IAGT SYMPOSIUM 17

IAGT Industrial Application of Gas Turbines

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PM2.5 Emissions Estimates for Natural Gas-Fired Gas Turbines and Other Natural Gas Combustion Sources

By

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OVERVIEW

BACKGROUND

- Sources of PM emissions
- Filterable and condensable PM
- Measurement methods

RECENT TESTS

- Natural gas pipeline engines
- Approach
- Results

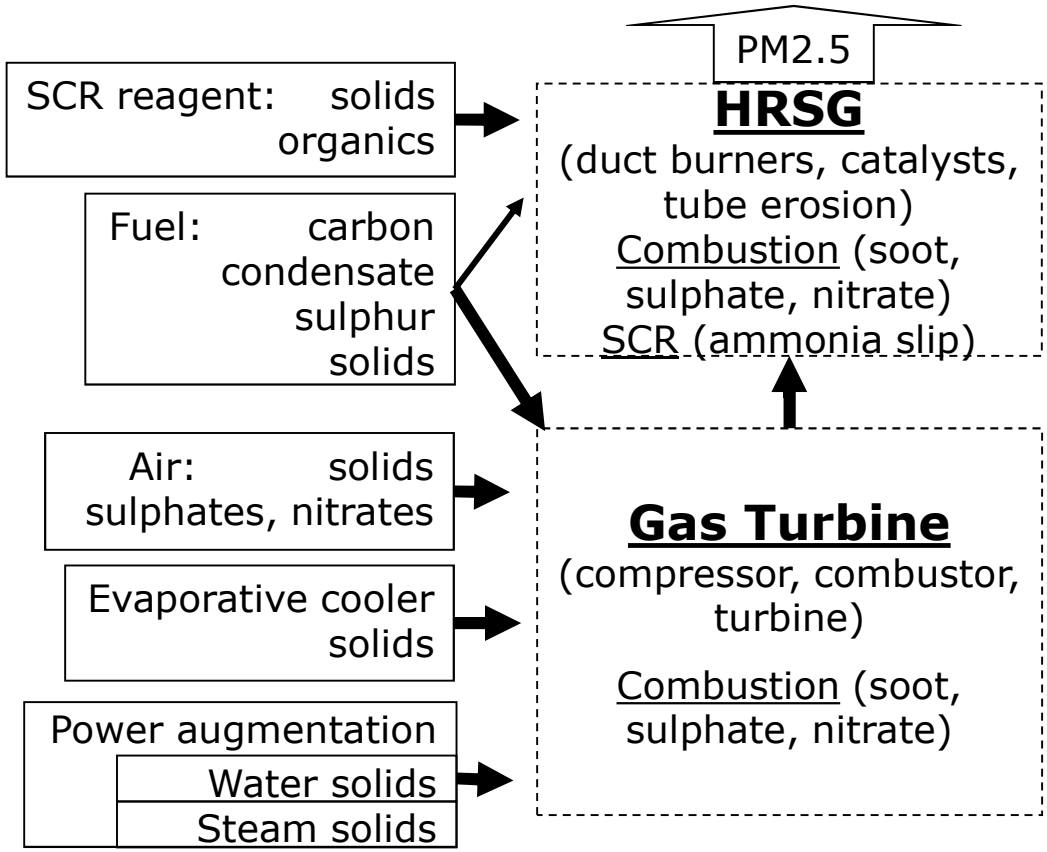
EMISSION FACTORS

- Emission factor data
- PM2.5 mass & species
- Application
- Summary

PM2.5 EMISSION FACTOR IMPROVEMENT FOR NATURAL GAS-FIRED ENGINES

- PM2.5 in ambient air
  - ❖adverse human health and environmental effects
- PM2.5 emissions from gas-fueled combustion systems
  - ❖Very low compared with other source types
  - ❖Barrier to licensing & permitting at gas transmission facilities, power plants, refineries, etc.
- Typical filterable & condensable PM emission factors
  - ❖Significantly <u>overestimate actual emissions</u> for gas combustion
  - ❖Inaccuracy of the underlying test methods at very low concentrations

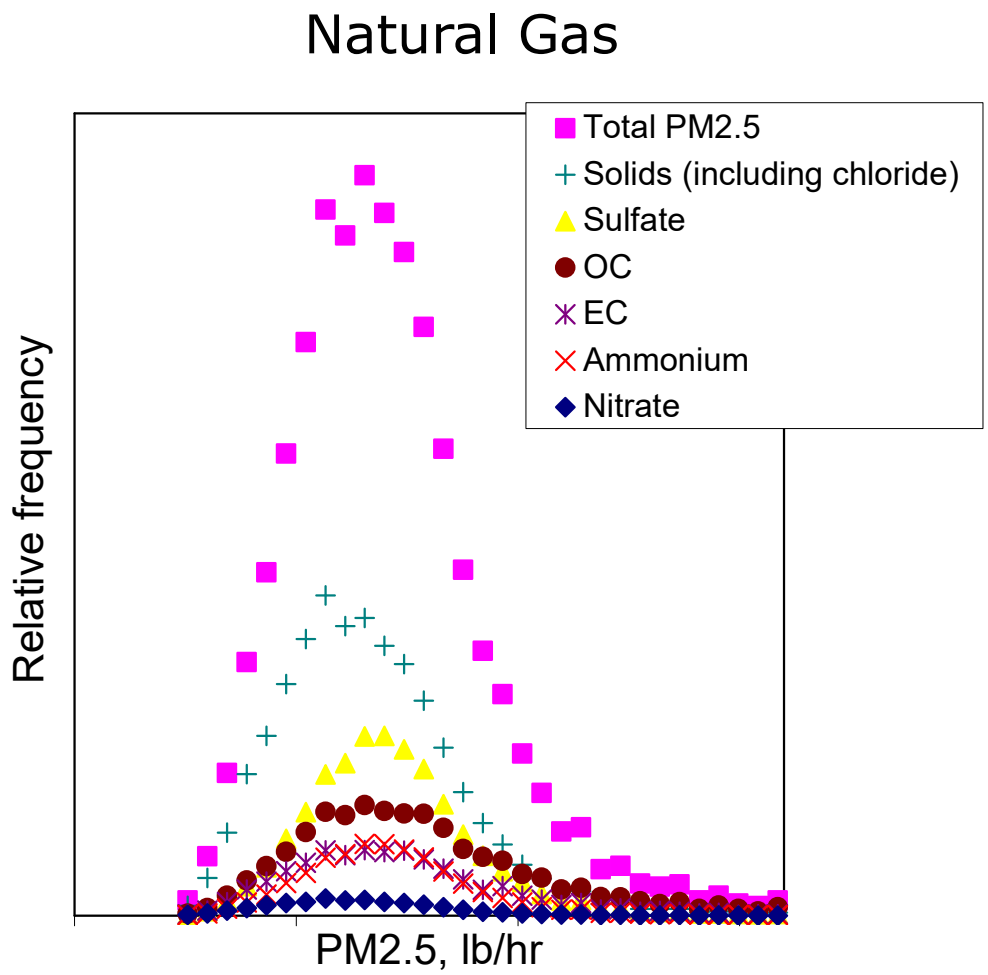
SOURCES OF PM2.5 IN GAS COMBUSTION SYSTEMS



- Combustion and post-combustion conversion of sulphur (& chlorine) to acid aerosols & salts (e.g., ammonia, transition elements)
- Incomplete fuel combustion (carbon conversion to soot, organics)
- Vaporization and condensation of volatile species
- Transmission of non-volatile species
- Size transformations
- Corrosion/erosion of system components

ESTIMATED PM2.5 FROM INPUTS

- Input streams have finite impact on probable PM2.5 emissions



WHAT IS PRIMARY (DIRECTLY EMITTED) PM?

Filterable $PM_{2.5}/PM_{10}$
"Particles that are directly emitted by a source as a solid or liquid at stack or rel ease conditions and captured on the ***filter of a stack test train****."*

Defined by the test methods

Condensable PM
"Material that is vapor phase at stack conditions, but which ***condenses and/or reacts upon cooling and dilution*** *in the ambient air to form solid or liquid PM immediately after discharge from the stack."*

Defined by behavior in the plume near the stack

Definitions – U.S. Code of Federal Regulations (40 CFR 51, § 51.50)
Consolidated Emissions Reporting Rule

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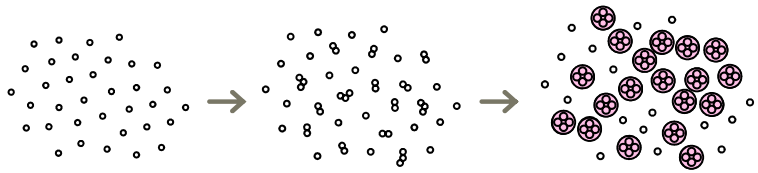
WHAT IS PRIMARY PM?

Condensable PM forms from vapors in diluted stack gas plume as it mixes with atmosphere → Examples of cPM precursors

- Sulfuric acid
- Nitric acid
- Semivolatile organic compounds



molecules → clusters → stable clusters

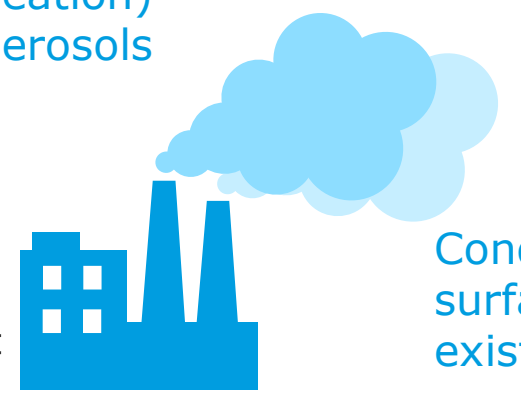
Direct gas-to-particle condensation (nucleation) forms ultrafine liquid aerosols

Fast liquid-gas and gas-gas reactions near stack: (fPM & cPM)

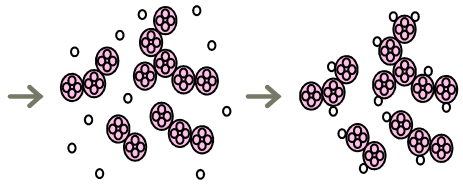
$HCl\ (g) + NH_3\ (g) = NH_4Cl\ (s)$

$H_2SO_4\ (l) + NH_3\ (g) = (NH_4)_2SO_4\ (s)$

Filterable PM: fly ash, soot, process solids, solid & liquid aerosols at filter temperature



Condensation on surface of new or existing fine aerosols



The way cPM forms in the plume is important when deciding how to best measure it in exhaust emissions

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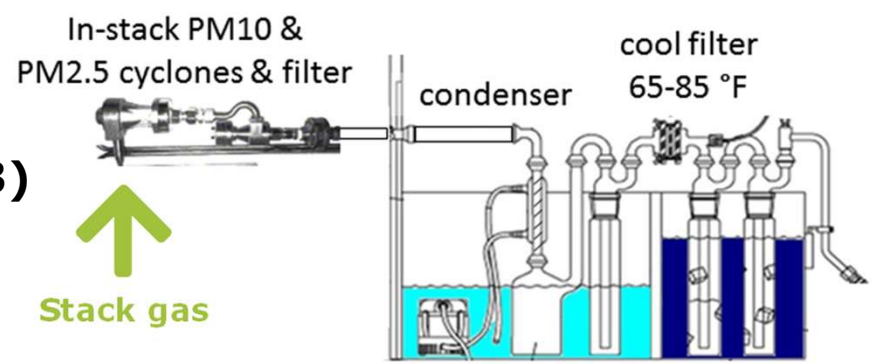
PM10/2.5 MEASUREMENTS

TRADITIONAL HOT FILTER/COOLED IMPINGER METHODS

- Filterable PM10/2.5 collected on hot filter after cyclones to remove larger particles
- Condensable PM collected in cooled impingers (with condensed water vapor)
- **Measurement issues for gas combustion**:
  - *Insufficient sensitivity at low concentrations*
  - *cPM: measurement artifacts in liquid phase (gases converted to residues e.g. SO_2, NH_3, VOC)*
  - *Both contribute to high bias in test results*

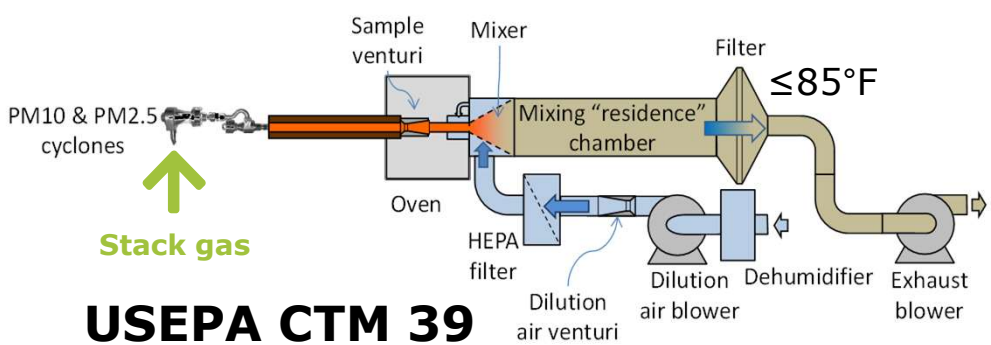
E&CCC EPS 1/RM/55 Methods G/H (2013)
USEPA 201A/202 (2010)



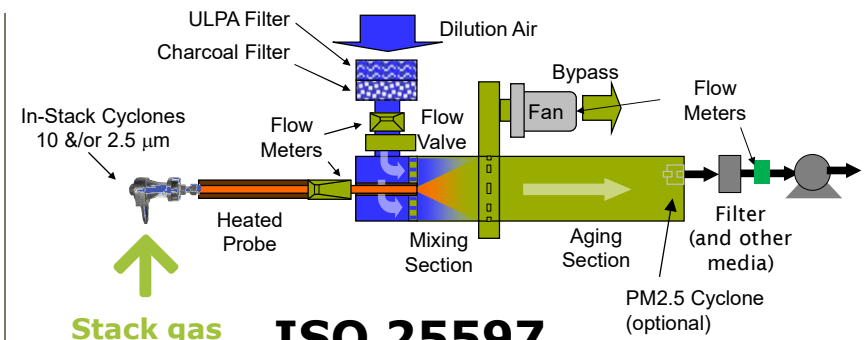
PM10/2.5 MEASUREMENTS

DILUTION SAMPLING METHODS *for stationary sources*

- In-stack cyclones to remove particles larger than PM10/2.5
- Cool hot stack gas to ambient temperature by dilution
  - ❖Filterable PM2.5 & condensable PM collected together on same filter
- Replicates condensable PM formation in stack plume
- No water vapor condensation (therefore no liquid-phase artifacts)



USEPA CTM 39 (2004)

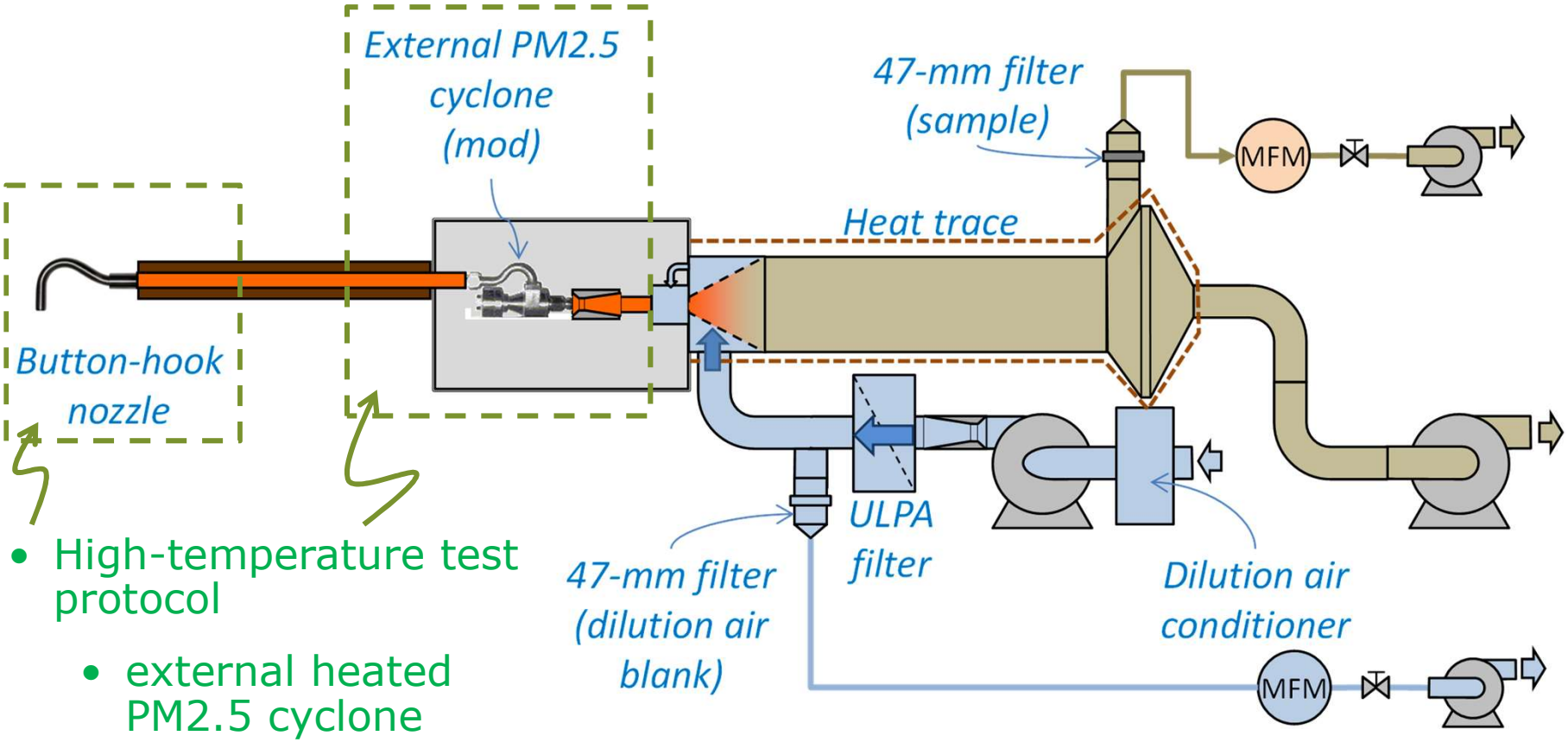


ISO 25597 (2013)

MODIFIED USEPA CTM 39 DILUTION METHOD

- Test protocol is well-developed (3rd generation/9 tests from 2008 inception)
  - ❖Power plant (combined cycle); Refinery (boilers/heaters); CEPEI (pipeline compressor engines)
  - ❖Has been approved for compliance performance tests (relative to limit based on similar method)
  - ❖Test method publication in progress
- Modified hardware (electropolish, ULPA filter, sample filter attachments, others)
- Exclude recovery rinses (if below method detection limits)
- Modified calculations (elements of ISO 25597)

MODIFIED USEPA CTM 39 DILUTION METHOD



- High-temperature test protocol
  - external heated PM2.5 cyclone (~OTM 36)

MODIFIED USEPA CTM 39 DILUTION METHOD

- Ambient air sample collection and analysis methods
- Well proven & validated
- Collect mass on 47-mm Teflon membrane filters
  - ~10x more sensitive (precision) than glass fiber filters
- 1 microgram analytical balance
  - 100x more sensitive
- Equilibrate filters at T and RH rather than dry

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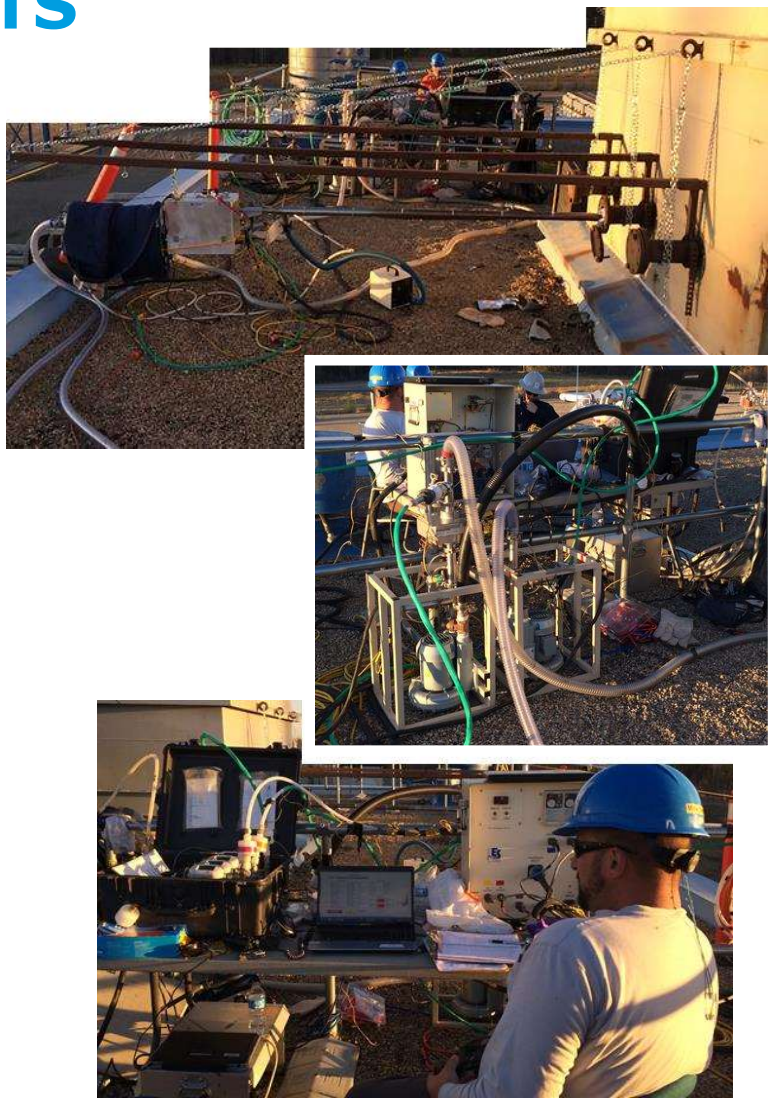
CEPEI PREOJECT FIELD TESTS

- Natural gas
- Reciprocating IC engine "RICE"
  - ❖3130 hp with precombustion chambers & A/F controller
- Gas turbine
  - ❖27.5 MW with DLE combustors
- Tests
  - ❖Samples 3x 240 minutes
  - ❖Blanks



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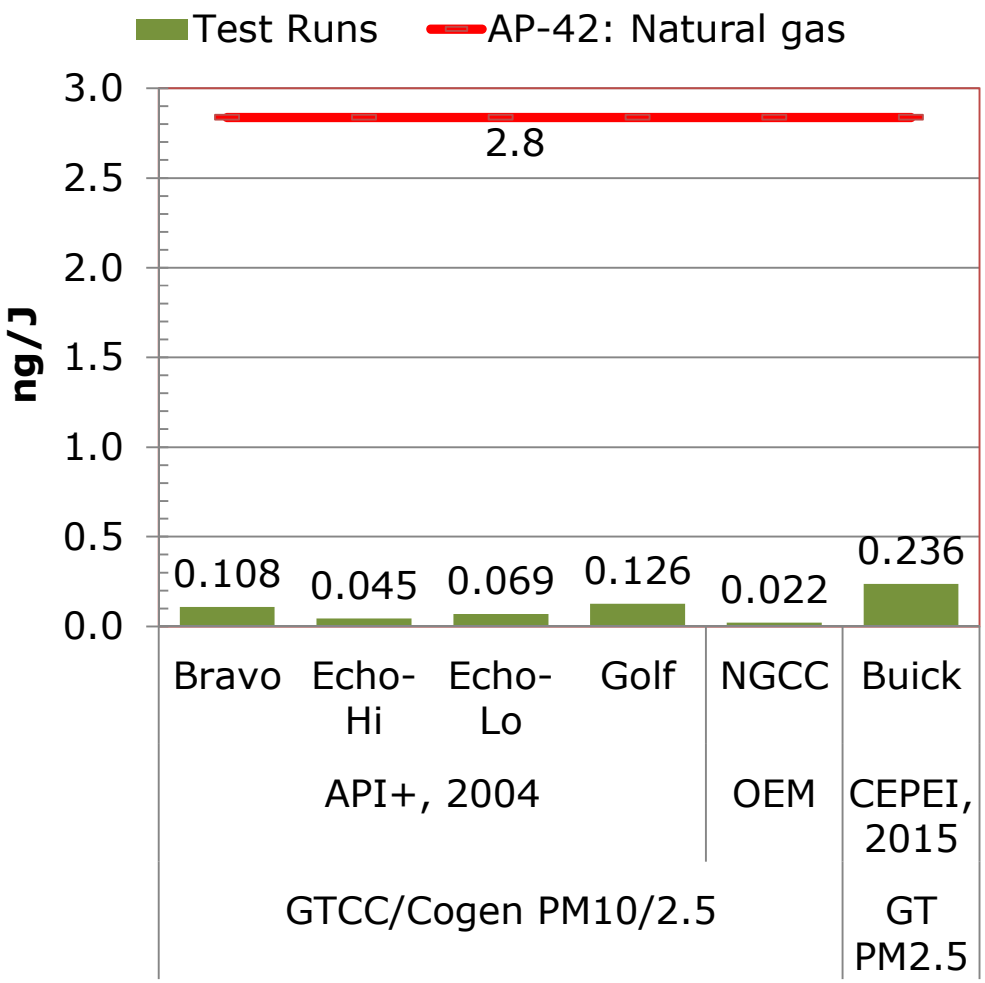
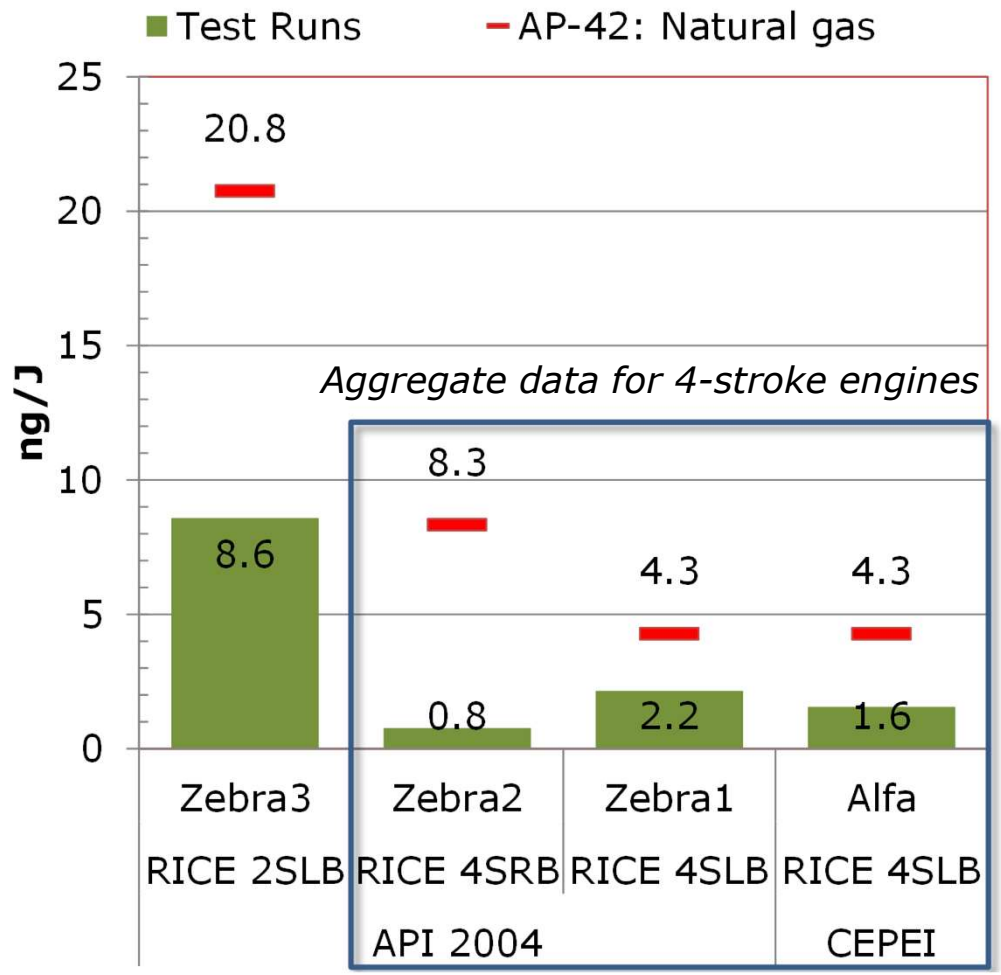
EMISSION FACTOR DATA SET: GAS TURBINES

- 5 units/27 runs
  - ❖27.5 MW simple cycle, LPC
  - ❖160 MW combined cycle w/ duct burners, LPC+SCR+CO catalyst
  - ❖170 MW combined cycle w/ duct burners, LPC+SCR+CO catalyst
    - ○high and low load tests (with & without duct burners)
  - ❖170 MW combined cycle, LPC+SCR
  - ❖48 MW cogen w/ duct burners, WI+SCR+CO catalyst
- Insufficient data to subcategorize by size or emission controls



EMISSION FACTOR DATA SET: RECIPROCATING ENGINES

- Natural gas
- Three four-stroke engines
  - ❖Two lean burn engines
    - ○3130 hp, PCC+A/FC
    - ○1665 hp, no controls
  - ❖One rich burn engine
    - ○1626 hp + NSCR, turbo
  - ❖Insufficient data to subcategorize by four-stroke engine family
- One two-stroke engine
  - ❖2700 hp, lean burn, PCC, turbo
  - ❖Design makes PM emissions significantly higher than four-stroke engines



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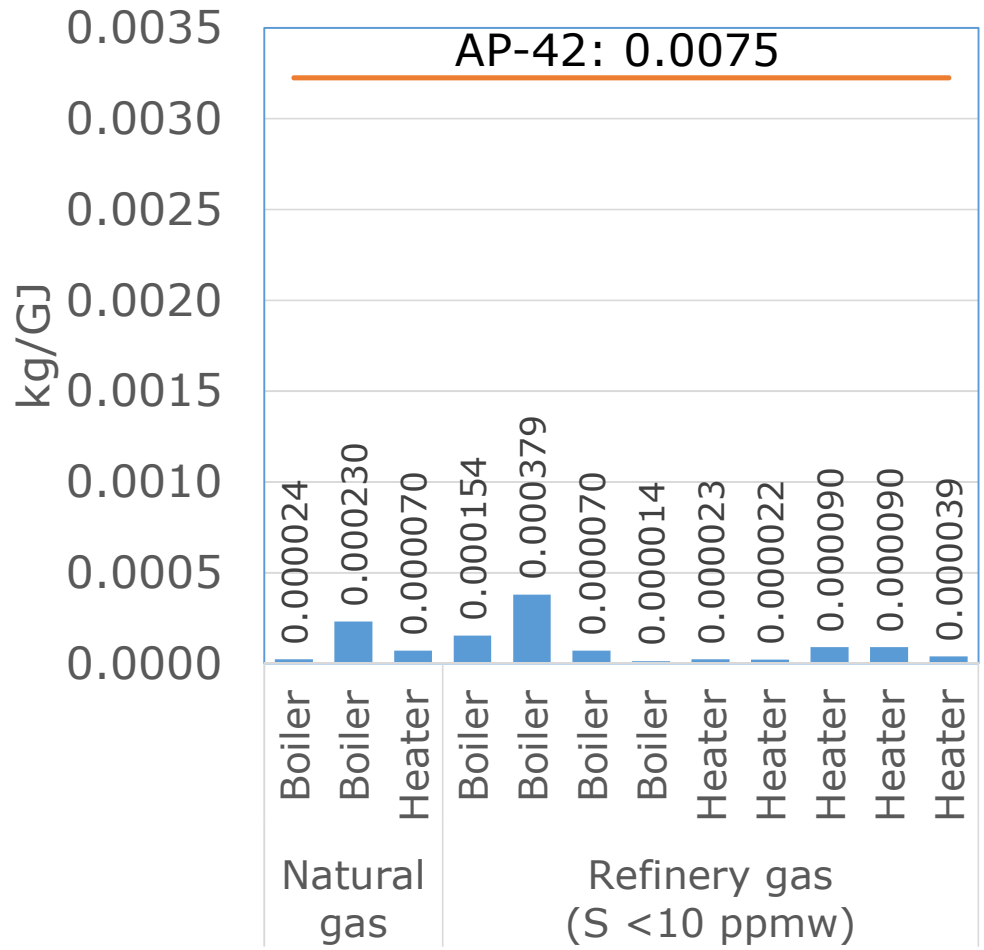
EMISSION FACTOR DATA SET: BOILERS/HEATERS

- Natural gas (3 units)
  - ❖Dual fuel institutional boiler (no controls)
  - ❖Steam generator (low-NO_X burner)
  - ❖Refinery heater (low-NO_X burner)
- Refinery gas (9 units)
  - ❖4 Refinery boilers (3 with SCR, 2 with low–NO_X burners)
  - ❖5 Refinery heaters (low- or ultra-low NO_X burners, 1 with SCR)



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PM10/2.5 EMISSION FACTORS: COMPARE WITH AP-42

		PM10/2.5, kg/GJ		
	Parameter	gas turbines /NGCC/Cogen	four-stroke reciprocating engines	external combustion (Boilers/heaters)
CEPEI	Recommended default: 99% upper prediction limit	0.00038	0.0071	0.00064
	average±95% uncertainty	0.00010±80%	0.0015±116%	0.00010±69%
	# of units (tests)	5 (6)	3	12
AP-42	average±95% uncertainty	0.0028±85%	0.0067±446%	0.0032±122%
	# of units	5	5 filterable PM *2* condensable PM	21 filterable PM *4* condensable PM

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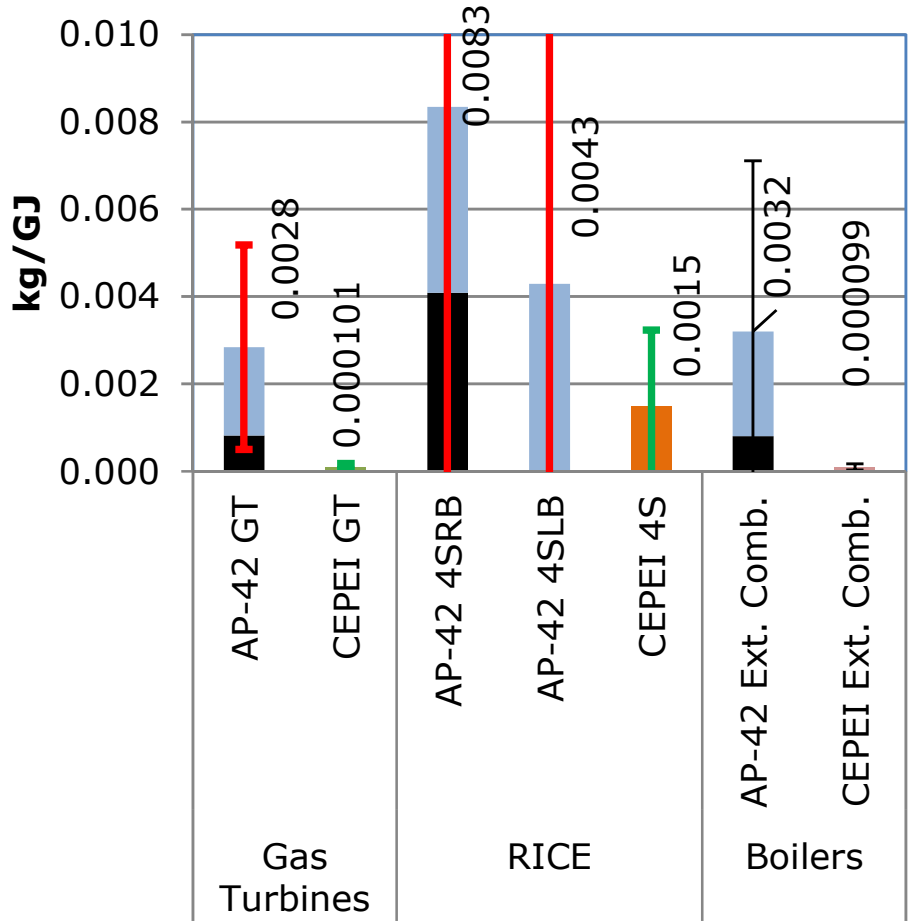
PM2.5 MASS EMISSION FACTORS

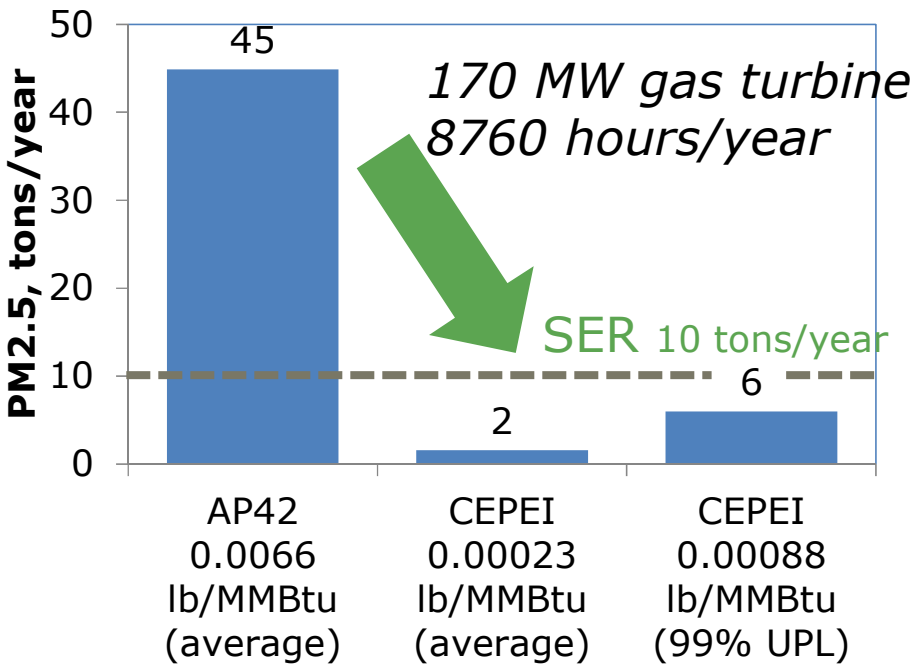
- CEPEI vs AP-42
  - ❖Lower average emission factors based on more accurate dilution test method
  - ❖Significantly less statistical uncertainty



Error bars = ±95% uncertainty

IMPLICATIONS: US NSR PM2.5 PERMITTING

- Estimated PM emissions using more accurate dilution-based emission factor below major source PM2.5 significant emission rate (SER)
  - ❖No PSD analysis
  - ❖No offsets/mitigation required
  - ❖Less time until start-up
  - ❖Less cost to permit



Can be a significant advantage when faced with PSD permitting in PM2.5 non-attainment areas…BUT with some risks due to limited test availability and small data sets

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KEY FINDINGS – NATURAL GAS-FIRED ENGINES

- 3rd-generation **dilution sampling protocol is more accurate** than hot filter/cooled impinger methods due to more sensitive gravimetric procedures and absence of measurement artifacts
- Improved PM2.5 mass emission factors for natural gas-fired engines
  - ❖**More accurate** PM2.5 emission estimates that are lower than AP-42
  - ❖**More robust** data set with **lower uncertainty**
  - ❖Includes engines in U.S. and Canada
- PM2.5 species profiles for use with dilution-based PM2.5 mass measurements enable **more accurate** source apportionment and health risk assessment
- **Lower PM10/2.5 emissions estimates** can avoid need for PSD analysis and mitigation, shortening time for permitting and enabling earlier production

CONSIDERATIONS

- Small emission factor data sets
  - As with AP-42, vulnerable to new data
  - Limited range of source & emission control configurations
  - Test results not yet widely reproduced by others
- Test protocol not yet widely available
  - Method currently offered by few testers
  - Learning curve – best practices
  - Currently developing a test method for publication
- Engine, boiler manufacturers not yet willing to guarantee at these lower levels
- Prospect of lower PM2.5 BACT (without consideration of test method?)

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CONSIDERATIONS

- PM2.5 NSR and NNSR permitting with condensable PM since 2012 much more challenging
  - Modified CTM 39 protocol enables precise measurements at lower PM limits
- Lower emission factors, PM speciation profiles are beneficial for health risk impact assessments
- Cost & strategic benefits of avoiding PSD (modeling, offsets, time) can increase permitting flexibility and significantly outweigh technical risks
- Net benefit will be site specific

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ACKNOWLEDGEMENTS

- This work was supported by
  - ❖Canadian Energy Partnership for Environmental Innovation (CEPEI)
  - ❖British Columbia Oil and Gas Research and Innovation Society (BC OGRIS)
  - ❖Petroleum Technology Alliance Canada (PTAC)
- The American Petroleum Institute contributed additional test data for natural gas-fired reciprocating engines
- Montrose Air Quality Services LLC assisted with measurements

Questions?

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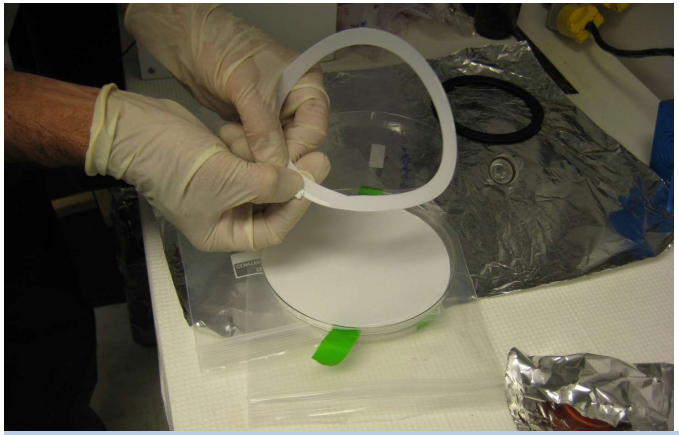
BACK UP SLIDES

SOME CTM 39 ISSUES (AS PUBLISHED)

142-mm PTFE coated glass fiber filters



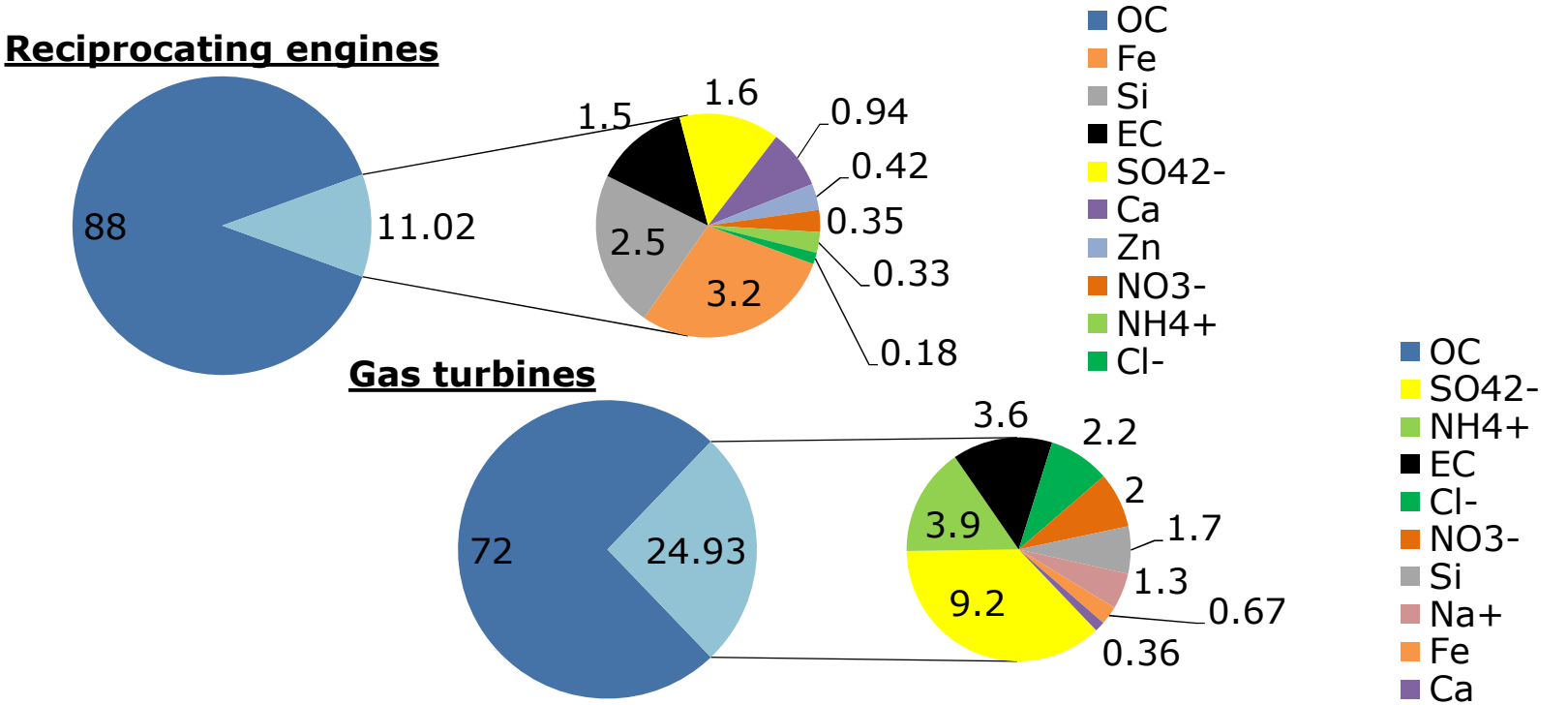
Fragmentation of fiber filters leads to imprecision & loss of sensitivity

- Teflon-coated surfaces – promote surface deposits due to electrostatic charge
- Dilution air supply – blank levels can contribute significantly to stack levels for gas-fired sources

Recovery rinses

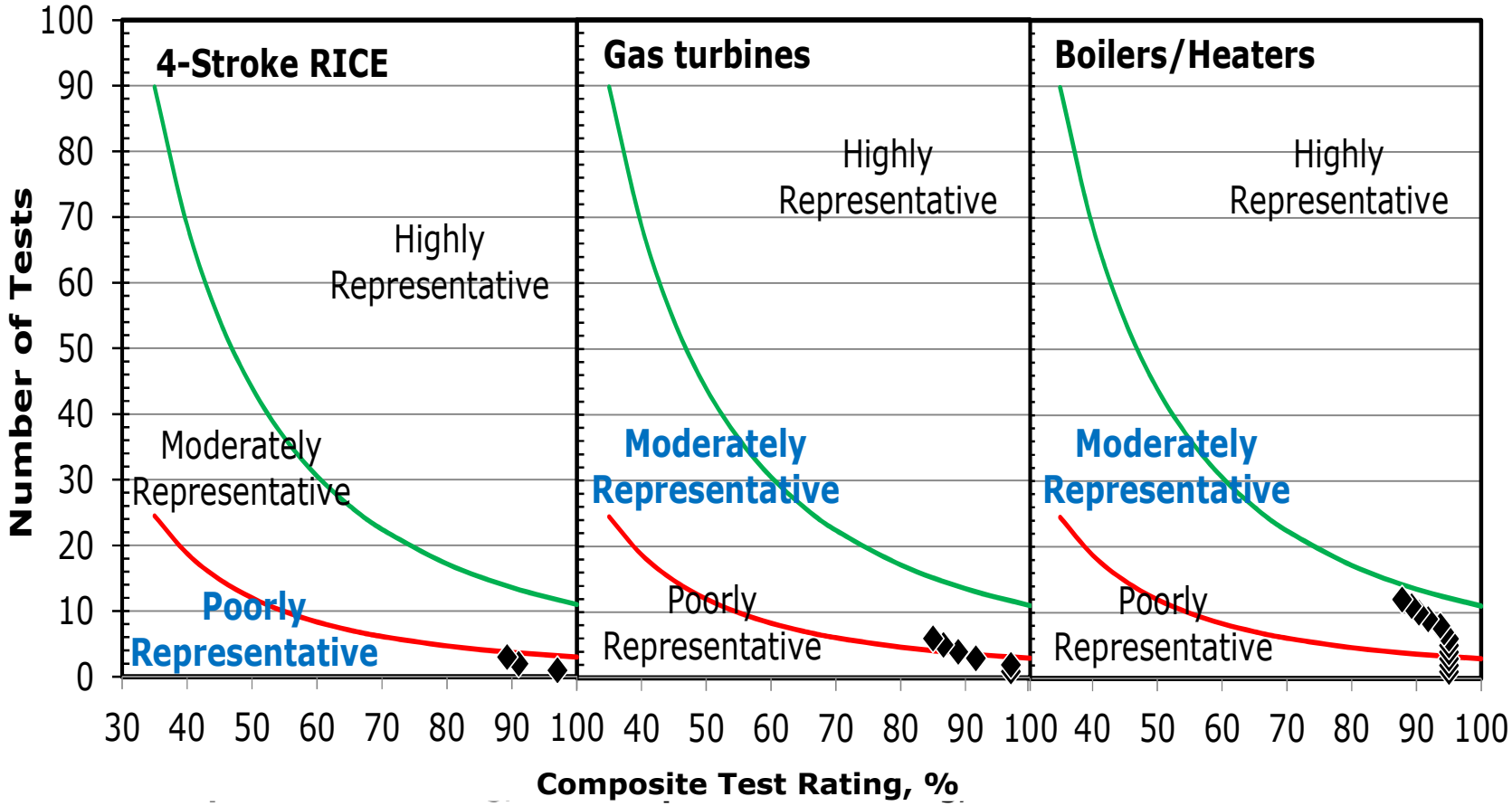
Sample recovery rinse procedure lacks sensitivity

PM2.5 SPECIES PROFILES FOR GAS FUELS COMBUSTION



Use **only** with PM2.5 mass determined by dilution method!

EMISSION FACTOR QUALITY RATING



- U.S. EPA 2013 emission factor development guidelines

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