Measurement Challenges and Metrology for Monitoring CO$_2$ Emissions from Smokestacks

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The National Metrology Institute of the U. S.
Greenhouse Gas and Climate Science Measurements

NIST
- Is a non-regulatory agency of the U.S. Department of Commerce
- Is the U.S. National Metrology (measurement) Institute, and
- Develops unbiased, state-of-the-art measurement science that advances the nation's technology infrastructure

Mission:
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.

NIST and Greenhouse Gas Measurements and Standards
- Recent focus established by the NIST Director – 2009
- Mid-Term Objective:
  - Improve performance capabilities of measurements and standards needed to enhance the accuracy of Greenhouse Gas Measurements in the U. S.
  - Promote recognition of these internationally
- Long-Term Objective:
  - Transfer measurement technologies developed to other government agencies and the private sector
  - Support standards responsibilities as needed
NIST’s Greenhouse Gas and Climate Science Measurements Program

Objectives:

• Develop advanced measurement tools and standards to improve accuracy capabilities for:
  • Greenhouse gas emissions inventory data
    ▪ Improving emissions measurement data & thereby reporting accuracy
    ▪ Independent methodologies to diagnose and verify emissions data with internationally-recognized methodologies
    ▪ 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

U.S. Emissions in 2012 - 6,526M Metric Tons CO₂ equivalent
# NIST Greenhouse Gas and Climate Science Measurements Program Components

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| **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 |

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STATIONARY EMISSION SOURCE METROLOGY

• Motivation and Rationale
• What NIST is Doing
Early CFD Modeling Results in a Stack

Axial Stack Flow Velocities Fields

Swirl Fields
Plume Behavior Appears not to be Laminar

- Flow exiting a stack on a clear, low-wind condition day
- Local Power plant with relatively new stack
- Two vortices appear to be exiting non-partitioned stack
Point Source Metrology: Comparing Fuel Calculation and Direct CO₂ Measurements Using Reported Emission Data

Electricity Generation ~40% of U.S. CO₂ Emissions Inventory

Question:

What is the Agreement Between the 2 Mainly-Used Methods of CO₂ Emissions Reporting Information?

– Fuel Calculation vs. Continuous Emissions Monitoring (CEMs) Methods

• Fuel Consumption and Measured CO₂ Emissions Data – 2005 & 2009 U.S. Reporting
  – Pre-Combustion – Fuel Calculation Method
    • Amount of carbon burned and converted to CO₂
    • Dept. of Energy – Energy Information Administration
      ▪ Annual Steam-Electric Power Plant Design Data  Fuel Type & Quantity
      ▪ Carbon factor or Fuel Carbon Content (kg CO₂/mmBTU)
  – Post-Combustion – CO₂ Direct Measurement via CEMs Technology
    • Direct Measurement (CEMs Data) and Reporting of CO₂, SO₂, NOₓ Required by U.S. EPA

• eGRID and EIA 767 databases contain >4800 entries
  • 1664 with primary fuel and annual CO₂ (CEMs) reported values
  • 1066 (2005) and 944 (2009) boilers have complete data for fuel type, mass, energy content, and CEMS CO₂ data
Comparative Analysis:
Fuel Calculated vs Measured CO₂

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 CO₂ emission source & test bed

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Non-Gaussian
Mean ~1.5%
FWHM ~ 20%

~20%

~1,000 Differences
2005 Reporting Yr.

CEM Measured to EIA Calculated CO₂ Emission Differences vs EIA Calculated CO₂ Annual Emissions

CEM Measured to EIA Calculated CO₂ Emissions, (% Difference)

EIA Calculated Annual CO₂ Emissions (1000’s of tons)
Smoke Stack Simulator - Cold Flow Simulator
NFRL - Well Characterized 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 1/10$^{th}$ 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
Thanks for your Attention

Best Wishes for Successful Discussions