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A Roadmap for Humidity and Moisture Measurement

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Abstract An initial roadmap for humidity and related measurements was developed in Spring 2006 as part of the EUROMET iMERA activity toward increasing impact from national investment in European metrology R&D. The conclusions address both humidity (for which standards and traceability methodologies exist, but need to be developed) and moisture content of materials (for which measurement traceability is more problematic and is not so well developed in general). The roadmap represents a shared vision of how humidity and moisture measurements and standards should develop over the next 15 years to meet future needs, open to revision as needs and technologies evolve. The roadmap identifies the main social and economic triggers that drive developments in humidity and moisture measurements and standards—notably, global warming and advanced manufacturing processes. Stemming from these triggers, key targets that require improved humidity and moisture measurements are identified. In view of global warming, one key target is the development of improved models of climate through improved measurements of atmospheric water vapor. A further target is the reduction of carbon emissions through humidity measurement to optimize industrial heat treatment and combustion processes, and through humidity and

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moisture measurements to achieve energy-efficient buildings. For high-performance manufacturing, one key target is improved precision control of manufacturing processes through better humidity and moisture measurements. Another key target is contaminant-free manufacture in industries such as microelectronics, through high-purity gases of known moisture content at the parts-per-trillion level. To enable these outcomes, the roadmap identifies the advances needed in measurement standards. These include the following: improved trace humidity standards; new humidity standards to cover high temperatures and pressures, steam, and non-air gases; and improved standards for moisture content of materials. Technologies that are likely to be harnessed are also identified, such as emerging laboratory techniques, existing and new research-grade hygrometers, hygro-thermal modeling, and nanotechnology.

Keywords Humidity · Moisture · Roadmap

1 Introduction

"Roadmapping" is a business planning tool for identifying pathways for development in a field (in this case, humidity and moisture metrology). It was first used as a planning approach in the 1970s in the electronics industry. The analysis is generally based on existing enabling factors (technologies), real-world triggers (benefits) and targets, plus the steps (or resources) necessary to achieve these. A roadmap is a "live" document, which can and should be updated as developments progress. The primarily graphical output of the roadmaps makes them a useful format for communication.

A roadmap for humidity and moisture measurement was drafted at a two-day workshop by the authors on behalf of the relevant EUROMET technical committee (EUROMET TC Therm Humidity Sub-field). It was part of the EUROMET iMERA project (Implementing Metrology in the European Research Area [1]) aimed at increasing impact of national investment in European metrology research and development. During the workshop, participants considered the following in sequence: triggers, targets, enabling science and technology, and lastly, metrological science and technology and experimental realization.

The Roadmap for Humidity and Moisture Measurement is shown in Fig. 1. The vertical axis shows increasing specialization of technology toward targets. The horizontal axis shows an approximate timescale. Arrows on the roadmap can reflect parallel development chains and alternative routes of progress. The steepness of slope of an arrow implies the rate (and sometimes the difficulty) of a step.

Sections 2–6 below provide the accompanying text to the Humidity and Moisture Roadmap, as agreed by EUROMET TC Therm Humidity Sub-field (with minimal adjustments for publication).

2 Background to Humidity and Moisture Roadmap

An initial roadmap for humidity and related measurements was developed in Spring 2006 as part of the EUROMET iMERA activity toward increasing impact of national investment in European metrology R&D. The conclusions address both humidity (for

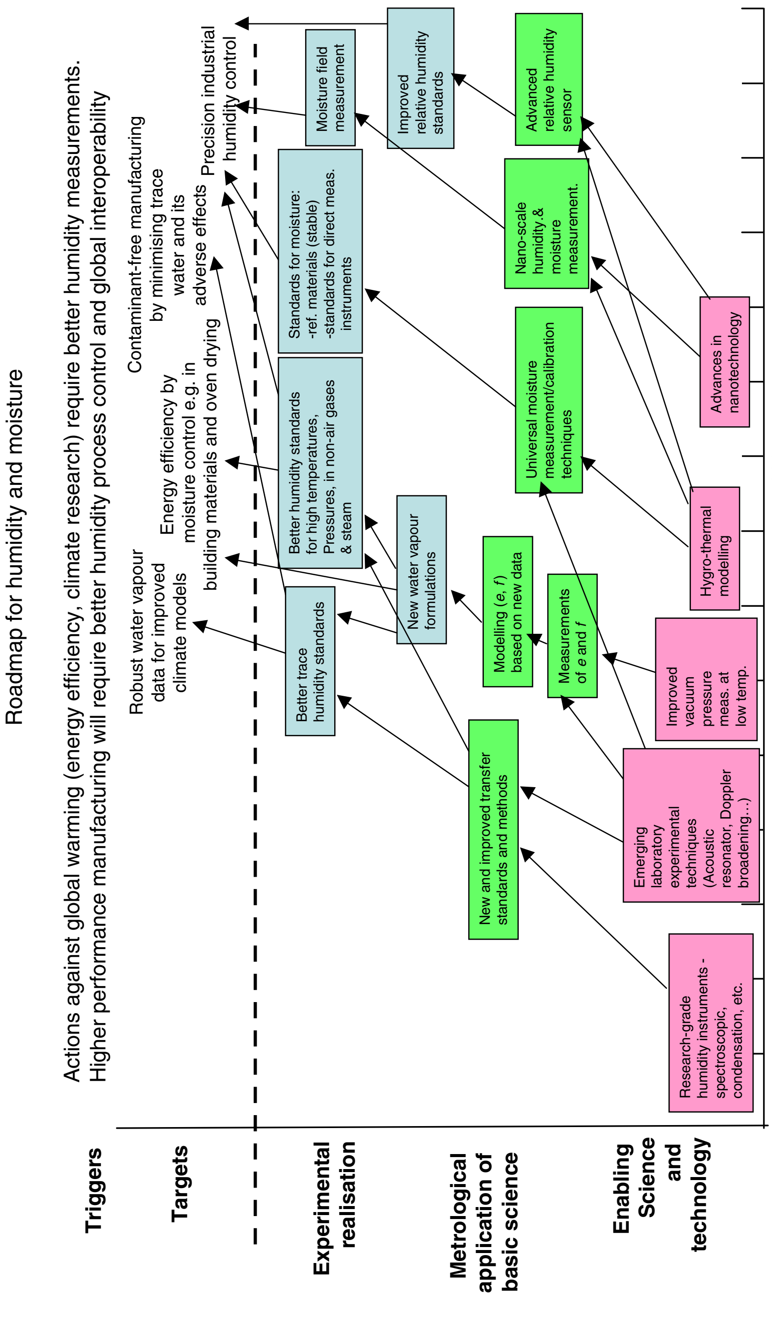

Fig. 1 Roadmap for Humidity and Moisture Measurement: vertical axis shows increasing specialization of technology towards targets; horizontal axis shows approximate timescale

which standards and traceability methodologies exist, but need to be developed) and moisture content of materials (for which measurement traceability is more problematic and is not so well developed in general).

3 Triggers

The social and economic drivers of development in humidity measurement and standardization can be viewed in terms of just two key triggers:

- Actions against **global warming** (energy efficiency and climate research) will require increasingly accurate humidity measurements and their interpretation.
- Ever-increasing consumer demand and global market forces will require better humidity control in **manufacturing processes** and increased global technical interoperability.

4 Targets

Stemming from these triggers, key targets are envisaged as follows.

4.1 Global warming

4.1.1 Target: Improved Climate Models—By Characterizing the Critical Component of Water Vapor

Water vapor is a main greenhouse gas, and a key reagent and marker in atmospheric chemistry. Climate models depend ever more sensitively on accurate airborne and land-based measurements of air humidity and ground moisture content, and meaningful handling of these data—problems that are far from solved.

4.1.2 Target: Reduction of Carbon Emissions Through Energy Conservation

(a) Using and developing humidity measurement to optimize combustion and heat treatment processes across all industries: intelligent humidity monitoring of water driven off in baking, curing, and other heat treatments; processes can be optimized, end points detected, and energy consumption minimized. This has the added benefit of reducing emissions of pollutants, thus reducing the cost of preventing or mitigating pollution. However, humidity sensors are not yet robust enough for these applications.

(b) Using and developing measurements of building humidity, moisture content of building materials, and water vapor flux to achieve energy-efficient buildings: humidity and moisture measurements are central to the evaluation of human comfort (together with air temperature measurement, heat flow, and air flow), sealing and condensation prevention, and thermal properties of insulation and other building materials. However, humidity measurements need further development and application in this context, and material moisture content and flux measurement are challenging to achieve. Throughout Europe, potential savings and productivity gains from ensuring a "good" indoor environment are enormous. Expenses incurred by employee salaries exceed building energy and maintenance costs by a factor of 80–100; they exceed annual construction or rental costs by an equal amount. Thus, even a minor increase of productivity is sufficient to justify investments that are instrumental in improving the indoor environment. The consequence of poor indoor environment in houses and office buildings costs society, in general, enormous sums.

4.2 Higher-Performance Manufacturing

4.2.1 Target: Precision Industrial Humidity Measurement for Manufacturing Process Control

Measurement of water vapor is important wherever organic, corrodible, or reactive materials are manufactured, handled, or stored. Humidity- and moisture-critical processes include manufacture of pharmaceuticals, foodstuffs, defense equipment, microelectronics, and the supply chains for these, plus several others.

Market forces naturally lead to ever-more specialized and innovative products. As a result, increasingly sophisticated manufacturing processes will need greater precision control of humidity as a process variable. To meet this challenge, more robust and accurate humidity sensors will be required. The need to qualify and calibrate these for tough real-world conditions (in various gases, pressures, contaminants) will require better and more diverse calibration capabilities.

Very often, a humidity measurement is a "proxy" for the variable of real interest—moisture content of a solid or liquid. However, although basic measurements of moisture content of materials can sometimes be made, strong advances are needed.

4.2.2 Target: Contaminant-free Manufacture

High-purity manufacturing processes, such as silicon substrate fabrication and deposition processes for microelectronics, require ultra-pure process gases. Reduction of water vapor to levels of parts per billion, or even parts per trillion, are demanded. Already, these conditions are practically unverifiable, yet the requirements will predictably become even more stringent with the increasing drive toward nanotechnology. Trace moisture measuring instruments, and methods for their calibration, will be pushed to their limits, and will need extending downward in the detection range, and broadening in scope, to deal with non-air gases (some aggressive) at various pressures.

5 Enabling Science and Technology

Enabling science/technologies (inputs to the developments in the humidity and moisture field) have been noted. Present-day enabling technologies can be easily described. Those in the future are foreseeable but speculative.

6 Metrological Application of Basic Science, Experimental Realization

6.1 Experimental realizations

Outcomes/targets at the national laboratory/standards level. Explanatory notes for selected boxes on the roadmap diagram are as follows:

(a) Better trace humidity standards—high-purity manufacturing increasingly requires gases pure to parts per billion or even parts per trillion. Existing standards only underpin measurements to slightly below 1 part per million.
(b) Better humidity standards for high temperatures and pressures in non-air gases and steam—current measurement traceability is mainly in moderate "laboratory" conditions—provision must be extended to real industrial process conditions.
(c) Moisture field measurement—to control moisture processes in materials, significant advances are needed toward measuring moisture movement, moisture profile, surface moisture, as well as bulk moisture content.
(d) Improved relative humidity standards—the possibility of an "advanced" robust, stable, drift-free, high-resolution relative humidity sensor would transform industrial process control. Such a sensor would enable direct measurement traceability of relative humidity, instead of the current step-wise traceability via dew point and temperature.

Though not shown in any single place in the roadmap diagram, **improved air (gas) temperature measurement** is a need across the field, which is critical to improving humidity measurement and calibration, especially for relative humidity.

6.2 Metrological Applications of Basic Science

Steps on the route from enabling science/technology to the outcomes/targets at the national laboratory/standards level. Explanatory notes for selected boxes on the roadmap diagram are as follows:

(a) New and improved transfer standards and methods—more accurate standards and fewer steps in the chain of traceability can lead to smaller uncertainties in applied measurements.
(b) New water vapor formulations, modeling (e, f) based on new data, and measurements of e, f—for accurate humidity calculations, accurate data for fundamental properties of water vapor are needed (e is saturation vapor pressure at a given temperature, and f is the non-ideality of "real" gases, e.g., at high pressure). Existing vapour-pressure formulae are only weakly substantiated.
(c) Universal moisture measurement/calibration techniques—to measure moisture in materials, there are several measurement methods; all methods are differently calibrated, and the calibrations must be tailored to the material being measured. Harmonizing this complex field is an extreme challenge, which would ideally call for development of a universal calibration method.

Some applications span several techniques and target areas on the roadmap. A notable example is the research and improvement of hydrogen fuel cells, especially cell lifetime, which critically depends on humidity. This calls for advanced extremely miniaturized relative humidity and gas temperature sensors, which are robust against extreme conditions.

7 Conclusion

The objectives of the roadmapping process have been to advise the direction of metrological research, and to highlight the opportunities for collaboration and co-operation in the international metrology community. It is anticipated that the Roadmap for Humidity and Moisture Measurement will be a useful tool for demonstrating the need and rationale for humidity research, development, and metrology infrastructure, wherever justifications are needed at national and international levels.

Advances will continue in the field of humidity and moisture measurement, and the requirements for these measurements will gradually evolve. To remain useful, this roadmap will need to be updated to incorporate short-term developments and their long-term implications. Responsibility for this rests with the technical committee EUROMET TC Therm, which can be contacted though the technical committee chair (currently Jovan Bojkovski, mail to: jovan.bojkovski@fe.uni-lj.si). Comments on the present version of the roadmap, and proposals for input to future revisions, are welcome at any time. It is proposed to make a copy of the Humidity and Moisture Roadmap publicly available for the foreseeable future at http://www.technology-roadmaps.eu/doku.php.

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Reference

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