tubes containing approximately 100 mg of activated charcoal, with desorption performed using carbon disulfide and subsequent analysis via gas chromatography [86]. BS EN 14662-3:2015, Part 3 of the European Standard, specifies a semi-continuous measurement method for determining ambient benzene levels through automated sampling and gas chromatograph analysis. This method is applicable to various areas, including rural, urban traffic-oriented, and industrial areas, and can measure up to 50 μg/m³ of benzene in ambient air [84]. Both Parts 4 (BS EN 14662-4:2005) and 5 (BS EN 14662-5:2005) of the European Standard describe methods for measuring benzene concentrations using diffusive samplers for sample collection, but differs by desorption procedures i.e thermal desorption for Part 4 and solvent desorption for Part 5 [87-88].

Occupational Safety and Health Administration Standard 1910.1028, Appendix D, Part No. 1910, outlines sampling and analytical methods for monitoring and measuring benzene. OSHA Laboratory Method 12 provides two analytical approaches for measuring benzene levels in ambient air [89].

1. OSHA Method 12 for Air Samples: This method employs charcoal tubes to adsorb organic vapours present in ambient air using a personal sampling pump, followed by desorption with CS_2 and analysis using GC. The detection limit for this method is 0.04 ppm, with a sampling rate ranging from 10 L to 0.2 L/min

2. OSHA Method 12 for Bulk Samples: In this approach, samples are analysed using HPLC (high-performance liquid chromatography). The detection limit for this method is 0.01 % by volume.

The United States Environmental Protection Agency (USEPA) describes two methods, 325A and 325B, for monitoring VOCs from fugitive and area sources. Method 325A explains sampler deployment and VOC sample collection, while Method 325B covers sample preparation and analysis. Both methods are suitable for measuring benzene using GC-FID/MS within a concentration range of approximately 0.5 to 500 μg/m³ [90-91]. Other US EPA measurement method of VOCs in ambient air given in Table 5.

Table 5. USEPA method for measurement of VOCs including benzene in ambient air.

Method	Compound	Sampling and Analysis	Detection Limit
TO -1	VOCs (80 °C to 200 °C)	TENAX-GC Adsorption and GC/MS or GC/FID analysis	0.01-10 ppbv
TO - 14 A	VOCs Non polar	Canister and GC/FID/ECD or GC/MS detection	0.2-25 ppbv
TO - 15	VOCs	Canister and GC/MS analysis	0.2-25 ppbv
TO - 16	VOCs	FTIR open path spectroscopy	25-500 ppbv
TO - 17	VOCs	Multi-bed adsorbent tube followed by GC/MS, FID	0.2-25 ppbv

Sampling and measurement techniques of benzene

Sampling methods

Sampling of benzene in ambient air is very important for assessing air quality and ensuring public health associated due to its exposure in air. There are several methods for sampling of benzene in ambient air, each have their advantages and disadvantages. Here, most commonly sampling divided as active and passive sampling.

Active sampling: A pump is used to sucked a known volume of air through sampling device over a specific period of time. During this process, pollutants present in the air are collected on the sampling medium. The flow rate and sampling time carefully controlled to maintain accuracy. Charcoal sorbent tubes are used most preferably to adsorbed VOCs including benzene. Sorbent tube is analysed by desorption in CS2 or other solvents followed by gas chromatography (https://www.cpcb.nic.in/). In 2023, Poonam Kumari et al find out concentration of BTEX at fuel station [2] and benzene concentration at traffic interjection using active sampling [3]. The health risk associated with VOCs and carbonyl compounds was determined using active sampling in beauty salons [92].

Passive sampling

A diffusion sampling tube consists adsorbents are used to reinforce the targeted analytes. Analytes present in the ambient air diffuse through the permeable membrane or are absorbed by the sorbent material within the passive sampler. The rate of diffusion and absorption is determined by the concentration gradient between the air and the sampler, as well as the specific properties of the sampler and the target analytes. After exposure, the sorbent is analyzed using techniques such as thermal desorption coupled with GC-FID or GC-MS. Passive sampling is useful for long-term monitoring and can provide time-weighted average concentration (https://www.cpcb.nic.in/). In last few decades, passive sampler has been mostly used due factor like easy to use, their simplicity and low cost. In 2019 Vallecillos et al. use passive sampler for volatile organic compounds analysis in industrial atmosphere [93]. Recently in 2023, the concentration of pollutants is measured using passive sampling in Brazilian urban areas, the level of benzene exceeded the limit according to the WHO, i.e 1.7 μg m³ associated with the probability of leukemia [94].

Grab sampling

In grab sampling sample air is taken in a container like polished stainless-steel canisters, bags in a very short periods of time (10-30 seconds). Then analysis of the sample is done using gas chromatography or other suitable techniques. In 2010, Tiwari et al analysed the concentration of VOCs in petrochemical industrial area using active grab sampling [95]. Other details of sampling procedure and with their advantage and disadvantage given in Table 6.

Table 6. Sampling medium and method of benzene in ambient air .

Sampling medium	Method	Advantage	Disadvantage
SUMMA Canister	Air is sucked into a SUMMA canister, which contains a vacuum. The benzene present in the ambient air goes into canister.	Canisters can capture a wide range of VOCs, including benzene, and provide accurate results	Canisters are relatively expensive and require careful handling to prevent contamination.
Sorbent tubes	Air is sucked through a sorbent tube filled with an adsorbent material (such as activated charcoal) that captures benzene and other volatile organic compounds (VOCs)	Cost-effective, easy to use, and suitable for personal or area sampling.	Sampling flow rate, time and temperature can affect the accuracy of results obtained.
Tedlar bags	Tedlar bags are designed to collect gas/air samples. It fitted with two components i.e Poly Vinyl Fluoride film and Teflon/PTFE valve fitting.	Portable for on-site use, easy to handle.	Out-gassing of bag material, incorrect analytical results, inconsistency in blank levels.
Passive Diffusion Samplers	A diffusion tube containing an adsorbent material. Pollutants diffuses through a membrane and gets adsorbed onto the material	Low-cost, and suitable for long-term sampling. Obtained time-weighted average concentrations of pollutants.	Less accurate than active sampling methods. Results might be affected by weather conditions such rain, wind speed etc.
Real-time monitoring instruments	Online monitoring analyser attached with photoionization detectors (PID) or flame ionization detectors (FID) can provide real-time measurements of benzene concentrations in ambient air.	Instantaneous results, suitable for on-site monitoring and industrial applications.	Large size instruments, heavy weight and extraordinary expensiveness. Also, calibration and maintenance are crucial for accuracy.

Measurement techniques

Various methods are present for determining the concentration of benzene in different environments, including ambient air, workplaces, water, food, fuel stations, and soil. Gas chromatography (GC) is a commonly used technique for separation, employing different detectors like FID, MS, or PID. The limit of detection for GC-FID/PID ranges from low parts per billion (ppb) to parts per trillion (ppt) levels. GC-MS considered more reliable and accurate for separation of similar GC elution characteristics. The limit of detection for benzene in ambient air has been quantified at sub-ppb levels using GC-MS [46]. A schematic diagram of GC is given in Fig. 5.

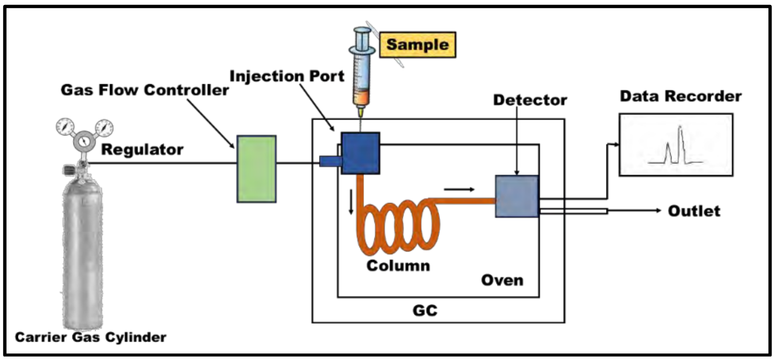


Figure 5. Schematic diagram of Gas chromatography

In the literature, GC-FID is predominantly used. In 2019, Garg et al. utilized activated charcoal tubes to collect BTEX samples in ambient air, subsequently analyzed using GC-FID [78]. Sousa et al studied benzene levels in indoor and outdoor environments using the GC-FID technique, with tandem mass spectrometric detection (MS/MS) used to confirm benzene in ambient air [96]. Bayatian et al reported a new method involving a sampling needle trap device (NTD) and analysis performed using GC-FID, with benzene level measured in the range of 0.15 to 1.2 ppm [97]. Kumari et al reported benzene concentrations at fuel stations and traffic intersections, with sampling conducted using charcoal sorbent tubes and subsequent analysis using GC-FID [2-3]. Tabatabaei et al examined BTEX concentrations emitted by Hookah smoke in indoor air, with sampling carried out using charcoal adsorbent tubes and subsequent analysis using GC-FID [79]. Disadvantages of gas chromatography include longer analysis times and limitations in real-time monitoring or lack of direct quantification of analytes [98].

Proton transfer reaction mass spectrometry is a technique used for real-time monitoring of pollutants in the atmosphere. It is employed for measurement of VOCs in atmosphere using low chemical energy. The separation of volatile organic compounds occurs based on their mass/charge ratio. Literature [99-101] reported this technique for separating VOCs, including benzene in the atmosphere. The advantages of PTR-MS include short time resolution (sub-minutes), suitability for long-term continuous measurement, and a low limit of detection. A disadvantage of this technique is its inability to distinguish between pollutants with the same nominal mass [98].

The BTEX Analyzer is a real-time monitoring instrument for pollutants, capable of analyzing BTEX concentrations simultaneously. Data obtained can be transferred via modem. However, a drawback of this technique is its high cost, as well as the need for carrier gas to operate the instrument. APCI-MS means atmospheric pressure chemical ionization mass spectrometry, offers high ionization efficiency and sensitivity, allowing for direct sampling. However, it is not suggested for measurement of BTEX at low concentrations due to the formation of water clusters and it is very expensive. Many techniques used for measurement of volatile organic compounds including benzene reported by Sylwia et al. [102].

Level of benzene in ambient air

Benzene is considered a carcinogenic pollutant according to EPA and WHO guidelines, and it may have numerous adverse health effects on both humans and animals. Due to its detrimental health impacts, continuous monitoring of this pollutant is necessary. Several studies have been conducted in major hotspot areas around the world [2,3,15,21,31,35,47,75, 103-111]. Literature related to observed values of benzene and other VOCs at fuel stations has been published [2, 112-117]. Jafari et al studied atmospheric benzene and its health effects in Tehran megacity from 2010- 2013, with yearly average benzene concentration ranging from 1.84 to 2.57 μg/m³ [118]. Continuously three-year (24 hrs average) benzene concentration from 2019-2021 was observed through online monitoring station at shadipur New Delhi set by central pollution control board (CPCB). Maximum duration concentration of benzene was exceeding the annual limit given in NAAQS parameter i.e 5 μg/m³ except lockdown period during corona pandemic shown in Fig 6.

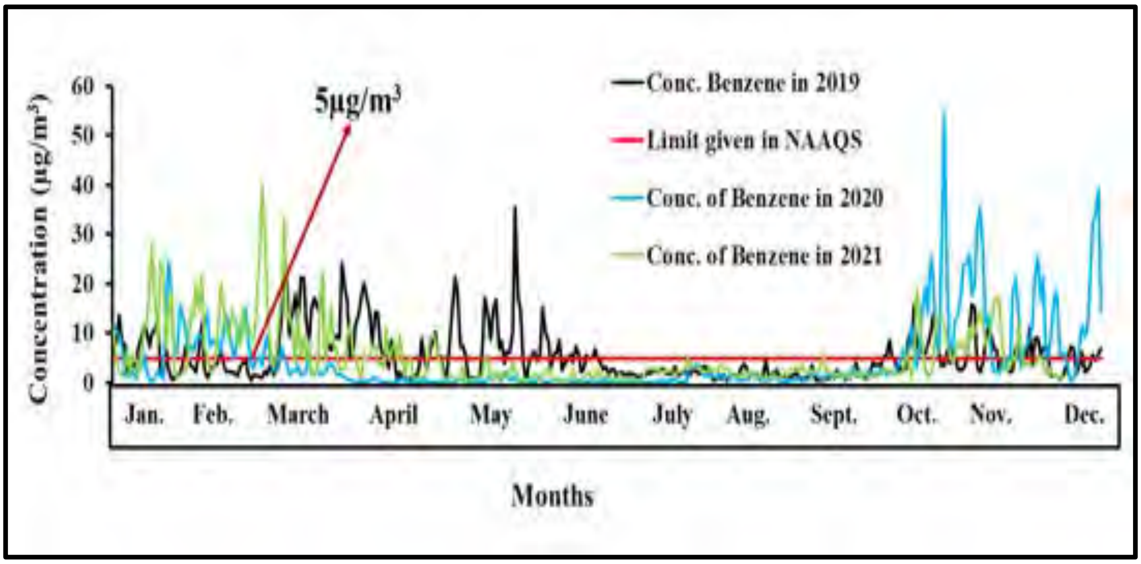


Figure 6. Monthly concentration of benzene from 2019-2021.

Popitanu et al examined the seasonal impact of BTEX pollutants in Arad City, Romania. BTEX (Benzene, Toluene, Ethylbenzene, Xylene) concentrations were highest in winter and lowest in autumn, with benzene being the most dominant pollutant. The mean value of benzene ranged from 2.47 ± 0.74 μg/m³ to 18.00 ± 1.32 μg/m³. The LTCR (Lifetime Cancer Risk) for benzene was higher than the limit set by WHO guidelines during the winter season, reaching 3×10^{-5}, categorized as 'possible cancer risk.' However, during the summer, LTCR for benzene was less than 10^{-5}, indicating 'probable cancer risk.' The observed level of benzene exceeds the limit i.e 5 μg/m³ limit set by Directive 2000/69/E.C [103].

Fariba et al studied benzene in a Middle Eastern city and found a concentration of 2.95 μg/m³, within the range [119]. The mean ILCR for benzene were 6.49×10^{-7} for infants (0-1 year), 7.21×10^{-6} for children (2-18 years), and 1.27×10^{-5} for adults (19-70 years), exceeding the limits set by the US EPA and WHO (1×10^{-6} - 1×10^{-5}). Various studies on benzene pollutant in ambient air have been conducted in Western urban areas in Europe, North America, and Japan, with concentration ranges provided [120-121].

A study by Garg and Gupta in 2019 investigated benzene concentrations in New Delhi during busy and non-busy hours. The average benzene concentration during busy hours was 12.32 ± 6.69 μg/m³, while during non-busy hours, it was 8.50 ± 5.83 μg/m³ [78]. Srivastava et al conducted a study in Mumbai on VOCs in ambient air, covering various types of areas. The annual mean benzene values with standard deviations were obtained for different locations, including residential areas, commercial areas, industrial areas, traffic intersections, and petrol pumps, ranging from (45.31 ± 18.68) to (539.95 ± 51.20) μg/m³ [44]. Kashyap et al carried out a study on BTEX concentrations in urban vegetative sites in New Delhi, India, area of his study was SJP (Swarn Jayanti Park), Rohini, and JNU (Jawaharlal Nehru University) and also Yamuna biodiversity park, reporting an average benzene value of 8.98 mg/m³ [107]. Similarly, a study on non-methane hydrocarbons (NMHC) was conducted in India by Kumar et al. (2019) at different locations, with the highest concentration of benzene (67.8 μg/m³) observed at ITO (Income Tax Office Crossing) [122].

Masih et al studied BTX pollutant concentrations in North India and reported a total BTX concentration of 30.95 μg/m³ at Gorakhpur in urban and rural areas, with mean benzene values of 12.1 and 7.4 μg/m³, respectively [123]. Garg et al observed benzene concentrations at six locations in Delhi, with the highest value reaching 58.73 μg/m³ at Anand Vihar during the winter season. Most locations in Delhi recorded benzene concentrations higher than the 5 μg/m³ NAAQS standards, highlighting the need for improved air quality measures in urban areas. Concluded that urban atmosphere like in Delhi city, hazardous pollutant like benzene not easily dissipate into ambient air. so, we need to improved our technologies for better air quality like improve fuel quality, traffic management strategies, odd-even policy, growing plants on road sides, planning meeting time to time for pollution management and increase greenery areas in such megacity may result in reduction of such toxic pollutions [111]. In a recent publication, Kumari et al observed benzene concentrations at fuel stations and traffic intersections in Delhi that exceeded the prescribed limits set by NAAQS parameters. The average benzene concentration was found to be (84 ± 40) μg/m³ at fuel stations, using charcoal sorbent tubes for sampling, with the maximum average value of benzene reaching 33 μg/m³ at traffic intersections [2-3]. Another study in India by Buddhadev Ghosh et al. (2023) studied the spatio-temporal distribution and health risk assessment of BTEX in the urban atmosphere from 2019 to 2022. The average value of benzene was (8.85 ± 4.34) μg/m³ in Kolkata and (7.25 ± 0.42) μg/m³ in Howrah, both exceeding the annual limits set by NAAQS for ambient air in India.

Notario et al conducted a study on ambient benzene in metropolitan and industrial areas of Spain from 2014-2017. The yearly average benzene level change from 0.3 μg/m³ to 2.4 μg/m³, with hourly maximum values reaching 112 μg/m³ [124]. Behnami et al investigated the spatiotemporal variation of benzene and other VOCs using charcoal sorbents in Iran, finding a mean benzene value of (29 ± 1.07) μg/m³ [125]. Mostly benzene concentration was found above the yearly average limit i.e 5 μg/m³ in developing countries due to rapidly increase industrialization, urbanization as compare to rural areas. So, we concluded that benzene pollution vary area wise depending on their specific regulatory frameworks, industrial activities, and environmental challenges.

In India, most studies on benzene pollutants have focused on metro cities like Delhi and Kolkata, primarily examining exposure in urban areas. Given the hazardous health and environmental impacts of such pollutants, more research is needed in rural areas, raising awareness among rural communities regarding emissions from sources such as crop burning, wood cooking, furniture, and painting. Monitoring benzene in both rural and urban areas is crucial, especially since a significant portion of the population resides near high-traffic junctions or alongside roads [123]. A literature survey on benzene concentration worldwide given in Table 7.

Table 7. Concentration of benzene worldwide

City	Benzene (μg/m³)	Study area	Sampling method/ Measurement Technique	Reference
Delhi (India)	2 - 43	Shadipur, Traffic junction	Coconut charcoal sorbent tubes (SKC, Anasorb CSC, sorbent; extraction with acetone/ GC-FID; Agilent 6890N	[3]
Tehran (Iran)	5200	Fuel station	Personal samplings pump using activated charcoal tube, GC-FID	[114]

Table 7. Continued

Delhi (India)	142.2	IIT Delhi & UP Boarder, Traffic junction	ORBO™-32 Charcoal tube/GC-FID; Nucon 5700 gas chromatography	[126]
Ardabil (Iran)	1690	Fuel station	SKC personal sampling pumps, Coconut charcoal sorbent tubes, GC-FID	[113]
Delhi (India)	1.98 -10.26	Shahdara, Traffic-Congested Area	Charcoal tubes (ORBOTM32)/ GC-FID	[111]
USA	2900	Fuel station	Passive monitor, Tenax adsorbent, GC/FID	[127]
Leon, Guanajuato (Mexico)	1.96	Traffic, Industrial Urban area	Active sampling using Charcoal sorbent tubes, 1.5 h, 200 mL min−1, CS2 solvent for desorption/ GC-FID	[106]
Bangkok (Thailand)	590 ± 107	Fuel station	Charcoal glass tube, personal air pump, GC-FID	[128]
Kolkata (India)	24.97 - 79.18	Traffic, Industrial Urban area	Active sampling using Charcoal sorbent tubes, 100 mL min−1, 6 h, CS2 desorption solvent/ GC-FID	[129]
Uttar Pradesh (India)	17 - 29	Fuel station	Real-time measurements using PID detector	[4]
Iran	2 - 108	Industrial and local road traffic area	Active sampling using activated carbon ,2 h, SKC Inc., England, model 222-3	[105]
M.P (India)	2 - 12	Fuel station	Benzene sampler, GC-FID	[112]
Arad City (Romania)	18.00 ± 1.32	High-density traffic area	Stainless steel tubes, SKC 1003, GC-MS attached with a thermal desorption system.	[103]
Delhi (India)	6406	Fuel station	Sampling pump using Charcoal tube, GC-FID	[115]
Delhi (India)	48 - 110	Traffic area, industrial area	Diffusive sampling using coconut shell charcoal, Thomas Baker Pvt. Ltd. for one week. CS2 desorption/GC-FID (PerkinElmer Auto-XL)	[37]
Delhi (India)	112	Fuel station	Sampling pump using charcoal/Tenax sorbent tubes, GC-FID	[2]
Tehran	1.84 - 2.57	Air quality monitoring stations	Gas chromatograph (GC) VOC analyzer	[118]
Shiraz (Iran)	2.95	Population density traffic area	Passive samplers (Radiello RAD 130), GC-MS	[119]

Certified reference material for monitoring of benzene in ambient air

A primary reference gas materials or certified reference materials (CRMs) are an important factor to certify the traceability of measurement results. [39-40,130]. The literature [38-39,131-137] reported certified reference material of volatile organic compounds including benzene in different matrix gas. CSIR-NPL national metrology institute (NMI) of India have been developed (2.79 ± 0.015) to (13.64 ± 0.020) µmol/mol benzene in nitrogen calibration gas mixture [38]. Different National Metrology Institute (NMI) of world-wide developed Gravimetric prepared CRM for multicomponent of VOC like BTEX and participate in international inter comparison. Latest last key comparison CCQM-K10.2018 final report was published in 2022. More details about preparation procedure and measurement techniques of reference gas mixture is given in a published review article [138]. Detail description of benzene certified reference material participation by different NMI are given in Table 8 and 9.

Table 8. Details of certified reference material of benzene developed worldwide.

NMI	Country	Techniques	Gravimetric amount-of substance fraction (nmol/mol)	Standard uncertainty (k=1) (nmol/mol)
KRISS	Korea	GC-FID	5.03	0.098

Table 8. Continued

LNE	France	GC-FID	5.09	0.050
NIST	USA	GC/FID/preconcentration	5.47	0.042
NIMSA	South Africa	Cryogenic pre-concentration coupled with GC	5.02	0.063
NPL	United Kingdom	GC-FID	5.00	0.050
VNIIM	Russia	Chromato-mass-spectrometer	4.97	0.055
VSL	Netherlands	GC/FID	5.00	0.050
METAS	Switzerland	ATD-GC-FID	6.21	0.360
UBA	Germany	GC Clarus 680 GL and Turbomatrix 300 a	5.09	0.020
CHMI	Czech Republic	GC/ FID Preconcetration	5.15	0.157

Source: [133]

Table 9. Details of component transfer method and column used for analysis.

NMI	Component transfer method	Column	Cylinder Pressure
KRISS	Binary-micro -syringes	-	9.3 Mpa
LNE	Binary-syringes	CP-xylene capillary column	125 bars
NIST	Binary-capillary tubes	-	1500 psi
NIMSA	Syringe injection	60 m × 0.32 mm × 0.5 mm AT_WAX (heliflex)	132 bar.
NPL	Binary 3-way transfer vessels	60 m ×0.32 um, df = 1 um RTX-Wax (Restek corporation).	100 bar
VNIIM	-	Restek Stabilwax (30m × 0.25mmID × 0.25μm)	10.5 MPa
VSL	Liquid mixture; transfer line	CPWAX 52CB (60m× 0.32mm×0.25μm).	125 bar
METAS	Permeation and dynamic dilution using adsorption tube	Stabilwax, Restek	90 bars
UBA	Capillary tubes	-	-
CHMI	-	DB-1 (60m × 320μm × 1 μm) HP-Plot Al2O3S (50m × 320μm × 8 μm)	11.0-10.4 MPa

Source: [133]

Mitigations strategies

Vehicular emission and fuel vaporization at fuel stations are found to be the main sources based on the results of the emission inventory and reported monitoring data of benzene in ambient air. Priority mitigation strategies should mainly focus on these sources.

- Prefer walking or riding instead of driving nearby workplaces, use public transport instead personal vehicle.
- Promote electric vehicles project and develop smart traffic management controller agencies to reduce jam [139].
- Developing traffic efficient applications for road networks in the smart cities [140].
- Promote public transportation project to encourage residents use buses [141].
- Developing a red alert warning system at monitoring stations whenever high concentration of benzene observed to protect human.
- Choose a fuel-efficient vehicle when replacing new car.
- Proper fuel handling training to be given the employers follow up during loading and unloading the fuel.
- Promote self-service fuel stations.
- Mandate protective gear such as gloves and breathing masks for all employers at fuel station [115].
- Incorporate the features in designing of the fuel stations which will improve the air exchange rate.

Implementation of stringent emission standards for industrial processes and vehicular emissions, urban planning and traffic management, Continuous monitoring and surveillance, Reduction of benzene content in gasoline, green spaces and vegetation, public awareness and control of tobacco uses, Installation of Vapour recovery system at fuel stations, use eco- friendly cleaning products are the key factor to mitigate the benzene emission in air.

Gardening of the toxic filter plants i.e Spider plants, Snake plants, Weeping figs, Peace Lily, Bamboo palms, Boston ferns, Aloe Vera, Dracaenas, English ivy, Janet Craig, Barberton Daisy, Chrysanthemums that absorbed benzene from air.

Continuous monitoring of benzene concentration in ambient air is important for identifying pollution hotspots and assessing the desired output of mitigation measures. Timely accurate measurement results to be provided to policy decision-makers which help them to take prompt appropriate action to enhance the air quality.

Conclusions

In this article, we have discussed the significance of hazardous pollutant benzene in our environment. There are many complexities and challenges associated with accurate assessment and mitigation of benzene exposure. Attention must be given to this silent killer to ensure the safety of individuals and the environment. The profound impact of benzene on human health, including its association with cancer and other adverse health, reinforces the top priorities of comprehensive mitigation strategies. The concentration of benzene measured at different sites in different countries is found to be higher than the exposure limits in air. Even though standards of benzene are accessible, in most cases they are not capable of safeguarding public health. Metrological traceability plays an important role to ensure the accuracy of the measured data. A very few countries are developing certified reference material of benzene worldwide. In summary, this review article discussed complicated nature of benzene assessment and will contribute to determine the potential risks on populations due to presence of the ambient benzene. The study promotes the monitoring strategies, implementation in air quality monitoring station designed and will help experts in decision making and risk management. The benzene pollution could be controlled by authorities or policy makers (by implementing stringent air quality standard, promoting alternative transportation), researcher (by developing advanced monitoring techniques, case studies to investigate the health effects of benzene exposure on communities), industry stakeholders through partnerships with government agencies, research institutions, and share best practices, data, and resources for addressing benzene pollution effectively. It is essential for researchers, policymakers, and industries to collaborate in a concerted effort to refine measurement methodologies, establish various reference materials, amend exposure limits, and improve mitigation strategies. Only through such collective action we can reduce the risks associated with benzene exposure and protect both individuals and the environment from its harmful effects.

Acknowledgement

Poonam Kumari is thankful to the Council of Scientific and Industrial Research (CSIR) for providing the fellowship under the CSIR-SRF scheme (P-81-101). The authors thank the Director, CSIR-NPL for providing a platform to carry out experimental work and for providing research facilities and funding from OLP 230332 to carry out experimental work. The authors are also thankful to the head of the Environmental Sciences and Biomedical Metrology Division and all staff members of Gas Metrology for their encouragement and support.

Conflict of interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

CRediT author statement

PK: Methodology, Investigation, analysis, Data Curation, Writing-Original draft preparation. DS: Conceptualization, Methodology, Supervision, Writing-Reviewing and Editing. SGA: Visualization, Writing-Reviewing and Editing.

References

[1] United States, Environmental Protection Agency (US EPA). Toxicological review of Rev. Lit. Arts Am. [cited Nov 13, 2023]. Available from: http://www.epa.gov/iris/toxreviews/0070tr.pdf

[2] Kumari P, Garg G, Soni D, Aggarwal SG. Measurement of benzene and other volatile organic compounds: implications for its inhalation health risk associated with the workers at a fuel station in Delhi. Asian Journal of Atmospheric Environment 2023;17(7):1-11. https://doi.org/10.1007/s44273-023-00007-8

[3] Kumari P, Soni D, Aggarwal SG, Singh K. Seasonal and diurnal measurement of ambient benzene at a high traffic inflation site in Delhi: Health risk assessment and its possible role in ozone formation pathways. Environ Anal Health Toxicol 2023;38(3):e2023016-0. https://doi.org/10.5620/eaht.2023016

[4] Chaudhary S, Kumar A. Study on refuelling pump stations caused by BTEX compounds in firozabad city. International Archive of Applied Sciences and Technology 2012;3(2):75-79.

[5] World Health Organization, International Agency for Research on Cancer, IARC Working Group on the Evaluation of Carcinogenic Risks to Humans. A review of human carcinogens: Chemical agents and related occupations.. IARC Monogr Eval Carcinog Risks Hum 2012;100F:249–294.

[6] Lloyd AC, Denton JE. Technical support document for describing available cancer potency factors. Secretary for Environmental Protection California Environmental Protection Agency; 2005.

[7] Goverment of India, Ministry of Environment, Forest and Climate Change, Central Pollution Control Board (CPCB). National ambient air quality standards, Central Pollution Control Board, Notification New Delhi the 18th November, 2009. [cited Nov 13, 2023]. Available from: https://scclmines.com/env/DOCS/NAAQS-2009.pdf

[8] Williams PRD, Robinson K, Paustenbach DJ. Benzene exposures associated with tasks performed on marine vessels (circa 1975 to 2000). J Occup Environ Hyg 2005;2(11):586-599. https://doi.org/10.1080/15459620500339147

[9] Wang L, Zhou Y, Liang Y, Wong O, Armstrong T, Schnatter AR, et al. Benzene exposure in the shoemaking industry in China, a literature survey, 1978-2004. Regul Toxicol Pharmacol 2006;46(2):149-156. https://doi.org/10.1016/j.yrtph.2006.06.009

[10] Verma DK, des Tombe K. Benzene in gasoline and crude oil: occupational and environmental implications. AIHA J (Fairfax, Va) 2002;63(2):225-230. https://doi.org/10.1080/15428110208984708

[11] Capleton AC, Levy LS. An overview of occupational benzene exposures and occupational exposure limits in Europe and North America. Chem Biol Interact 2005;153–154:43–53. https://doi.org/10.1016/j.cbi.2005.03.007

[12] Weisel CP. Benzene exposure: An overview of monitoring methods and their findings. Chem Biol Interact 2010;184(0):58–66. https://doi.org/10.1016/j.cbi.2009.12.030

[13] Sahu SK, Mangaraj P, Tyagi B, Yadav R, Paul O, Chaulya S, et al. Estimating NOX, VOC, and CO variability over India's 1st smart city: Bhubaneswar. Frontiers in Environmental Science 2022;10:997026. https://doi.org/10.3389/fenvs.2022.997026

[14] Chelani AB. Fractal behaviour of benzene concentration near refinery, traffic junctions and residential locations in India. Atmospheric Pollution Research 2023;14(7):101798. https://doi.org/10.1016/j.apr.2023.101798

[15] Correa SM, Arbilla G, Marques MRC, Oliveira KMPG. The impact of BTEX emissions from gas stations into the atmosphere. Atmospheric Pollution Research 2012;3(2):163-169. https://doi.org/10.5094/APR.2012.016

[16] Glass DC, Schnatter AR, Tang G, Irons RD, Rushton L. Risk of myeloproliferative disease and chronic myeloid leukaemia following exposure to low-level benzene in a nested case-control study of petroleum workers. Occup Environ Med 2014;71(4):266-274. https://doi.org/10.1136/oemed-2013-101664

[17] Smith MT. Advances in understanding benzene health effects and susceptibility. Annu Rev Public Health 2010;31:133-148. https://doi.org/10.1146/annurev.publhealth.012809.103646

[18] Durmusoglu E, Taspinar F, Karademir A. Health risk assessment of BTEX emissions in the landfill environment. Journal of Hazardous Materials 2010;176(1-3):870-877. https://doi.org/10.1016/j.jhazmat.2009.11.117

[19] Koh DH, Jeon HK, Lee SG, Ryu HW. The relationship between low-level benzene exposure and blood cell counts in Korean workers. Occup Environ Med 2015;72(6):421-427. https://doi.org/10.1136/oemed-2014-102227

[20] Neghab M, Delikhoon M, Baghani AN, Hassanzadeh J. Exposure to cooking fumes and acute reversible decrement in lung functional capacity. Int J Occup Environ Med 2017;8(4):207–216. https://doi.org/10.15171/ijoem.2017.1100

[21] Ran J, Qiu H, Sun S, Tian L. Short-term effects of ambient benzene and TEX (toluene, ethylbenzene, and xylene combined) on cardiorespiratory mortality in Hong Kong. Environ Int 2018;117:91-98. https://doi.org/10.1016/j.envint.2018.04.049

[22] Xiong F, Li Q, Zhou B, Huang J, Liang G, Zhang L. et al. Oxidative stress and genotoxicity of long-term occupational exposure to low levels of BTEX in gas station workers. Int J Environ Res Public Health 2016;13(12):1212. https://doi.org/10.3390/ijerph13121212

[23] Moolla R, Curtis CJ, Knight J. Assessment of occupational exposure to BTEX compounds at a bus diesel-refueling bay: A case study in Johannesburg, South Africa. Sci Total Environ 2015;537:51-57. https://doi.org/10.1016/j.scitotenv.2015.07.122

[24] Ye D, Klein M, Chang HH, Sarnat JA, Mulholland JA, Edgerton ES, et al. Estimating acute cardiorespiratory effects of ambient volatile organic compounds. Epidemiology 2017;28(2):197-206. https://doi.org/10.1097/EDE.0000000000000607

[25] Crebelli R, Tomei F, Zijno A, Ghittori S, Imbriani M, Gamberale D, et al. Exposure to benzene in urban workers: environmental and biological monitoring of traffic police in Rome. Occup Environ Med 2001;58(3):165–171. https://doi.org/10.1136/oem.58.3.165

[26] Bahadar H, Mostafalou S, Abdollahi M. Current understandings and perspectives on non-cancer health effects of benzene: a global concern. Toxicol Appl Pharmacol 2014;276(2):83-94. https://doi.org/10.1016/j.taap.2014.02.012

[27] Parker JD, Woodruff TJ, Basu R, Schoendorf KC. Air pollution and birth weight among term infants in California. Pediatrics 2005;115(1):121–128. https://doi.org/10.1542/peds.2004-0889

[28] Liu N, Li X, Ren W, Li L, Su C, Wang C. Concentration characteristics and photochemical reactivities of VOCs in Shenyang, China. Atmosphere 2021;12(10):1240. https://doi.org/10.3390/atmos12101240

[29] Sato K, Takami A, Kato Y, Seta T, Fujitani Y, Hikida T, et al. AMS and LC/MS analyses of SOA from the photooxidation of benzene and 1,3,5-trimethylbenzene in the presence of NOx: effects of chemical structure on SOA aging. Atmospheric Chemistry and Physics 2012;12(10):4667-4682. https://doi.org/10.5194/acp-12-4667-2012

[30] Ng NL, Kroll JH, Chan AWH, Chhabra PS, Flagan RC, Seinfeld JH. Secondary organic aerosol formation from m-xylene, toluene, and benzene. Atmospheric Chemistry and Physics 2007;7(14):3909-3922. https://doi.org/10.5194/acp-7-3909-2007

[31] Bauri N, Bauri P, Kumar K, Jain VK. Evaluation of seasonal variations in abundance of BTXE hydrocarbons and their ozone forming potential in ambient urban atmosphere of Dehradun (India). Air Quality, Atmosphere & Health 2016;9(1):95-106. https://doi.org/10.1007/s11869-015-0313-z

[32] Marć M, Bielawska M, Simeonov V, Namieśnik J, Zabiegała B. The effect of anthropogenic activity on BTEX, NO2, SO2, and CO concentrations in urban air of the spa city of Sopot and medium-industrialized city of Tczew located in North Poland. Environ Res 2016;147:513-524. https://doi.org/10.1016/j.envres.2016.03.014

[33] Borrás García EM, Tortajada Genaro LA. Secondary organic aerosol formation from the photo-oxidation of benzene. Atmospheric Environment 2012;47:154-163. https://doi.org/10.1016/j.atmosenv.2011.11.020

[34] Atkinson R. Atmospheric chemistry of VOCs and NOx. Atmospheric Environment 2000;34(12–14):2063-2101. https://doi.org/10.1016/S1352-2310(99)00460-4

[35] Kumar A, Tyagi SK. Benzene and toluene profile in ambient air of Delhi as determined by active sampling and GC analysis. Journal of Scientific & Industrial Research 2006;65(3):252-257.

[36] Wang H, Xue S, Hao R, Fang L, Nie L. Emission characteristics and ozone formation potential assessment of VOCs from typical metal packaging plants. Atmosphere 2022;13(1):57. https://doi.org/10.3390/atmos13010057

[37] Hoque RR, Khillare PS, Agarwal T, Shridhar V, Balachandran S. Spatial and temporal variation of BTEX in the urban atmosphere of Delhi, India. Sci Total Environ 2008;392(1):30-40. https://doi.org/10.1016/j.scitotenv.2007.08.036

[38] Kumari P, Soni D, Singh K, Aggarwal SG. Preparation, verification and stability of calibration gas mixture of benzene in nitrogen. MAPAN-Journal of Metrology Society of India 2023;38(3):707-713. https://doi.org/10.1007/s12647-023-00659-5

[39] Neves LA, Almeida RRR, Rego EP, Rodrigues JM, de Carvalho LJ, de M Goulart AL. Certified reference material of volatile organic compounds for environmental analysis: BTEX in methanol. Anal Bioanal Chem 2015;407(11):3225-3229. https://doi.org/10.1007/s00216-014-8314-6

[40] Ihara T, Saito T, Sugimoto N. Expansion of organic reference materials for the analysis of hazardous substances in food and the environment. Synthesiology English edition 2009;2(1):13-24. https://doi.org/10.5571/syntheng.2.13

[41] Derwent R. Source, distribution and fates of VOCs in the atmosphere. In: Hester RE, Harrison RM, editors. Volatile organic compounds in the atmosphere. Royal Society of Chemistry; 1995. 1-15.

[42] Winebrake JJ, Deaton ML. Hazardous air pollution from mobile sources: A comparison of alternative fuel and reformulated gasoline vehicles. J Air Waste Manag Assoc 1999;49(5):576-581. https://doi.org/10.1080/10473289.1999.10463828

[43] Sahu LK, Saxena P. High time and mass resolved PTR-TOF-MS measurements of VOCs at an urban site of India during winter: Role of anthropogenic, biomass burning, biogenic and photochemical sources. Atmospheric Research 2015;164–165;C:84-94. https://doi.org/10.1016/j.atmosres.2015.04.021

[44] Srivastava A, Joseph AE, Devott S. Volatile organic compounds in ambient air of Mumbai India. Atmospheric Environment 2006;40:892-903. http://doi.org/10.1016/j.atmosenv.2005.10.045

[45] American Cancer Society. Cancer Facts & Figures 2023. [cited Feb 1, 2023]. Available from: https://www.cancer.org/content/dam/CRC/PDF/Public/6646.00.pdf

[46] Agency for Toxic Substances and Disease Registry (ATSDR). Toxicological profile for benzene. [cited July 16, 2018]. Available from: https://www.atsdr.cdc.gov/toxprofiles/tp3.pdf

[47] Caselli M, de Gennaro G, Marzocca A, Trizio L, Tutino M. Assessment of the impact of the vehicular traffic on BTEX concentration in ring roads in urban areas of Bari (Italy). Chemosphere 2010;81(3):306-311. https://doi.org/10.1016/j.chemosphere.2010.07.033

[48] European Union. Directive-2009/30-EN-EUR-Lex. [cited Nov 13, 2023]. Available from: https://eur-lex.europa.eu/legal-content/EN/NIM/?uri=celex:32009L0030

[49] International Agency for Research on Cancer (IARC). Benzene. [cited Nov 13, 2023]. Available from: https://www.ncbi.nlm.nih.gov/books/NBK550161/

[50] Statista. Market volume of benzene worldwide from 2015 to 2022, with a forecast for 2023 to 2030. [cited Nov 13, 2023]. Available from: https://www.statista.com/statistics/1245172/benzene-market-volume-worldwide/

[51] Wilbur S, Wohlers D, Paikoff S, Keith LS, Faroon O. ATSDR evaluation of health effects of benzene and relevance to public health. Toxicol Ind Health 2008;24(5-6):263-398. https://doi.org/10.1177/0748233708090910

[52] Merchant Research & Consulting. Benzene: 2024 world market outlook and forecast up to 2033. [cited Nov 13, 2023]. Available from: https://mcgroup.co.uk/researches/benzene

[53] Tassi F, Venturi S, Cabassi J, Capecchiacci F, Nisi B, Vaselli O. Volatile Organic Compounds (VOCs) in soil gases from Solfatara crater (Campi Flegrei, southern Italy): Geogenic source(s) vs. biogeochemical processes. Applied Geochemistry 2015;56:37-49. https://doi.org/10.1016/j.apgeochem.2015.02.005

[54] Misztal PK, Hewitt CN, Wildt J, Blande JD, Eller ASD, Fares S, et al. (2015) Atmospheric benzenoid emissions from plants rival those from fossil fuels. Scientific Reports 2015;5:12064. https://doi.org/10.1038/srep12064

[55] Wentworth GR, Aklilu YA, Landis MS, Hsu YM. Impacts of a large boreal wildfire on ground level atmospheric concentrations of PAHs, VOCs and ozone. Atmospheric Environment 2018;178:19-30. https://doi.org/10.1016/j.atmosenv.2018.01.013

[56] Neves FM, Kawano CY, Said S. Effect of benzene compounds from plants on the growth and hyphal morphology in Neurospora crassa. Brazilian Journal of Microbiology 2005;36(2):190-195. https://doi.org/10.1590/S1517-83822005000200016

[57] Dickinson GN, Miller DD, Bajracharya A, Bruchard W, Durbin TA, McGarry JKP, et al. Health Risk Implications of Volatile Organic Compounds in Wildfire Smoke During the 2019 FIREX-AQ Campaign and Beyond. Geohealth 2022;6(8):e2021GH000546. https://doi.org/10.1029/2021GH000546

[58] Dave PN, Sahu LK, Tripathi N, Bajaj S, Yadav R, Patel K. Emissions of non-methane volatile organic compounds from a landfill site in a major city of India: impact on local air quality. Heliyon 2020;6(7):e04537. https://doi.org/10.1016/j.heliyon.2020.e04537

[59] Kalabokas PD, Hatzianestis J, Bartzis JG, Papagiannakopoulos P. Atmospheric concentrations of saturated and aromatic hydrocarbons around a Greek oil refinery. Atmospheric Environment 2001;35(14):2545-2555. https://doi.org/10.1016/S1352-2310(00)00423-4

[60] Khoder MI. Ambient levels of volatile organic compounds in the atmosphere of Greater Cairo. Atmospheric Environment 2007;41(3):554-566. https://doi.org/10.1016/j.atmosenv.2006.08.051

[61] The International Council on Clean Transportation and DieselNet. India: fuels: dieseil and gasoline. [cited Nov 13, 2023]. Available from: https://www.transportpolicy.net/standard/india-fuels-diesel-and-gasoline

[62] Loomis D, Guyton KZ, Grosse Y, El Ghissassi F, Bouvard V, Benbrahim-Tallaa L, et. al. Carcinogenicity of benzene. Lancet Oncol 2017;18(12):1574-1575. https://doi.org/10.1016/S1470-2045(17)30832-X

[63] International Agency for Research on Cancer (IARC). Lyon France. [cited Nov 13, 2023]. Available from: https://www.iarc.who.int/

[64] United States, Environmental Protection Agency (US EPA). Principles of environmental impact assessment review. [cited Nov 13, 2023]. Available from: https://nepis.epa.gov/Exe/ZyNET.exe/50000J3B.TXT?ZyActionD=ZyDocument&Client=EPA&Index=1995+Thru+1999&Docs=&Query=&Time=&EndTime=&SearchMethod=1&TocRestrict=n&Toc=&TocEntry=&QField=&QFieldYear=&QFieldMonth=&QFieldDay=&IntQFieldOp=0&ExtQFieldOp=0&XmlQuery=&File=D%3A%5Czyfiles%5CIndex%20Data%5C95thru99%5CTxt%5C00000013%5C50000J3B.txt&User=ANONYMOUS&Password=anonymous&SortMethod=h%7C-&MaximumDocuments=1&FuzzyDegree=0&ImageQuality=r75g8/r75g8/x150y150g16/i425&Display=hpfr&DefSeekPage=x&SearchBack=ZyActionL&Back=ZyActionS&BackDesc=Results%20page&MaximumPages=1&ZyEntry=1&SeekPage=x&ZyPUR

[65] Eden T. Aetiology of childhood leukaemia. Cancer Treat Rev 2010;36(4):286-297. https://doi.org/10.1016/j.ctrv.2010.02.004

[66] Mchale CM, Zhang L, Smith MT. Current understanding of the mechanism of benzene-induced leukemia in humans: implications for risk assessment. Carcinogenesis. 2012;33(2):240–252. https://doi.org/10.1093/carcin/bgr297

[67] Baak YM, Ahn BY, Chang HS, Kim JH, Kim KA, Lim Y. Aplastic anemia in a petrochemical factory worker. Environ Health Perspect. 1999;107(10):851–853. https://doi.org/10.1289/ehp.99107851

[68] Ward E, Hornung R, Morris J, Rinsky R, Wild D, Halperin W, et al. Risk of low red or white blood cell count related to estimated benzene exposure in a rubberworker cohort (1940-1975). Am J Ind Med 1996;29(3):247-257. https://doi.org/10.1002/(SICI)1097-0274(199603)29:3<247::AID-AJIM4>3.0.CO;2-N

[69] Lan Q, Zhang L, Li G, Vermeulen R, Weinberg RS, Dosemeci M, et al. Hematotoxicity in workers exposed to low levels of benzene. Science 2004;306(5702):1774-1776. https://doi.org/10.1126/science.1102443

[70] Lupo PJ, Symanski E, Waller DK, Chan W, Langlois PH, Canfield MA, et al. Maternal Exposure to Ambient Levels of Benzene and Neural Tube Defects among Offspring: Texas, 1999–2004. Environ Health Perspect. 2011;119(3):397–402. https://doi.org/10.1289/ehp.1002212

[71] Khattak S, K-Moghtader G, McMartin K, Barrera M, Kennedy D, Koren G. Pregnancy outcome following gestational exposure to organic solvents: a prospective controlled study. JAMA 1999;281(12):1106-1109. https://doi.org/10.1001/jama.281.12.1106

[72] Chen D, Cho SI, Chen C, Wang X, Damokosh AI, Ryan L, et al. Exposure to benzene, occupational stress, and reduced birth weight. Occup Environ Med 2000;57(10):661–667. https://doi.org/10.1136/oem.57.10.661

[73] United States, Environmental Protection Agency (US EPA). Risk assessment guidance for superfund (RAGS): Part A. [cited Nov 13, 2023]. Available from: https://www.epa.gov/risk/risk-assessment-guidance-superfund-rags-part

[74] The Risk Assessment Information System (RAIS). Chemical Data Profiles. [cited Nov 13, 2023]. Available from: http://rais.ornl.gov/tools/tox_profiles.html

[75] Dehghani M, Fazlzadeh M, Sorooshian A, Tabatabaee HR, Miri M. Baghani AN, et al. Characteristics and health effects of BTEX in a hot spot for urban pollution. Ecotoxicol Environ Saf 2018;155:133-143. https://doi.org/10.1016/j.ecoenv.2018.02.065

[76] United States, Environmental Protection Agency (US EPA). Risk assessment guidance for superfund (RAGS): Part F. [cited Nov 13, 2023]. Available from: https://www.epa.gov/risk/risk-assessment-guidance-superfund-rags-part-f

[77] Zhang Y, Mu Y, Liu J, Mellouki A. Levels, sources and health risks of carbonyls and BTEX in the ambient air of Beijing, China. J Environ Sci (China) 2012;24(1):124-30. https://doi.org/10.1016/s1001-0742(11)60735-3

[78] Garg A, Gupta NC. A comprehensive study on spatio-temporal distribution, health risk assessment and ozone formation potential of BTEX emissions in ambient air of Delhi, India. Sci Total Environ 2019;659:1090-1099. https://doi.org/10.1016/j.scitotenv.2018.12.426

[79] Tabatabaei Z, Baghapour MA, Hoseini M, Fararouei M, Abbasi F, Baghapour M. Assessing BTEX concentrations emitted by hookah smoke in indoor air of residential buildings: health risk assessment for children. J Environ Health Sci Eng 2021;19(2):1653–1665. https://doi.org/10.1007/s40201-021-00721-x

[80] Sekar A, Varghese GK, Varma MKR. Analysis of benzene air quality standards, monitoring methods and concentrations in indoor and outdoor environment. Heliyon 2019;5(11):e02918. https://doi.org/10.1016/j.heliyon.2019.e02918

[81] Centers for Disease Control and Prevention (CDC). NIOSH Pocket guide to chemical hazards. [cited Nov 13, 2023]. Available from: https://www.cdc.gov/niosh/npg/default.html

[82] The American Conference of Governmental Industrial Hygienists (ACGIH). TLV/BEI guidelines. [cited Nov 13, 2023]. Available from: https://www.acgih.org/science/tlv-bei-guidelines/

[83] Bureau of Indian Standards (BIS). IS 5182 (Part 11): Methods for measurement of air pollution, part 11: Benzene, toluene and xylene (BTX). [cited Nov 13, 2023]. Available from: https://archive.org/details/gov.law.is.5182.11.2006

[84] iTeh, Inc. EN 14662-3:2015. Ambient air - Standard method for the measurement of benzene concentrations - Part 3: Automated pumped sampling with in situ gas chromatography. [cited Nov 13, 2023]. Available from: https://standards.iteh.ai/catalog/standards/cen/c32c512a-2ae4-440d-b3e9-22f6bcab96b6/en-14662-3-2015

[85] iTeh, Inc. EN 14662-1:2023. Ambient air quality - Standard method for measurement of benzene concentrations - Part 1: Pumped sampling followed by thermal desorption and gas chromatography. [cited Nov 13, 2023]. Available from: https://standards.iteh.ai/catalog/standards/cen/96d575c6-477c-427d-a04d-0a3c834140ef/en-14662-1-2023

[86] iTeh, Inc. EN 14662-2:2005. Ambient air quality - Standard method for measurement of benzene concentrations - Part 2: Pumped sampling followed by solvent desorption and gas chromatography. [cited Nov 13, 2023]. Available from: https://standards.iteh.ai/catalog/standards/cen/e7544dbc-f0bc-4a1d-9f74-e2cbd84e10f0/en-14662-2-2005

[87] The Ministry of Business, Innovation and Employment (MBIE). BS EN 14662-4:2005. Ambient air quality. Standard method for measurement of benzene concentrations, Diffusive sampling followed by thermal desorption and gas chromatography. [cited Nov 13, 2023]. Available from: https://www.standards.govt.nz/shop/bs-en-14662-42005/

[88] iTeh, Inc. EN 14662-5:2005. Ambient air quality - Standard method for measurement of benzene concentrations - Part 5: Diffusive sampling followed by solvent desorption and gas chromatography. [cited Nov 13, 2023]. Available from: https://standards.iteh.ai/catalog/standards/cen/3f600ab8-ea42-4bcf-85c4-eeca4b6c35af/en-14662-5-2005

[89] United States, Department of Labor, Occupational Safety and Health Administration. Occupational Safety and Health Standards. [cited Nov 13, 2023]. Available from: https://www.osha.gov/laws-regs/regulations/standardnumber/1910/1910.1028AppA

[90] United States, Environmental Protection Agency (US EPA). Method 325A-Volatile organic compounds (VOCs) from fugitive and area sources: Sampler deployment and VOC sample collection. [cited Nov 13, 2023]. Available from: https://www.epa.gov/sites/default/files/2019-08/documents/method_325a.pdf

[91] United States, Environmental Protection Agency (US EPA). Method 325B-Volatile organic compounds (VOCs) from fugitive and area sources: Sampler Preparation and Analysis. [cited Nov 13, 2023]. Available from: https://www.epa.gov/sites/default/files/2019-08/documents/method_325b.pdf

[92] Choi Y, Kim HJ, Sohn JR, Seo JH. Occupational exposure to VOCs and carbonyl compounds in beauty salons and health risks associated with it in South Korea. Ecotoxicol Environ Saf 2023;256:114873. https://doi.org/10.1016/j.ecoenv.2023.114873

[93] Vallecillos L, Espallargas E, Allo R, Marcé RM, Borrull F. Passive sampling of volatile organic compounds in industrial atmospheres: Uptake rate determinations and application. Sci Total Environ 2019;666:235-244. https://doi.org/10.1016/j.scitotenv.2019.02.213

[94] Campos da Rocha FO, Campos VP, da Rocha GO, Bezerra MA, Brito AVS, dos Santos Sampaio I. Concentration levels of atmospheric contaminants in Brazilian cities measured by passive sampling. Urban Climate 2023;52:101739. https://doi.org/10.1016/j.uclim.2023.101739

[95] Tiwari V, Hanai Y, Masunaga S. Ambient levels of volatile organic compounds in the vicinity of petrochemical industrial area of Yokohama, Japan. Air Qual Atmos Health 2010;3(2):65-75. https://doi.org/10.1007/s11869-009-0052-0

[96] Sousa JA, Domingues VF, Rosas MS, Ribeiro SO, Alvim-Ferraz CM, Delerue-Matos CF Outdoor and indoor benzene evaluation by GC-FID and GC-MS/MS. J Environ Sci Health A Tox Hazard Subst Environ Eng 2011;46(2):181-187. https://doi.org/10.1080/10934529.2011.532435

[97] Bayatian M, Azari M, Ashrafi K, Jafari M, Mehrabi Y. Validation of a new method for the monitoring of environmental benzene at low concentration using the needle trap device. Journal of Pollution Effects & Control 2018;6:2014. https://doi.org/10.4172/2375-4397.1000214

[98] Kajos MK, Hill M, Hellén H, Rantala P, Hoerger CC, Reimann S, et al. Comparison of PTR-MS and GC-MS measurements of oxidized VOC and aromatic VOC concentrations at a boreal forest. [cited Nov 13, 2023]. Available from: https://ui.adsabs.harvard.edu/abs/2013AGUFM.A23A0166K

[99] Blake RS, Monks PS, Ellis AM. Proton-transfer reaction mass spectrometry. Chem Rev 2009;109(3):861-896. https://doi.org/10.1021/cr800364q

[100] Sulzer P, Edtbauer A, Hartungen E, Jürschik S, Jordan A, Hanel G, et al. From conventional proton-transfer-reaction mass spectrometry (PTR-MS) to universal trace gas analysis. International Journal of Mass Spectrometry 2012;321–322:66-70. https://doi.org/10.1016/j.ijms.2012.05.003

[101] Kang M, Zou X, Lu Y, Wang H, Shen C, Jiang H, et al. Application of a self-developed proton transfer reaction-mass spectrometer to on-line monitoring trace volatile organic compounds in ambient air. Chemical Research in Chinese Universities 2016;32(4):565-569. http://doi.org/10.1007/s40242-016-5462-6

[102] Król S, Zabiegała B, Namieśnik J. Monitoring VOCs in atmospheric air I. On-line gas analyzers. TrAC Trends in Analytical Chemistry 2010;29(9):1092-1100. https://doi.org/10.1016/j.trac.2010.05.007

[103] Popitanu C, Cioca G, Copolovici L, Iosif D, Munteanu FD, Copolovici D. The seasonality impact of the BTEX pollution on the atmosphere of Arad City, Romania. Int J Environ Res Public Health 2021;18(9):4858. https://doi.org/10.3390/ijerph18094858

[104] Rad HD, Babaei AA, Goudarzi G, Angali KA, Ramezani Z, Mohsen MM. Levels and sources of BTEX in ambient air of Ahvaz metropolitan city. Air Quality, Atmosphere and Health 2014;7(4):515-524. https://doi.org/10.1007/s11869-014-0254-y

[105] Hajizadeh Y, Mokhtari M, Faraji M, Mohammadi A, Nemati S, Ghanbari R, et al. Trends of BTEX in the central urban area of Iran: A preliminary study of photochemical ozone pollution and health risk assessment. Atmospheric Pollution Research 2018;9(2):220-229. https://doi.org/10.1016/j.apr.2017.09.005

[106] Bretón JGC. Bretón RMC. Morales SM, Kahl JDW, Guarnaccia C, Severino RCL, et al. Health risk assessment of the levels of BTEX in ambient air of one urban site located in Leon, Guanajuato, Mexico during two climatic seasons. Atmosphere 2020;11(2):165. https://doi.org/10.3390/atmos11020165

[107] Kashyap P, Kumar A, Kumar K. BTEX concentrations and associated health risks at urban vegetative sites in Delhi, India. Environmental Claims Journal 2019;31(4):349-365. http://doi.org/10.1080/10406026.2019.1640441

[108] Lappalainen HK, Petäjä T, Vihma T, Räisänen J, Baklanov A, Chalov S, et al. Recent advances on the understanding of the Northern Eurasian environments and of the urban air quality in China - Pan Eurasian Experiment (PEEX) program perspective. [cited Nov 13, 2023]. Available from: https://acp.copernicus.org/preprints/acp-2021-341/acp-2021-341-ATC2.pdf

[109] Salama KF, Omer EOM, Zafar M. Assessment of BTEX concentration around fuel station in Eastern Province Kingdom of Saudi Arabia. Indian J Occup Environ Med 2020;24(3):163–167. http://doi.org/10.4103/ijoem.IJOEM_157_19

[110] Liu Q, Liu Y, Zhang M. Personal exposure and source characteristics of carbonyl compounds and BTEXs within homes in Beijing, China. Building and Environment 2013;61:210-216. https://doi.org/10.1016/j.buildenv.2012.12.014

[111] Garg A, Gupta NC, Tyagi SK. Levels of benzene, toluene, ethylbenzene, and xylene near a traffic-congested area of East Delhi. Environmental Claims Journal 2019;31(1):5-15. http://doi.org/10.1080/10406026.2018.1525025

[112] Chaurasia S, Tiwari AK. Status of benzene, toluene and xylene near petrol pumps of Satna city M.P. International Journal of Applied Research and Technology 2017;2(6):257-263. https://doi.org/10.24163/ijart/2017/2(6)257-263

[113] Hazrati S, Rostami R, Fazlzadeh M, Pourfarzi F. Benzene, toluene, ethylbenzene and xylene concentrations in atmospheric ambient air of gasoline and CNG refueling stations. Air Quality, Atmosphere & Health 2016;9(4):403–409. https://doi.org/10.1007/s11869-015-0349-0

[114] Azari MR, Konjin ZN, Zayeri F, Salehpour S, Seyedi MD. Occupational exposure of petroleum depot workers to BTEX compounds. Int J Occup Environ Med 2012;3(1):39-44.

[115] Sehgal M, Suresh R, Sharma VP, Gautam SK. Variations in air quality at filling stations, Delhi, India. International Journal of Environmental Studies 2011;68(6):845-849. https://doi.org/10.1080/00207233.2012.620320

[116] Esmaelnejad F, Hajizadeh Y, Pourzamani H, Amin MM. Monitoring of benzene, toluene, ethyl benzene, and xylene isomers emission from Shahreza gas stations in 2013. International Journal of Environmental Health Engineering (IJEHE) 2015;4(May):1-7. https://doi.org/10.4103/2277-9183.157716

[117] Eisaei HR, Dehrashid SSA, Khani MR, Hashemi SM. Assessment and control of VOCs emitted from gas stations in Tehran, Iran. Pollution 2015;1(4):363-371. https://doi.org/10.7508/pj.2015.04.002

[118] Jafari AJ, Faridi S, Momeniha F. Temporal variations of atmospheric benzene and its health effects in Tehran megacity (2010-2013). Environ Sci Pollut Res Int 2019;26(17):17214-17223. https://doi.org/10.1007/s11356-019-05086-1

[119] Abbasi F, Pasalari H, Delgado-Saborit JM, Rafiee A, Abbasi A, Hoseini M. Mohammad H Characterization and risk assessment of BTEX in ambient air of a Middle Eastern City. Process Safety and Environmental Protection 2020;139:98-105. https://doi.org/10.1016/j.psep.2020.03.019

[120] Vardoulakis S, Solazzo E, Lumbreras J. Intra-urban and street scale variability of BTEX, NO_2 and O_3 in Birmingham, UK: Implications for exposure assessment. Atmospheric Environment 2011;45(29):5069-5078. https://doi.org/10.1016/j.atmosenv.2011.06.038

[121] Su FC, Mukherjee B, Batterman S. Determinants of personal, indoor and outdoor VOC concentrations: an analysis of the RIOPA data. Environ Res 2013;126:192-203. https://doi.org/10.1016/j.envres.2013.08.005

[122] Kumar RP, Kashyap P, Kumar R, Pandey AK, Kumar A, Kumar K. Cancer and non-cancer health risk assessment associated with exposure to non-methane hydrocarbons among roadside vendors in Delhi, India. Human and Ecological Risk Assessment 2020;26(5):1285-1299. https://doi.org/10.1080/10807039.2019.1570077

[123] Masih A, Lall AS, Taneja A, Singhvi R. Exposure levels and health risk assessment of ambient BTX at urban and rural environments of a terai region of northern India. Environ Pollut 2018;242(Pt B):1678-1683. https://doi.org/10.1016/j.envpol.2018.07.107

[124] Notario A, Gutiérrez-Álvarez I, Adame JA. Atmospheric benzene measurements in the main metropolitan and industrial areas of Spain from 2014 to 2017. Atmospheric Research 2020;238:104896. https://doi.org/10.1016/j.atmosres.2020.104896

[125] Behnami A, Jafari N, Benis KZ, Fanaei F, Abdolahneja A. Spatio-temporal variations, ozone and secondary organic aerosol formation potential, and health risk assessment of BTEX compounds in east of Azerbaijan Province, Iran. Urban Climate 2023;47:101360. https://doi.org/10.1016/j.uclim.2022.101360

[126] Mehta D, Hazarika N, Srivastava A. Diurnal variation of BTEX at road traffic intersection points in Delhi, India: source, ozone formation potential, and health risk assessment. Environ Sci Pollut Res Int 2020;27(10):11093-11104. https://doi.org/10.1007/s11356-019-07495-8

[127] Egeghy PP, Tornero-Velez R, Rappaport SM. Environmental and biological monitoring of benzene during self-service automobile refueling. Environ Health Perspect 2000;108(12):1195–1202. https://doi.org/10.1289/ehp.001081195

[128] Rattanajongjitrakorn P, Prueksasit T. Temporal variation of BTEX at the area of petrol station in Bangkok, Thailand. APCBEE Procedia 2014;10:37-41. https://doi.org/10.1016/j.apcbee.2014.10.011

[129] Dutta C, Som D, Chatterjee A, Mukherjee AK, Jana TK, Sen S. Mixing ratios of carbonyls and BTEX in ambient air of Kolkata, India and their associated health risk. Environ Monit Assess 2009;148(1-4):97-107. https://doi.org/10.1007/s10661-007-0142-0

[130] Koziel JA, Martos PA, Pawliszyn J. System for the generation of standard gas mixtures of volatile and semi-volatile organic compounds for calibrations of solid-phase microextraction and other sampling devices. J Chromatogr A 2004;1025(1):3-9. https://doi.org/10.1016/j.chroma.2003.10.079

[131] Guenther FR, Rhoderick GC, Miller WR, Marschal A, Medem A, Kato K, et al. Final report on key comparison CCQM-K7: benzene, toluene, m-xylene, o-xylene and ethylbenzene in nitrogen. Metrologia 2002;39(1A):8006-08006. https://doi.org/10.1088/0026-1394/39/1A/24

[132] Guenther FR, Rhoderick GC, Marschal A, Medem A, Kato K, Heo GS, et al. Final report on key comparison CCQM-K10: benzene, toluene, o-xylene in nitrogen. Metrologia 2002;39(1A):08007. https://doi.org/10.1088/0026-1394/39/1A/25

[133] Cecelski CE, Rhoderick GC, Possolo AM, Carney J, Vokoun M, Privoznikova J, et al. International comparison CCQM-K10.2018: BTEX in nitrogen at 5 nmol mol^{-1}. Metrologia 2022;59(1A):08003. https://doi.org/10.1088/0026-1394/59/1A/08003

[134] Rhoderick GC, Yen JH. Development of a NIST standard reference material containing thirty volatile organic compounds at 5 nmol/mol in nitrogen. Anal Chem 2006;78(9):3125-3132. https://doi.org/10.1021/ac052136r

[135] Yarita T, Takatsu A, Inagaki K, Numata M, Chiba K, Okamoto K. Matrix certified reference materials for environmental monitoring from the National Metrology Institute of Japan (NMIJ). Accreditation and Quality Assurance 2007;12(3-4):156-160. http://doi.org/10.1007/s00769-006-0204-y

[136] Grenfell RJP, Milton MJT, Harling AM, Vargha GM, Brookes C, Quincey PG et al. Standard mixtures of ambient volatile organic compounds in synthetic and whole air with stable reference values. Journal of Geophysical Research: Atmospheres 2010;115(D14):D14302. https://doi.org/10.1029/2009JD012933

[137] Nohr M, Horn W, Jann O, Richter M, Lorenz W. Development of a multi-VOC reference material for quality assurance in materials emission testing. Anal Bioanal Chem 2015;407(11):3231-3237. http://doi.org/10.1007/s00216-014-8387-2

[138] Komal, Soni D. A review on preparation methods and measurement techniques of reference gas mixtures. Microchemical Journal 2024;197(4):109742. https://doi.org/10.1016/j.microc.2023.109742

[139] Guerra E. Electric vehicles, air pollution, and the motorcycle city: A stated preference survey of consumers' willingness to adopt electric motorcycles in Solo, Indonesia. Transportation Research Part D: Transport and Environment 2019;68:52-64. https://doi.org/10.1016/j.trd.2017.07.027

[140] Younes MB, Boukerche A. Traffic efficiency applications over downtown roads: A new challenge for intelligent connected vehicles. ACM Computing Surveys 2020;53(5):1-30. https://doi.org/10.1145/3403952

[141] Miller P, de Barros AG, Kattan L, Wirasinghe SC. Public transportation and sustainability: A review. KSCE Journal of Civil Engineering 2016;20:1076-1083. https://doi.org/10.1007/s12205-016-0705-0