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Isotope Fingerprinting for Trusted Low-Carbon Fuels: Enabling Climate Action, Fair Trade, and Transparency

NMC has developed regional and interregional training and capability building activities for isotope-based chemical profiling and country-specific source attribution of low-carbon fuels

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The Challenge

The Asia-Pacific region is undergoing a rapid transition toward low-carbon and alternative fuel sources as part of national and regional decarbonization strategies. Hydrogen, bio-based fuels, and synthetic fuels are increasingly traded across borders, often supported by sustainability claims such as “renewable,” “low-carbon,” or “carbon-neutral.” However, the credibility of these claims depends on the availability of robust, independent, and internationally comparable verification methods. Without trusted measurement frameworks, there is a growing risk of greenwashing, fragmented certification schemes, and unequal market access—particularly for developing economies.

In this context, stable isotope analysis provides a powerful tool to fingerprint fuel origin, production pathways, and associated emissions. Recognizing the strategic importance of isotope-based measurement capabilities initially developed for greenhouse gas (GHG) emissions monitoring and source attribution, Singapore’s A*STAR National Metrology Centre (NMC) was designated under the IAEA INT7020 project as a Regional Expert Centre for Analysis and Training (RECAT), supporting Asia-Pacific Member States in building traceable, harmonized isotope measurement capabilities that can be extended to the verification of low-carbon fuels.

Many countries can measure bulk GHG concentrations or fuel properties but lack the capability to apply stable isotope techniques needed to distinguish between fossil-based, biogenic, and low-carbon energy sources. As a result, certification schemes may rely on self-reporting or inconsistent methodologies, and sustainability claims for low-carbon fuels cannot always be independently verified. This may result in a lack of trust in cross-border trade due to non-comparable data. Further, policymakers may lack the reliable evidence needed to assess the real climate benefits of alternative fuels.

However, this challenge presents a major opportunity. Metrologically traceable isotope fingerprinting can provide an objective, science-based mechanism to verify fuel origin and emissions pathways, enabling transparent markets and supporting fair trade in the low-carbon economy. This approach enables clear differentiation between fossil-derived, biogenic, and synthetic fuel pathways (e.g., green vs blue hydrogen, bio vs fossil methane), providing an independent basis for verification. Such differentiation supports fair market pricing, prevents mislabelling or greenwashing, and incentivizes sustainable production and responsible consumption practices.

The Solution

As a RECAT under the IAEA Technical Cooperation Program, Singapore's NMC delivers targeted metrological interventions by transferring knowledge of stable carbon and hydrogen isotope techniques relevant to low-carbon fuels and greenhouse gases, thereby developing harmonized sampling, analytical, and data-interpretation procedures applicable across national laboratories. The technical foundation of this initiative is built on high-precision laser-based isotope-ratio measurement technologies capable of resolving subtle isotopic differences between fuel sources and emission pathways. These techniques are supported by metrologically traceable reference materials, standardized sampling protocols, and quantified measurement uncertainties.

Further capacity-building for the national laboratories is conducted through interlaboratory comparability exercises across participating national laboratories in Asia-Pacific (e.g., NIM, China) and partner regions (e.g., IAEA, BIPM), together with local and regional training courses and hands-on workshops for technical experts, regulators, and policy stakeholders. Implemented under IAEA Technical Cooperation projects INT7020 and aligned with WMO Global Atmosphere Watch principles¹, these activities assess measurement equivalence, reproducibility, and metrological traceability so that isotope data generated in different countries can be directly compared, integrated into certification frameworks, and used as independent evidence to verify sustainability and climate claims associated with low-carbon fuels. This work has also been shared through regional engagements such as the APMP Focus Group Workshop on Climate Change and Clean Air, and the meetings of ASEAN Metrology Network in Chemistry and Biology.

These interventions help harmonize isotope measurement practices across borders for fuel certification and emissions monitoring.

A Quantifiable Impact

The IAEA INT7020 project has delivered measurable improvements in regional and interregional capability for isotope-based source attribution. These activities expanded regional participation and increased the number of laboratories engaged in isotope-based analysis, with growing interest from ASEAN national laboratories in participating in future interlaboratory studies and proficiency testing.

For example, in August 2025, the first interregional training course under INT7020 was hosted at A*STAR National Metrology Centre, bringing together 25 participants from Asia, Africa, Europe, and the Pacific, including laboratory specialists, regulators, and policymakers. Participants received hands-on training in isotope-based air and fuel sampling, metrologically

¹ World Meteorological Organization (WMO), *Global Atmosphere Watch (GAW) Science and Implementation Plan 2024–2027* (GAW Report No. 312, 2025), Appendix A2: "GAW Quality Assurance Principles"; and WMO GAW Quality Assurance Framework, emphasizing common reference standards, measurement traceability, harmonized methods, quality objectives, audits, and interlaboratory comparability.

traceable analysis and calibration, and the interpretation of isotope fingerprints for source verification.

Building directly on the technical capabilities, regional networks, and training foundations established under INT7020, the Phase 2 IAEA Technical Cooperation project INT1058 (“Building Capacity for the Use of Stable Isotope Techniques for Source Attribution of Atmospheric Greenhouse Gases”) commenced in January 2026. This project expands regional participation and strengthens the role of isotope techniques in supporting climate mitigation planning and low-carbon fuel governance.

By enabling independent verification of low-carbon fuel claims, this initiative directly supports the strengthening of evidence-based climate policy and emissions reporting. It also addresses the growing policy need to prevent greenwashing in sustainability markets and ensure that environmental claims are backed by scientifically defensible data.

Institutionally, Singapore’s role as a RECAT reinforces the strategic goal of partnering to achieve sustainable development goals by fostering long-term international partnerships, reducing capability gaps, and promoting mutual recognition of measurement competence. The shared isotope measurement framework supports fair and transparent trade, ensuring that countries with genuine low-carbon production pathways are not disadvantaged by inconsistent or opaque certification systems.

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