Climate Change and Renewable Energy
A Perspective from a Measurements Viewpoint

Regional Workshop on
Metrology and Technology Challenges of
Climate Change and Renewable Energy

Bogota, Columbia

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National Institute of Standards and Technology

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U.S. Department of Commerce

Agenda

Greenhouse Gas Impacts Earth's Climate

- Atmospheric Trace Gases & Earth's Greenhouse
- Greenhouse Gas Mitigation – International Aspects
- U.S. Greenhouse Gas Emissions Data and Reporting
- NIST Program Efforts

Renewable Energy and Energy Efficiency

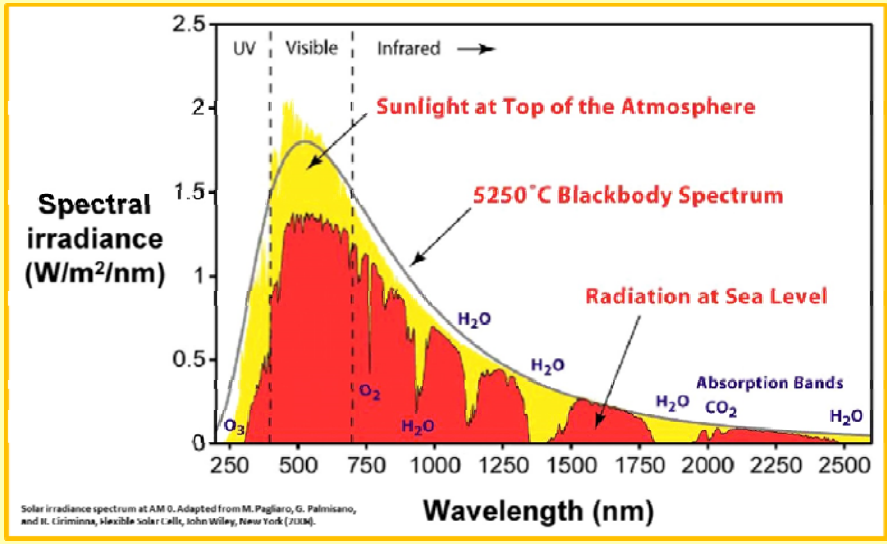
- Photovoltaic Performance Assessment
- Building Energy Efficiency Research and Standards

Earth's Greenhouse

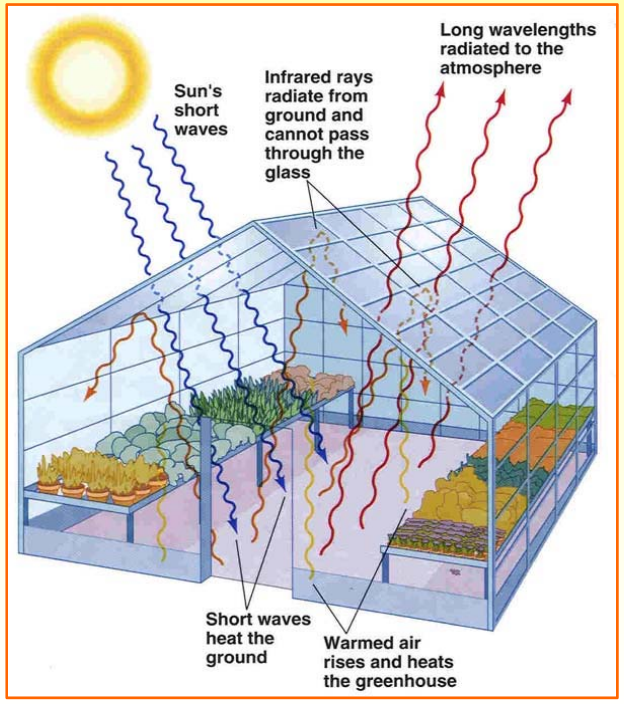
Powered Both by Solar & Terrestrial Radiation

Earth's Surfaces Emit Radiation

- Earth's surface absorbs & converts shortwave radiation, visible and near ultraviolet, to longer wave radiation in the infrared
- Thermal, or Blackbody, radiation intensity depends on surface temperatures
- ~9.7 μm radiation emitted at ~295 K (~23 °C) surface temperature



Earth's Greenhouse



Selective Absorption Warms Atmospheric Gases

- Earth's surface acts as a radiation source, emitting thermal radiation in the infrared spectral region
- Molecular gases, CO_2, CH_4, N_2O, & H_2O strongly absorb thermal radiation over the ~ 2 – 30 μm range,
- Relatively small concentrations of these gases have large effects because their absorption of thermal radiation is much larger than nitrogen and oxygen (~99% of the atmosphere)
- Molecular collisions quickly transfers absorbed thermal energy to N_2 & O_2
- Radiate back to the surface

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Impacts of Greenhouse Gases on the Earth

- **The Impact on Earth's Climate of its Greenhouse**
  - **Without this effect, the average temperature of Earth's surface could be -20° C or below and life as we know it would not exist**
  - **Operates in a relatively delicate balance between incoming solar radiation and the thermal radiation either escaping to space or absorbed by the atmosphere**
- **The International Panel on Climate Change (IPCC) has developed significant scientific information on our climate and asserts that man made greenhouse gas emissions are beginning to significantly alter this energy balance**
- **Concerns about climate changes that adversely impact Earth's population place increased emphasis on greenhouse gases produced by human activities.**
- **A range of measurements and standards challenges result**

International Climate Policy Drivers

Focus on Greenhouse Gas Mitigation Issues

The Bali Action Plan, Section 1:

UNFCCC Convention of the Parties #13, 2007

- **Recognizing that deep cuts in global emissions will be required …,**
- **Decides to launch a comprehensive process to enable the full, effective and sustained implementation of the Convention … to reach an agreed outcome and adopt a decision at its fifteenth session, by addressing, inter alia:**
  - **A shared vision for long-term cooperative action, including a long-term global goal for emission reductions, … ;**
  - **Enhanced national/international action on mitigation of climate change, including, … of:**

    a) ***Measurable, Reportable and Verifiable (MRV) Nationally Appropriate Mitigation Commitments Or Actions (NAMAs)***, **including quantified emission limitation and reduction objectives, by all developed country Parties, while ensuring the comparability of efforts among them, taking into account differences in their national circumstances;**

    b) **Nationally appropriate mitigation actions by developing country Parties in the context of sustainable development, supported and enabled by technology, financing and capacity-building, in a measurable, reportable and verifiable manner;**

    c) **…**

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International Climate Policy Drivers

Focus on Greenhouse Gas Mitigation Issues

International Greenhouse Gas Mitigation Efforts based central concepts and practices is strongly aligned with the missions of National Metrology Institutes and of the International NMI Community.

- **Consistency, Transparency, Accuracy and Comparability of GHG inventories.**
- **The Capability to Measure, Report, and Verify GHG Inventories will be keystones for their recognition internationally.**
- **Concepts in UNFCCC's Bali Action Plan, & its likely antecedents, are based on proven scientific principles fundamental to NMI standards operations – Independent Validation of Observed Values**

MRV Issues & Linkages

- **MRV – Measureable, Reportable, and Verifiable GHG inventory data**
- **A fundamental *mitigation effectiveness metric***
- **MRV concepts are:**
  - **Pervasive in climate mitigation**
  - **Closely linked to renewable energy and energy security concepts**
  - **Applied to technology, finance, and capacity building concepts**
  - **Directly linked to Sustainability concepts**
  - **Verifiable methodologies should be independent of sources for scientific stringency**

Greenhouse Gas Emissions and Climate Communities

A Range of Interests, Needs, Capabilities, & Practices

Emissions Reporting Community ⟷ **Climate Science Community**

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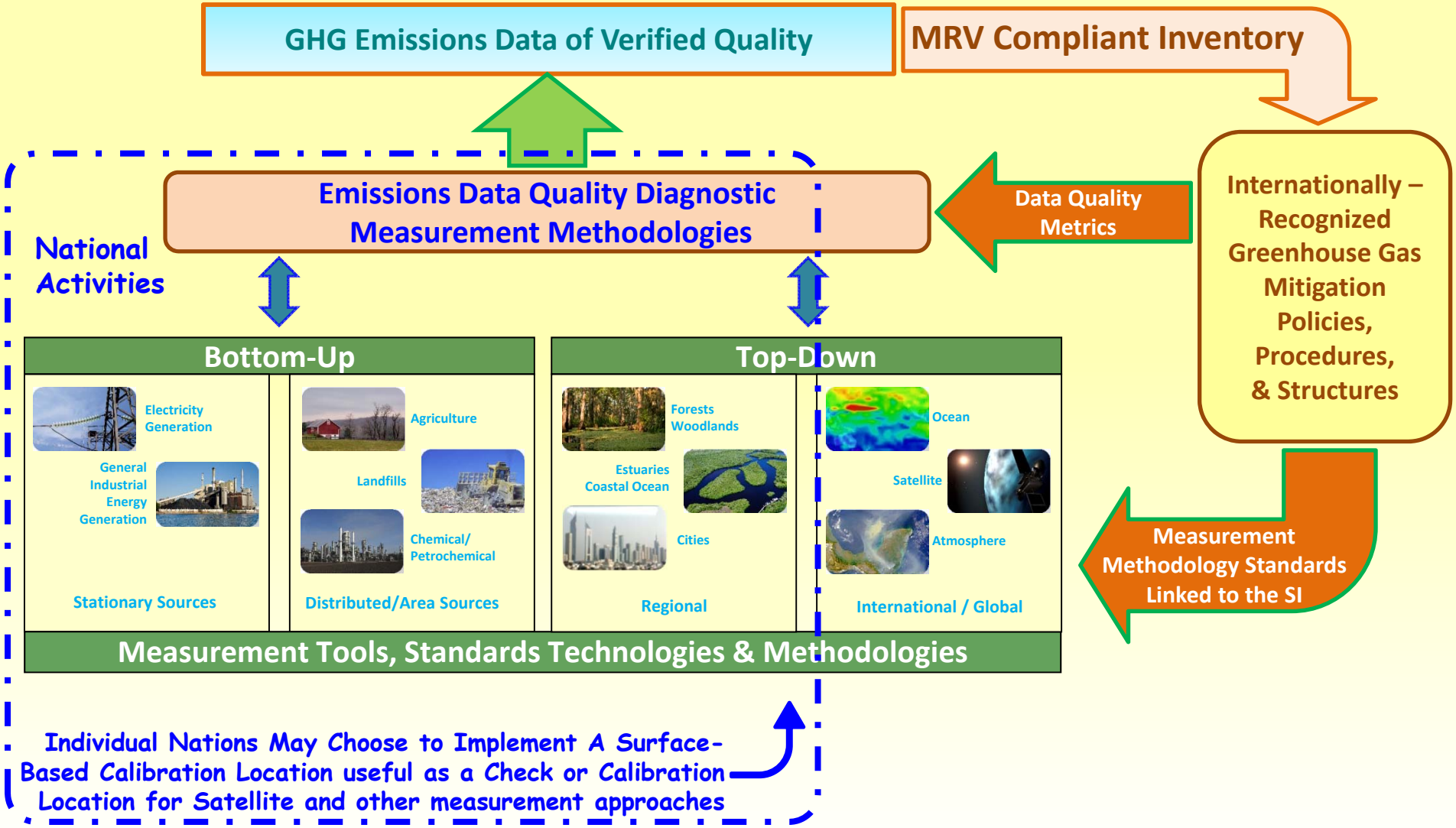
A Notional Measurement Systems Concept for Mitigation

Enhancing Consistency, Transparency, Comparability, and Accuracy



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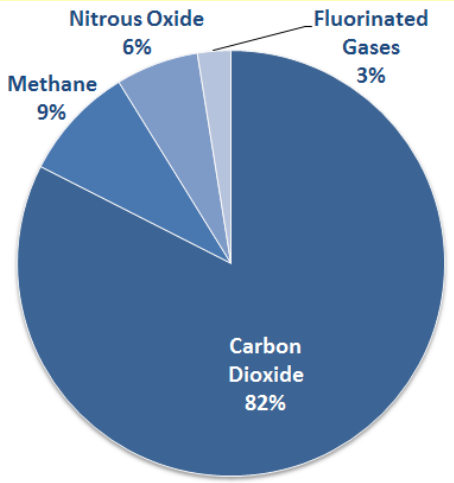
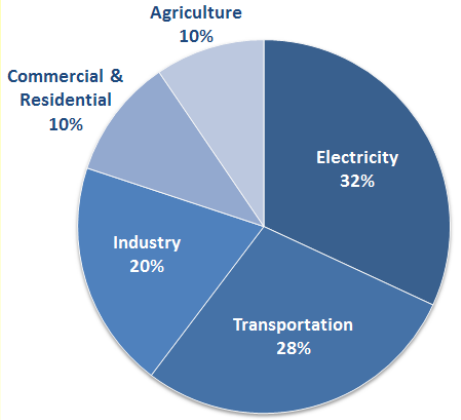
U.S. Greenhouse Gas Emissions Reporting

- **U.S. Environmental Protection Agency develops an annual report, the Inventory of U.S. Greenhouse Gas Emissions and Sinks (Inventory).**
  - **Tracks total annual U.S. emissions and uptake by source, economic sector, and greenhouse gas going back to 1990.**
  - **National energy, agricultural activities, and other data and statistics to provide a comprehensive accounting of total greenhouse gas emissions and uptake for man-made greenhouse gases in the US.**
- **Greenhouse Gas Reporting Program:**
  - **Collects greenhouse gas emissions data from individual facilities and suppliers of certain fossil fuels and industrial gases.**
- **U.S. EPA submits this report yearly to the UN in accordance with the UN Framework Convention on Climate Change (UNFCCC)**

U.S. Greenhouse Gas Emissions in 2012



Emissions by Economic Sector



Total Emissions in 2012
6,526 Million Metric Tons of CO_2 equivalent

http://www.epa.gov/climatechange/ghgemissions/usinventoryreport.html

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Greenhouse Gas Emissions Reporting Methodology

The Emission – Activity Factor Model

$$GHG\ Mass\ Emitted/Absorbed = EF * AF$$

EF – Emission Factor (GHG mass/unit activity)
AF – Activity Factor – amount of activity
(miles traveled – transportation systems)
(miles of pipeline – natural gas trans. & distribution)
(hectares or acres – land surface, agricultural or forest)

- **Primary conceptual method for computation of the mass of greenhouse gas either absorbed or emitted to the atmosphere from a process or an entity.**
- **Emission Factor contains the quantity of GHG of interest**
  - **Units: tons/megawatt, tons/mile traveled, tons/mile of pipeline, tons/hectare**
  - **Applicable to both emission and uptake**
  - **CO_2 uptake – a natural process, almost always a biogenic process such as the growth of forests**
- **Activity Factor counts the number engaged in the process of interest**
  - **Megawatts, miles travelled or of pipeline, area**

Greenhouse Gas Emissions Reporting Methodology

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(hectares or acres – land surface, agricultural or forest)

- **Strength : A simple concept easily applied**
  - Simplicity can also raise issues in it's application to specific situations
- **A Potential Deficiency**
  - Based on data derived from emission source characteristics
  - Can accurately characterize processes where the emission/uptake mechanism is well-understood – *Emission Factor is stable in time*
  - May require periodic revision in cases where:
    - the emission process has changed, for example, where technological changes have changed the nature of the process
    - New measurement capabilities have improved accuracy
- **Incorporated into the UNFCCC national GHG reporting methodology**
- **Bottom-up emissions data for inventory reporting**

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Inventories and Reduction Targets

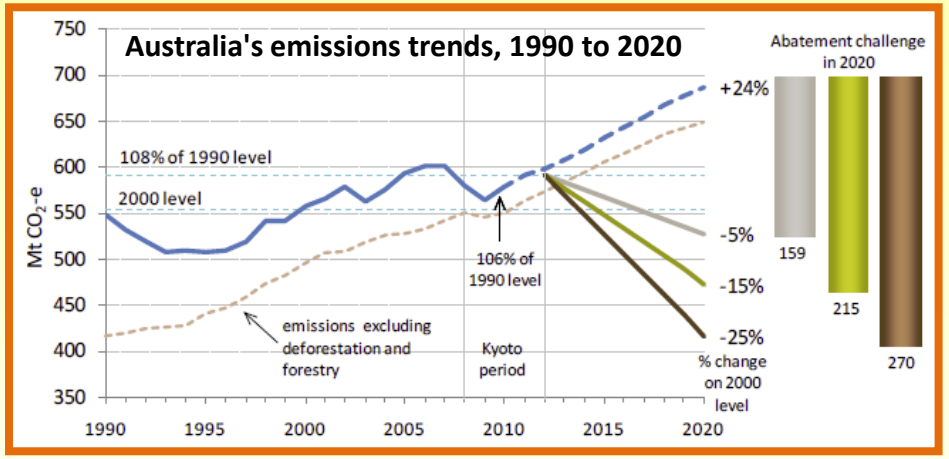
What Accuracy is Needed to Support Policies

Greenhouse Gas Emission Inventories

- The performance metrics for national and international reduction activities and the performance gauge of future policy effectiveness
- Reliable quantification is fundamental to reduction *target achievement and progress monitoring* and foundational to equity in trade and/or fairness in regulation
- Advances in a range of measurement capabilities are needed to *assess progress toward and attainment of* reduction targets.

Reduction Targets – U.S. and International

- U.S.
  - President Obama's Climate Action Plan: 17 % relative to 2005 by 2020
  - EPA's recent Carbon rule ~30 % relative to 2012 by 2030
- UK: At least 80 % (from the 1990 baseline) by 2050
- Australia: 5 % below 2000 level by 2020



Indicators of Progress Toward and Achievement of GHG Reduction Targets Likely Require Quantification Capabilities at the 1% – 5% of the Target Level Using Internationally-Recognized Methodologies

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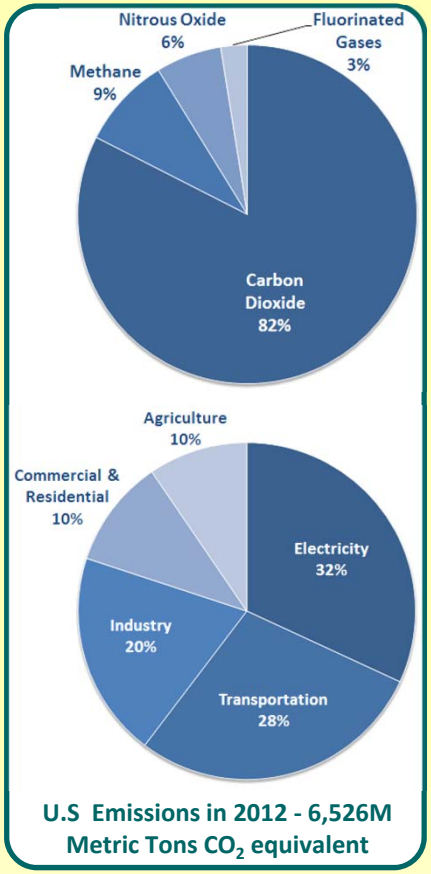
NIST's Greenhouse Gas and Climate Science Measurements Program

Objectives:

- **Develop advanced measurement tools and standards to improve accuracy capabilities of:**
  - **Greenhouse gas emissions inventory data**
    - Improving emissions measurement & reporting accuracy
    - Independent methodologies to diagnose and verify emissions data both nationally and internationally
    - Applications focused on cities and metropolitan areas
  - **Remote observing capabilities – satellite and surface-based**
    - Extend measurement science and tools underpinning advances in understanding and description of Earth's climate and its change drivers



NIST Greenhouse Gas and Climate Science Measurements Program Components

- **Stationary/Point Source Metrology**
  - Increase accuracy of Continuous Emission Monitoring technology
    - Flow Test Beds - smoke stack simulators
- **Geospatially Distributed GHG Source Metrology**
  - Measurement Tools and Test Beds Characterizing Emission in Urban GHG Concentration Domes
    - Compare methods to determine GHG Emission Inventory Accuracy – Bottom-up vs. Top-Down
    - Urban GHG dome test beds
      - Indianapolis Flux Experiment (INFLUX)
      - Los Angeles Megacity Carbon Project
      - Northwest Corridor Project
    - Propose an International GHG Metrology Framework Supporting Inventory Diagnosis and MRV Based on Megacities

- **Measurement Tools, Standards, and Ref. Data**
  - GHG Concentration Standards
  - Spectroscopic Reference Data
  - Surface Air Temperature Assessment
  - Atmospheric Flux Measurement Tools
- **Climate Science Measurements - Advanced Satellite Calibration Standards**
  - Microwave Observations
  - Advanced Optical Radiometric Methods
  - TOA and Surface Solar Irradiance
  - Surface Albedo Standards
- **Measurement Science of Carbonaceous Aerosols**
  - Advanced Optical Property Measurements
  - Development of Reference Materials

STATIONARY EMISSION SOURCES

ELECTRICAL AND POWER GENERATION

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Point Source GHG Metrology:

Comparing Fuel Calculated & Measured CO_2 Emissions

Electricity Gen. ~32% of U.S. CO_2 Emissions & Focus of the new EPA carbon rule

Question: What's the Level of Agreement Between the 2 Mainly-Used Methods of CO_2 Emissions Reporting Information? An Estimate of Accuracy in Reported Values?

- Fuel Calculation vs. Direct Stack Gas Flow Measurement Methods

- **Data Sources Used**
  - eGRID (EPA) and EIA 767 Databases ~ 4800 Entries – Publically Available
  - Pre-Combustion – Fuel Calculation Method
    - Amount of carbon and hydrocarbon burned (oxidized) and converted to CO_2
  - Post-Combustion – CO_2 Direct Measurement via CEMs Technology
    - Direct Measurement (CEMs Data) and Reporting of CO_2, SO_2, N_2O

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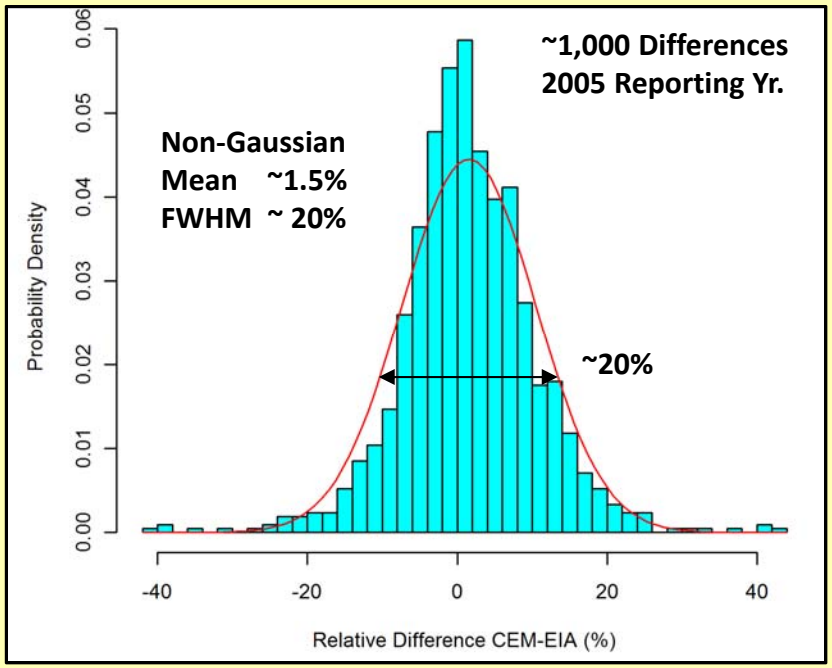
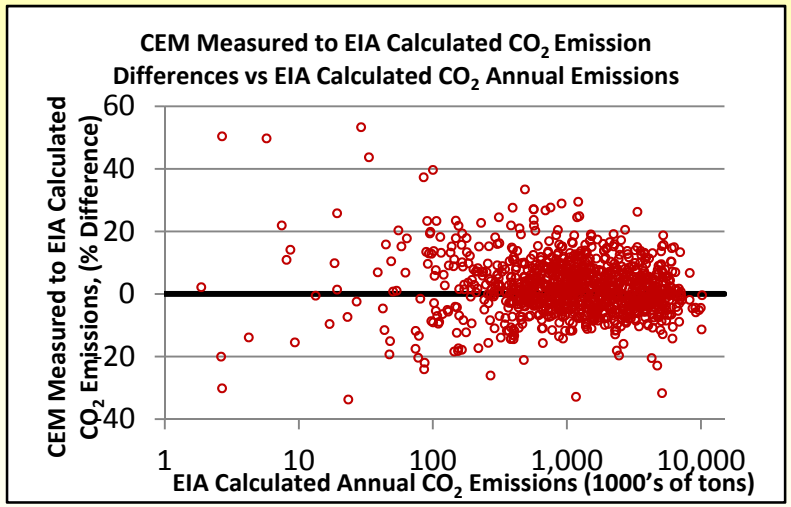
Comparative Analysis:

Fuel Calculated vs Measured CO_2

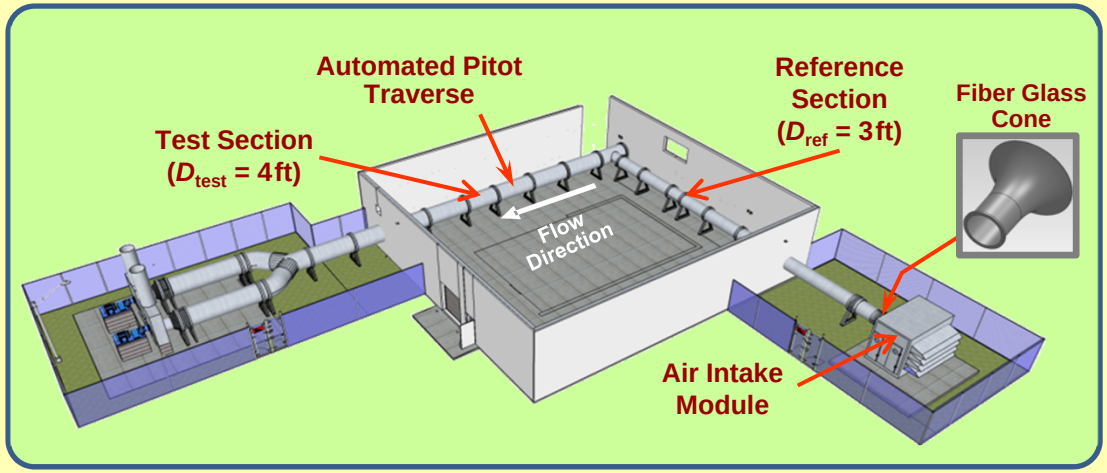
Accuracy Improvement Potential

- **CEM Measurements**
  - Improve stack gas mass flow measurement
  - Reduce gas concentration uncertainty
- **Fuel Based Calculations**
  - Increase fuel carbon (energy content) accuracy
    - Calorimetry and sampling issues
  - Improved mass determination
    - Where to make the measurement
- **NIST's Investment in Pt. Source Metrology**
  - Smoke stack simulator - improved flow measurements
  - Large Fire Facility – large CO_2 emission source & test bed





Smoke Stack Simulator – Cold Flow Simulator NFRL – Known CO_2 Emission Source



Address flow calibration issues in known, turbulent, swirling flows similar to those in stacks

- Horizontal orientation for cost and safety
- Smokestack Simulator is 1/10th the diameter of typical stack
- At the same velocity range – 5 to 25 m/sec
- Flow traceable to NIST flow standards

Large Emission Source with Accurately Known CO_2 Flux

- Characterize exhaust duct flows (flow RATAs*)
- Establish a mass balance for CO_2 emissions for the facility – O_2 depression calorimetry method
- Apply research results from the NIST Smokestack Simulator
- Provide test bed for new and existing stack mounted flow measurement technologies

* Relative Accuracy & Test Audit

National Fire Research Laboratory (NFRL)

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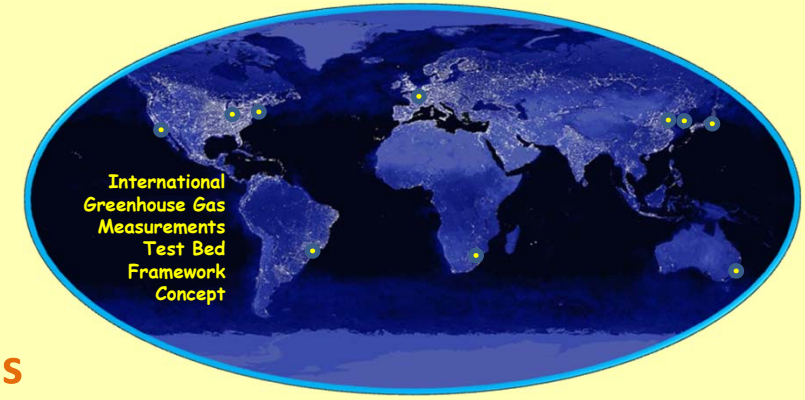
International GHG Measurements Framework

Engaging the Metrology & Climate Communities



Concept:

- Enables joint development of advanced measurement tools, standards, & methods
- Provides a multi-community and global focus
- Facilitates open, internationally-recognized measurement methodology development, performance evaluation, and open data exchange and utilization across national borders
- Could serve as a frequent GHG satellite calibration system

Approach:

- Engage with countries/regions having Megacities for use as test bed sites
- Use existing structures of the Mètre Convention, World Meteorological Organization and other international climate change/science communities and organizations

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Tools and Test Beds –Diagnosing Greenhouse Gas Inventory Accuracy in U. S. Urban Domes

Developing and Assessing Performance of Greenhouse Gas Measurement Tools at Urban Scales

The Indianapolis Flux Experiment (INFLUX)

- *A Top-Down/Bottom-Up Greenhouse Gas Quantification Experiment*
- *in the City of Indianapolis, Indiana*

The LA Megacity Carbon Project

- *Estimating the Emissions Trends in a Megacity Having*
- *Complex Topography & Meteorology*

The Northeast Corridor

- *The Largest U.S. Megacity*
- *A Test Bed Having Moderately Complex Topography & Meteorology*
- *Effort Initiated in Mid-FY 14 in the Baltimore / Washington Region*

Moving in the U.S. Towards an International Urban Greenhouse Gas Measurements Test Bed Framework

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PHOTOVOLTAIC PERFORMANCE ASSESSMENT

AND

BUILDING ENERGY EFFICIENCY COUPLED WITHIN THE SMART GRID FRAMEWORK

PHOTOVOLTAIC CELL & ARRAY PERFORMANCE METRICS

- PV panel array testing methods & test beds
- Improving panel materials failure mechanism models
- Advancing characterization methods for individual cells

Photovoltaic Test Beds

Assessing Module / Panel Performance

- PV performance combined with meteorological and solar irradiance data for solar panel systems
- Scales ranging from laboratory to field-installed single panels and arrays in roof and PV farm configurations

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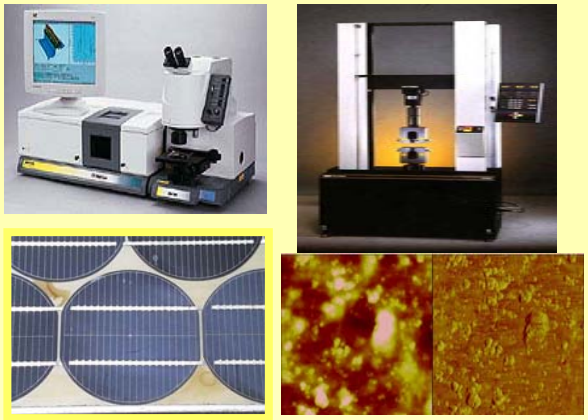
Improving Service Life Prediction for Polymers Used in PV Systems

NIST is advancing the understanding of failure mechanisms of polymeric materials utilized in solar cell assemblies

- Engage industry partners and end-users.
- Fabricate a state-of-the-art PV accelerated weathering facility.
- Define, design, and expose PV materials, components and mini-modules.
- Characterize degradation mechanism under multiple simultaneous stresses.
- Develop and validate service life prediction models.

NIST SPHERE for Accelerated Weatherability Testing



Degradation Measurement and Failure Analysis

Linking Laboratory and Field

Total Effective Dosage Model

$$D_{total}(t) = \int_0^t \int_{\lambda_{min}}^{\lambda_{max}} E_o(\lambda,t)(1-e^{-A(\lambda)})\phi(\lambda)\,d\lambda\,dt$$

Cumulative Damage Prediction Model

$$Damage_{CUM}(t) = \sum_{i=0}^{t} \Delta D(t)$$

Service Life Prediction Models

Underwriters Laboratories 3M ARKEMA DUPONT DAIKIN First Solar

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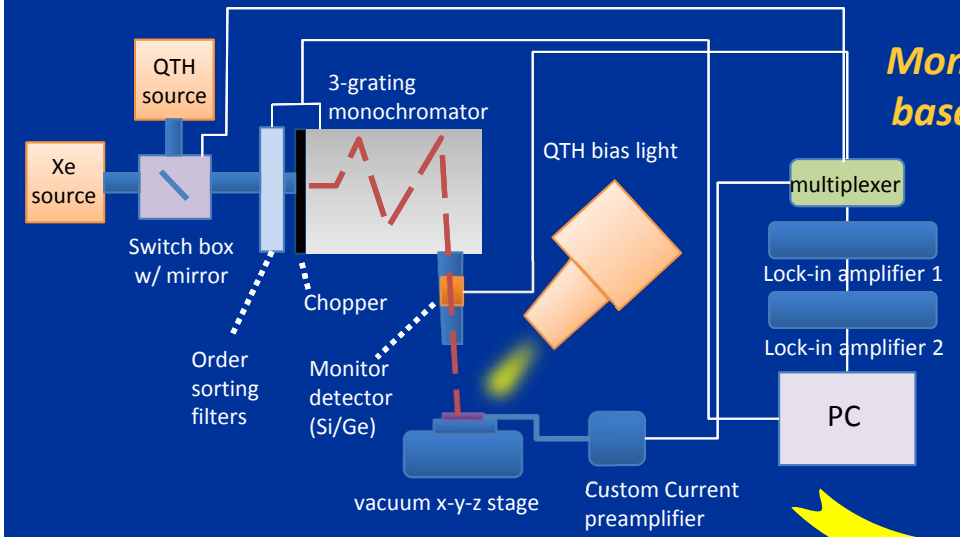
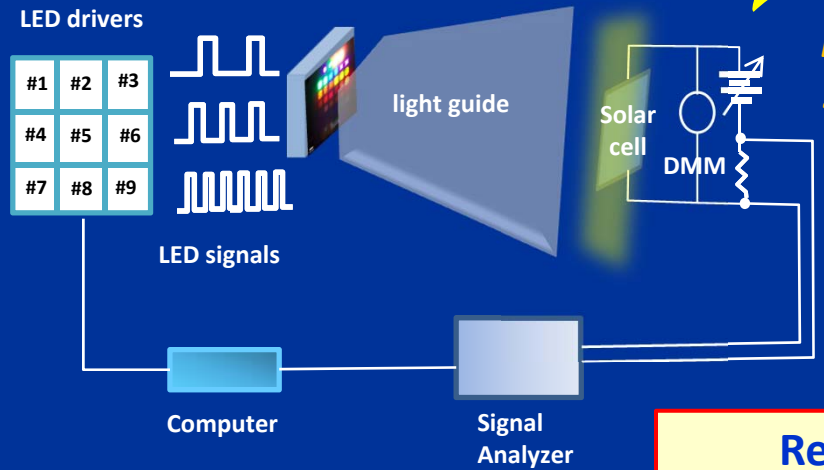
Solar Cell/Module Characterizations

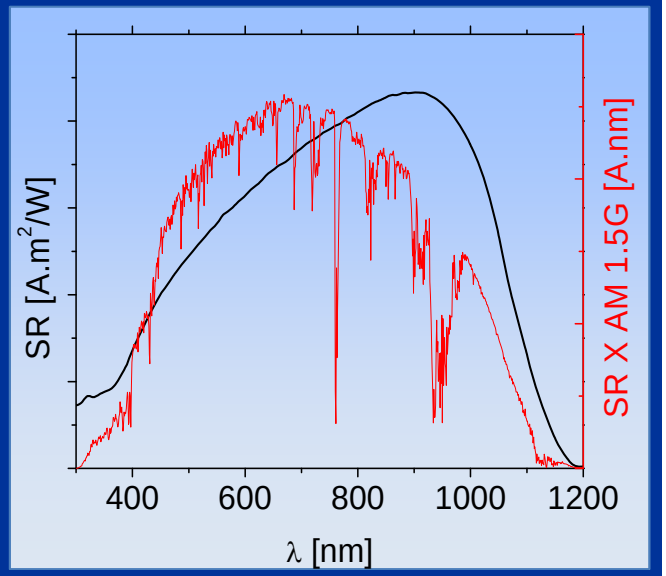
Developing, utilizing, and combining aspects of two techniques for measuring a cell's absolute spectral responsivity (SR)



Monochromator-based SR System



LED-based SR System



I_{sc} for Air Mass 1.5

Reference Cell Calibrations with SI-Traceability

MEASUREMENT SCIENCE SUPPORTING ENERGY EFFICIENCY & PERFORMANCE STANDARDS FOR BUILDING

Energy Efficiency in Buildings

Net-zero Residential Building Performance Research

- **Residential building test bed to test various high-efficiency and alternative energy systems, materials, and designs.**
- **1st year goal: Demonstrate 1-year net-zero operation**
  - Simulated a family of four living in an energy efficient home monitor house performance
- **Longer-Term Goals:**
  - Testing of existing and advanced energy efficiency technologies
  - Develop test methods that better reflect how those technologies will perform in a real home, rather than a laboratory.
  - Lifetime performance characterization of building components and materials

http://www.nist.gov/el/nzertf/index.cfm

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Net-Zero Energy Residential Test Facility

- Demonstrate various technologies and operating strategies to achieve net-zero energy in a typical home
- Compare actual installed performance to controlled laboratory measurements
- Quantify impacts of embedded controls intelligence & building-to-grid interactions
- Develop guidelines for performance measurement and operation of net-zero homes
- Provide “real-world” field data to improve models and test procedures

LEED Platinum

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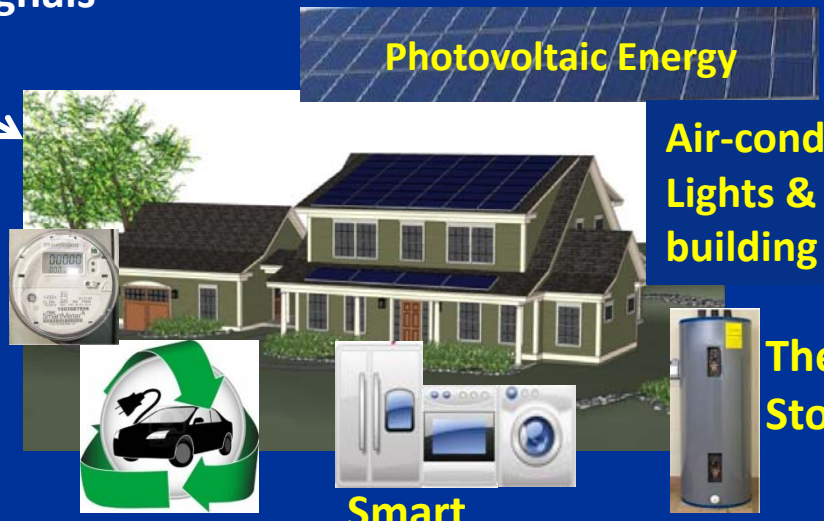
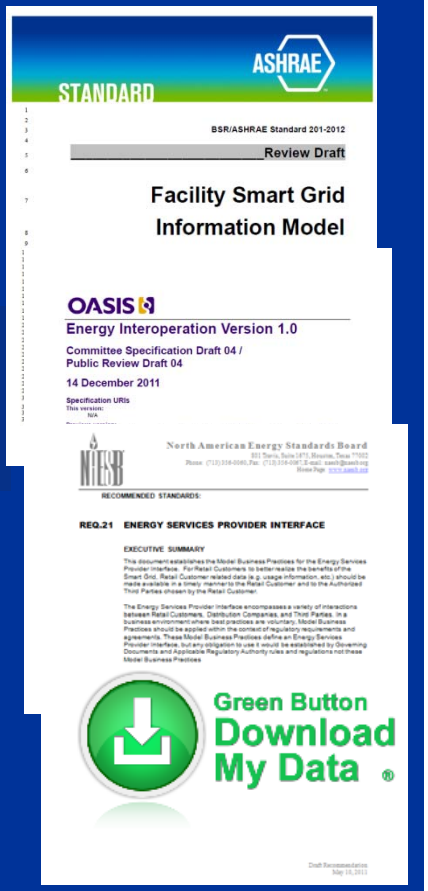
Building Design for Smart Grid Integration

- Home and building energy management using smart grid technologies and standards
- Interoperability standards for buildings communicating with the smart grid

Standard electric price, usage, weather signals

$, kWh





SGIP SMART GRID INTEROPERABILITY PANEL

NIST Building Energy Efficiency Measurements & Performance Assessment Research Project Summary

- Advanced Insulation Measurement Techniques
- Novel Working Fluids for High-Efficiency Air Conditioning & Refrigeration Equipment
- Fault Detection, Diagnosis, and Commissioning for Air Conditioners and Heat Pumps
  - Automatic Fault Detection and Diagnostics (FDD) Embedded in Commercial Buildings
- Whole-Building Energy Modeling and Measurements
  - Sensors for Improved Building Monitoring
  - Performance of Wireless Sensor Networks for Building Applications
  - Commissioning Building Systems for Improved Energy Performance

Muchas Gracias
Thank You for Your Attention
Questions and/or Comments

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