Economic Impact of NMI Metrology Programs

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Chief Scientist (Retired), NIST

Symposium Celebrating 10th Anniversary
of the CIPM MRA
October 8-9, 2009
To promote U.S. innovation and industrial competitiveness by advancing

*measurement science, standards, and technology*

in ways that enhance economic security and improve our quality of life
Driving Forces for Improved Metrology

... Have evolved over the years

- domestic commerce
- international trade
- global competitiveness
- quality of life
  personal and global

all have economic implications!

How do we evaluate them on a quantitative basis?
Consumers Count on Standards for Equity in Trade
Early measures based on natural objects

- Royal Egyptian cubit, based on the size of the Pharaoh’s forearm and hand.
- Chinese length standards based on the resonance tone of ‘standard’ bamboo whistles.
- Carob seeds, used to derive the carat.
Weights and Measures: Bringing Equity to the Marketplace

From laboratory, primary fluid-flow and volume standards

To assisting the States in their Weights and Measures regulation

- Responsible for coordination with Standards Development Organizations, such as the American Petroleum Institute (API) and the American Society of Mechanical Engineers (ASME), and the National Conference on Weights and Measures (NCWM)

- US imports 5 B barrels of oil each year; measurement uncertainty of 0.1% would translate to about $350 M per year.
Measurements and Standards Help Reduce Healthcare Costs

Healthcare costs amount to ~ 16% of the GDP, an estimated $1.8 trillion

Prevention

Folic Acid Binding Protein

Treatment/Therapy

CSTL Maintains and Refines Definitive Methods for 12 Health Status Markers

<table>
<thead>
<tr>
<th>Marker</th>
<th>Condition</th>
</tr>
</thead>
<tbody>
<tr>
<td>Calcium</td>
<td>Cancer, Blood Clotting</td>
</tr>
<tr>
<td>Chloride</td>
<td>Kidney Function</td>
</tr>
<tr>
<td>Cholesterol</td>
<td>Heart Disease</td>
</tr>
<tr>
<td>Creatinine</td>
<td>Kidney Function</td>
</tr>
<tr>
<td>Glucose</td>
<td>Diabetes</td>
</tr>
<tr>
<td>Lithium</td>
<td>Antipsychotic Treatment</td>
</tr>
<tr>
<td>Magnesium</td>
<td>Heart Disease</td>
</tr>
<tr>
<td>Potassium</td>
<td>Electrolyte Balance</td>
</tr>
<tr>
<td>Sodium</td>
<td>Electrolyte Balance</td>
</tr>
<tr>
<td>Triglycerides</td>
<td>Heart Disease</td>
</tr>
<tr>
<td>Urea</td>
<td>Kidney Function</td>
</tr>
<tr>
<td>Uric Acid</td>
<td>Gout</td>
</tr>
</tbody>
</table>

Nutrition
**Title:** SRMs for Cholesterol Measurements

**Products:** NIST SRMs 911, 909, 1951,1952

**Users Impacted:**
- Instrument and reagent manufacturers
- Network laboratories
- Clinical labs and hospitals

**Results:**
- Social Rate of Return 154%
- Benefit to Cost Ratio 4.5:1
- Net Present Value $3.5M

*Data from GAO and CAP*
Health Care Measurements and EU IVD Directive

Assuring Market Access

Directive went into effect in December 2003

Worldwide in vitro diagnostic device market is ~$20B; >60% of European market is supplied by U.S.

IVD Calibrators and/or control materials must: be traceable to “standards of a higher order”; have traceability and uncertainty statements

US IVD Manufacturers sought NIST help to meet the traceability requirements

NIST response: led industry driven workshops (2000, 2002, 2003), and leadership in the JCTLM

...and in the International Community

- Leading the effort to establish higher order reference methods and standards under JCTLM, recognized by BIPM, WHO, ILAC and IFCC
  - List I: approximately 100 Reference Methods for 58 markers (30 from NIST), and approximately 150 entries for 96 measurands (72 from NIST)
- Webbased information widely accessible through NIST and BIPM
That global body, consisting of two task oriented Working Groups was established in Paris on 12 June 2002

- **WG1 - Reference Materials and Reference Methods**
- **WG2 - Reference Measurement Services**

A Declaration of Cooperation was established between the International Committee of Weights and Measures (CIPM), the International Federation for Clinical Chemistry and Laboratory Medicine (IFCC), and the International Laboratory Accreditation Cooperation (ILAC)
Effective mitigation of greenhouse gas-induced global warming will require precise and comparable measurements to:

- Determine accurate emissions levels and baselines
- Monitor GHG levels over sources and sinks
- Assess impact of mitigation strategies

This will require:

- Point emission source monitoring and standards
- Remote monitoring and standards
- Accreditation of private and state laboratory networks
- International comparability of GHG emission measurements

**Huge Economic Implications!**
Gas Mixture NIST Traceable Reference Material (NTRM) Program

Potential Model for underpinning a cap-and-trade program

History and Drivers

• 1990 Amendment to Clean Air Act required significant increase in pollution monitoring
• Market for standards for compliance with EPA air quality regulations too large for demand to be met directly with the NIST Gas SRM program
• Acid Rain Emissions Trading program required robust traceability to provide comparability

NIST Response

• Established NTRM program in 1992
  – Commercially produced
  – Market driven
  – Well-defined traceability linkage to NIST primary standards
• NIST works directly with commercial Specialty Gas Companies (SGCs) for dissemination

“... the NTRM program has served as an excellent vehicle for production of the high quality standards - of known pedigree - required by both industry and the regulatory community in the implementation of Title IV (SO2 emissions trading) of the 1990 Clean Air Act.”

Stephen Miller, Technical Director
Scott Specialty Gases
Title: The Economic Impact of the Gas-Mixture NTRM Program

Products: Gas-Mixture NTRMs

Users Impacted:
- Specialty Gas Companies
- End Users: Electric Utilities, Transportation Equipment Firms, Petrochemical Firms, Commercial Labs, Government Agencies

Results:
- Social Rate of Return: 225%
- Benefit to Cost Ratio: 24:1
- Net Present Value: $56M

Since 1992, 8624 NTRM cylinders have been produced by 15 SGCs, resulting in the production of 500,000 EPA Protocol Gas Standards, valued at $140,000,000

CSTL works directly with commercial Specialty Gas Companies (SGCs)
- AGA
- Air Liquide
- Air Products
- Airgas
- BOC Gases
- MG Industries
- Praxair
- Matheson TriGas
- Scott Specialty Gas
- Spectra Gases
Sulfur in Fossil Fuel SRMs

An Economic Impact Study

**improved production efficiency... improved environment... improved health**

**Industries Impacted:**
- Transportation: Diesel, Gasoline
- Energy: Coal
- Steel: Coke

Certification of NIST SRMs for sulfur in fossil fuels uses a definitive method, developed at NIST, that virtually eliminates bias and significantly reduces the measurement uncertainty ... which translates to improved production efficiency.

**Benefit-Cost Ratio:** 113
**Social Rate of Return:** 1,056%
**Net Present Value:** $409M
Measurements and Standards Needed for Climate Change Assessment

Critical measurement uncertainties limit ability to model global climate change

Greenhouse Gas Measurements & Standards For Cap-and-Trade
Ozone Concentration Standards
Reflectance Standards
NMI Support for Global Monitoring Program

- World Meteorological Organization (WMO)
- International Committee for Weights and Measures (CIPM)
- International Bureau of Weights and Measures (BIPM)
- National Institute of Standards and Technology (NIST)
- National Oceanic and Atmospheric Administration

The GAW gets traceability via linkages to NMI Community
Surface Ozone Monitoring

BIPM-NIST program to maintain the comparability of the worldwide network of ozone reference standards.

World Meteorological Organization
Global Atmospheric Watch Global Network
Alternative Refrigerants Research Program

An Economic Impact Study

Problem

• CFC and HCFC refrigerants deplete stratospheric ozone and contribute to global warming

NIST was in a unique position to aid transition to CFC replacements

NIST SRD 23 REFPROP database

• Constructed with expt’l data as foundation
• Models the behavior of refrigerant mixture
• Effective form of information dissemination
  • Key to developing CFC replacements
• Facilitated the development of new products that are energy efficient, environmentally safe, timely, and economical

Internationally Adopted

• IEA Annex 18 – Int’l Standard Equations of State
  • ISO Standard 86
• Distributed through ARI, IIR, ASHRAE, etc.

CFCs and HCFCs

Used as refrigerants, solvents, foam-blowing agents ($28B/year)
Used in manufacturing processes ($350B worth of installed equipment)

Economic Impact Study: Published January 1998
Comments: Scope of study included manufacturers and users
Internal Rate of Return: 433%
Policy Drivers & Incentives Supporting Biofuels

Energy
- Energy Security/Political Tensions
- Resource Diversification
- Petroleum Prices/Volatility

Environment
- Climate Change
- Air Pollution

Agriculture
- Economic Development
- Farm Income

Biofuels
- Ethanol is currently the most prevalent US biofuel

Examples of Policies

United States
- State tax credits, blend requirements...

Europe
- Tax credits: most common incentive
- EU set target for biofuels consumption (similar to RFS, but not a mandate)

Asia
- China, India, and Malaysia introducing policies to support biofuels
- Japan has tax credits in place

South America
- Brazil: Ethanol blending requirements in place and a requirement for biodiesel starting in 2008

Biofuels require a comprehensive & effective policy framework

Source: Navigant
Measurements and Standards for Biofuels

- Brazil-US Ministerial Meeting – June 2006
- INMETRO-NIST Workshop – Sept. 2006
- EU Conference on Biofuels – Feb. 2007
- IBF Established – 2007
- International Biofuels Symposium – June 2007
- Tripartite WGs Formed – 2007
- White Papers on Ethanol and Biodiesel -2008
- INMETRO-NIST, NIST-IRMM Agreements – 2008
- International Conf. on Biofuels – March 2009
Planned Supportive Activities of the Governments through their National Metrology Institutes

NIST (U.S.), and INMETRO (Brazil) have established plans for cooperative development of

Certified Reference Materials:

- Anhydrous and Hydrated bioethanol
- Soy and Animal-based biodiesel

- for calibrating measurement instruments to a known and internationally accepted reference
- for validating the accuracy of measurement results and measurement platforms, space and time.

Reference Measurement Methods:

- Chemical pattern recognition to identify feedstock source of biodiesel (e.g. soy, rapeseed, animal fat)
- Isotope metrology to distinguish between renewable/nonrenewable fuels
Advanced Isotope Ratio Measurements to Establish Source-type of Ethanol

- Petroleum-derived ethanol is chemically identical to bio-ethanol
- Measurement strategy needed to distinguish non-renewable sources from renewable sources for:
  - Establishment of appropriate tax credits
  - Metrics to support assessment of achieving national/international fuel composition targets
  - Verification of meeting customer criteria as to source of ethanol,
  - Etc.
- **Carbon-14 and carbon-13 measurements provide a means to authenticate ethanol source**

<table>
<thead>
<tr>
<th></th>
<th>non-renewable</th>
<th>renewable</th>
</tr>
</thead>
<tbody>
<tr>
<td>C 14/12</td>
<td>$10^{-12}$</td>
<td>$10^{-15}$</td>
</tr>
<tr>
<td>C 13/12</td>
<td>0.0111</td>
<td>0.0109</td>
</tr>
</tbody>
</table>
Metrology Supports Industrial Competitiveness

- Aerospace & Transportation
- Biotechnology
- Semiconductors
- Energy
- Chemical Processing
- Health and Food
The NIST/EPA/NIH Mass Spectral Library
Reference Standard Mass Spectra for Chemical Identification

Fragments of charged molecules provide reproducible, discriminating fingerprints for small molecules in complex mixtures in:

- Environmental Analysis
- Health Research
- Homeland Security
- Drug Testing
- Chemical Processing
- Food Analysis

Content
- NIST Evaluated spectra for 163,198 compounds
  - QA/QC by documented computer-assisted evaluation
  - Verified, implemented spectrum matching methods
  - Other relevant data: structure, retention, ...

Usage
- Installed on >4000 instruments per year
  - World’s most widely used MS library
- Integrated into instruments by distributors
- Common element in GC/MS ‘gold standard’ identifications

Extensions
- Large molecule ‘MS/MS’
  - proteomics, metabolomics, glycomics, …
**Primary Method for Sulfur Determination**
**Finds Wide Range of Applications**

**Sulfur in Fossil Fuels**
- Kerosenes
- Fuel Oil
- Coal
- Lubricating Base Oil
- Fly Ash
- Gasoline
- Coke

**Sulfur in Aerospace Superalloys**
- High temperature turbine is the most critical component of jet turbine
- Industry requires sulfur measurements at 1 µg/g and below in Ni-based alloys
- Adherence of protective oxide coating is enhanced by reducing sulfur below 0.5 µg/g
Microelectronics

Surface Characterization

Value of Semiconductor Shipments Nearly $200B

Data for Process Modeling

Standards for Process Control

Thermophysical Properties

Plasmas

Humidity

SRM 2134, Arsenic in Silicon
Ion-Implanted Dopants in Silicon

New SRMs Improve Quality Control in Silicon Wafer Production

- SIMS is the primary tool used in process control in the semiconductor industry
- Ion-implanted reference materials are used routinely for SIMS calibration

**ITRS** specifies in-line dopant profile concentration precision requirements ... to 2% in 2008, ... with “low systematic error”.

- Newly released **SRM 2134**, As in Si, has a rigorously evaluated expanded uncertainty of 0.38%

- Certified Reference Materials with low systematic error are required for ISO compliance, international and inter-site comparability, and comparing experimental results with simulation models.
  - The use of **SRM 2137**, B in Si, is incorporated into ISO documents 14237 and 17560

**SEMATECH** ... identified P, As, and B were identified as having highest priority.

**SRM 2137** B-10 implant in Si (released 8/93)
**SRM 2134** As implant in Si (released 8/00)
**SRM 2133** P implant in Si (scheduled release 9/02)

**Calibration of Phosphorus Implantation Dose in Silicon by RNAA**
Nanomanufacturing

Nano Gauge Blocks
Using the interferometer-guided probe of the Molecular Measuring Machine, accurate calibration patterns can be produced.

Force Metrology for Nanoscale Measurements and Standards
Nanonewton range -- Force 1 billion times smaller than the force required to hold an apple against Earth’s gravity.

Nano-Manipulation of nanowires with "optical tweezers." A highly focused laser beam attracts microscopic objects and can be used to pick up and precisely position nano-components for building semiconductor circuits or biosensors smaller than a red blood cell.
NIST’s Pivotal Role in U.S. Economy

Productivity

Competitiveness

Industry

Technology

NIST

Standards

Metrology

R & D

Innovation

Commerce

OUTCOMES

CUSTOMERS

OUTPUTS

Market Access

Quality of Life

Productivity

NIST
Results of the 5 year (2 phase) study were published in two reports:

- “Measure for Measure: Chemical R&D Powers the U.S. Innovation Engine” - 2005

The Council for Chemical Research
Macroeconomic Implications

- $1 B Federal R&D Funding in Chemical Sciences
- $5 B Chemical Industry R&D Funding
- $10 B Chemical Industry Operating Income* 
- $8 B Taxes**
- $40 B GNP**
- 0.6 M Jobs**

Basis:
*estimated from CCR study
**extrapolated from LANL study by Thayer et al., April 2005 using REMI economic model

The Council for Chemical Research
CCR Studies - Overall Conclusions

- Chemical companies get $2 of operating income for every $1 of R&D invested; that’s a 17% after tax return
- Chemical technology is highly dependent on publicly funded chemical science research
- U.S. economy gains roughly $40 dollars in GDP growth and $8 in increased tax revenues for every dollar of federal investment in chemical sciences research
- Technology quality, innovation speed and strong scientific links deliver greater shareholder value
- All industries are significantly impacted by the chemical sciences. It is the most enabling science and technology
- The big opportunity is to reduce the 20-year innovation time lag from initial public research funding to commercialization
## NIST Formal Impact Studies

<table>
<thead>
<tr>
<th>Industry</th>
<th>Project</th>
<th>SRR</th>
<th>BCR</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Semiconductors</strong></td>
<td>Resistivity</td>
<td>181%</td>
<td>37</td>
</tr>
<tr>
<td></td>
<td>Thermal conductivity</td>
<td>63%</td>
<td>5</td>
</tr>
<tr>
<td></td>
<td>Wire Bonding</td>
<td>140%</td>
<td>12</td>
</tr>
<tr>
<td></td>
<td>Electromigration</td>
<td>117%</td>
<td>12</td>
</tr>
<tr>
<td></td>
<td>Software for design automation</td>
<td>76%</td>
<td>23</td>
</tr>
<tr>
<td><strong>Communications</strong></td>
<td>Electromagnetic interference</td>
<td>266%</td>
<td></td>
</tr>
<tr>
<td></td>
<td>ISDN</td>
<td>156%</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Data encryption standards</td>
<td>267-272%</td>
<td>58-145</td>
</tr>
<tr>
<td></td>
<td>Role-based access control, security</td>
<td>44%</td>
<td>109</td>
</tr>
<tr>
<td><strong>Automation</strong></td>
<td>Real-time control systems</td>
<td>149%</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Machine tool software error compensation</td>
<td>99%</td>
<td>118</td>
</tr>
<tr>
<td><strong>Manufacturing</strong></td>
<td>Standards for product data exchange</td>
<td>32%</td>
<td>21</td>
</tr>
<tr>
<td><strong>Photonics</strong></td>
<td>Optical fiber</td>
<td>423%</td>
<td></td>
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<tr>
<td></td>
<td>Spectral irradiance</td>
<td>145%</td>
<td>13</td>
</tr>
<tr>
<td></td>
<td>Optical detection calibration</td>
<td>72%</td>
<td>3</td>
</tr>
<tr>
<td></td>
<td>Laser &amp; fiberoptic power calibrations</td>
<td>43-136%</td>
<td>3-11</td>
</tr>
</tbody>
</table>

- lower transaction costs  
- lower compliance costs  
- energy conservation  
- increase R&D efficiency  
- increase product quality  
- enable new markets
<table>
<thead>
<tr>
<th>Industry</th>
<th>Project</th>
<th>SRR</th>
<th>BCR</th>
</tr>
</thead>
<tbody>
<tr>
<td>Energy</td>
<td>Electric meter calibration</td>
<td>117%</td>
<td>12</td>
</tr>
<tr>
<td></td>
<td>Software conformance</td>
<td>41%</td>
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<tr>
<td>Electronics</td>
<td>Josephson voltage standard</td>
<td>87%</td>
<td>5</td>
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<tr>
<td>Materials</td>
<td>Thermocouple calibration</td>
<td>32%</td>
<td>3</td>
</tr>
<tr>
<td></td>
<td>Phase equilibria for advanced ceramics</td>
<td>33%</td>
<td>10</td>
</tr>
<tr>
<td>Pharmaceuticals</td>
<td>Radiopharmaceuticals</td>
<td>138%</td>
<td>97</td>
</tr>
<tr>
<td></td>
<td>Cholesterol</td>
<td>154%</td>
<td>4.5</td>
</tr>
<tr>
<td>Chemicals</td>
<td>Alternative refrigerants</td>
<td>433%</td>
<td>4</td>
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<tr>
<td></td>
<td>Sulfur in fossil fuel</td>
<td>1,056%</td>
<td>113</td>
</tr>
<tr>
<td></td>
<td>Gas Mixture NTRMs</td>
<td>225%</td>
<td>24</td>
</tr>
<tr>
<td>Construction</td>
<td>Building codes</td>
<td>57%</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Roofing shingles</td>
<td>90%</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Fire safety evaluation systems</td>
<td>35%</td>
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http://www.nist.gov/director/planning/impact_assessment.htm
Summary

- Historically, metrology has provided the foundation for domestic trade
- Globalization of trade has put increasing emphasis on measurements and their mutual recognition
- Economic impact of metrology is demonstrated .... and will continue to be demonstrated
- Improved measurement capabilities will be needed to enable innovation in the 21st century and meet global challenges