METROLOGY IS FUNDAMENTAL TO ECONOMIC AND SOCIAL DEVELOPMENT

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Plenary Lecture

Good morning friends, colleagues, and distinguished guests. It is an honor to participate in this symposium, and it is a great pleasure to take part in this well-deserved celebration of the tenth anniversary of CENAM.

In only a decade, CENAM has progressed to become one of the world's top National Metrology Institutes and one of my organization's most valued collaborators.

And, as most of you can appreciate, strong and capable partners are always welcome in the international business of measurements.

So, on behalf of the entire staff of the National Institute of Standards and Technology, I wish to congratulate all of our counterparts at CENAM and to extend our wishes for continued success in the years and decades to come.

The close cooperation between NIST and CENAM began when a new Mexican national metrology institute was but a twinkle in the eyes of planners and funding sources. During this formative stage, NIST offered advice and technical assistance, when called upon.

We responded, to be sure, because we wanted to be good neighbors. But I must confess that we also were motivated by self-interest. The North American Free Trade Agreement – or NAFTA – also went into effect in 1994. We knew the need for reference materials, calibrations, and other measurement-related support was sure to grow with the anticipated increase in trade between Mexico, Canada, and the United States.

Indeed, it did grow. Today, we are happy to refer customers to CENAM for high-volume flow measurements and other world-class measurement services. At the same time, NIST continues to supply hundreds of reference materials and other tools and services to Mexican organizations. This kind of cooperation prevents needless duplication of facilities, and it stretches scarce resources at a time when needs for new measurement services are proliferating.

Other opportunities for NIST and CENAM to leverage each other's special competencies are sure to arise. We are continually learning from and about each other through frequent consultations and, *most important*, through regular exchanges of staff members. Over the last decade, nearly 80 CENAM scientists and engineers have come to NIST to work as guest researchers.

Beyond bilateral cooperation, CENAM and NIST have worked to rejuvenate and strengthen the Inter-American Metrology System – or SIM. Canada's National Research Council and Brazil's INMETRO have been especially valuable allies in this effort to build a system of harmonized measurements for the entire Western Hemisphere – a system that benefits the economies and citizens of 34 nations and that links to the entire globe.

So, CENAM has grown from infant to productive adult in a quick ten years – literally, a blink of the eye on institutional time scales.

Anniversaries are, of course, a time for reflection and for recounting. But they also are an appropriate time for re-calibrating, so to speak – for doing a systems check and setting a course for the future.

NIST did that a few years ago – in 2001 when we celebrated our centennial. And I'm sure CENAM's managers are doing that now. I'd like to contribute by sizing up the role of metrology in economic and social development at this particular juncture – at the start of the 21st Century.

This kind of assessment is useful for all of us. I don't know about you, but it seems that, almost every day, NIST is being asked to justify its existence and to prove that we are paying our way.

Whether posed by elected officials, customers, or tax payers, the question usually consists of two parts. First, we are asked, *What have you done for me lately?* Then, attention shifts to the future, and the question becomes, *What will you do for me tomorrow?*

These are fair questions, and we – and by "we" I mean the measurement scientists and metrology institutes of the world – can respond with good answers, backed up by solid examples of impact, effectiveness, utility, and social benefit.

Before presenting the evidence, however, I'd like to recast the question, with the intention of broadening the scope of inquiry and evaluation. And why not? We metrologists truly do have an impressive story to tell.

So the question becomes this, *Do individual nations, trading partners, or, for that matter, the entire global economy need a strong and continually improving measurement infrastructure?*

Permit me to answer rhetorically:

- Does a Roman arch require a keystone?
- Does an automobile engine need oil?
- Does the human body need to breathe?

In other words, the answer is yes, a resounding yes. Our nations and our world require a reliable, robust measurement infrastructure.

Metrology is a vital, integrating element of economies, societies, and more. It is the subdivision of science that underlies and assists all others. It reduces friction in the marketplace, smooths the way for technological progress, and enables discoveries.

With no fanfare and, usually, without notice, metrology helps to build capabilities in nearly every area of human endeavor – from making more powerful microprocessors and increasing the efficiency of manufacturing processes to improving medical care and reducing pollution.

Sir Isaac Newton – the father of classical mechanics and much more – invoked a heavenly explanation to account for why metrology is so tremendously helpful and why the work of metrologists may never be finished.

"God," Newton wrote, "created everything by number, weight and measure."

At times, it does seem that securing funds for critically needed personnel and equipment will require an act of divine intervention. At least, it feels that way to me when submitting NIST's annual budget request.

Whether metrology qualifies as a divine calling is for philosophers to decide. At a more mundane and much more practical level, the truth of the matter is, the more we aspire to in science and technology, *the more important measurement capabilities become.*

And the more complex and more powerful our technology becomes, *the more important metrology becomes.*

And the more interrelated our innovations, our businesses, our industries, and our economies become, *the more important metrology becomes.*

The bottom line on metrology can be summed up in a tenet of good management: *What gets measured gets done!*

The corollary, of course, is: What can't be measured – or at least not efficiently or with the necessary level of accuracy – is less attainable, a more difficult and more uncertain prospect.

In today's world and, I believe, in the world of tomorrow, the role of metrology in supporting economic growth and social well-being is best understood in the context of technology. Technological progress is an already large and growing component of economic growth. It also is fundamental to accomplishing many important social and environmental goals, from reducing the deadly toll of natural disasters to easing dependence on non-renewable sources of energy.

For now, however, I would like to describe trends that are making technology an even more essential ingredient of economic growth. In turn, these same trends are placing an ever-higher premium on measurement capabilities. These capabilities reside at the very core of the technical infrastructures that underpin and sustain national innovation systems.

Technology's contribution to economic growth is increasing in nearly all economies around the world. Among the 30 nations that are members of OECD – that's the Organization for Economic Cooperation and Development – almost all depend on technological change for at least 50 percent of growth in their Gross Domestic Product.

Productivity, however, is the mechanism by which technology drives economic growth; technology accounts for as much as three quarters of long-term productivity growth.

Unfortunately, too many people still think of technology as a "black box," or a kind of mysterious genie that brings good things to store shelves and business loading docks, while sprinkling the marketplace with new types of services.

This hazy, amorphous notion of technology prevents a thorough understanding and full appreciation of the roles of technical infrastructure in supporting economic growth. A challenge for leaders of NMIs all around the world is to articulate – clearly and convincingly – the complex set of contributions that metrology infrastructure, in particular, makes in support of technology-driven economic growth.

In short, we need to better define measurement infrastructure, its economic roles, and, equally important, its vital contributions to scientific advancement.

On this last point consider the connections between measurement, quantum mechanics, and today's budding nanotechnology revolution. Jack Marburger, the science adviser to President Bush, drew these connections earlier this year. He spoke at the dedication of NIST's new Advanced Measurement Laboratory, a kind of research refuge from environmental interference and a bastion for NIST's most exacting metrology research and development.

Quantum mechanics began with careful measurements of the spectrum of thermal radiation. Most scientists were convinced of the need for the special theory of relativity by careful measurements of the effect of the earth's motion upon the speed of light, in this case a negative result. And one of the triumphs of Einstein's general theory of relativity was the explanation of a tiny discrepancy with Newton's theory in the observed precession of Mercury's orbit about the sun. These are among the most profound innovations in the entire history of science.

The rich legacy of measurement-inspired achievements continues to grow. Now, established companies and aspiring start-up firms around the world are working to harness and exploit curious quantum effects and properties in novel technologies that range from tamper-proof computing and communication to environmentally benign magnetic refrigeration to regenerative medicine.

To make it all the way to the marketplace, into the home, to the hospital, and to almost countless other areas of application, the vast array of emerging nanotechnologies will require new types of measurement tools – methods and equipment that enable fast, efficient fabrication and assembly processes with unprecedented levels of control. And, of course, all this must be achieved at a reasonable cost.

In the words of a Massachusetts Institute of Technology researcher, "The 'nanotechnology revolution' is dead in the water without a metrology infrastructure."

While the most ambitious nanotechnology prospects may lie a decade or more ahead, it is true that the power and utility of reliable, accurate measurements grow as their sphere of application and practical relevance expands. After all, metrology has its origins in practical purposes. Think of the Egyptian pyramids or the Mayan calendar.

So, to realize the tremendous promise of future nanotechnology applications now in the making, we must begin now to build the necessary measurement and standards infrastructure that will serve all regions.

NMI-traceable measurements will be the bedrock of this infrastructure, just like they are in today's more established fields of technology. Such measurements are seamlessly woven into the everyday operations and activities of industry, of national and global commerce, of national defense, of health care systems, and on and on.

These measurements are, as I said earlier, like breathing. For the most part, we are not conscious of the continuous, life-sustaining process of inhaling and exhaling. So to for measurements. They are taken for granted. They are invisible. They function behind the scenes. They are embedded deep into the foundations of industry and commerce.

Society does not give measurements – much less the underpinning science of metrology – a second thought, *unless something goes wrong!*

That *something* could be underfilled milk cartons, a lost satellite, or unsynchronized traffic lights and accumulating hordes of irate, rush-hour motorists.

Or it could be out-of-tolerance parts rejected by unhappy customers or shipments of exported merchandise barred from market entry, or, a printer or external hard drive that doesn't interoperate with a personal computer.

Measurement-related errors and problems can be at the root of waste, inefficiencies, inequities, disputes, and numerous other troubles that, quite literally, can take away the breath of consumers, businesses, and even regulators.

That reliable, accurate, and, yes, traceable measurements are intrinsically important in the workings of economies and societies should be evident to all who pause, even for a moment, to contemplate their myriad functions and ever-present contributions.

Unfortunately, few outside the metrology community do pause for such contemplation. So, how do we get their attention, and how do we prove that spending to build and maintain a strong metrology infrastructure is a wise investment, for today and tomorrow?

One way is through case and impact studies and broader economic assessments. The fact is, metrology is a critical infrastructure for industrialized and industrializing economies alike – especially for established and emerging high-technology sectors. So, economic impact is the *bottom line.*

Over the last few decades NIST has commissioned nearly 40 economic impact studies, which are conducted by neutral, third-party organizations. Most of these are retrospective evaluations of both the benefits and costs attributable to completed measurement research and development work or to existing services over spans of several years. Collectively, these studies constitute a convincing database of economic impacts that provide credibility for future proposed metrology research and service programs.

To date, there have been 30 retrospective studies of the economic impact of NIST infrastructural technologies, or "infratechnologies" for short. Examples of these infratechnologies are tests, measurement methods, calibration services and reference materials, collections of evaluated data, process models, and software standards.

Most of these studies use three metrics common to corporate finance– net present value, benefit-cost ratio, and internal rate of return. The idea is that businesses use these same metrics to evaluate their investment decisions, facilitating comparison and communication of results.

Across the 27 NIST impact studies, internal rates of return range from 32 percent to more than 1,000 percent. The average rate of return is 209 percent. In industry, an acceptable rate of return on research and development investments is about 20 to 25 percent.

So, on average, returns on the NIST-developed infratechnologies top industry's so-called investment hurdle rate by better than a factor of eight.

What accounts for this rather sizable difference? The high rates of return attest to the infrastructural nature of metrology tools. They are broadly useful, typically benefiting many companies, often in several industries. These substantial spillover benefits are compelling evidence of the "public good" nature of metrology R&D.

Widely needed and advantageous to many, the outputs of measurement research and the benefits that accrue cannot be captured adequately in proprietary R&D efforts funded by individual companies. In short, accurate measurements are basic to many industries.

The results of retrospective impact studies also provide government officials and taxpayers with a gauge to assess the value realized on public funding support of measurement research and services. The returns can be lucrative.

In the 11 impact studies conducted since 1998, benefit-to-cost ratios range from 3 to 1 to more 100 to 1. The average was 32 to 1. This means that, for every dollar NIST invested in metrology related programs, taxpayers earned $32.

In reality, total benefits were even greater, since only quantifiable returns were tabulated. Important qualitative benefits, such as enabling standards or opening new avenues of research, are not included.

I'll use an example to illustrate how pervasive the benefits of measurement tools can be: NIST Standard Reference Materials (SRMs) for measuring the sulfur content of fossil fuels. In addition to aiding enforcement of air quality regulations, these 29 different types of reference materials were designed help industry achieve demonstrable, cost-efficient compliance with tightening environmental requirements.

NIST's sulfur-related SRMs have provided support for an entire supply chain, from instrument manufacturers and testing laboratories to coal processors and petroleum refiners to electric utilities and other major users of fossil fuels. These organizations use the references to design and calibrate pollution monitoring and control equipment.

A study conducted for NIST estimated that, altogether, these industries reaped benefits totaling about $440 million (2002 dollars), thanks to more efficient equipment calibration and monitoring. The estimate does not include sizable environmental and health benefits attributable to reduced sulfur emissions, which were made possible by improved measurement accuracy.

Since NIST maintains a diverse portfolio of almost 1,300 SRMs, this example begs a question. What is the total benefit U.S. industry realizes from the entire collection of measurement references?

A back-of-the-envelope calculation provides a very rough estimate. Extrapolating the average benefit attributable to one sulfur SRM to the entire portfolio suggests industry benefits in the neighborhood of $20 billion.

In summary, the accumulating body of retrospective impact studies provides convincing qualitative and quantitative evidence of the important economic contributions of metrology. Not only that, the results imply significant *under funding* of metrology infrastructure research.

Another way to assess the impact of measurement capabilities is to reverse the perspective; that is, to estimate the costs due to unmet industry needs for metrology tools or other infratechnologies. That is what we do in our prospective studies, which we use in our strategic planning.

A few years ago, for example, we assessed economic costs attributable to inadequate software testing, a relatively new area of measurement need. In fact, the results suggest that effective responses to this need would pay tremendous dividends.

According to the study, U.S. software suppliers and their customers spend an estimated $60 billion a year to identify and remove software program "bugs" in excess of what an efficient software testing infrastructure would cost. Moreover, this estimate does not include the cost of lost business and other end user costs that are the consequences of relying on problematic software.

Software testing is a measurement activity that merits investment to build the missing industry-supporting infrastructure. For software, activities such as developing conformance testing code can be more time consuming and expensive than developing the product that will be tested. The solution is to automate the generation of this code and provide associated standards to facilitate widespread use.

So, who is going to take on this important job?

Because of the lack of standardized test data, metrics, and automated test suites, performance testing programs for software are too expensive to develop and maintain for smaller software companies. Hardware platform developers only conduct performance testing for the more popular or largest software systems. Often, small, new or less widely used systems undergo no pre-market testing at all.

So, again, the infrastructural nature of software testing inhibits adequate investment and undermines domestic software companies' competitive positions in global markets. Moreover, because of the broad dependence on software, virtually all sectors of society and industry are paying a hefty price for this deficiency in test and measurement support.

The fear, of course, is that costs due to unmet measurement needs will grow as technology increases in sophistication and complexity. Many nations aim to drive future economic growth through innovation and global competitiveness in markets for high-technology products and services. To succeed, these nations must fully reckon with measurement intensiveness of high technology.
Consider the U.S. semiconductor industry.

On the basis of a NIST study conducted in 1998, we estimate that the U.S. semiconductor industry will spend about $7.6 billion on measurement this year – not including labor and overhead. That's approximately 18-20 percent of this year's projected revenue for North America.

Extrapolating from the semiconductor industry to all of the nation's high-tech industries, expenditures on measurement by the entire U.S. high-tech cluster would be about $70 billion.

Can the private sector, by itself, keep up with escalating measurement demands wrought by technological progress?

That's not likely. In the view of the Semiconductor Industry Association, for example, "One of the biggest barriers to continued miniaturization of semiconductor circuits is the inability to measure many of the critical dimensions at the desired feature size."

"Consequently," the association concludes, "additional research in metrology at the National Institute of Standards and Technology is critical to future chip development."

That's another type of evidence – customer assertions of the need for and value of measurement support in accomplishing technology goals tied to future economic growth.

In general, advanced measurement capabilities are intrinsic to advances in technology, across the board. Now, factor in the increasing complexity and interdependency of modern technology.

Each element of a technology has demanding performance requirements that require an elaborate measurement infrastructure. Moreover, virtually every technology today is a system of individual technologies. This means that system-level performance is an increasingly important attribute that affects corporate strategies and performance. System performance requires a whole new layer of measurement infrastructure to support specific performance attribute assessments and the effectiveness of interoperability protocols or standards.

Global supply chains are a case in point. Expenditures on supply chain integration software now account for about one-third of the average company's IT budget. Unfortunately, the level of integration achieved rarely qualifies as "seamless."

A recent NIST-commissioned study estimated the costs of inadequate interoperability for the exchange of business information in two major manufacturing supply chains: automotive and electronics.

For the U.S. automotive industry, total estimated costs exceeded $5 billion per year, or about 1.25 percent of the total value of shipments. Estimated costs incurred by the U.S. electronics sector were nearly $4 billion per year, or, again, almost 1.25 percent of the value of shipments.

These costs translate into significant losses for manufacturing firms, including their shareholders. Consumers also are penalized, since interoperability costs are embedded in the price of finished goods. Again, inadequate test and measurement elements in the technology infrastructure impede economic and productivity growth.

Today, achieving productivity gains is a systems problem, a multiple market problem, and a national infrastructure problem. We must be concerned with the productivity of research, the productivity of manufacturing processes, and the productivity of the market transaction. *Each of these activities is measurement-intensive.*

And, so is economic development, overall. By definition, economic development is driven by *technological* and *social* progress. Metrology contributes to both types of progress.

In this context, technological progress encompasses more than high-technology products and services. To be sure, the number of nations competing for shares of these markets is growing. The list of able competitors will continue to grow, and no nation is guaranteed a spot among the leaders. Expanding competition of this type will benefit the entire world.

Today, however, many developing countries, which are home to 80 percent of the world's population, still face the challenge of assembling resources and building the capabilities necessary to compete at the global level.

For aspiring economies, the job of constructing a capable measurement infrastructure is tremendously important. The value-added realized from metrology investments in these nations are likely to be significantly greater than in advanced economies. A robust metrology infrastructure commensurate with a nation's goals for development and economic growth is a necessity, not a luxury.

The list of benefits to be reaped is lengthy. As its measurement system strengthens, a nation improves its performance in diffusing acquired technologies and, ultimately, in inventing and applying new ones. Returns on public and private research and development also increase, the result of the leveraging effects of domestic metrology contributions. Likewise, prospects for increased trade grow in step, as it becomes easier to demonstrate measurement traceability and regulatory compliance. And because measurements and test methods are key elements of most standards, a nation strengthens its own standards system and also can participate more effectively at the international level.

Internally, a nation can utilize its measurement capabilities to improve the efficiency and transparency of processes for making and enforcing regulations and for demonstrating compliance. Similarly, domestic measurement organizations can be used to evaluate technical risks and to promote social consensus on the appropriate use of particular technologies. Genetically modified organisms, baseline assessments for tracking global climate change, and homeland security come to mind.

As I said before, what gets measured, gets done. And at every tier of social or economic organization – company, industry, government – there's a lot to be done. In areas ranging from domestic security to sustainable development to nanotechnology, new challenges and opportunities continually emerge. At the same time, long-established goals, such as combating infectious diseases or removing impediments to free trade, have not diminished in importance.

This means that the strategic, economic, and social value of a robust metrology infrastructure will only increase over the coming decades. For National Metrology Institutes and their stakeholders, the scale, diversity, and complexity of the tasks ahead likely will increase faster than available resources.

Devising effective responses to measurement needs that run the gamut from forensics to fuel cells and far, far beyond cannot be done piecemeal fashion or in geographic isolation.

Today, most technologies, imperatives, and needs span the globe. The metrology community must respond in kind – that is, collaboratively. We all need a common infrastructure of supporting tools—measurements, standards, and instruments, for example. And *nobody*—no company, no nation, and no region—has a monopoly on the many brands of knowledge or the many specialized capabilities that will be required to realize the commercial and social opportunities stemming from research progress.

In many ways, our countries, our organizations, and our professional specialties need one another. Progress in metrology and in the broader realm of technology is now the product of an interactive process – the success of one depends on the success of others.

So to CENAM, on the occasion of its 10th anniversary, and to all the other organizations represented here, I wish much success in meeting the challenges and opportunities that lie ahead.

Thank you.