Testing, Testing, 1 2 3… What's in Your AIR?

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How I spent last summer…

In the summer of 2019 BC (Before Coronavirus), Aaron Soh, the son of a former colleague, called me to discuss Piera Systems and his claim of an accurate, low-cost sensor, the Piera-1, intended to measure air pollution. I knew very little about air pollution let alone particulate. The only thing I knew was that in Silicon Valley, where I once lived, we had 'Spare the Air' days when the EPA declared the air was poor. You could see it was bad, but for most healthy people who work indoors in a 'clean' office it was something to note but not lose sleep over.

I was looking for a new challenge, and since I am an electrical engineer and have worked in technology since 1970, I set about learning everything I could about air pollution. What causes it, how you measure it (testing, testing…) and how technology could be used to improve it. By November I was convinced that Piera had achieved a breakthrough and with global warming on the rise, I decided it to invest in Piera and help bring the technology to market. After raising seed funds and starting to engage with customers, the novel coronavirus and Covid-19 changed everything. Now it was no longer just air pollution, but viruses like Covid-19 that made it more critical than ever to know "What's in your AIR?"

I often get asked, mostly by healthy people who live in areas with good air quality, why should I care? I'll just buy an Air Purifier. The UN's Environment Program (UNEP) lists five reasons why you should care; starting with the fact that polluted air is creating a health emergency. According to the World Bank, air pollution costs the global economy more than US $5 trillion every year in welfare costs and $225 billion in lost income. Maybe you don't care, but what about your children and the rest of the planet?

As I learned more, it was clear that Piera-1 would need to undergo exhaustive testing, and this would take time, money and expertise. I started to read everything I could about test methods, protocols, instrumentation, etc. My first 15 years was spent in test and instrumentation, so I had a good foundation but testing for PM has a whole science behind it. We couldn't expect our customers and consumers to immerse themselves in the details. That's the purpose of this article, to educate the reader about testing and guide them so they can understand how to interpret the data and when to take action. The foundation for today's testing originated in 1970.

Measuring Air Quality: The EPA, FRM/FEM's, Mass Concentration, Particle Count, Size and Distribution ….

The Clean Air Act of 1970 is what created the testing infrastructure and enforcement mechanisms to improve air quality in the US. Signed by Richard Nixon, it brought together a hodgepodge of state regulations and gave enforcement authority to the newly formed EPA. The act's passage grew out of the first Earth Day, April 22, 1970.

I remember that day clearly, I was in Boston attending Northeastern University and joined some of the demonstrations. Little did I know 50 years later I would invest in and dedicate myself to a startup whose mission was to reduce the health impact of air pollution globally. Since 1970, the act has seen multiple amendments, and my home state of California has led the way in measuring, enforcing and improving air quality.

While the EPA is responsible for testing, standards setting and enforcement across the US, one of the premier testing and monitoring facilities in the US is the South Coast AQMD which is responsible for most of Los Angeles County. AQ-SPEC, the Air Quality Sensor Performance Evaluation Center run by South Coast AQMD, has an extensive program for testing the performance of 'low-cost' air quality sensors in both field and laboratory settings. Their reports provide independent testing and validation of sensors used in a variety of commercially available products. Their approach guided the Piera Systems engineering team as they put together our testing, calibration and validation protocols for Piera-1.

Air Quality Index

AQI Category and Color	Index Value	Description of Air Quality
Good Green	0 to 50	Air quality is satisfactory, and air pollution poses little or no risk.
Moderate Yellow	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.
Unhealthy for Sensitive Groups Orange	101 to 150	Members of sensitive groups may experience health effects. The general public is less likely to be affected.
Unhealthy Red	151 to 200	Some members of the general public may experience health effects; members of sensitive groups may experience more serious health effects.
Very Unhealthy Purple	201 to 300	Health alert: The risk of health effects is increased for everyone.
Hazardous Maroon	301 and higher	Health warning of emergency conditions: everyone is more likely to be affected.

This is the table the EPA uses to report air quality, the index value is ug/m3 or mass concentration. In 1997, the EPA issued new Air Quality Standards for Particulate Matter, and in 1998 developed a method for measuring Fine PM (PM2.5). The EPA operates a nationwide air monitoring network (SLAMS) to measure six primary air pollutants: carbon monoxide, lead, sulfur dioxide, ozone, nitrogen dioxide, and particulate matter (PM_{10} and $PM_{2.5}$).

SLAMS utilize 'methods' to measure — called Federal Reference Methods (FRMs). FRMs are the "gold standard" of air pollution monitoring systems and ensure air quality data collected at different sites are gathered in the same manner and are accurate. FRM's use gravimetric (filter-based) techniques to weigh the amount of PM called mass concentration (ug/m3). This approach, while accurate, is slow (every 3 or 6 days), labor intensive and does not provide any details on what is in the PM, which can help identify its source.

To foster innovation and advance new technologies, the EPA also reviews, tests, and approves other methods, called Federal Equivalent Methods (FEMs), which are based on different sampling and/or analyzing technologies than FRMs, but are required to provide the same decision-making quality when measuring air quality. These FRM's are faster (minutes), provide the same mass concentration data but also the size, count and distribution of PM utilizing opto-electronic and other measurement approaches. However, they are still expensive (~$10-25k), require ongoing calibration and certification and, more importantly, a trained operator. Examples of FRM's include the Met One BT-620 and the Grimm Aerosol 11-D. In fact, the EPA co-locates FRM's and FEM's to improve data quality. Since the FRM's count actual particles and size, they 'estimate' mass concentration using formulas to convert count and size to mass. Assumptions about the shape (sphere) and density mean that the estimates require calibration and correlation to the MC measured by the gravimetric instruments. This is done by the FRM vendors and is reported in their specifications. While mass concentration provides a simple, easy to understand metric for air quality, to quickly and accurately measure and classify PM, the count, size and distribution of PM is more important than MC. Furthermore, this data can be used to adjust for changes in humidity and temperature in real-time which can negatively impact accuracy.

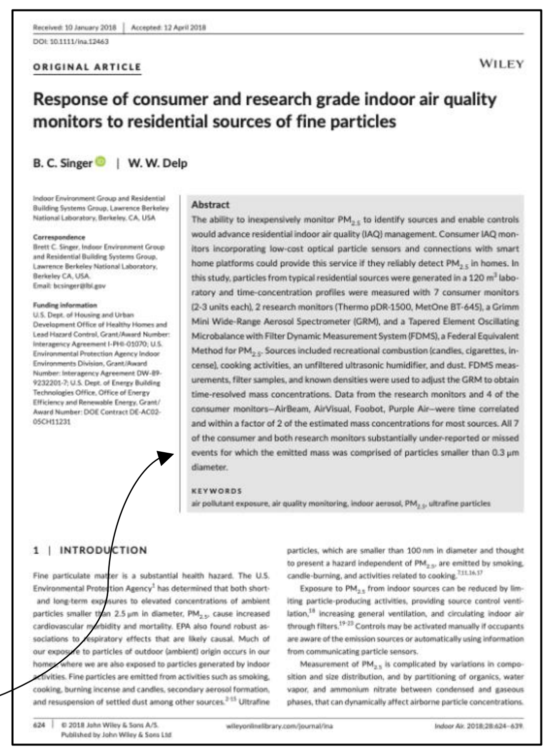
The EPA would like to improve resolution with more 'spatial data' and is monitoring advancements in air sensor monitoring technology in order to provide new lower-cost devices to help air quality managers, communities and citizens with understanding air quality. EPA researchers are at the forefront of the development and evaluation of air sensor monitors and conduct workshops to assess advances in lower cost sensors together with regular assessments by the AQ-SPEC team in Southern Ca. The EPA has an Air Sensor Toolbox if you want to find out more. In this capacity, the EPA only monitors technology developed by private companies like Piera and they only monitor, report and enforce outdoor air quality, not the air in your home, office, restaurant, public space or where you spend most of your time.

Indoor Air Quality: A More Negative Impact to Your Health

Indoor air quality has been under increased scrutiny for some time now by consumers, researchers, and regulatory bodies. The ingress of bad outdoor air together with the introduction of other PM by residents (smoking, cooking, chemicals, etc.) has created a need for better monitoring in real-time and the use of air purifiers, smart HVAC systems, scrubbers, filters, etc. to clean the air. With Covid-19, the need to monitor and improve is dramatically higher. The threat is highest indoors due to the concentration of the virus, its spread through the air and its residual presence without good, fresh air flow. Indoor air quality is not in the EPA's charter, but some excellent research has been done by a number of government labs.

Lawrence Berkeley National Laboratory has an Indoor Environment Group and Residential Building Systems Group. In 2018 they conducted research into indoor air quality monitors ability to detect sources of fine particles. This report discusses exhaustive testing for a wide range of PM created in a typical household including; dust, cigarettes, incense, candles, gas, and by cooking (toast, bacon, pizza, oil, pancakes, etc.). They controlled the conditions in their lab using FEM's from Grimm and Met One as mentioned above and compared them to a number of air quality monitors which use existing optical PM sensors (Not Piera-1). From the abstract…

All 7 of the consumer and both research monitors substantially under-reported or missed events for which the emitted mass was composed of particles smaller than 0.3 µm diameter.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ORIGINAL ARTICLE

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Response of consumer and research grade indoor air quality monitors to residential sources of fine particles

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Abstract
The ability to inexpensively monitor $PM_{2.5}$ to identify sources and enable controls would advance residential indoor air quality (IAQ) management. Consumer IAQ monitors incorporating low-cost optical particle sensors and connections with smart home platforms could provide this service if they reliably detect $PM_{2.5}$ in homes. In this study, particles from typical residential sources were generated in a 120 m^3 laboratory and time-concentration profiles were measured with 7 consumer monitors (2-3 units each), 2 research monitors (Thermo pDR-1500, MetOne BT-645), a Grimm Mini Wide-Range Aerosol Spectrometer (GRM), and a Tapered Element Oscillating Microbalance with Filter Dynamic Measurement System (FDMS), a Federal Equivalent Method for $PM_{2.5}$. Sources included recreational combustion (candles, cigarettes, incense), cooking activities, an unfiltered ultrasonic humidifier, and dust. FDMS measurements, filter samples, and known densities were used to adjust the GRM to obtain time-resolved mass concentrations. Data from the research monitors and 4 of the consumer monitors—AirBeam, AirVisual, Foobot, Purple Air—were time correlated and within a factor of 2 of the estimated mass concentrations for most sources. All 7 of the consumer and both research monitors substantially under-reported or missed events for which the emitted mass was comprised of particles smaller than 0.3 µm diameter.

KEYWORDS
air pollutant exposure, air quality monitoring, indoor aerosol, $PM_{2.5}$, ultrafine particles

1 | INTRODUCTION

Fine particulate matter is a substantial health hazard. The U.S. Environmental Protection Agency[1] has determined that both short- and long-term exposures to elevated concentrations of ambient particles smaller than 2.5 µm in diameter, $PM_{2.5}$, cause increased cardiovascular morbidity and mortality. EPA also found robust associations to respiratory effects that are likely causal. Much of our exposure to particles of outdoor (ambient) origin occurs in our homes, where we are also exposed to particles generated by indoor activities. Fine particles are emitted from activities such as smoking, cooking, burning incense and candles, secondary aerosol formation, and resuspension of settled dust among other sources.[2-15] Ultrafine particles, which are smaller than 100 nm in diameter and thought to present a hazard independent of $PM_{2.5}$, are emitted by smoking, candle-burning, and activities related to cooking.[7,11,16,17]

Exposure to $PM_{2.5}$ from indoor sources can be reduced by limiting particle-producing activities, providing source control ventilation,[18] increasing general ventilation, and circulating indoor air through filters.[19-23] Controls may be activated manually if occupants are aware of the emission sources or automatically using information from communicating particle sensors.

Measurement of $PM_{2.5}$ is complicated by variations in composition and size distribution, and by partitioning of organics, water vapor, and ammonium nitrate between condensed and gaseous phases, that can dynamically affect airborne particle concentrations.

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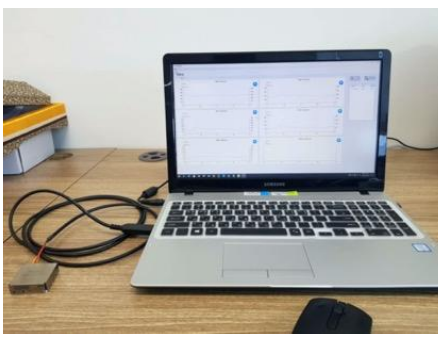
With Covid-19 at ~.125, one can see an urgent need for identifying PM in sizes from 0.1-0.3 um.

So why hasn't someone invented an accurate, low-cost sensor that can measure the full range of PM from 0.1 um – 10 um both indoors and outdoors per the EPA's requirements? Enter Piera Systems and the Piera-1 Intelligent Particle Sensor.

Piera Systems Intelligent Particle Sensor: Piera-1

Piera-1 uses a breakthrough approach for detecting and measuring the quantity and size of particles suspended in air. Unlike existing PM sensors that are inaccurate, low in resolution and slow, Piera-1 has superior accuracy, can detect smaller particles (PM0.1-PM10) and counts them in real time with low power consumption. Piera-1 uses a patented, photon-counting custom ASIC to deliver a highly sensitive optoelectronic particulate sensor. Piera-1 can be programmed to detect a wide range of particle sizes allowing for a single sensor to be used in many applications. For the first time, applications can be developed that take advantage of low cost, accurate, detailed, real-time data about PM. Machine Learning/AI and algorithms can be used to classify this data. An example is Piera Systems vape/smoke detector, **Canāree,** that can identify and discriminate between cigarette and vape smoke, calculate it's mass concentration, dissipation, etc.



Piera-1 comes calibrated and correlated utilizing FRM devices. A test report is available under NDA and a Piera-1 Evaluation Kit is available for developers to conduct their own testing, certification and integration into their products. In the coming months we'll conduct further testing over a range of temperature and humidity conditions with FRM's, independent testing labs and customers to refine and improve our algorithms and data. Piera-1's ability to count individual particles, size and distribution for PM <0.1-2.5 um is unique. No other low-cost sensor can measure accurately PM <1.0 um. Piera-1 can be programmed to 'zoom in' and focus on specific sizes such as PM0.1-0.3, the size of viruses such as Covid-19 and influenza. This requires additional testing with expensive, specialized instruments and labs. We have started working with a leading instrument supplier and a major automotive supplier on a project measuring PM01.-0.3 air quality in automobile interiors. Detection can lead to adjustments in climate control systems, filtering and using fresh air to remove the PM.

"What's in your AIR" is more than a marketing slogan, it's critical to staying healthy and slowing global warming. Accurate, real-time information from low cost sensors like Piera-1 integrated into air quality monitors, air purifiers, HVAC systems, automobiles and numerous digital health applications can address this threat. If you are developing a product that would benefit from complete, accurate real-time data about PM and are interested in testing our sensor yourself, contact us.