GE Power Systems

Fine Particle and Precursor Emissions From Power, Oil & Gas Industry Sources

PM2.5 and Electric Power Generation: Recent Findings and Implications
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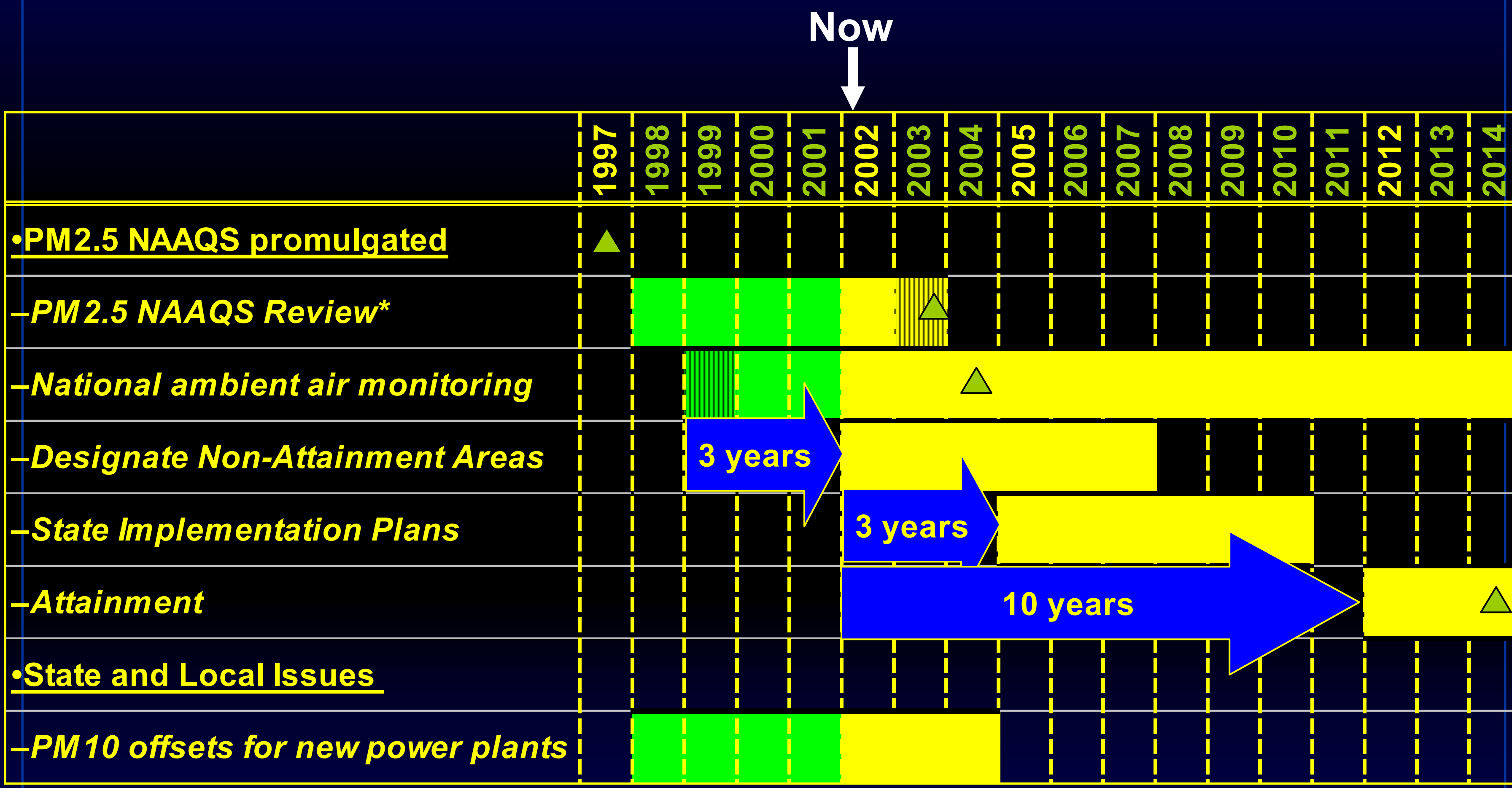
Overview

- Program background
- Measurements and results
- Findings and plans

PM 2.5 Drivers

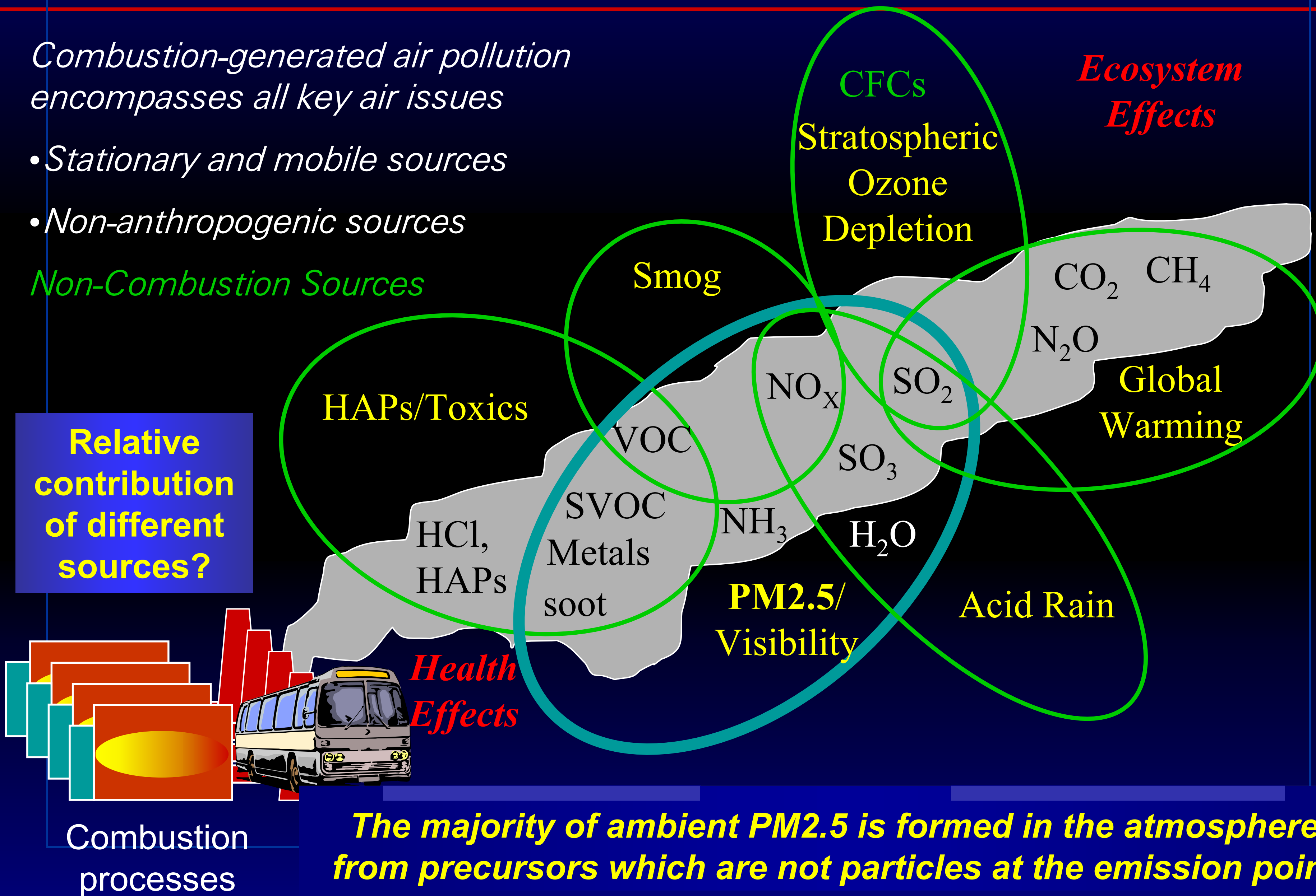


Sources of Ambient PM2.5

Combustion-generated air pollution encompasses all key air issues

- *Stationary and mobile sources*
- *Non-anthropogenic sources*

Non-Combustion Sources



The majority of ambient PM2.5 is formed in the atmosphere from precursors which are not particles at the emission point

The Program

***<u>Source Apportionment</u>*: Need Valid PM2.5/Precursor Emission Factors and Source PM2.5 Speciation Profiles**

- **Background**
  - API Critical Review (Q4 1996)
  - API/DOE NPTO refinery heater/FCCU tests (Q3 1998)
  - API/GTI steam generator test (Q3 2000)
  - GTI/NYSERDA/CEC fine/ultrafine PM2.5 test method & sampling project (plan Q1 2000)
  - DOE NPTO/API/GE (Q3 2000)
  - CEC/NYSERDA/GTI and DOE/API projects develop common work scope (Fall, 2000)
- **Improved PM2.5 source characterization data & method development for emission inventory and source apportionment:**
  - Among the ten top research priorities cited by the National Research Council *Committee on Research Priorities for Airborne Particulate Matter* (2000, 2001)
  - PM2.5 emission factors, characterization, chemical speciation
  - A proven test method (based on dilution tunnel)
- **Current Project**
  - Year 1: Definition and data collection
  - Year 2: Next generation sampler; data collection
  - Year 3: Data collection; method

Gas Fired Test Units

	Site A	Site B	Site C	Site 1	Site 2	Site 3
Unit type	Boiler	Process Heater	Steam Generator	Process Heater	Gas Turbine	Process Heater
Configuration	Tangentially fired	4 radiant wall-fired box-type heaters	Single burner	2 bottom-fired box-type heaters	Single shaft combined-cycle/duct burners cogen unit	2 bottom-fired box-type heaters
Size	650 MMBtu/hr	114 MMBtu/hr	62.5 MMBtu/hr	185 MMBtu/hr	240 MW (2000 MMBtu/hr)	300 MMBtu/hr
APCD	None	None	Flue-gas recirculation	None	DLN combustor, oxidation catalyst, SCR	SCR
Fuel type	Refinery gas	Refinery gas	Natural gas	Refinery gas	Natural gas	Natural gas

← Previous Projects → | ← Current Project →

Other Test Units

	Site A	Site 4	GE EER Test Site
Unit type	Refinery FCCU	Dual-Fuel Boiler	Pilot-scale boiler simulator
Configuration	Fluid Bed Catalyst Regenerator + Fired CO Heater	Boiler (hot water)	Furnace + convective section
Size	47,000 bbl/day	165 MMBtu/hr	1 MMBtu/hr
APCD	Electrostatic precipitator	None	None
Fuel type	Refinery gas (heater)	No. 6 oil, natural gas	Natural gas, No. 6 oil, coal

← Previous Projects → | ← Current Project →

Measurements Overview

Traditional Stack Sampling

stack

PM10, PM2.5, filterable and Condensable Particulate (cyclones, heated filter, Impinger train)

NO, NOx, SO_2, CO, CO_2, O_2 (continuous monitors)

Solid/Condensable Particle size dist. (dual cascade impactors)

Ammonia (in-stack filter, impingers)

SO_3 (controlled condensation)

Combustion Sources

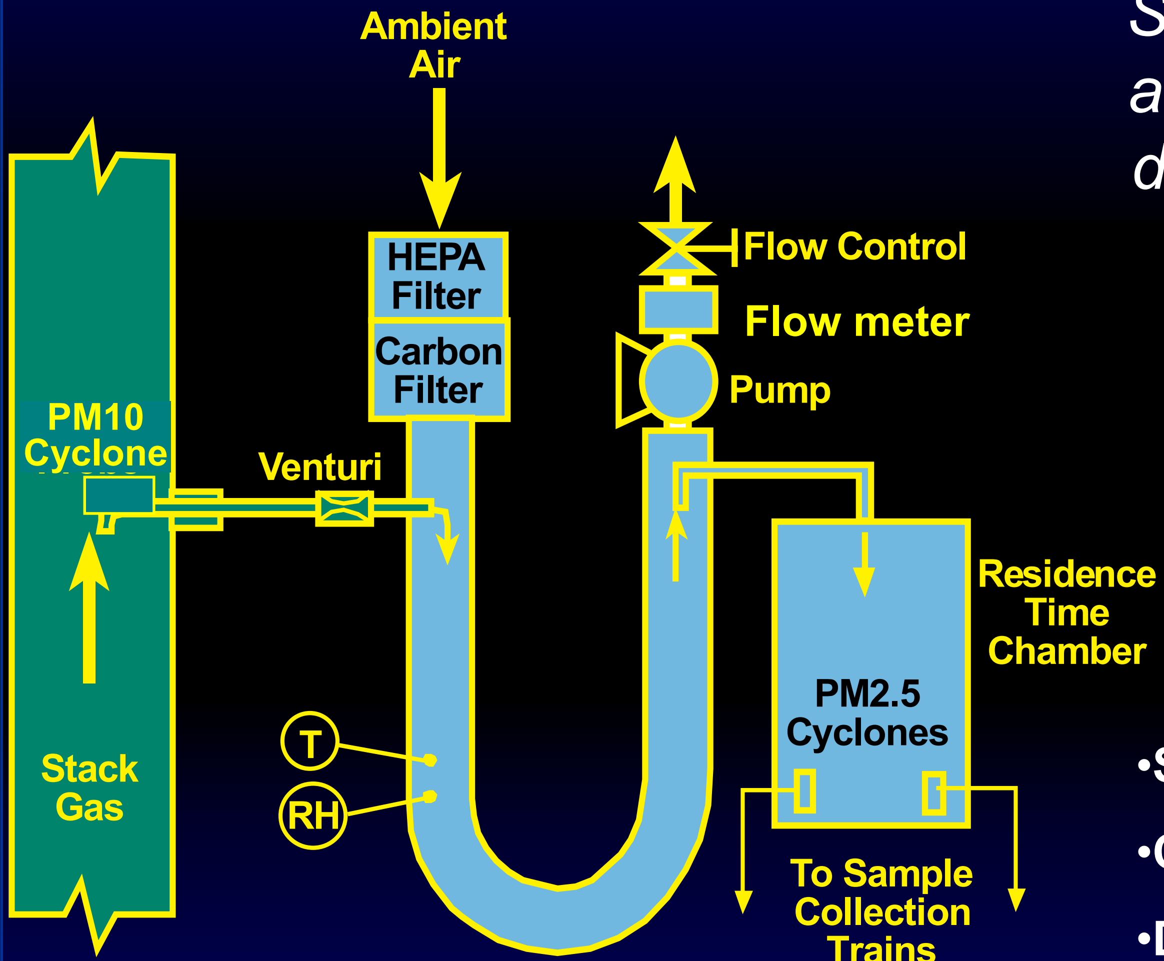
Dilution Tunnel

- PM2.5 mass
- Primary particle speciation
- VOC & SVOC
- PM2.5 Size Distribution
- Ultrafines (<0.1 µm)

6-hour test runs

Ambient Air and Stack

Dilution Sampler



Sample gas is cooled to ambient temperature by dilution with ambient air

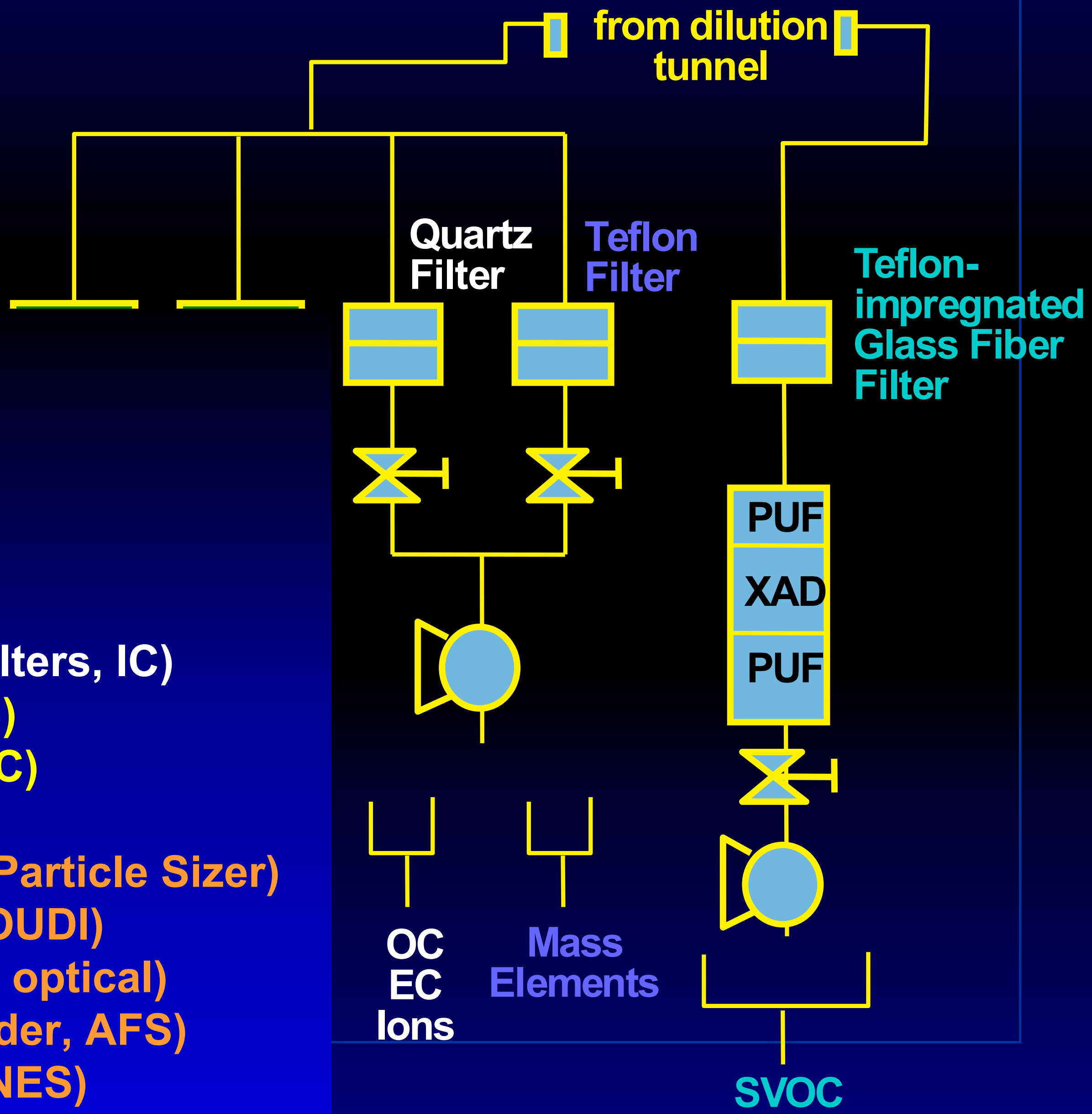
- Stainless steel
- Cross-flow jet mixing
- Dilution Ratio *10-40:1*
- Residence time *80-90 sec*

Dilution Tunnel Sample Collection

- *Ambient air methods assure comparability*
- *Broad range of media and analytical techniques*

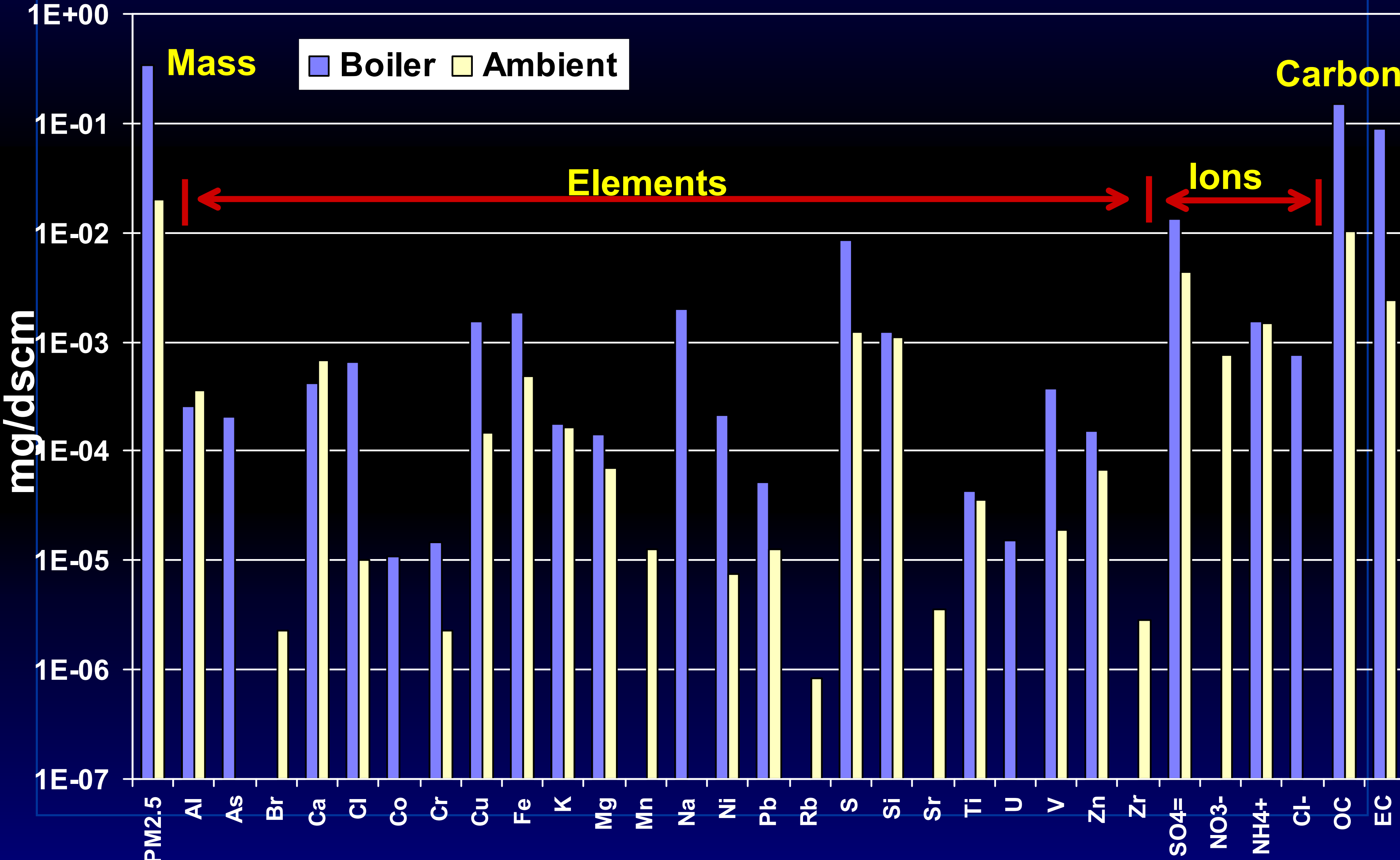
<u>*Sample Analysis*</u>

•PM2.5 mass (gravimetric)
•40+ Elements Al-Zn (XRF)
•OC/EC (TOR)
•Ions: $SO_4^=$, NO_3^-, Cl^- (IC)
•Ammonium (colorimetry)
•SO_2, ammonia (impregnated filters, IC)
•VOC (Tenax/Canisters, GC/MS)
•Carbonyls (sorbent tube, HPLC)
•SVOC (PUF/XAD, GC/MS)
•Ultrafines (Scanning Mobility Particle Sizer)
•Chemically-speciated size (MOUDI)
•Real-time PM2.5 mass (TEOM, optical)
•Mercury speciation (KCl denuder, AFS)
•Ni, V, Fe speciation (filter, XANES)



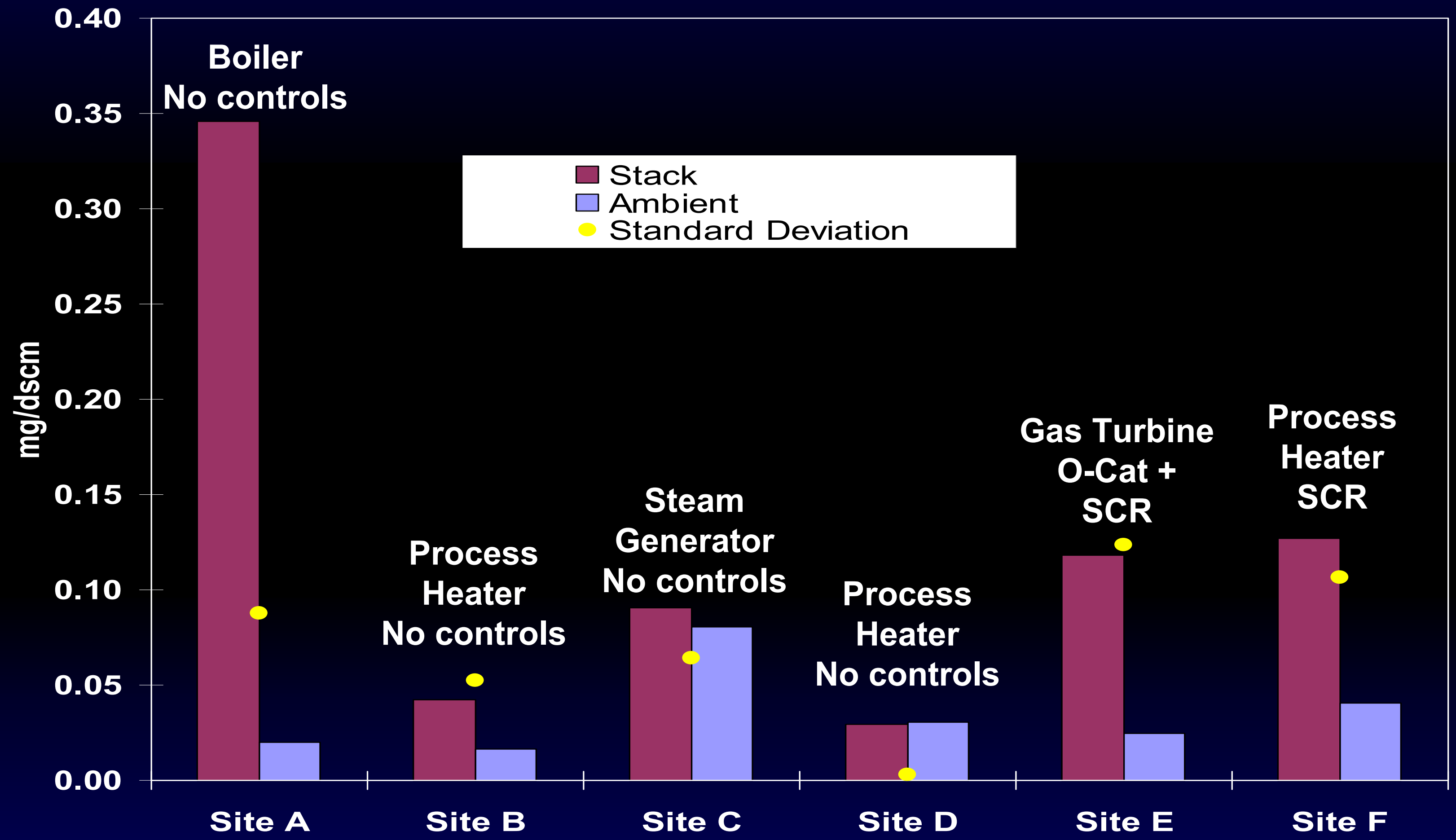
Speciation Profile – Gas-Fired Boiler

- Mass (dilution tunnel)



Comparison to Ambient Air Background

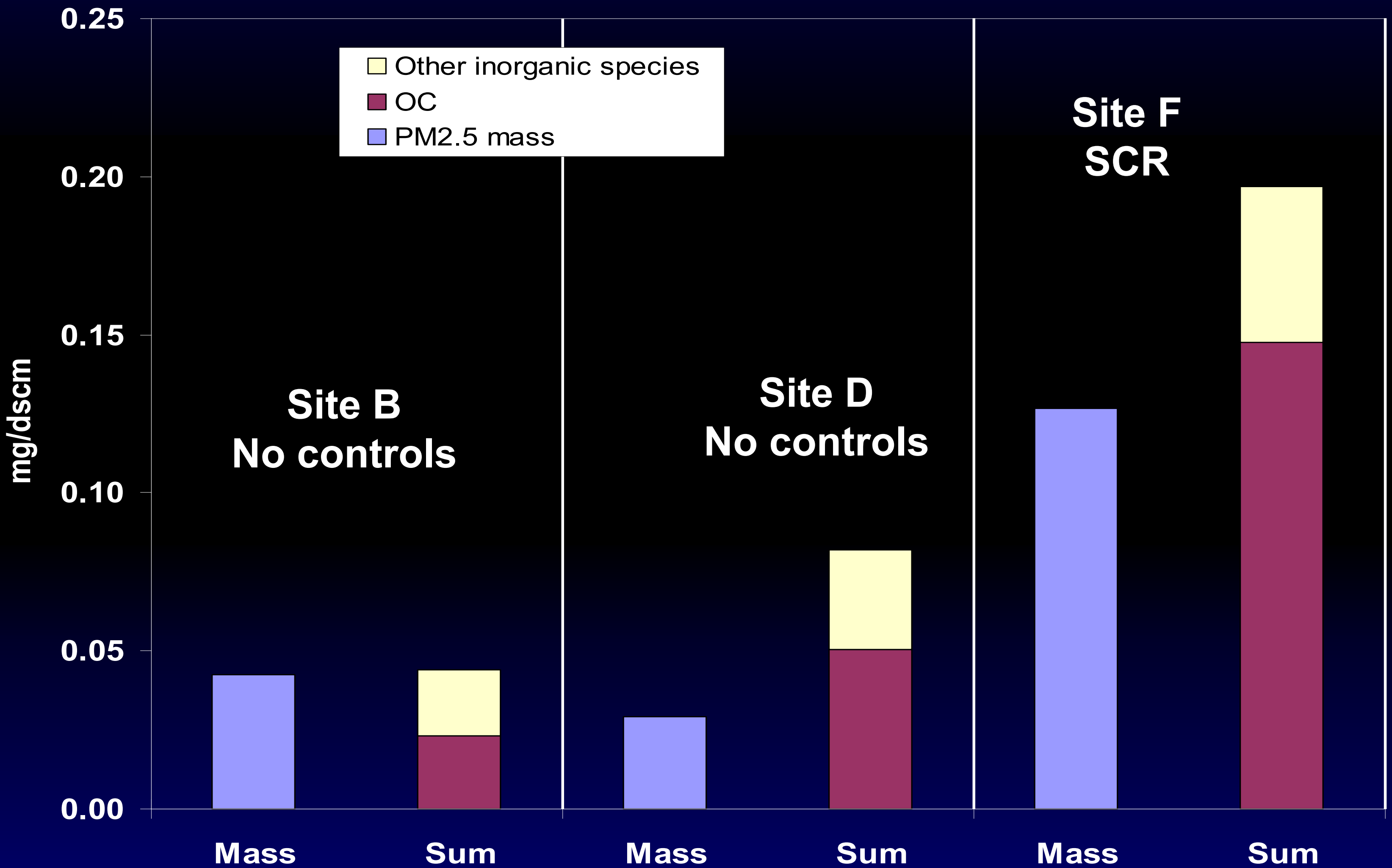
- **PM2.5 Mass (dilution tunnel)**



In-stack PM2.5 concentration from gas-fired sources is near ambient

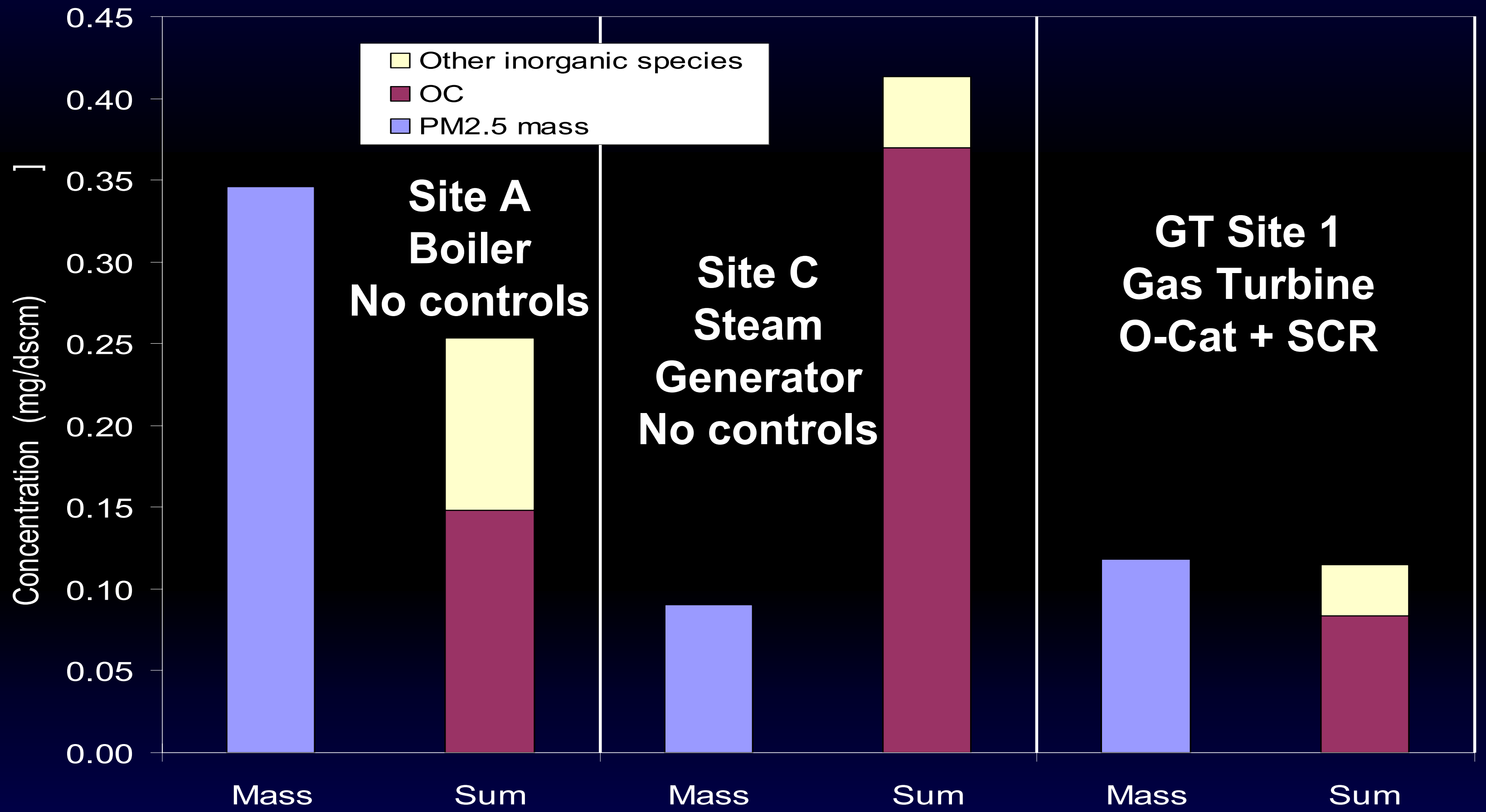
PM2.5 Mass Speciation Closure

- Gas-fired process heaters (dilution tunnel)



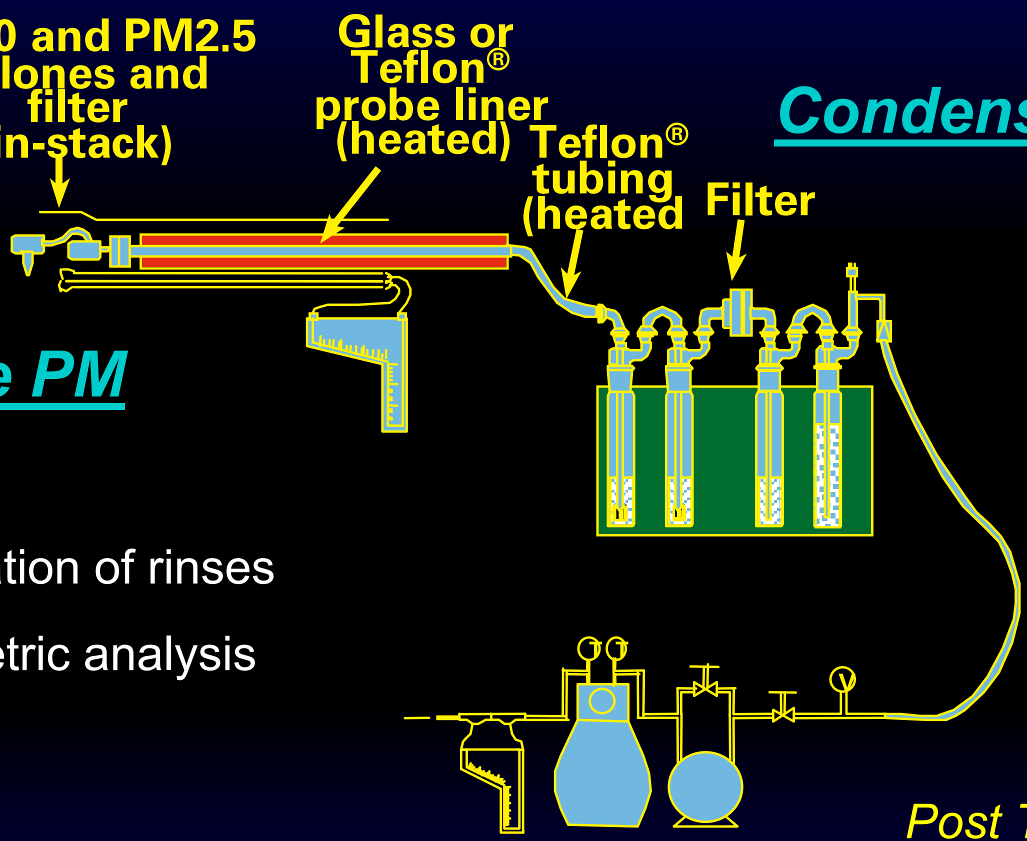
PM2.5 Mass Speciation Closure

- Other gas-fired sites (dilution tunnel)



Organic carbon artifact may bias species sum in sources with high organic emissions

Traditional Filter/Impinger Methods



Condensable PM

Analysis:

- Organic extraction
- Titration of inorganic fraction
- Gravimetric analysis
- $SO_4^{=}$ and Cl^{-}

Filterable PM

Analysis:

- Evaporation of rinses
- Gravimetric analysis

Post Test Purge with N_2 or Air

Sample gas is cooled to 60-70F in iced impingers

EPA Methods PRE4 & 202

PM10 Methods

- **Traditional Source Test Methods**

Method	Cyclone	Probe Catch	Filter Catch	Impingers			
				1	2	3	4
PRE-4	PM10 and PM2.5	Yes	Yes	Front-half only			
5	No	Yes	Yes	W	W	E	SG
5i	No	yes	yes	W	W	E	SG
8	Back-half only			IPA	H2O2	H2O2	SG
17	No	Yes	Yes	W	W	E	SG
201A	PM10	Yes	Yes	Front-half only			
202	Back-half only			W	W	E	SG

W - Deionized water
H2O2 - Hydrogen peroxide
IPA - Isopropyl alcohol
E - Empty
SG - Silica gel

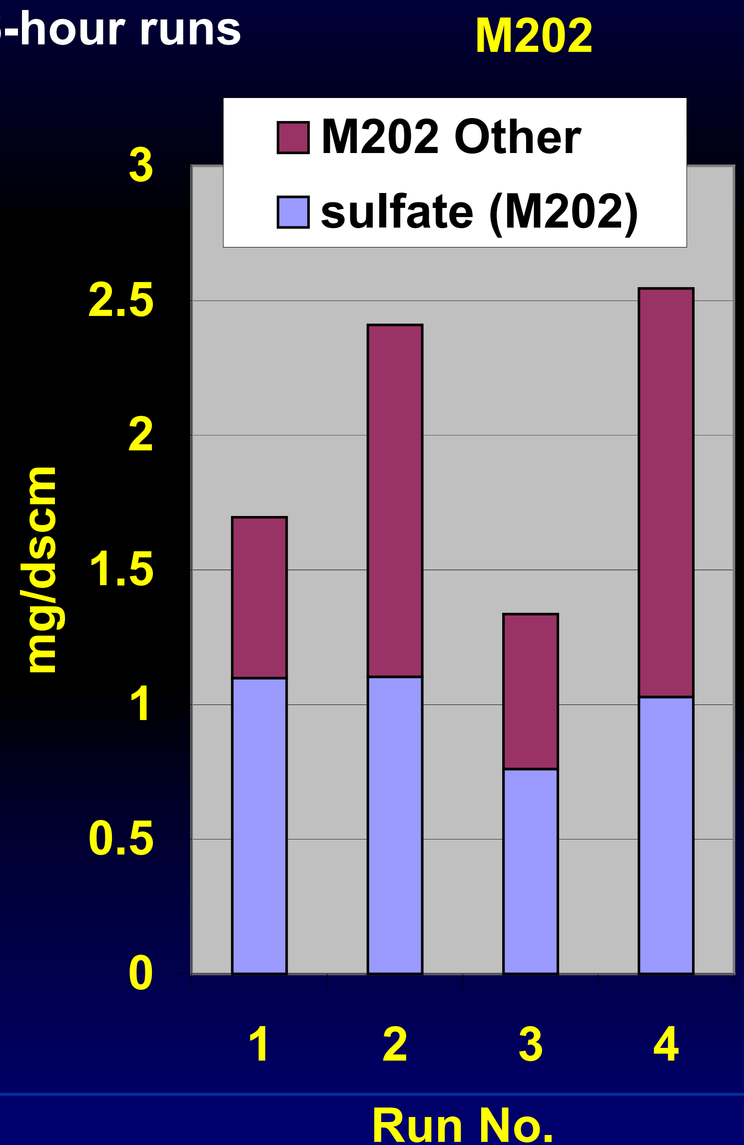
Post-test purge:
Method 8: 10 min air
Method 202: Recommended 30 min air or N2 but not required if pH<4.5

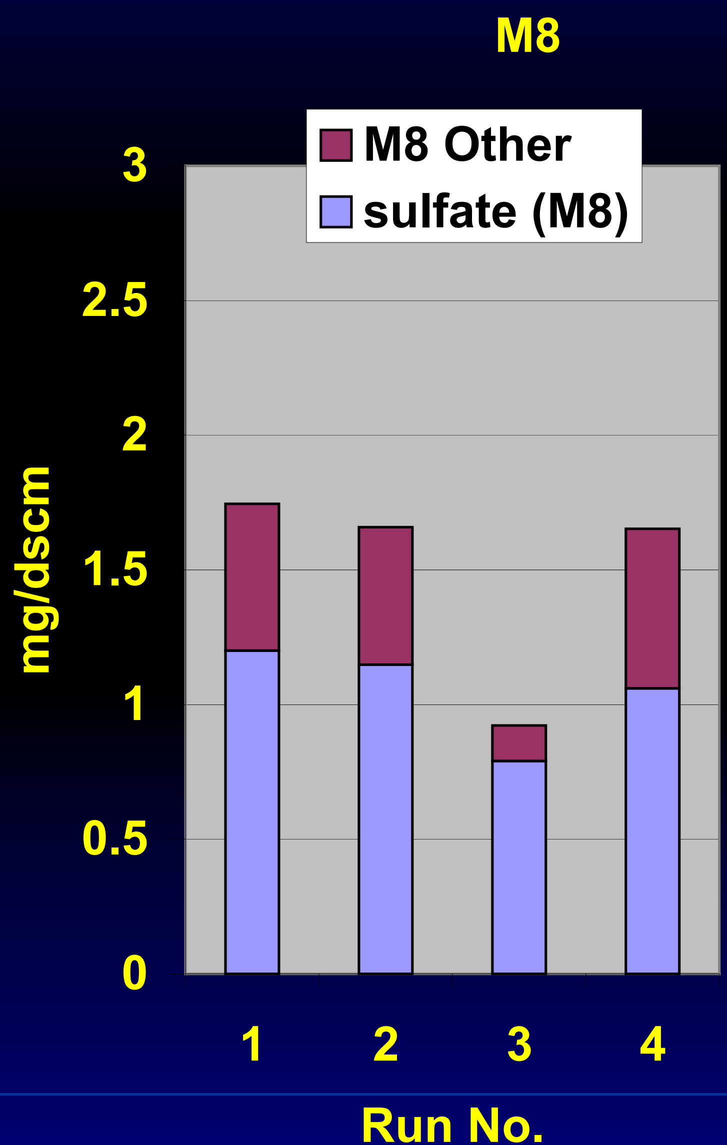
(Rubenstein, 2001)

Many state/local variations on impinger collection/analysis method

Gas Turbine Condensable PM (Impinger)

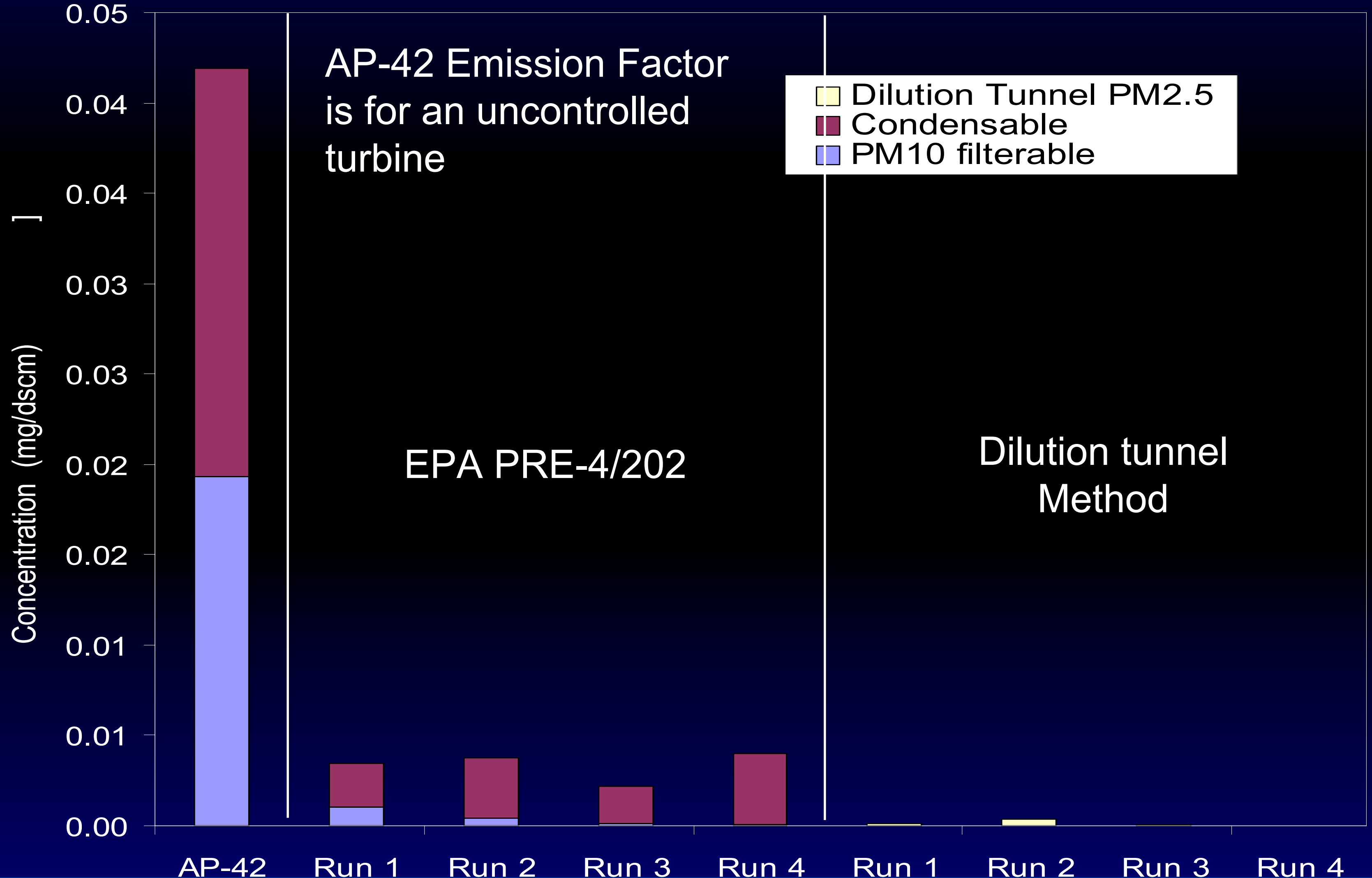
- Simultaneous M202 and MM8 sampling trains
- 6-hour runs





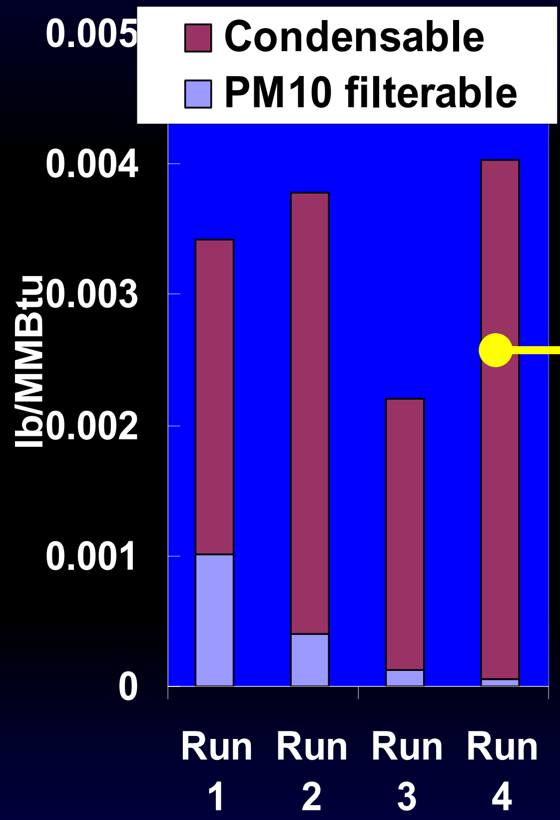
Gas Turbine Emissions – GT Site 1

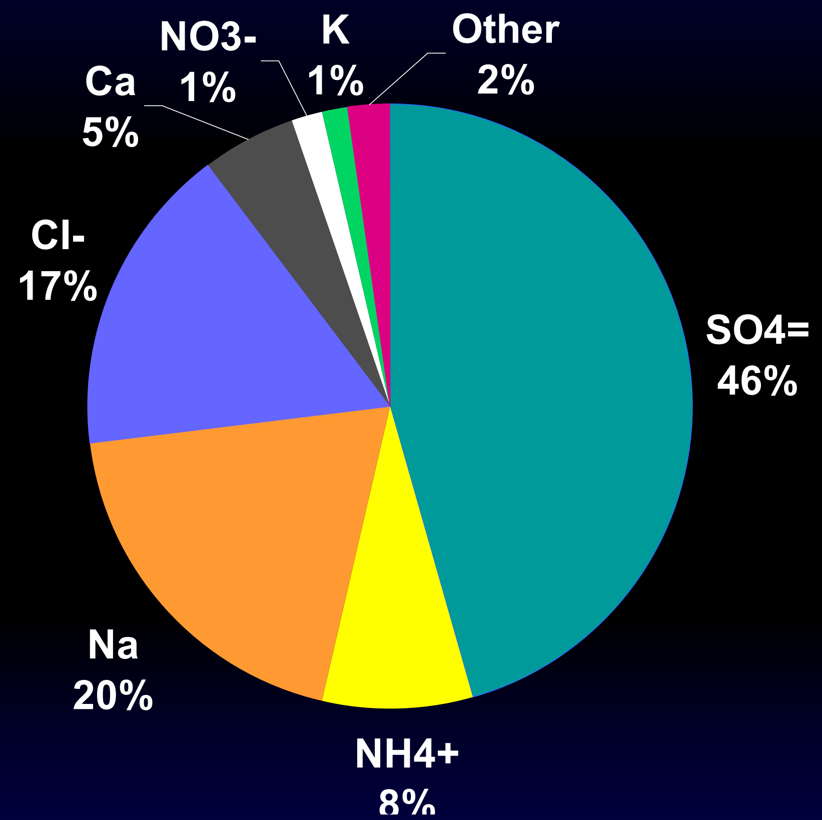
Method Comparison with AP-42 Emission Factor



Gas Turbine PM10 Emissions

- Condensable PM (M202) Residue Speciation

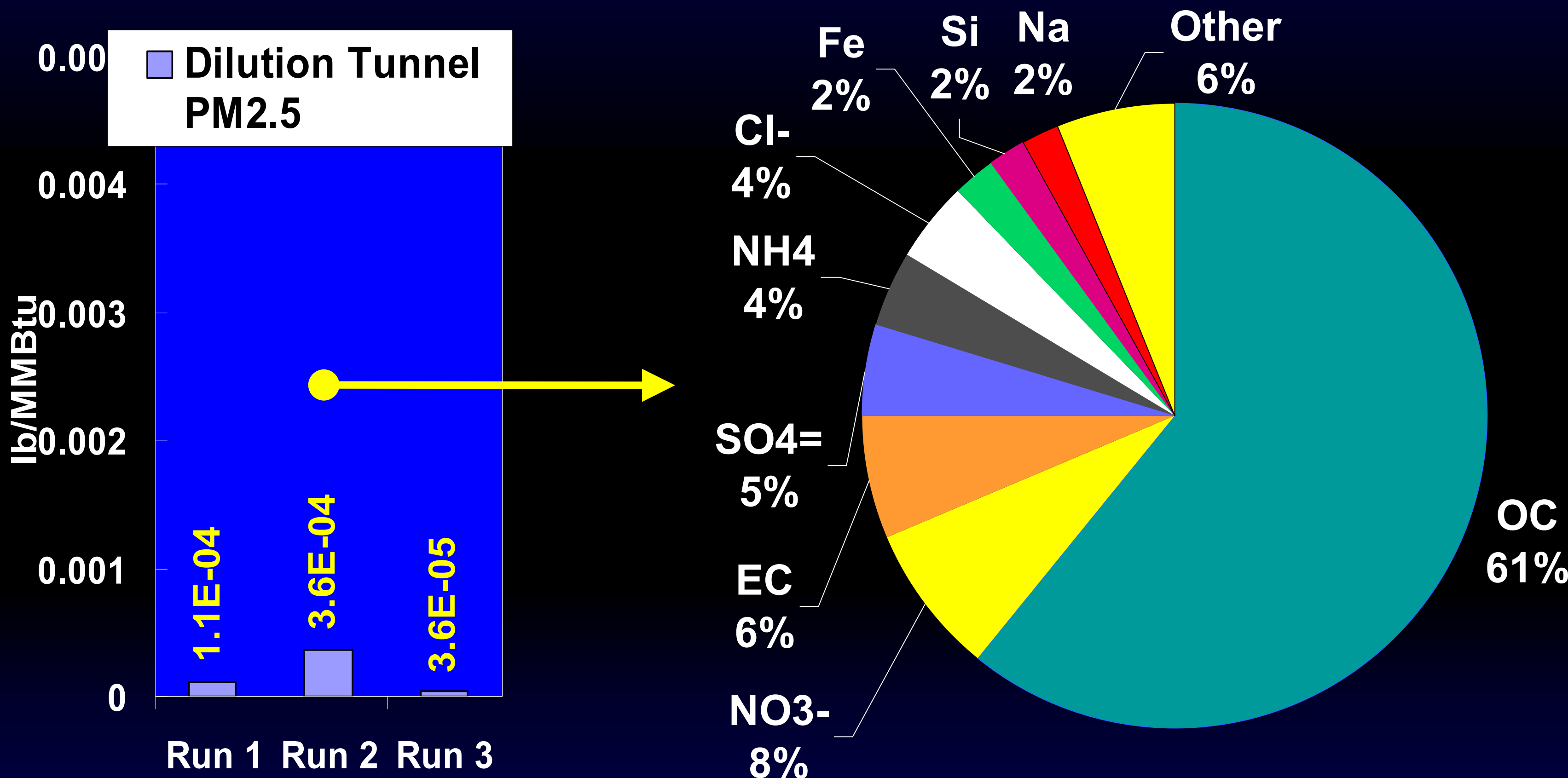




- The majority of PM10 is PM2.5
- Sulfate is largest fraction of CPM mass

Gas Turbine PM2.5 Emissions

- Dilution tunnel PM2.5 speciation



Carbon is majority of PM2.5 mass measured by the dilution tunnel

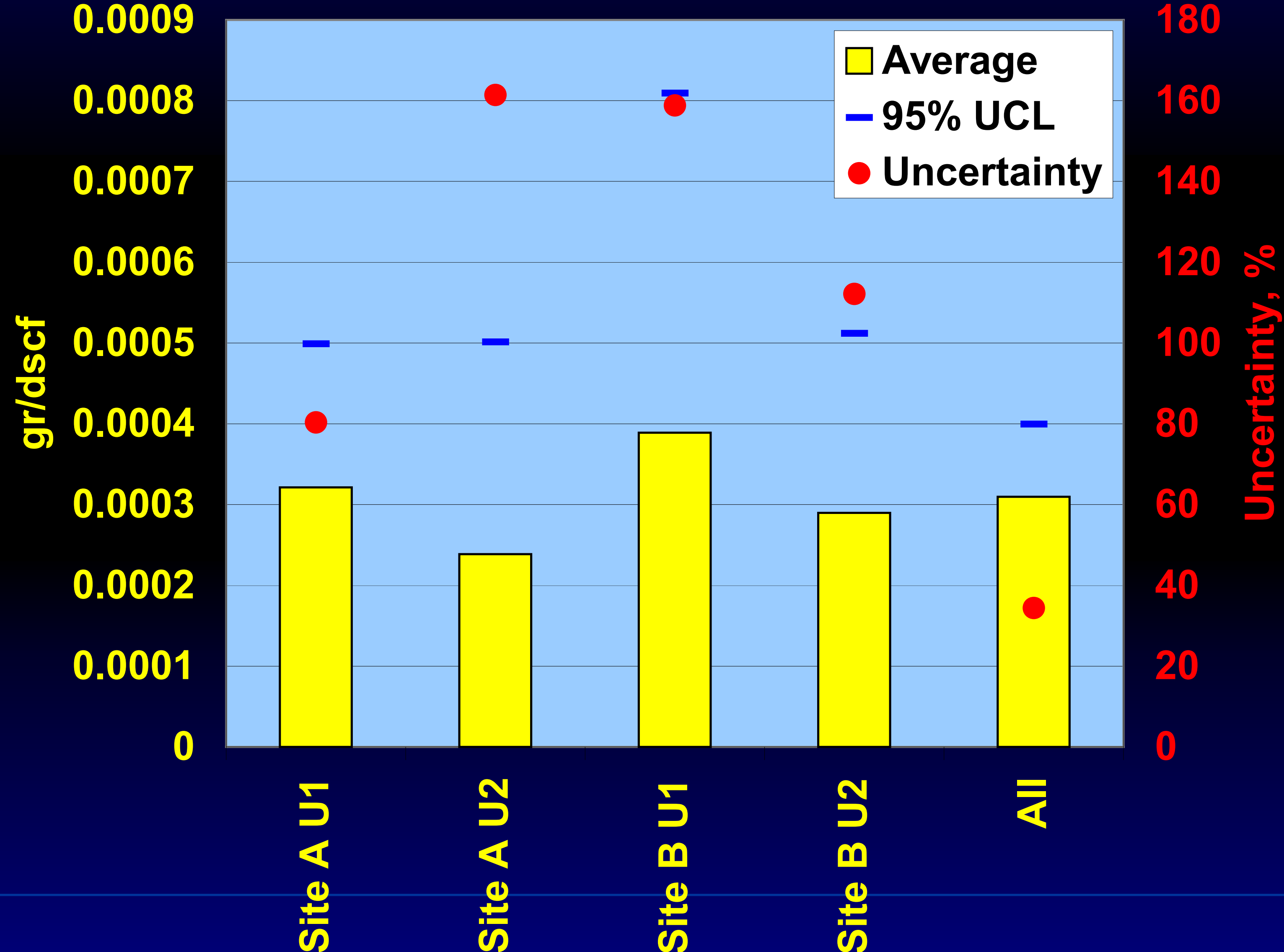
Measurement Artifacts

- Impinger method positive bias from SO_2 oxidation to sulfate
  - Sulfur in natural gas significant relative to PM
  - Artifact increases with time and SO_2 concentration
  - Minimize by post-test purge with N_2
- Fundamental difference between current stack test and dilution tunnel methods
  - Aerosol nucleation driven by saturation ratio
  - Impinger method cools without changing concentration
    - High saturation ratio leads to more condensation
  - Dilution tunnel (and stack plume) cools with decreasing concentration
    - Low saturation ratio leads to less condensation
- Dilution method
  - Positive OC bias from VOC
  - Negative PM mass bias from losses in tunnel

Dilution tunnel provides results more representative of plume than traditional methods

PM10 Emissions – Gas Turbines

- EPA Method 202 Results



Dilution Tunnel Issues

- Successfully applied to 9 diverse sources
  - Gas, oil, and coal
  - Comprehensive inorganic and organic chemical speciation profiles developed
- Current size limits applications to units with adequate platforms
  - Traversing impractical
  - Costly
- Future development underway for use as routine test method
  - Design parameters for different applications
    - Pilot-scale combustion tests
    - Comparison to other dilution systems
  - Consensus standard adoption
  - Better-SMALLER-faster-cheaper

Findings – Gas Turbines – EPA Methods

- Improved method techniques reduce PM10 variability
  - 4-6 hr sampling time
  - PM10 cyclone on probe (to remove spurious large particles)
  - Post-test nitrogen purge
  - Use all Method 202 analytical options
  - Other data and QA/QC improvements
- Results from single test:
  - typically near or below method MDL (3 sigma)
  - Always below PLQ (10 sigma)
  - Uncertainty always >100% of result (95% confidence)
- Method 202 vs. Modified Method 8
  - Sulfate results very similar
  - Non-sulfate slightly greater with M202
  - Modified Method 8 looks promising
- SO_2 artifact leads to significant sulfate bias for natural gas combustion
  - Post-test purge helps but doesn't eliminate artifact

Findings

- Extremely low PM concentrations in gas-fired sources challenge the limits of all current methods
- The condensable portion of primary PM2.5 may be overestimated using impinger-based methods
  - Sulfate artifacts significant even for gas-fired sources
  - Aerosol formation and growth is a function of both cooling and concentrations
- Improved protocol for dilution methods necessary for both emission factors and chemical speciation

Different test methods give very different results!

Dilution tunnel results best for source apportionment and source-receptor modeling

Don't mix emission factors from traditional methods with speciation from dilution methods

Next Steps

- Advanced dilution sampler design and construction
  - Pilot-Scale Tests
    - » Develop design criteria and improve procedures
    - » Compare dilution tunnel designs
  - Evaluate additional characterization techniques
    - » Ultrafines (SMPS/DMA)
    - » Real-time monitoring (TEOM)
    - » Denuders to reduce artifacts

Next Steps (cont'd)

- Additional Field Tests
  - Gas turbines (power generation)
  - Oil-fired utility boiler?
  - Pipeline compressors
    - Reciprocating and gas turbine engines
  - Distributed power generation
  - Expand characterization (HAPs, other key substances)
    - Ultrafines, mercury, N-PAH, carbonyls, metal species
- Refine data analysis and findings

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