LOW-COST SENSORS RIGHT PLACE, RIGHT TIME, RIGHT TOOL?

IDENTIFYING APPROPRIATE USE-CASE SCENARIOS AND BEST PRACTICE FOR LOW-COST SENSORS

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Who we are

Presenting today

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Co-authors

- Candice Allan and Sam Putland — WSP Australia
- Joan Daniel Echeverri Alvarez and Mark Skoroszewski — SLR Consulting, Australia
- Hamesh Patel — Mote Australia, Brisbane and ILAQH, Queensland University of Technology
- Paul Baynham — Mote Limited, Auckland, New Zealand

What we will cover

01 **Why this review**
A fast-moving market with no agreed performance metrics.

02 **How the sensors work**
Nephelometers, optical particle counters and their failure modes.

03 **Fundamental limitations**
Size cut-offs, humidity effects and the underlying physics.

04 **Assessment frameworks**
International standards and the US EPA performance targets for Co-location.

05 **Australian field evidence**
Gold Coast and Perth co-location results across two seasons.

06 **Where LCS fit**
Appropriate use cases, IAQM alignment and best practice.

WHY THIS REVIEW

A fast-moving market

Where we are now

- Rapid uptake – complementing, sometimes replacing, traditional monitoring
- Accuracy and precision concerns remain unresolved
- No agreed performance metrics or cross-validation methods

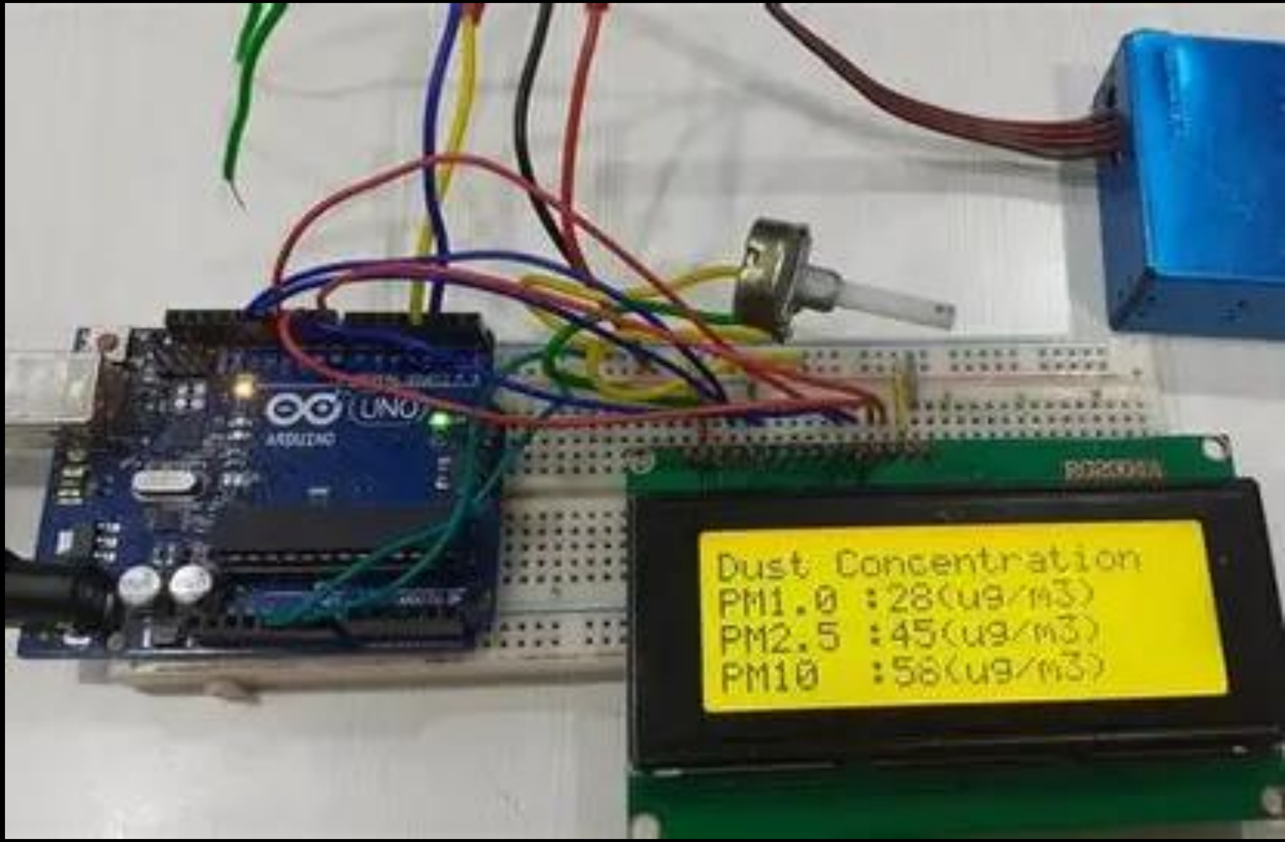
What's on the horizon

- New and evolving proprietary correction algorithms
- Blurring of the gap between low-cost and near-reference sensors (Low-Cost Heated-Inlet Sensors, etc.)

What we set out to do

- A critical review of PM sensor literature
- Tested against Australian co-location data
- Guidance for practitioners, not only air quality specialists
- **Help reduce frustrations currently experienced by site environmental managers**

HOW THE SENSORS WORK



Three classes*

Higher data quality, higher cost — **Lower cost, indicative only**

01
Reference

- Gravimetric measurement or equivalent
- Meets AS/NZS standards
- Used for compliance monitoring

02
Near-reference

- Sizes particles by light scattering
- Heated inlets and flow control
- Do not meet AS/NZS
- Used when indicative data is appropriate

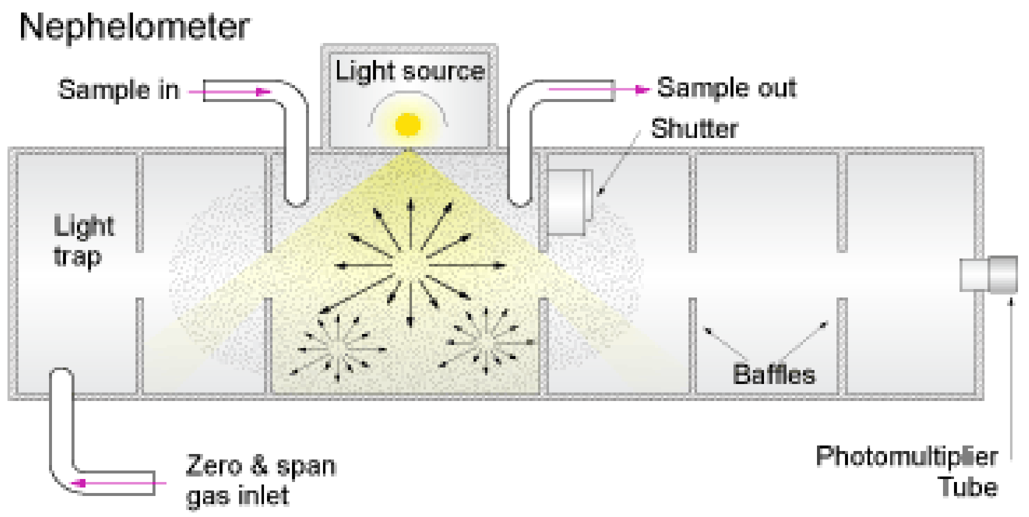
03
Low-cost sensors

- Sizes particles by light scattering
- Portable and easy to use
- Do not meet AS/NZS
- Screening and trends only

Two low-cost sensor types

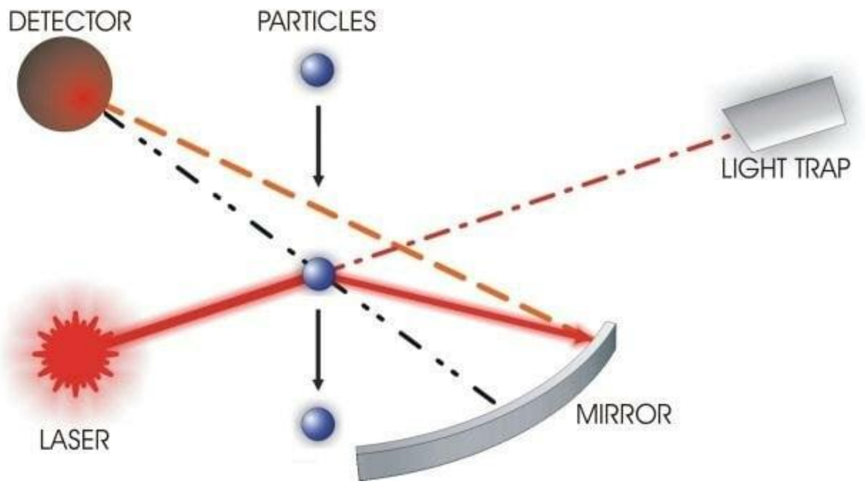
Nephelometers

- Measure (side) light scattered by the whole aerosol
- Technical limitations means only particles < 1 µm are measured
- Empirical calibrate with reference instrument
- Affected by changes in particle size and composition



https://www.qld.gov.au/environment/management/monitoring/air/air-monitoring/measuring/aerosols.gov.au

Two low-cost sensor types



Webe et al., 2010 Airborne measurements of the Eyjafjallajökull volcanic ash plume over northwestern Germany with a light aircraft and an optical particle counter: first results

Optical Particle Counters (OPC)

- Count and size individual particles into bins
- Blind to particles < 300 nm
- Assume spherical particles at a fixed density

$$PM_i = \rho \sum_k N_k \frac{\pi}{6} D_{p,k}^3$$

FUNDAMENTAL LIMITATIONS

Nephelometers

Performance degrades sharply as particle size increases.

Size fraction	Slope vs reference	R^2	Verdict
PM_1	0.87–1.44	0.83–0.90	**Usable**
$PM_{2.5}$	0.78–1.70	0.65–0.76	**Marginal**
PM_{10}	Not calculable*	0.07–0.23	**Unreliable**

Low-cost nephelometers assessed against reference instruments under real-world conditions (Molina Rueda et al., 2023).

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$PM_{1–2.5}$	0.01–0.09	–	**Unreliable**
$PM_{2.5–10}$	0.00–0.22	–	**Unreliable**

Low-cost nephelometers assessed against reference instruments under real-world conditions (Molina Rueda et al., 2023).

OPC

Performance depends on humidity and aerosol composition

Corrections based on κ-Köhler theory can be applied

Size fraction	Slope vs reference	R^2	Verdict
$PM_{2.5}$	2.9 – 3.9	0.7–0.74	**Unreliable**
$PM_{2.5\ corrected}$	0.98 – 1.33	>0.83	**Usable**
PM_{10}	2.5 – 3.5	0.64–0.68	**Unreliable**
$PM_{10\ corrected}$	0.8–1.06	0.5 – 0.8	**Marginal**

Low-cost OPC assessed against reference instruments under real-world conditions (Crilley et al., 2018; Kaur and Kelly 2023).

Why LCS struggle with particles above 1 µm

▪ 01

- **Truncated viewing angles** – sensing zones miss forward-scattered light, so signal drops away larger particles (*nephelometers*)

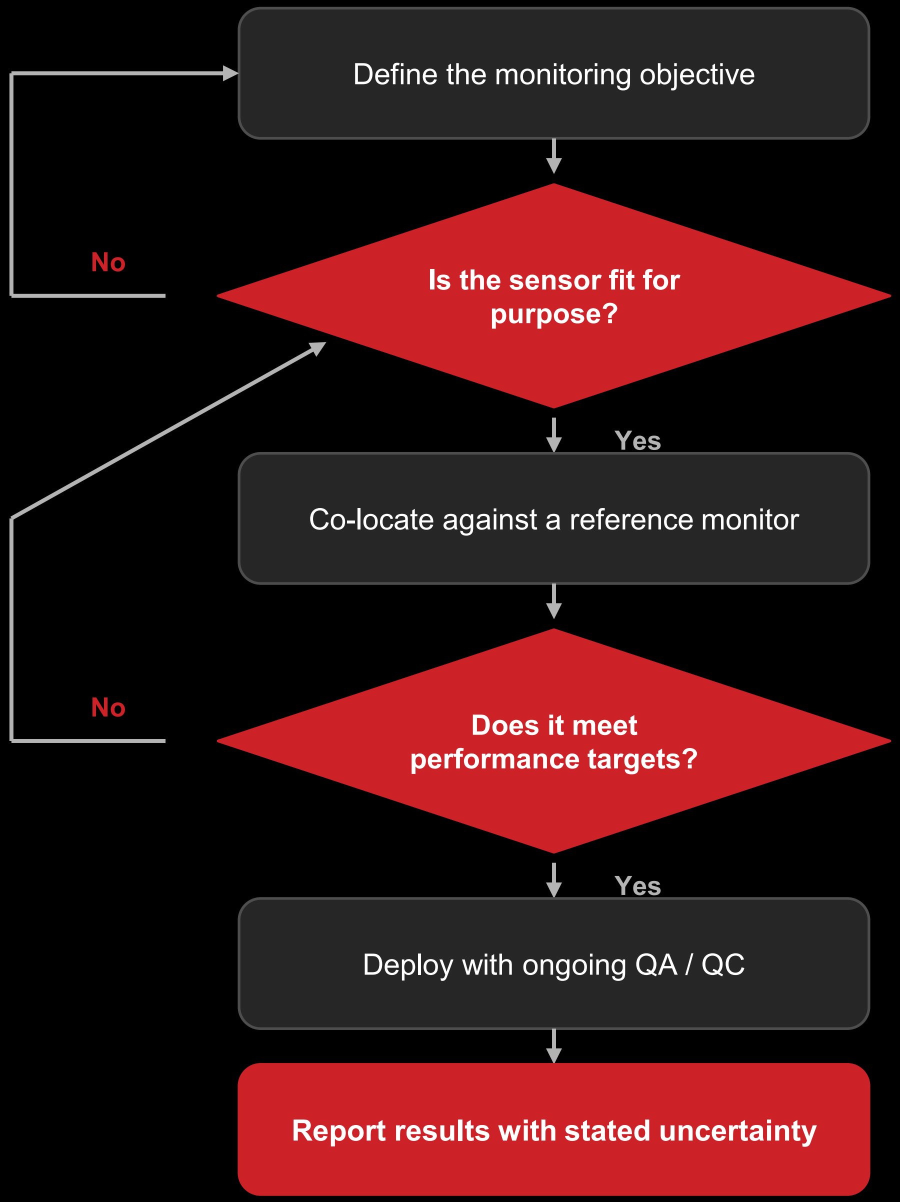
▪ 02

- **Inertial losses** – larger particles are preferentially lost before the sensing zone

▪ 03

- **Shape and refractive index** – coarse particles can scatter light differently from the factory calibration aerosol

Hagan and Kroll, 2020; Ouimette et al., 2024



ASSESSMENT FRAMEWORKS

Standards, co-location and US EPA targets

Standard / guideline	Minimum co-location	Data and statistical thresholds
Australia / New Zealand (AS/NZS 3580.9.17)	Enough for data pairs	At least 40 valid 24-hr data pairs; expanded uncertainty under 25%; two representative sites; may be adjusted using orthogonal regression
Environment Canterbury / Mote (2024)	12 months, 18 preferred	At least 60 valid 24-hr data pairs over 12 months; expanded uncertainty under 25%; prioritises highest-PM sites; re-testing every 5 to 10 years
US EPA (2021)	30 days	Triplicate sensors; at least one test day above 25 μg m^{-3} (24-hr average); two distinct locations across varied meteorological ranges
UK / EU (PAS 4023:2023)	14 days, longer preferred	Comparisons at regular intervals, maximum one-year gap; site classifications similar to intended use; permanently co-locate a subset of large networks
UK MCERTS (indicative ambient PM monitors)	Enough for data pairs	At least 40 valid 24-hr data pairs; expanded uncertainty under 50%; certified ranges PM2.5 0–75 and PM10 0–150 μg m^{-3}

US EPA (2021) performance targets

US EPA performance target	Target value
Precision — standard deviation (SD)	≤ 5 μg m^{-3}
Precision — coefficient of variation (CV)	≤ 30%
Bias — slope	**1.0 ± 0.35**
Bias — intercept (b)	$-5 \le b \le 5$ μg m^{-3}
Linearity — coefficient of determination (R^2)	**≥ 0.70**
Error — root mean square error (RMSE)	≤ 7 μg m^{-3}
Error — normalised RMSE (NRMSE)	≤ 30%

If a candidate instrument falls outside these targets, operators can either withdraw it from use or gather further co-location data.

AUSTRALIAN FIELD EVIDENCE

Field testing low-cost sensors under local conditions

Site	Dates	PM_x	Ref.	Low-cost sensor
Gold Coast	Nov 2024 July 2025	PM_{10} $PM_{2.5}$	BAM 1020	OPC + Nephelometer
Perth	Mar–May 2026	PM_{10}	E-BAM+	OPC

Sensor data was used as supplied by the manufacturer, after any proprietary post-processing and with no further correction.

PM_{10} does not hold up

The US EPA target is 1.0 ± 0.35.

$PM_{2.5}$ passed comfortably

None of three PM_{10} co-locations meet the full metric set.

Site and season	Fraction	Slope	R^2	N	Meets US EPA
Gold Coast, summer	$PM_{2.5}$	1.3	0.91	27	**Pass**
Gold Coast, winter	$PM_{2.5}$	1.1	0.93	59	**Pass**
Gold Coast, summer	PM_{10}	0.83	0.44	27	**Fail**
Gold Coast, winter	PM_{10}	3.0	0.62	59	**Fail**
Perth, autumn	PM_{10}	0.33	0.60	65	**Fail**

Slope against the reference instrument for 24-hour average concentrations


WHERE THEY FIT

Appropriate and inappropriate use cases

✓ Appropriate – where fine particles dominate

Urban background – traffic and combustion trends, hotspots

Smoke-dominated air – bushfires, planned burns, wood heating

Screening and community monitoring – citizen science, preliminary studies

Indicative and trend information only – never compliance data

✕ Inappropriate – where coarse particles dominate*

Construction and demolition – short-term dust from discrete activities

Mining and quarrying – coarse particles, elevated PM_{10} expected

Non-combustion industry – material handling, crushing, stockpiles

Compliance and regulatory reporting – must meet accuracy standards

**(unless site-specific co-location benchmarks are met)*

IAQM position paper meets proposed ANZ best practice

What IAQM say

IAQM position statement (September 2025)

- IAQM **Indicative only** – not for reporting against limit values
- IAQM **Certification is not enough** – PC4 caps indicative use at 150 µg/m³
- IAQM **Fit for purpose** – independently verified before deployment
- IAQM **Prove performance** – site-specific evidence it detects exceedances
- IAQM **Under-reporting** – some sensors under-read near the 190 µg/m³ action level
- IAQM **Adjust action levels** – coverage, not compliance
- IAQM **Not meeting the objectives** – act, or replace the system

What we suggest in practice

The paper authors recommendations for Australian and New Zealand projects

- **Report as indicative** – state the sensor technology and its limitations (not reference)
- **Choose an OPC over a nephelometer** – treat certification as a floor, not proof
- **Verify by pre-deployment co-location** – with CAQP oversight and responsibility
- **Co-locate before you start** – 30 days minimum, then derive a site-specific correction
- **Report the co-location results** – concentration range covered, R^2 and slope
- **Set lower site-specific triggers** – if used as early warning; escalate to proven instruments
- **Fail the co-location** – do not proceed with that instrument
- **Report every correction applied** – with co-location details and residual uncertainty

Where to Next?

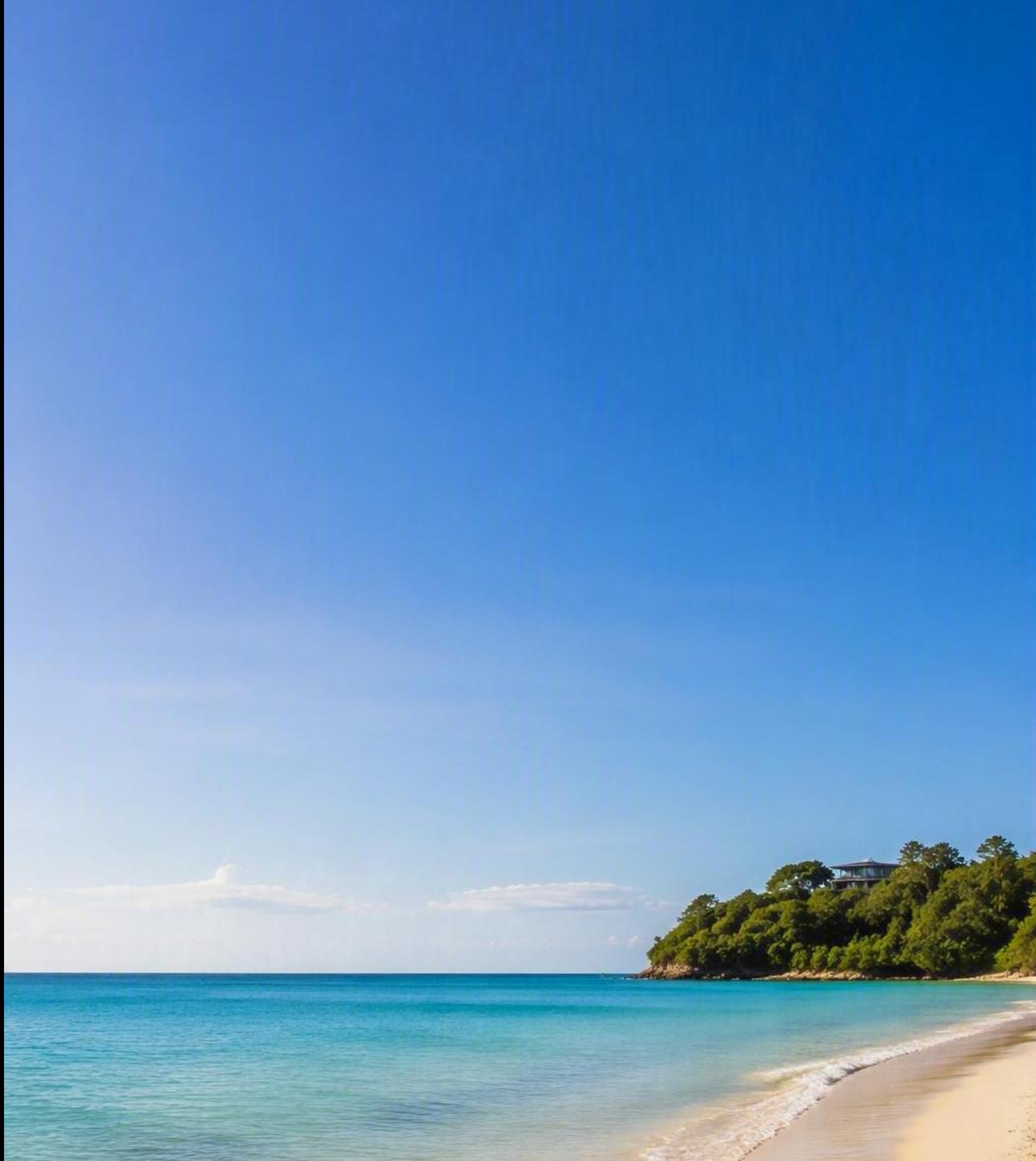
The IAQM issues Position Statements on matters that could affect the way in which Members carry out their professional tasks and on air quality topics and issues where the IAQM can provide a unique perspective from which to give a professional opinion.

Potentially a similar CASANZ position statement

- an IAQM-style statement to guide non-specialists.

Questions?

THANK YOU



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