# METROLOGY TRENDS FOR THE FUTURE – A VIEW FROM AN NMI

Belinda L. Collins, Ph.D.
Director, Technology Services
National Institute of Standards and Technology (NIST)
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What might the next five years and beyond hold for NIST, CENAM, and other National Metrology Institutes (NMIs) – and the entire measurement community world-wide?

We can be certain of one thing: there will be change! We can expect change not only in what we provide, but also in the ways in which we provide measurements and metrology services. We can anticipate changes in measurement capabilities – and the need to provide ever new capabilities to address such issues as nanoscale measurements. We have already seen some convergence of unrelated scientific disciplines, and can expect further combinations of biology, chemistry, and physics applied to emerging technologies and industries, including nanotechnology and biotechnology. These will pose new questions about how to measure their combined impact on the performance and safety of existing and new materials. Need will drive change in the ways in which we listen to, learn from, and work with colleagues in industry, academia, and government agencies. At the same time, not every NMI will be able to make every measurement needed by its own economy, so we should expect increased collaboration among NMIs and with industry laboratories. We can anticipate, and work towards, greater synergy among the key players to create the standards needed to support the global economy.

In the following pages, I'll describe some ideas emerging from my, albeit imperfect and cloudy, crystal ball. We can revisit in 2011 to see how on target these predictions were!

## MEASUREMENT SCIENCE

I'm going to begin with advances in measurement science and delivery, starting with the NMI at which I've spent my career. NIST recently revised its mission statement as follows:

> *To promote U.S. innovation and competitiveness by advancing measurement science, standards and technology in ways that enhance economic security and improve our quality of life*.

This mission focuses us squarely on metrology and standards. It is coupled with a long- range planning effort that concentrates on advancing measurement science to support innovation and competitiveness. Concomitant efforts will include creation and dissemination of physical standards and input into the documentary standards needed to support emerging technologies.

The areas that NIST is choosing for concentration are familiar to all of us from the daily newspaper, internet and TV. The first area, nanotechnology, involves the measurement science needed to enable nanotechnology from discovery to manufacture. NIST has just created its Center for Nanoscale Science and Technology to foster development of measurements and standards in support of nano-manufacturing and other technologies at the nanoscale. We are partnering with industry on appropriate user facilities at NIST/Gaithersburg, including the Advanced Measurement Laboratory, and at NIST/Boulder and elsewhere to strengthen and deepen our research focus.

The subject of new, reliable energy sources, including hydrogen fuels, is also of great public interest at this time. NIST recognizes that creating a viable hydrogen economy will require new measurements and standards, as well as the supporting technologies required to improve the efficiency, durability, and manufacture of hydrogen fuel cells. Standards and calibrations are needed for pipeline safety and reliability, as well as for the

legal metrology infrastructure essential for commercial sales of hydrogen fuel. Ensuring that consumers actually receive the labeled amount of hydrogen fuel is complex … and every bit as challenging as for petroleum products.

The biotechnology and healthcare industries are hot areas that are badly in need of sound metrology to underpin advances in disease treatments, pharmaceuticals, and agriculture, to name only a few opportunities for NMIs. NIST is partnering with the National Institutes of Health (NIH) and the bio-imaging industry to improve molecular imaging for understanding bioprocesses and for assessing the behavior of biomaterials in the body. This effort is essential for developing the measurement foundation for converting pictures of biological materials and systems into data that can be used reliably for diagnosis and analysis.

At the other end of the bio-spectrum is the need for measurement data and procedures for biometrics for identifying individuals, helping us to protect our borders and moving people through checkpoints more efficiently. NIST has already developed expertise in face recognition and fingerprints … but the development of new standards and test methods will be required to use this technology effectively.

The 20th century was dominated by advances in computing power, and we can anticipate continuing advances as we move forward in the 21st century. NIST is poised to conduct revolutionary research in quantum information science; to develop new measurement tools and methods that can be applied to new, ultra powerful computers; and to achieve "unbreakable" codes to protect financial and other transactions. This is accompanied by society's need for the measurement science and technologies essential for providing the cyber security that is required for protecting the nation's productivity and infrastructure including transportation systems, financial systems, power grids, etc. Earlier NIST research in encryption technologies is estimated to have saved these and other industries as much as $1B, but many more threats to cyber security remain to be addressed.

Although not all NMIs explicitly support the construction and building industries, NIST has a mandate to develop the measurements and standards for providing structural safety in hurricanes, fires, earthquakes and other disasters. This continuing effort calls for improvements in the modeling of measurements of extreme winds coupled with fire and smoke, as well as development of innovative techniques for earthquake-resistant design and construction. We have worked collaboratively with Japan for more than 20 years on the measurements and standards needed to improve construction to resist fires and earthquakes – and to enhance human safety in the built environment. This collaboration has benefited people throughout the world as building codes have been enhanced to address issues of seismic safety and fire resistance.

NIST has long supported manufacturing innovation through measurements and standards for better supply chain integration. These ongoing efforts center on better exchange of product designs and data through improved standards and test methods (ensuring compatibility with international standards). Along with other research institutions and NMIs, NIST has worked to embed our research findings and technologies into the standards needed by industry to create tomorrow's products and systems. We will continue these joint endeavors to ensure that industry standards are accepted globally.

These advances in measurement science and standards recognize the need for NIST and other NMIs to focus on new types and approaches to the measurements and standards to support competitiveness and innovation!

**LEARNING FROM OUR CUSTOMERS AND STAKEHOLDERS**

The foregoing concepts have arisen from the practitioners of measurement science, but additional ideas stem from customer needs and requirements. To assess these, NIST recently embarked on an ambitious review of the U.S. Measurement System (USMS) to determine how we can effectively address the multiplying needs for ever-more-exacting and more reliable measurement tools and associated services to support innovation. NIST is working with stakeholders across the U.S. to identify unmet or emerging needs for measurements to support emerging technologies of all types – from nanotechnology to biotechnology to energy to information technology and beyond. Technological innovation sustains U.S. competitiveness in the world while underpinning national security and defense. It has accounted for half of our economic growth, with productivity in "high tech" manufacturing growing three times as fast as for manufacturing as a whole. Measurements are needed to support innovation and growth. Test-equipment manufacturers, standards developers, product certifiers, accredited laboratories and all

participants in the measurement system at the national level will have to address these issues.

NIST has surveyed the USMS from different cross-cutting perspectives, including specific sectors, technologies, SI Units, and disciplines to explore measurement needs and the state of the entire U.S. measurement system. We plan to report specific industry measurement needs, analysis of trends and commonalities among specific innovation-limiting measurement needs, findings on the state of the system, and any identified systemic problems, with recommendations for follow-up actions that will achieve solutions. The NIST report will help to focus stakeholder attention on systemic issues that undermine the performance and utility of the whole system, catalyze further efforts to identify measurement needs and systemic problems that weren't identified initially, and enable efficient use of both public and private sector resources to resolve measurement problems.

The analysis of all the data gathered in the USMS effort promises to provide a wealth of information that will assist NIST and other NMIs around the world as we plan to accomplish the measurements and standards that will facilitate innovative technologies over the next five years and beyond!

**COLLABORATION TO ADDRESS MEASUREMENT CHALLENGES**

We should see much more enhanced collaboration in the years ahead. Andrew Wallard, Director of the Bureau International des Poids et Mesures (BIPM), has long discussed collaboration among the NMIs, but what about collaboration within an economy among different types of laboratories?

NIST has just initiated such collaboration with the Oak Ridge National Laboratory (ORNL) to promote measurement accuracy for nuclear medicine imaging driven by the need for calibrations of short-lived atomic species. In this effort, NIST scientists will use the NIST/ORNL Nuclear Medicine Calibration Laboratory to prepare and measure radioactivity standards used for Positron Emission Tomography (PET). PET is a non-invasive technique that helps doctors diagnose diseases (such as cancer), plan medical treatment, and measure the efficacy of therapies. In this procedure, a low-dose radiopharmaceutical (such as glucose molecules with radioactive particles attached) is injected and metabolized in the part of the body to be imaged by the PET scanner. As the scanning technology has improved and image analysis has become more sophisticated, demand has grown for more precise determination of the administered dose. The NIST/ORNL program will for the first time provide direct traceability of these radioactivity measurements to national standards. The NIST program will be carried out regionally because the short half-lives of most PET radiopharmaceuticals prevent shipment of standard test samples over long distances. We anticipate the need for additional such partnerships in the future!

NIST has also had excellent success in collaborating with others in several unique NIST facilities, including the NIST Center for Neutron Research. We anticipate expanding this center to provide an additional cold source and new generation of world-class instruments to conduct research into protein structures and functions as well as trace chemical analysis. Another opportunity for collaborative research is with the national synchrotron light source at Brookhaven national lab where joint work in imaging and analysis of chemical, electronic and structural properties will support the development of innovative materials

NIST has previously discussed the capabilities of the Advanced Measurement Laboratory (AML) at NCSLI and Measurement Sciences conferences; suffice it to say that the AML is being extensively used to support not only metrology for nanotechnology, but for all technologies requiring precision control over the environment in which the measurements are made.

**DEVELOPMENTS IN THE SI**

We are on the brink of seeing the emergence of an electronic kilogram within the next five years, as well as ever more precise measurements of time – perhaps down to the femtosecond level. Researchers in nanotechnology foresee a need for mass measurements even at the zeptogram and yoctogram levels – precise enough to measure the mass of an individual hydrogen atom. The measurement uncertainty required of such measures seems to defy belief – and yet NMIs are likely to need to address such concerns in the future.

We expect to need new combinations of measurements for work across disciplines as the lines between physics, chemistry and biology blur. Using quantum dots to identify bacteria is only one possibility. Metrology for carbon nanotubes may

well underpin the bio-nano materials and technologies of the future.

NIST is a member of the Comité International des Poids et Mesures (CIPM) and a signatory to its Mutual Recognition Arrangement (MRA). We take great pleasure in the Sistema Interamericano de Metrologia (SIM) acceptance of the NIST quality system for measurement services, first for calibrations and now for Standard References Materials (SRMs). Working collaboratively with the Centro Nacional de Metrologia (CENAM) here in Mexico has long been a priority for both our NMIs. However, we can't rest on our laurels: we, and all the NMIs of the world, must figure out how to weave together the measurement results from accredited laboratories, both in industry and at the sub-federal level.

Finally, NIST has already seen the emergence of requests for unusual Standard Reference Materials (SRMs), ranging from ephedra to nanotubes; such requests are likely to increase exponentially. Yet, industry still needs the early SRMs developed by NIST for metals such as iron and steel, and materials such as Portland cement. NIST, and its sister institutions, must continue to satisfy the needs of existing and emerging industries, recognizing and anticipating new and different measurement needs.

Having a reliable crystal ball is possible only when the NMIs and industry work closely together, to dream of new measurement capabilities needed to foster innovation!