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Implementation Guides June 2024

How to set standards and monitor outdoor air quality

Air Quality

Spotlight On: Climate and Clean Air

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Setting air quality goals is an important foundational step to air quality management, whether for meeting regulatory requirements or more ambitious health-based targets. Air quality monitoring enables cities to:

- assess levels of pollution relative to these goals;
- identify sources of pollution and local hot-spots;
- create public awareness;
- enforce policies and monitor their effectiveness; and
- measure progress.

Cities can assess pollution concentrations using individual monitoring locations or networks of connected sensors. To gather highly localised data, cities can utilise recent advancements in air pollution monitoring and surveillance: from remote sensing and satellite data that measure local pollution levels across the globe, to commercially available lower cost fixed and mobile sensors.

This article recommends that cities adopt ambitious, health-based air quality targets. It introduces how cities can develop high density and targeted air quality monitoring to inform action to reach those targets, as well as how to use this data to make a compelling public case for action.

Adopt WHO standards as local air quality targets

Setting an air quality target is important because it establishes the need to act, as well as the level of action required. Many national and subnational governments have set regulatory standards on air quality, but cities should raise their ambition to protect their citizens. In countries that don’t yet have national standards, cities can lead the way. Similarly, cities can set their own political targets to go beyond nationally-set, legally binding ones. These targets set a framework for controlling pollution sources within a city’s control, and create pressure on national governments to act on sources outside of the city’s boundary or authority.

The World Health Organization (WHO) has set universal health-based recommended guidelines on the ‘safe’ level of outdoor (ambient) air pollution. Cities should adopt these standards as ambitious goals and work to meet them as soon as possible.

Cities with very polluted air can work to meet one of four WHO interim standards to enable short- and long-term planning. However, there is no such thing as ‘too safe’ air – any level of pollution has some negative health effects for the people exposed.

WHO air quality guidelines for fine particulate matter

Fine particulate matter ($PM_{2.5}$) is the name for very small particles, drops or dust in the air. The number refers to its tiny size: $PM_{2.5}$ means things in the air that are less than 2.5 microns (or one 10,000th of an inch) across, which is smaller than the width of a human hair. When breathed in, these pollutants can get deep into a person’s lungs and also impact the heart function. Exposure to $PM_{2.5}$ is strongly linked to many diseases, affecting nearly every body system, and breathing in $PM_{2.5}$ increases the likelihood of chronic disease, hospitalisations and early death.

For safe air, annual average concentrations of $PM_{2.5}$ should not exceed 5 $\mu g/m^3$. 24-hour average exposures should not exceed 15 $\mu g/m^3$ more than 3-4 days per year.

For cities a long way from meeting that goal, four interim target (IT) standards are recommended:

- IT 1: 35 $\mu g/m^3$ annual mean, 75 $\mu g/m^3$ 24-hour mean.
- IT 2: 25 $\mu g/m^3$ annual mean, 50 $\mu g/m^3$ 24-hour mean.
- IT 3: 15 $\mu g/m^3$ annual mean, 37.5 $\mu g/m^3$ 24-hour mean.
- IT 4: 10 $\mu g/m^3$ annual mean, 25 $\mu g/m^3$ 24-hour mean.

Cities should also adopt WHO standards for other pollutants, namely:

- PM_{10} (particulate matter with a diameter of 10 microns or less).
- Ground level ozone (O_3, a major constituent of smog).
- Nitrogen dioxide (NO_2, an important component of $PM_{2.5}$).
- Sulphur dioxide (SO_2).
- Carbon monoxide (CO).

Read the WHO standards in full here.

English

Use existing air quality data to understand current pollution levels and identify gaps in your city's air quality monitoring network

Cities in countries with national air quality standards and monitoring requirements have access to regulatory data. Cities beginning air quality monitoring should explore what data has already been collected, for instance by universities, non-governmental organisations or citizen groups. Cities without air quality monitors can estimate pollution levels using satellite and remote sensing data.

Resources that collate regulatory data, or that can provide an initial understanding of the current state of your city's air include:

- World Health Organization's Global Ambient Air Quality Database provides city-level $PM_{2.5}$ and PM_{10} data, as reported by national authorities. This data is used for the interactive graph below.
- OpenAQ includes almost all regulatory monitors globally. Coverage is poor across most areas outside of North America, Western Europe, and China due to a lack of monitoring or public reporting.
- The State of Global Air provides national level, annual average air quality data for every country globally, with the capability to compare with other countries, derived from ground-level measurements, satellite-based estimates and other models. It also provides data on numbers of deaths attributed to air pollution.
- NASA satellites observe air pollution from space, providing estimates of pollution across the globe; this data is regional in scale but can give cities a sense of pollution levels relative to standards. Some of the NASA projects include MAIA, TEMPO or HAQAST.[1, 2, 3]
- National, regional and local environmental authorities often share data from monitors they operate. Examples include the United States' Environmental Protection Agency or the European Union's European Environment Agency.

These databases can provide valuable information from which to build a case for action and inform the level of risk, identify important local or regional sources, and provide the basis for planning denser and more targeted monitoring networks.

Select your city below to see annual average $PM_{2.5}$ concentrations for recent years in your city, relative to the WHO's guidelines[4]. View our Air Quality Data Explorer and the *Air quality status and trends in C40 cities* report to see more air quality data for your city.

English

Select a city

Air pollution over recent years

Select a city to start

< 10 10 - 20 20 - 35 35 - 50 > 50

Use high-density and targeted monitoring networks to evaluate pollution patterns within the city

High-density monitoring networks enable cities to pinpoint and monitor local emissions hotspots and sources. They also allow you to track the impact of action to improve air quality. The design of a high-density monitoring network must consider the mix of sensor types, how many are needed and where they are placed, responding to:

- Specific questions the city is seeking to answer. For example, do you need an initial understanding of air quality to inform longer-term planning, or detailed and real-time air quality data to predict and take preventative action against air quality incidents?[5] Are you measuring progress in a target area such as a Clean Air Zone?
- Local pollution sources and the density and patterns of local pollutant emissions.
- Locations and density of populations, including sensitive groups such as schoolchildren.
- Locations of existing monitors.
- Monitoring budget.

Cities with limited financial resources, or that are just beginning local air quality monitoring, can deploy filter-based instruments for $PM_{2.5}$, use passive samplers for gases, or use lower cost sensors to begin to characterise pollution levels. This can boost public support for action and provide the basis for longer-term air quality monitoring, such as a higher density monitoring network and high-quality reference sites.

Cities looking to build upon regulatory monitoring to better inform air quality action can supplement the core regulatory monitoring network with passive monitors or diffusion tubes, low-cost fixed sensors, and/or mobile sensors to achieve higher spatial density measurements. Air quality monitoring using networks of these sensors is sometimes called ‘hyperlocal’ monitoring. *Making the invisible visible: A guide for mapping hyperlocal air pollution to drive clean air action* explains this in more detail.

Cities with an advanced civic technology environment, or those planning major infrastructure upgrades, should consider building air quality sensors into their infrastructure. Cities with ‘Smart City’ agendas and advanced data management capabilities can measure air quality, traffic, weather, noise and other factors using multi-purpose sensors.

For quality assurance, high density networks of lower cost sensors must be calibrated with high-quality reference equipment, in a controlled environment where sensor performance can be evaluated and calibrations can be performed.

The core types of sensors cities can use to build a high-density monitoring network are:

Regulatory (or ‘reference grade’) monitoring stations

These are typically deployed in static and sparse networks. This highly accurate monitoring equipment can cost tens of thousands of dollars, and require significant infrastructure and trained personnel to operate. Cities should consult national regulatory guidance, if this exists, for information about their deployment.

- **Passive sensors and diffusion tubes.** These are lower cost sensors that absorb gases that are then analysed to measure pollution concentrations for the duration of the exposure. They monitor long-term average exposures. Unlike the other sensor types below, they don’t require power to operate and they cannot provide real-time data. This means that they cannot be used to take preventative action against air quality incidents.

- **Filter-based instruments for particulate matter.** These use pumps to draw air and collect particles onto a filter. Filters are weighed before and after sampling to determine the concentration of particles in the air. They are then analysed for metals, chemicals and other compounds, to determine sources of emissions. They monitor long-term average exposures.

- **High-quality sensors integrated into fixed infrastructure,** such as streetlights or benches, providing high quality and reliable data that allow cities to collect data over time and map trends.[6] These sensors are often multi-purpose, collecting data on air quality alongside information such as temperature and traffic. However, they are expensive (around $5,000 per sensor), so cities are usually unable to install them at high density.[7]

- **Lower cost sensors** range from simple single-pollutant sensors to multi-pollutant devices that include communications and meteorological monitoring capabilities. They range in price from around $100 to $5,000.[8] While they have great potential for real-time air quality monitoring in dense networks, these sensors are in an early stage of development with rapid changes in technologies and providers. The accuracy of their measurements is lower than the more sophisticated and regulatory-grade sensors – they are often unable to detect very fine particles, readings can be influenced by the weather and interferences from other pollutants, they require regular calibration, and readings can drift over long periods of time (months-years).[9] Therefore, while these sensors are useful for measuring spatial and temporal variability in air quality, allowing cities to understand where and when pollution levels are highest, they are not normally used to demonstrate compliance with legal standards or for measuring long-term trends due to their shorter sensor lifetimes.[10, 11]

The South Coast Air Quality Management District provides the best source of information on the accuracy of individual sensors through their sensor testing programme AQ-SPEC. The United States Environmental Protection Agency's Air Sensor Toolbox offers further information on how to select and use low-cost fixed and portable air sensor technology and understand the results. While the low cost means that cities can invest in more units,[12] there can be high human capital costs from installation, maintenance and management of large amounts of data.[13]

Cities are using new sensing technologies to achieve air quality goals

The City of Los Angeles and Watts Rising community groups, as part of the Watts Rising programme, delivered a project to deepen local air quality understanding and empowering residents of historically disadvantaged communities through a hyperlocal air quality monitoring network. This network featured 13 sensors tracking $PM_{2.5}$, NO_2, and O_3 levels at strategic locations like schools and parks, driven by community feedback. Launched in July 2020, the project aimed to engage residents, raise air quality awareness, and support LA's Green New Deal goals by providing real-time, actionable pollution data. The initiative also included educational outreach and long-term pollution tracking to evaluate the impact of other climate projects in Watts, with data shared through a dedicated online portal and community meetings. This work, along with other examples are detailed in the sensing change report which features case studies from Addis Ababa, Dar es Salaam, Denver, Lima, Lisbon, London, Los Angeles, Mumbai, Paris, Portland, and Quezon City.

- **Mobile sensors.** These include regulatory-grade and lower-cost sensors attached to moving objects that can measure levels at one or many locations across a city. They can provide a snapshot of the city's air quality, without the need to invest in large numbers of fixed sensors – one sensor could, theoretically, map an entire city.[14] By using multiple mobile sensors active over an extended period (for instance mounted on taxis or cycle hire bikes), cities can also track trends over time. While mobile monitoring has been in use for decades, recent advances in monitoring, data management and analysis have led to the use of mobile monitoring to map air pollution levels at a hyperlocal scale. For example, building on a hyperlocal air quality study in Oakland, California,[15] London is using two Google Street-view vehicles fitted with reference grade monitors to create a detailed map of air quality across the city (see box).

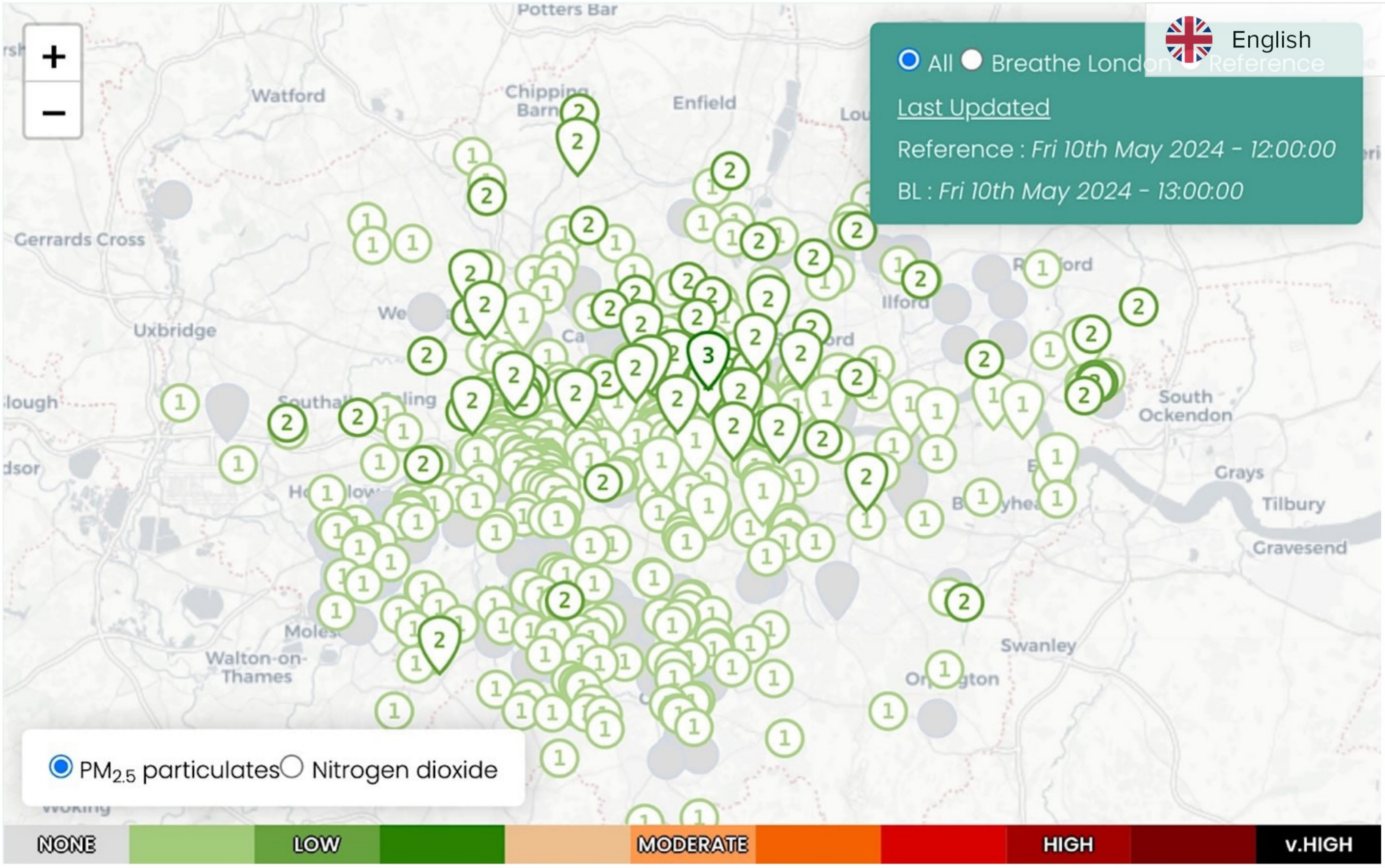
London's air quality monitoring networks[16, 17]

London has one of the most comprehensive monitoring networks in the world, funded and operated by local authorities. Air quality is monitored constantly by 140 regulatory-grade automatic stations monitoring NO_2 and/or PM_{10}, 36 $PM_{2.5}$ monitors city-wide, and 10-20 NO_2 diffusion tubes per London borough.

In 2018 the city launched Breathe London, a hyperlocal air quality project, to improve spatial and temporal monitoring. This is now providing the Greater London Authority (GLA) with actionable baseline data on current pollution levels, identify hotspots, assess levels near sensitive locations (particularly schools), evaluate policies to tackle air quality, and promote citizen engagement with air quality.

The initiative has installed an additional 100 streetlight-mounted low-cost sensors across London, monitoring a range of pollutants. Sensors are concentrated within the Ultra Low Emissions Zone (ULEZ), which was launched in April 2019, and also fill gaps in the existing network. The initiative is also using two Google Street-view vehicles fitted with reference grade monitors, measuring at regular 1-5 second intervals and prioritising the ULEZ zone. Data from the monitoring effort is shared publicly through the BreatheLondon.org site.

Hyperlocal study monitoring stations

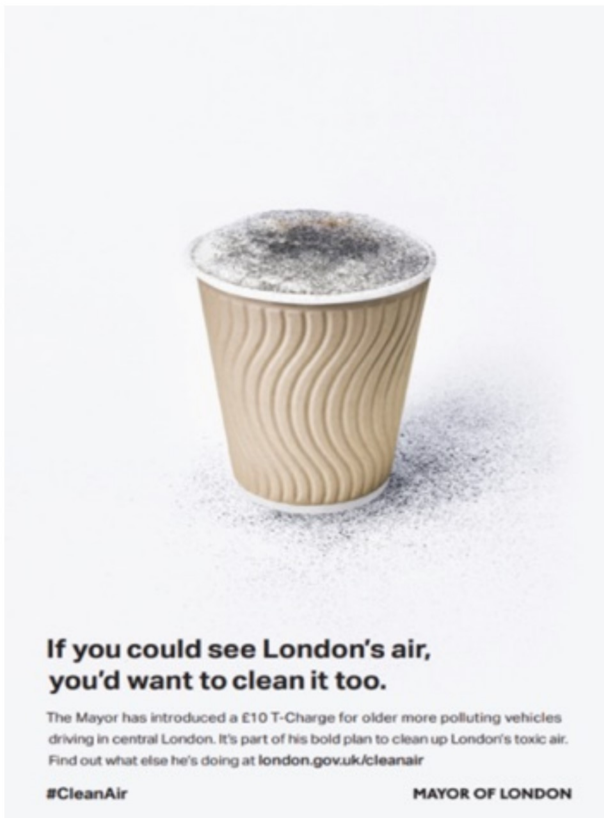


Google Street-view vehicle

Use monitoring data to make a compelling public case for action, inform the public of risks and track progress towards clean air goals

Cities should make air quality data available to the public in an accessible, meaningful and useful way. This can include:

Poster from the Mayor of London's clean air public awareness campaign



- **Directly communicating air quality updates.** Advise the public about high pollution days and areas via weather announcements, text message alerts, or using notifications at train stations, bus stops and digital signs along major roads.[18] Many cities use a colour coded or 'traffic light' system to communicate pollution levels clearly and simply: green means safe pollution levels, red means high pollution. This can help residents who are sensitive to air pollution to take measures to protect themselves, such as avoiding exercise during polluted periods.

- **Making real-time data available via an app or website.** Web or app-based platforms enable cities to communicate real-time air quality updates alongside information on the local health impacts, variation across the city and action the city is taking.

- **Pairing sensor data with other data to generate meaningful information.** This includes, but is not limited to, health data. For example, New York's air quality data is available to the public and other stakeholders via an interactive online portal, providing a range of health and environmental data at a neighbourhood level (see box).[19]

- **Delivering communications campaigns to drive public awareness.** Design the campaign according to the response or action you are seeking. For example, the Mayor of London's #CleanAir campaign accompanied the introduction of the ULEZ to raise awareness of health risks in order generate support for action. Be clear if you intend for citizens to take specific action on a high pollution day, such as limiting driving or avoiding physical activity.

New York's Community Air Survey

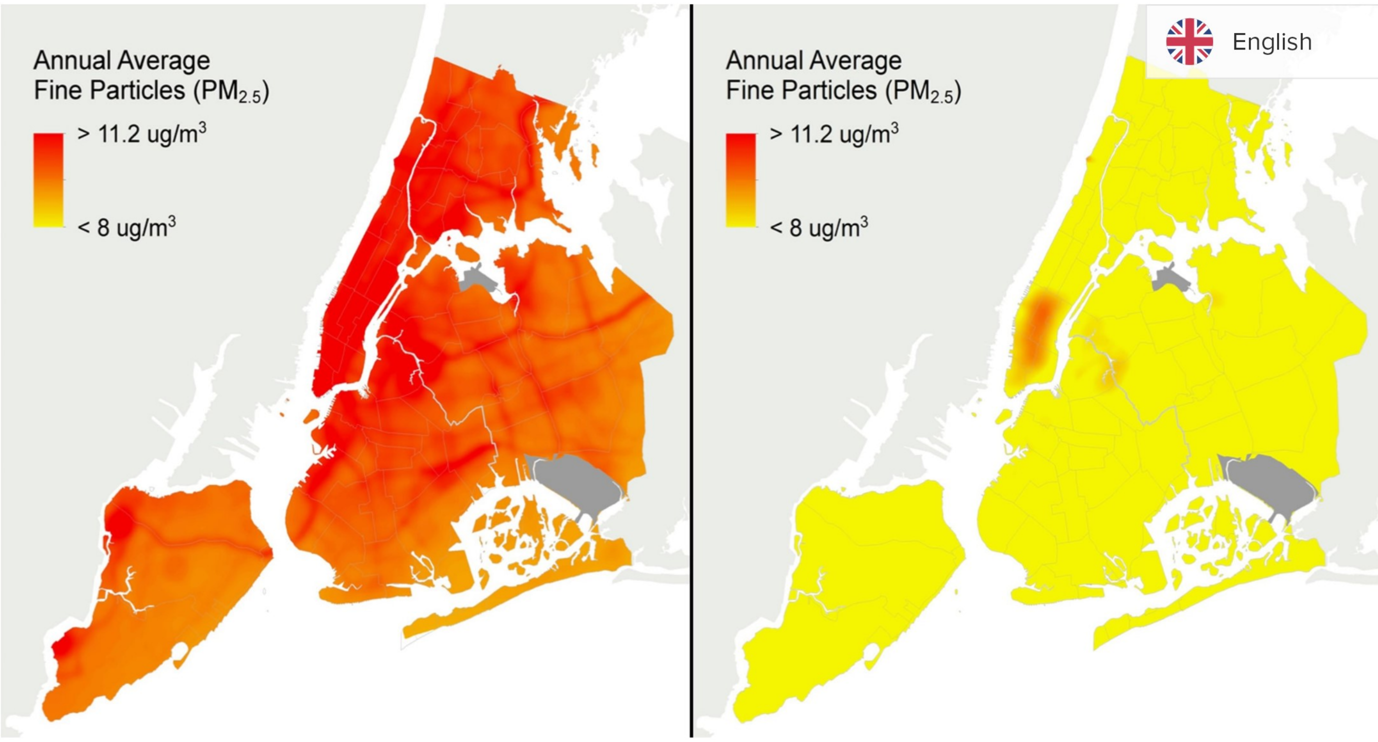
In New York City, United States, long-term exposure to $PM_{2.5}$ contributes to an estimated 2,000 excess deaths from lung and heart disease each year (1 out of every 25 deaths in NYC),[20] with the impact highest in the poorest neighbourhoods.

The New York City Community Air Survey (NYCCAS) programme is led by the New York Department of Health and Mental Hygiene, and Queens College of the City University of New York. For over a decade, it has been monitoring quality across the city to understand local sources of air pollution and how it varies. In 2022, air quality was monitored 78 routine locations and an additional 15 sites in low-income neighbourhoods that benefit from additional monitoring to understand potential sources of emissions.[21]

In addition, eight monitors measuring $PM_{2.5}$ levels in real time enabling to track air pollution based on time of day, weather, and local pollution sources. A more in-depth monitoring is conducted once per season for a two-week period at every selected location. The monitors used for this method capture a large range of pollutants. Data is analysed using a statistical model that estimates associations between pollutant levels and source activity near the monitoring site. The model then estimates average pollution levels at locations across the city. The data collected by the survey is available to the public via maps, annual reports and the Environment and Health Data portal. Data is presented by neighbourhood and users can download customised datasets or curated reports on air quality and health that compare selected neighbourhoods to the rest of the city.

Findings show the increase in commercial cooking emissions, particularly from restaurants using grills and charbroilers, has become a significant predictor of $PM_{2.5}$ concentrations than building density. In response, the city passed Local Law 38 in 2015, requiring restaurants to register charbroilers and install emissions control devices, helping to better understand and mitigate the impact on neighbourhood air quality. The NYC Community Air Survey showed that between 2009 and 2020 Annual average levels of fine particulate matter ($PM_{2.5}$), nitrogen dioxide and nitric oxide have declined 43%, 39% and 56%, respectively. Explore how building emissions, commercial cooking and traffic density affects air quality in New York on the data portal here.

Annual average fine particulate matter in New York in 2009 (left) and 2020 (right)[22]


Annual Average
Fine Particles ($PM_{2.5}$)
> 11.2 ug/m^3
< 8 ug/m^3
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English

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