SENIOR PLANET
FROM AARP®

Air Quality Monitoring by Citizen Scientists

Karen Donoghue and Craig Newell

◎ Local Haze

Hello! We're Karen & Craig

- Long careers in tech biz

Agenda

- Air quality is important

- You can't manage what you can't measure

- You can participate in understanding your air quality

Karen Donoghue and Craig Newell

WHY

Why is air quality important?

Why monitor your air quality?

- Health impacts for individuals
- Community wide impacts

The Guardian

Cancer breakthrough is a 'wake-up' call on danger of air pollution

Sat 10 Sep 2022 12.08 BST

Scientists uncover link between car fum[...] helps explain why so many non-smokers[...]

The Washington Post

HEALTH

Urban air pollution affects 2.5 billion people worldwide, study says

By Linda Searing
February 6, 2022 at 9:00 a.m. EST
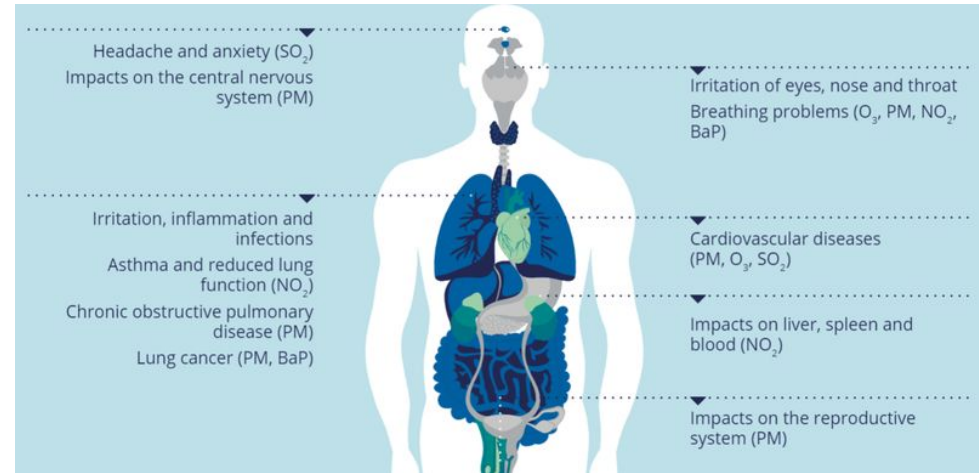
SCIENTIFIC AMERICAN®

Switching to Electric Cars Could Prevent 89,000 Deaths in the U.S.

By Mike Lee, E&E News on June 20, 2023

Human Health Impacts…

- Air pollution accounts for more than 1 in 8 deaths globally

- Air pollution contributed to 8.1 million deaths in 2021

- Air pollution is the 2nd leading risk factor for early death, surpassed only by high blood pressure

- Air pollution currently shortens the average person's lifespan by 1 year and 8 months

Headache and anxiety (SO_2)
Impacts on the central nervous system (PM)

Irritation of eyes, nose and throat
Breathing problems (O_3, PM, NO_2, BaP)

Irritation, inflammation and infections
Asthma and reduced lung function (NO_2)
Chronic obstructive pulmonary disease (PM)
Lung cancer (PM, BaP)

Cardiovascular diseases (PM, O_3, SO_2)

Impacts on liver, spleen and blood (NO_2)

Impacts on the reproductive system (PM)

Source: EU

The effects are still being understood

Stories from the Environmental Factor (NIEHS Newsletter):

- Outdoor air pollution may be linked to **uterine cancer** in U.S. women (June 2024)
- Air Pollution May Trigger DNA Modifications Tied to **Alzheimer's Disease** (April 2024)
- Scientific Journeys: Using AI to Track a Major Source of Pollution (March 2024)
- Indoor Wood-burning May Be Linked to **Lung Cancer** in U.S. Women (September 2023)
- Everyday Air Pollution Can Harm **Brain Development** in Adolescents (September 2023)
- Wildfire Smoke, Other Air Pollution Can Harm **Brain Health**, Expert Says (August 2023)
- Air Pollution and Forever Chemicals **Continue to Pose Health Risks** (March 2022)
- Air Pollution Affects Children's **Brain Structure** (February 2022)
- Increasing Evidence Links Air Pollution With **Breast Cancer** (November 2021)
- Fine Particulate Air Pollution Associated With Higher **Dementia Risk** (September 2021)
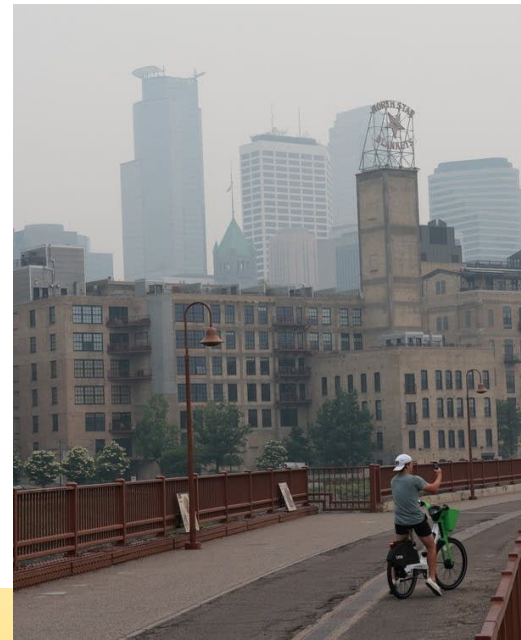
Air Quality is no longer improving

Clean Air Act

- Efforts starting in the 1960s have made a huge impact in North America
- Improvements have stalled after easy wins

Fires

- Affecting people everywhere
- No longer just "wildfires" (towns and cities)

Drought

- Pollutants from the Great Salt Lake

AIR

What exactly is the air that we breathe?

# What is Air?

Mixture of gases

- 99% Nitrogen and Oxygen

- Moisture

- Aerosols (Suspended particles)

Volume of the Most Abundant Gases in Our Atmosphere				
Gas	Volume in Parts Per Million (ppm)	Percent	Atomic Symbol	Bond
Nitrogen	780,840 ppm	78.0840%	N_2	triple
Oxygen	209,460 ppm	20.946%	O_2	double
Argon	9,340 ppm	0.934%	Ar	none
Carbon dioxide	400 ppm*	0.040%*	CO_2	double
Neon	18.18 ppm	0.001818%	Ne	none
Helium	5.24 ppm	0.000524%	He	none
Methane	1.79 ppm	0.000179%	CH_4	single
Krypton	1.14 ppm	0.000114%	Kr	none
Water vapor	40,000 ppm	0 to 4%	H_2O	single

Measuring gases is difficult

- Technically, it is really difficult to measure gases
- The sensors that do exist and expensive and require frequent recalibration or replacement
  - For example, CO_2 sensors used for indoor measurement require exposure to "outside air" every 3-4 weeks to recalibrate

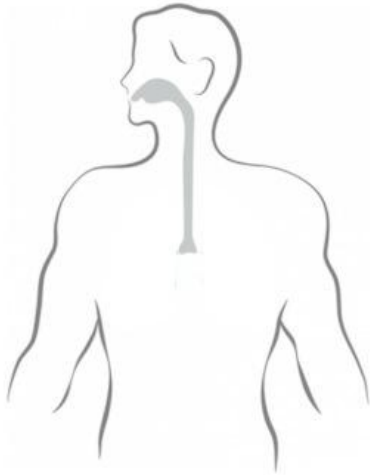- A lot of outdoor air quality monitoring focuses on aerosols or suspended particulate matter (PM)

What is particulate matter (PM)?
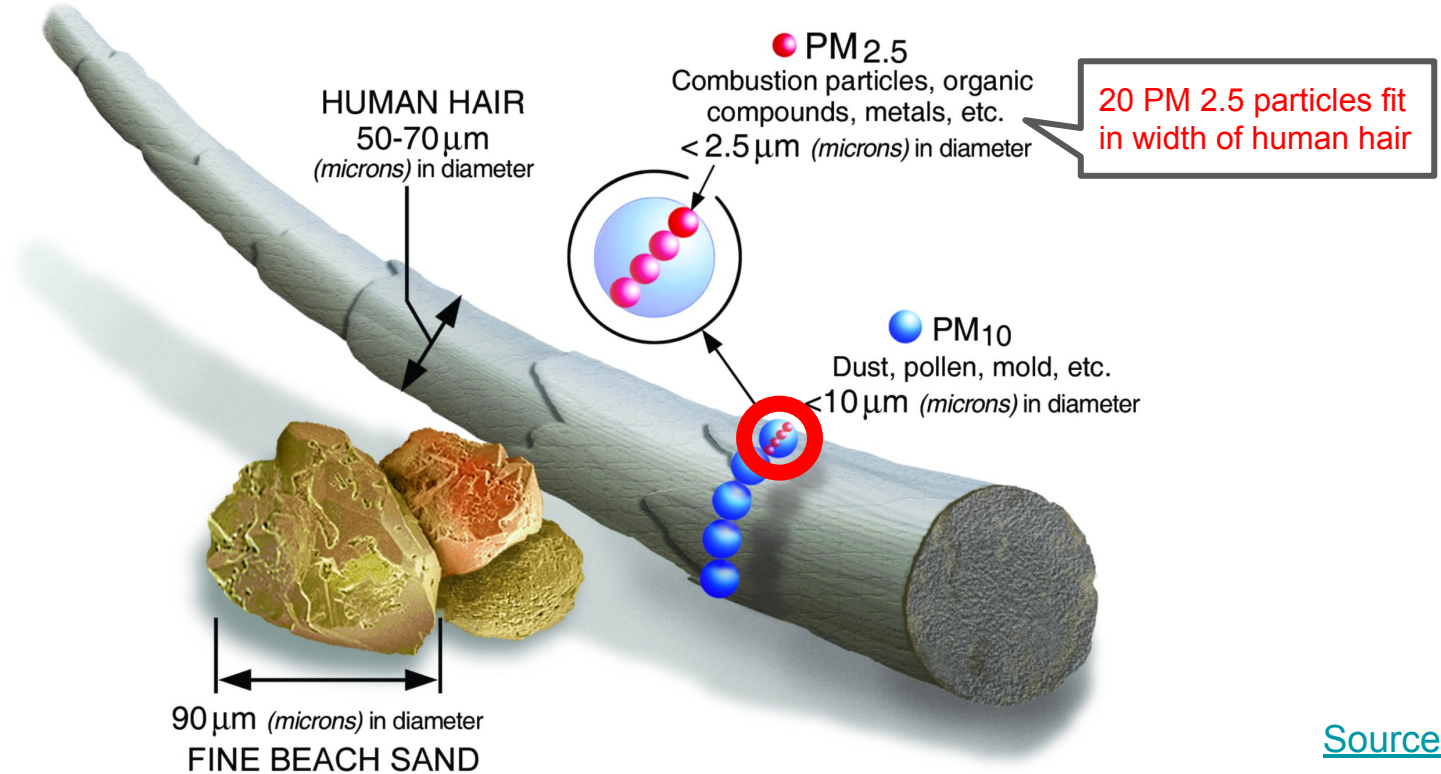
What do we measure?

PM_{10}	$PM_{2.5}$	PM_1
$<= 10\ \mu m$	$<= 2.5\ \mu m$	$<= 1.0\ \mu m$

| Coarse particles Upper respiratory tract | Fine particles Lower respiratory tract | Very fine particles Alveolus (tiny air sacs) |
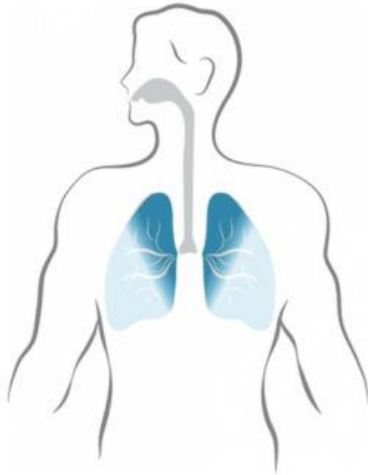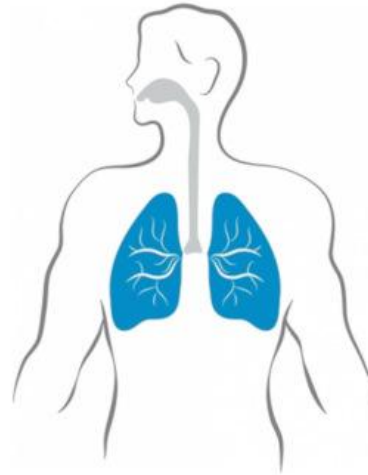
Source: © Encyclopédie de l'Environnement

How does PM relate to health impact?

Every country has created a health impact index for Air Quality including PM (e.g. US EPA AQI shown below)

Daily AQI Color	Levels of Concern	Values of Index	Description of Air Quality
Green	Good	0 to 50	Air quality is satisfactory, and air pollution poses little or no risk.
Yellow	Moderate	51 to 100	Air quality is acceptable. However, there may be a risk for some people, particularly those who are unusually sensitive to air pollution.
Orange	Unhealthy for Sensitive Groups	101 to 150	Members of sensitive groups may experience health effects. The general public is less likely to be affected.
Red	Unhealthy	151 to 200	Some members of the general public may experience health effects; members of sensitive groups may experience more serious health effects.
Purple	Very Unhealthy	201 to 300	Health alert: The risk of health effects is increased for everyone.
Maroon	Hazardous	301 and higher	Health warning of emergency conditions: everyone is more likely to be affected.

Health triggers vs. Long term exposure

The human impact can be:

- Concentrations triggering symptoms (acute exposure)
  - Asthma attacks

- Long-term health impact (chronic exposure)
  - Reduced lung capacity
  - High blood pressure
  - Primary focus of medical research and governmental monitoring
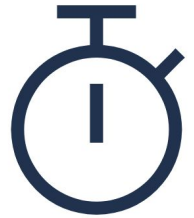
WHERE

Where should we monitor?

Where to measure?

To best understand health impact, a personal "dosage meter" would be optimal but inconvenient:

- Plume Flow
- Underground Mining

Monitoring at Fixed Locations

Near places where people spend time

- Home
- Office
- School

Access to power and communications

- Almost all air quality monitoring is at fixed sites

What is between fixed monitors?

But how to understand the space between fixed sensors?

- Mount sensors on things that move
  - Vehicles
    - Google Maps Street View cars
  - Even bicycles

Positioning Practicalities

Where to place a sensor?

- Isolated field as per weather sensors

- Sides of buildings are convenient
  - Watch for exhaust air (dryer vents, kitchen exhaust, HRV exhaust)
  - Where people hang out (smokers, vapers)

HOW

How is air quality measured?

Reference air quality monitoring = big and expensive
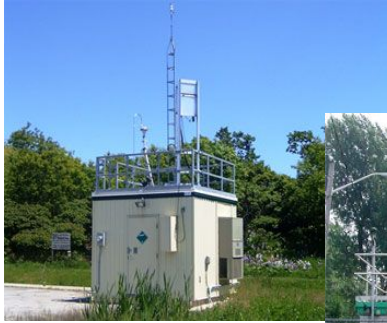
Classic air quality monitoring

Expensive to buy and operate

- Regular maintenance

- Regular calibration

Many alternatives to measure Particulate Matter (PM)

- **($$$) Gravimetric**
  - Batch process to weigh filter before and after air is blown in

- **($$$) Beta-ray absorption** (BAM)
  - Nuclear radiation absorption

- **($$) Tapered element oscillating microbalance** (TEOM)
  - A continuous system of weighing particles

- **($) Laser Particle Counting**
  - Fire a laser through the air and count the interruptions

- **($) Light scattering**
  - Measure visual haze at a small scale

How to measure Particulate Matter (PM)?

Gravimetric Measurement

- Gold standard
- Labor intensive
- Further analysis of physical & chemical composition possible
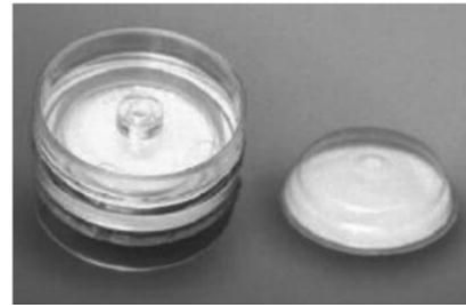
(a)
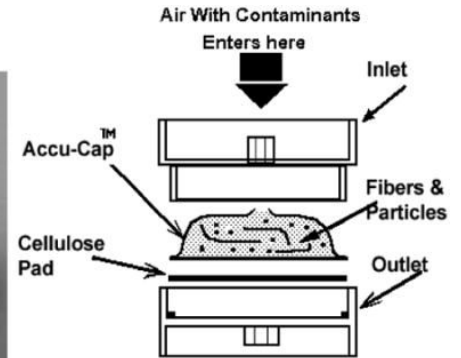
(b)

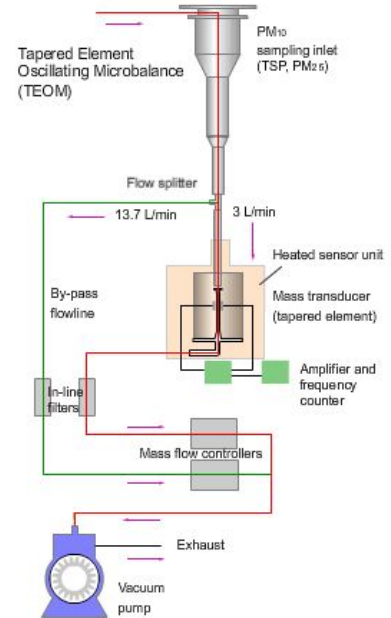# How to measure Particulate Matter (PM)?

Beta-ray Absorption (BAM)

- "Fun with radiation"
- Beta-rays absorbed proportionally to mass not size.
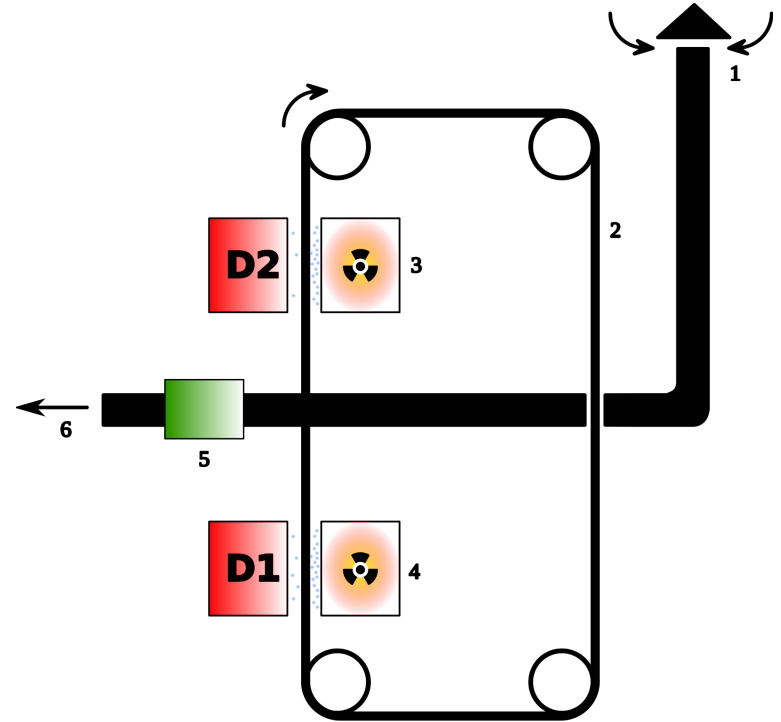
How to measure Particulate Matter (PM)?

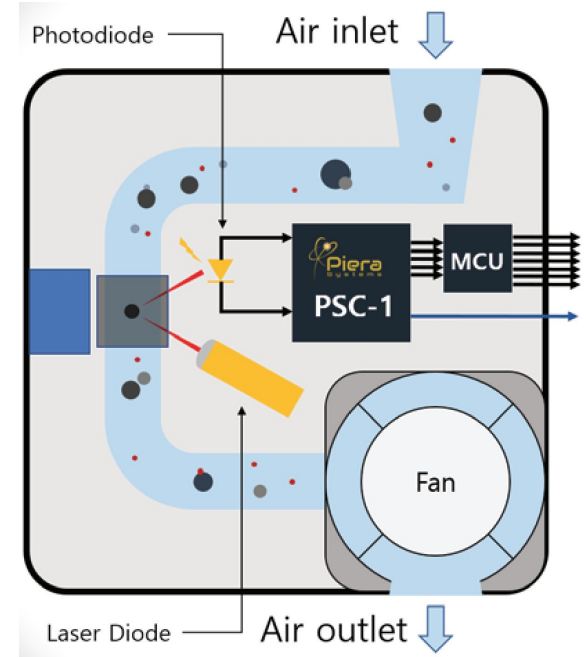Tapered element oscillating microbalance (TEOM)

- Practical outside the lab.
- Does not have to be a huge machine

How to measure Particulate Matter (PM)?

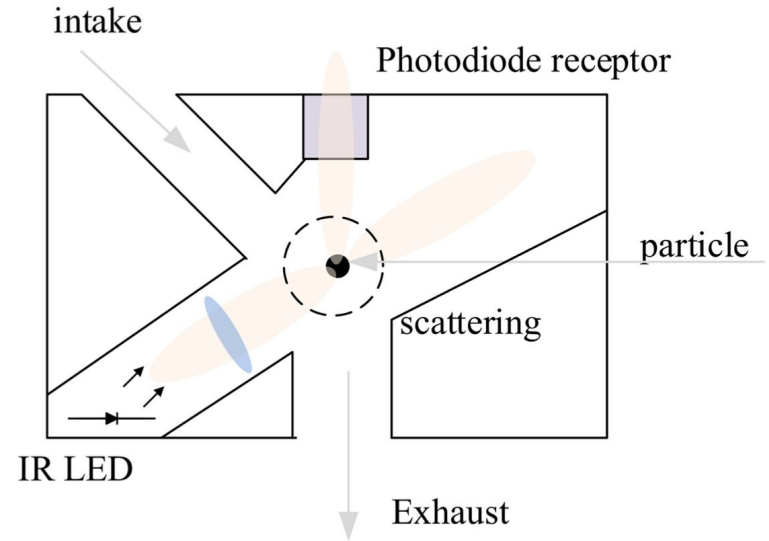With advances in solid state technology and ICs

- Count individual particles in the air giving both number and size
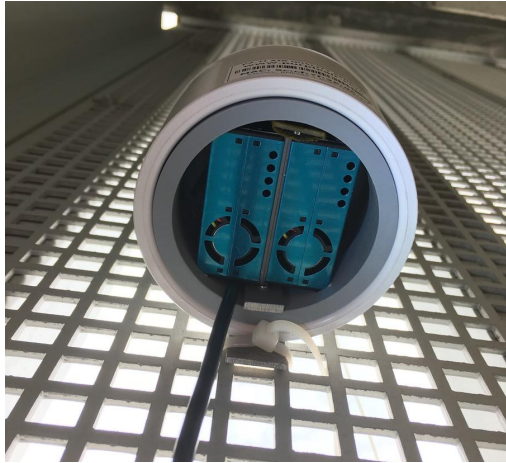- Size distributions are correlated with source

How to measure Particulate Matter (PM)?

Light scattering

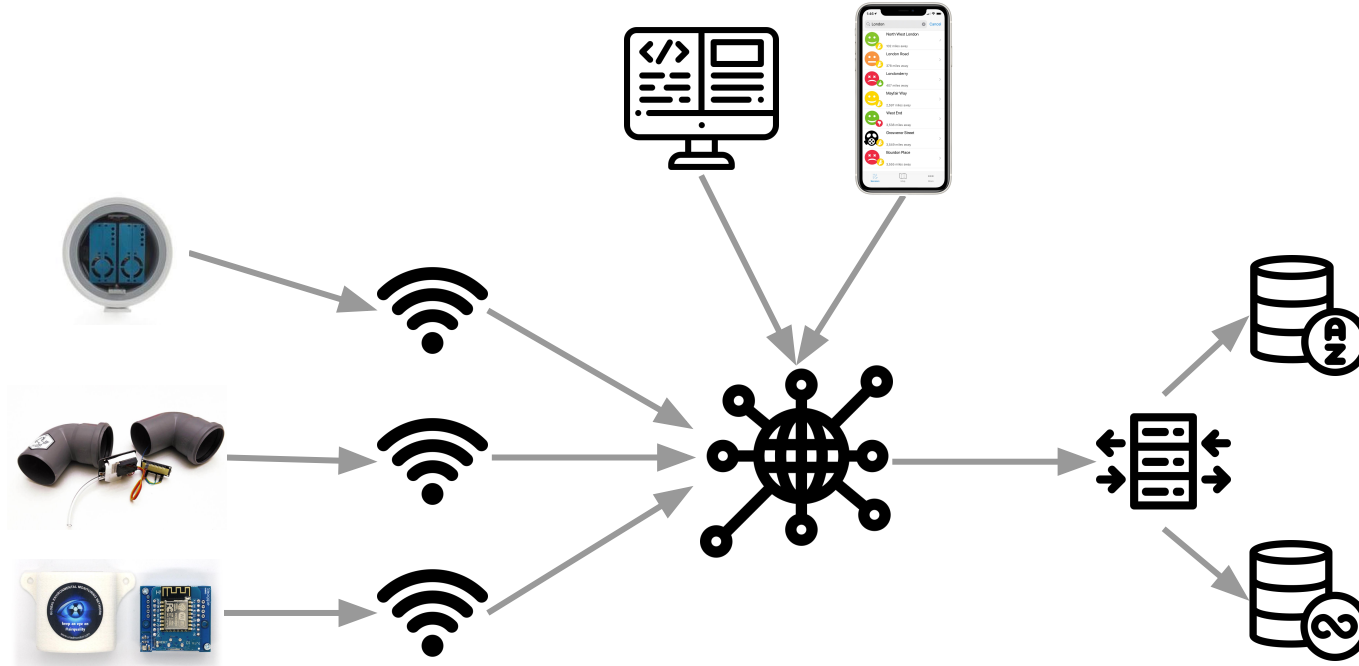- ○ The "lowest cost" approach
- ○ Poorest quality data

The rise of low cost PM sensors

PurpleAir

uRADMonitor
global environmental monitoring network

SENSOR.COMMUNITY

- Laser PM Sensor
- Microcontroller
- Case

airgradient

DAVIS

DAVIS

AIR QUALITY EGG

Basic Data Gathering IoT System

Basic IoT system has devices connected across a network, a database and application server

Communication to the cloud

- WiFi as almost everyone has it without extra costs
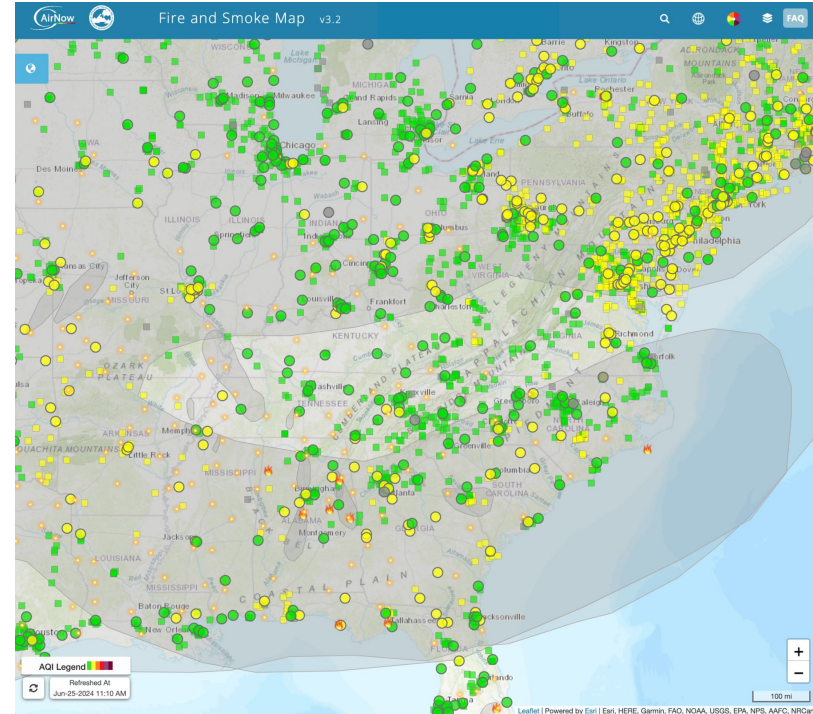
WHEN

When should we monitor?

All the time…

To understand long term exposure

- Measure all the time and at as many places as possible

- However this is not really practical…

Fires becoming more frequent and widespread

- PM sensors can serve as an early warning system as smoke often spreads well ahead of heat

- Low-cost sensors are being incorporated into smoke forecasting:
  - AirNow Fire and Smoke Map
  - FireSmoke Canada

When fires come to sensors…

- Public Safety Power Shutdowns (PSPS)
  - Sensors go offline when power is turned off and internet fails

- Monitoring after files often difficult due to long term lack of power and connectivity

After the fire…

Long after the particulate matter (PM) clears:

- Unlike general air pollution where the gases are correlated with PM

- Burnt structures, vehicles, etc. off-gas many things that are still being understood

WHO

Who is interested in air quality?

Consumers that are also citizen scientists

CRAIG / Persona role: Air quality enthusiast

Job title:
Engineer

Gender, age, location
M, 44, Boston, MA USA

Preferred channels
Email, SMS, web, mobile

Example quote

"I want to be able to see, understand and analyze my local air quality sensor data. "

Key characteristics
Very technical

Favorite brands

Frustrations & pain points

Concerned about local air quality

Can't find DIY AQ sensor to buy

Family member with asthma

Motivations & key influences

Interested in the rise of low-cost sensors and their ability to quantify air quality

Reads EPA scientific reports on air quality

Goals & needs

Wants to understand about AQ data and the ability to have confidence in sensor readings

Will build own hardware as required

Questions

How can I trust that the AQ sensor readings are accurate?

How many sensors are there and where are they located?

Applications used in work & life

iPhone X and iPad Pro

MacBook Pro

JIRA

Feature requests

iOS app to monitor local air quality

Simple way to understand the reliability of the data, not just the readings

HUMANLOGIC

Job title:
Engineer

Example quote
"I want to be able to see,

Key characteristics
Very technical

Gend...
M, 44

Prefe...
Email,

THE NORTH FACE
...TERYX

Frustrations & pain points

Concerned about local air quality

Can't find DIY sensor to buy

Family member with asthma

Frustrations & p...

Concerned about...

Can't find DIY AQ...

Family member w...

...nd about AQ
... to have
...sor readings

...ware as

Questions

How can I trust th...
sensor readings a...

How many sensors are there and
where are they located?

MacBook Pro

JIRA

...local air quality

Simple way to understand the
reliability of the data, not just the
readings

Citizen scientists monitoring air quality

Example motivations to monitor air quality:

- Living in an RV while avoiding wildfires

- Urban living in a retirement community

- Citizen scientist advocacy groups understanding local pollution sources

- Wildfire early warning

RV (Recreational Vehicle) living

- Using air quality monitoring as a "compass" to find locations with "good air" in wildfire-prone areas


All photos by Dr. Jiahong Juda.

Urban retirement community

- Sharing knowledge about air quality in a residential Continuing Care Retirement Community (CCRC) in San Francisco

- 350 residents

(Photo credit: MDR, San Francisco)

Citizen scientist advocacy groups monitoring air quality

- Community advocacy providing transparency in government AQ monitoring of a cement factory in Midlothian, Texas
- Established a citizen network of air quality sensors to share data
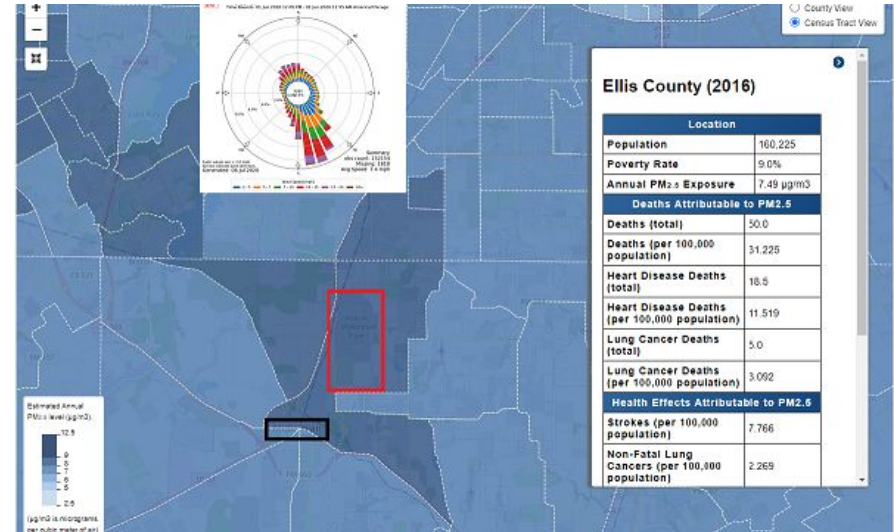
MIDLOTHIANBREATHE
www.midlothianbreathe.org

Local Haze crowdsources air quality sensor readings worldwide and rates sensor accuracy

Data Sources

PurpleAir	13319 sites	ⓘ
SENSOR.COMMUNITY	10961 sites	ⓘ
AirNow	1448 sites	ⓘ
(Department of State)	46 sites	ⓘ
uRADMonitor — global environmental monitoring network	465 sites	ⓘ
Total Active Sensors	**32,239 sites**	

LOW COST SENSORS

EXPENSIVE SENSORS

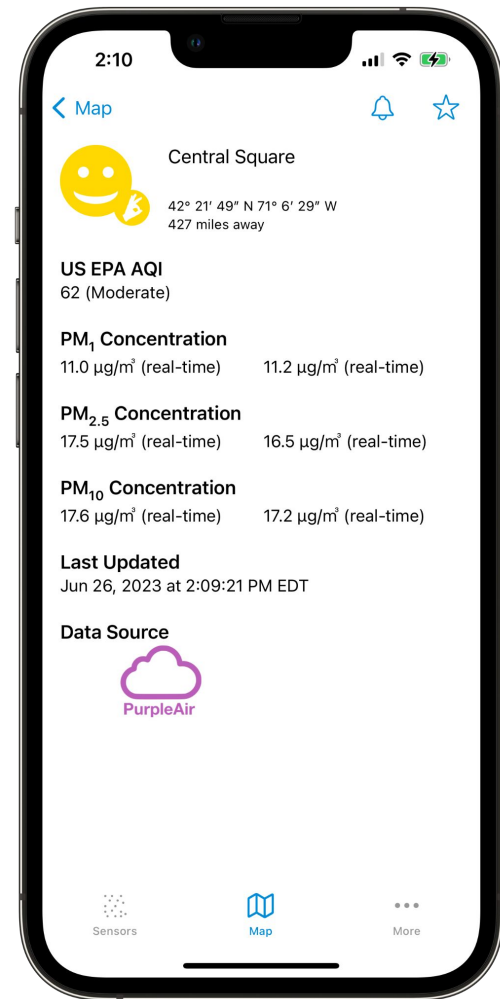# Design Challenge: Ranges of data quality and volume

- Large disparity in the volume and quality of data

- Lots of low quality data vs. a very small amount of high quality data

- UX presentation challenge to communicate the quality of the data, not just the value

Low cost sensors	% of total count
PurpleAir, uRADMonitor, SENSOR.COMMUNITY	**95.4 %**

High cost sensors	% of total count
AirNow	**4.6 %**

Visual language

Design challenges

- What's the correct way to notify for a specific AQ sensor?

- Filtering frequent notifications

- Should notifications remain persistent or should they be ephemeral? (i.e. fade away)
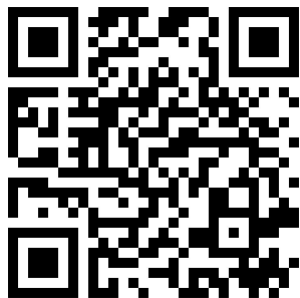
Local Haze

Preview: Air quality data on a watch form factor

◎ Local Haze

Consumers can easily understand their local air quality "on the go"

4.6
out of 5

30 Ratings

App Store feedback from Local Haze users:

"The graphics are simple and the features are few, but what it does, it does very well. Here in Northern California, that is critical."

"Local Haze offers a simple app to view PM 1, 2.5, and 10 data as well as AQI readings."

"Combines data from various sensors. Fast and easy to use."

Contact:
LOCALHAZE@HUMANLOGIC.COM

Key takeaways

- Air quality is important

- You can't manage what you can't measure

- You can participate in understanding your air quality

SENIOR PLANET
FROM AARP

Q & A

Please submit questions via chat