Test Experience for Harbor craft and Ocean Going Vessels to 2011

Ocean Going Vessels: main engines

- Feb 04 Container Ship I
- Oct 06 Container Ship IV
- Feb 07 Oil tanker
- July 07 Container Ship I
- Sept 07 Container Ship IV
- Sept 08 Container Ship IV
- Jun 09 Container Ship IV
- Aug 09 Container Ship IV
- Apr 10 Container Ship V
- Sept 10 Container Ship VI (Tier1)

Ocean Going Vessels: auxiliary engines

- Feb 04 Container Ship I
- May 05 Container Ship II
- July 05 Container Ship II
- Oct 05 Container Ship II
- Dec 05 Container Ship II
- Dec 05 Container Ship III
- Mar 06 Container Ship II
- Oct 06 Container Ship IV
- Nov 06 RORO
- Feb 07 Oil tanker
- Apr 10 Container Ship V

Ocean Going Vessels: auxiliary boiler

- Feb 07 Oil tanker
- Sept 07 Container ship IV

Harbor Craft: main & auxiliary engines

- Mar 06 Ferry exhaust control
- Jun 06 Shuttle: Biodiesel
- Aug 06 Activity studies
- Sept 06 Dredger: engine control
- Oct 06 Dredger: exhaust control
- Oct 08 Workboat: T2 & biodiesel
- Feb 09 Ferry: T2 & biodiesel –
- Sept 09 AZ Shuttle: T2 & biodiesel
- Oct 10 First hybrid tug
- Sept 11 Great Lakes vessel + algal fuel
- Dec 11 Retrofit tug

Developing Emission Factors

- Required for inventory and…
  - Planning air quality control strategies
  - Assessing air quality control effectiveness

$$E = EF \times P \times LF \times Activity \times (1 - Control)$$

Where,	E	total emissions from a source (g/day)
	EF	Emission Factor (g/kW-hr)
	P	Maximum rated power (kW)
	LF	Load factor (fraction of maximum rated power)
	Activity is expressed in hours per day	
	Control is emissions reductions due to control technology	

Discussion Topics

- Develop test protocols for measuring emission factors for:
  - Regulated emissions (criteria pollutants)
  - Greenhouse gases
  - Non-regulated emissions:
    - e.g., hazardous air pollutants (HAPs)
- Measure the efficiency of control technology
- Frontier measurements: in-use or real time emissions; health effects, …

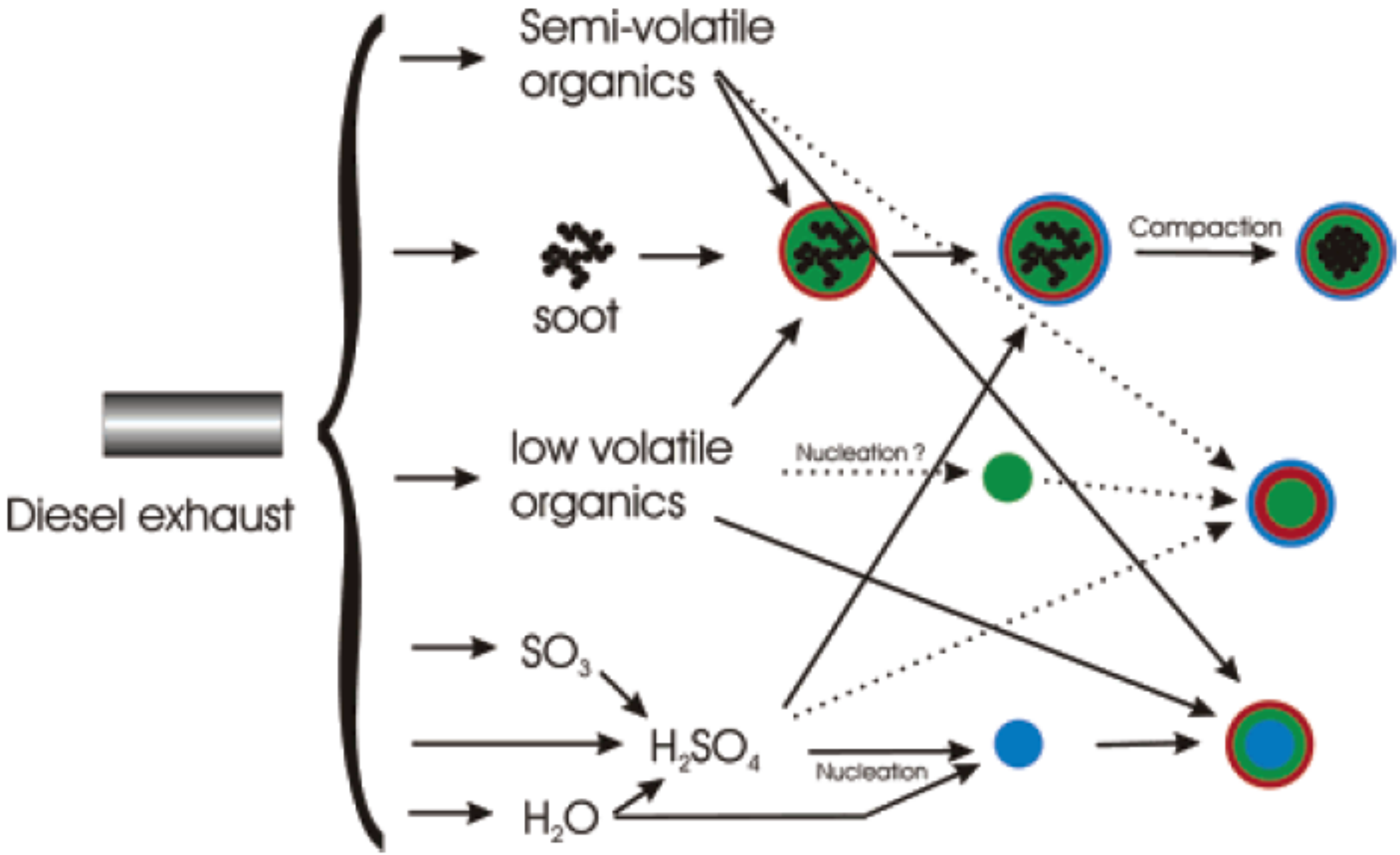
Measuring Emission Factors

- Pre-meeting with vessel crew to review:
  - Safety and environmental policies
  - Location of sample ports
  - Identification of utilities and ratings for electrical and compressed air
  - Location of fueling sites if fuel study
- First test day:
  - Install emission equipment
  - Measure engine map & check emission equipment.
- Specify engine operating conditions & test matrix
- Fix test schedule of the time at various loads.

Measuring Emission Factors

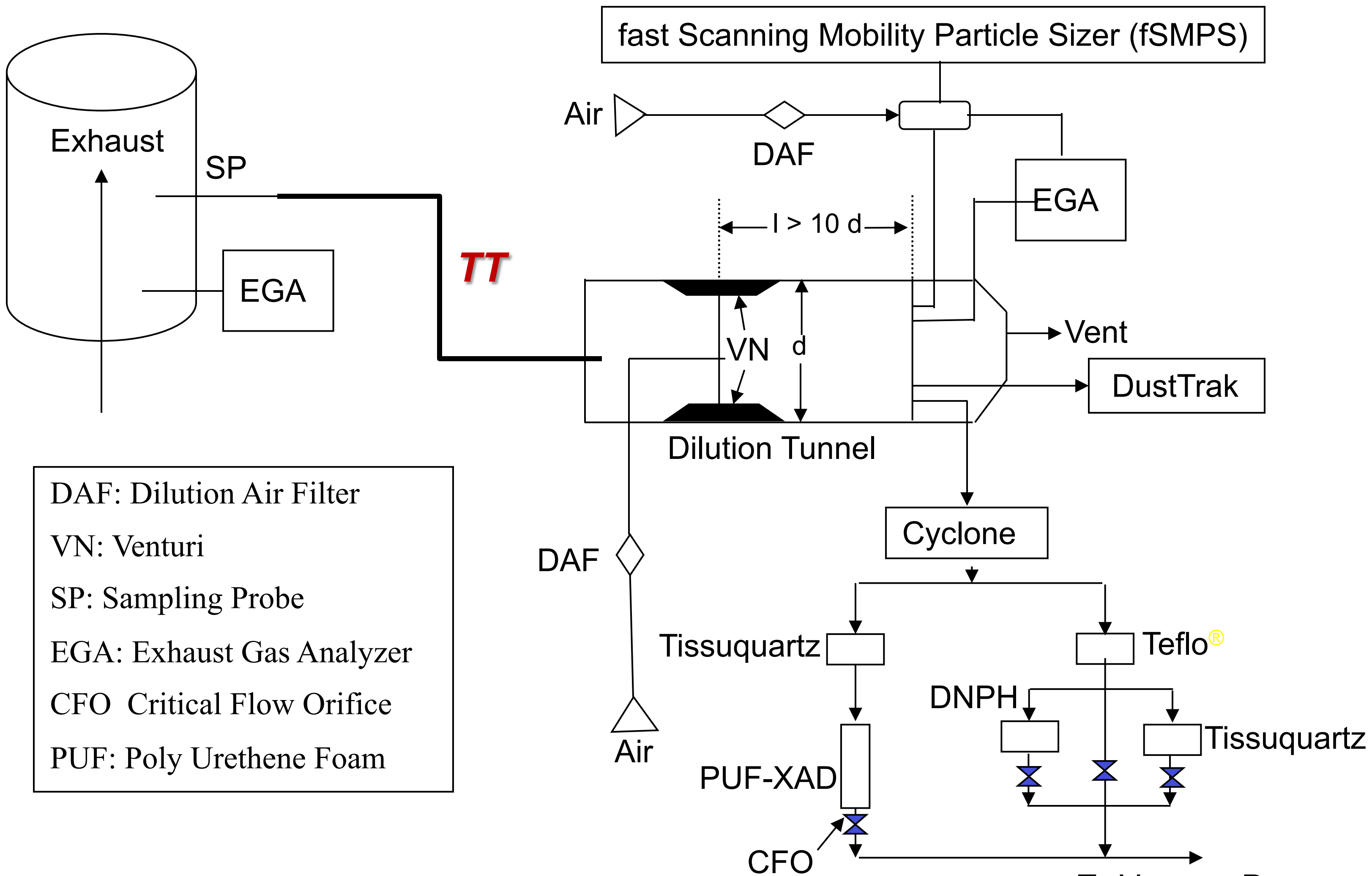
- Propulsion engine operation (AE different)
  - Near term: follow ISO 8178-4 cycle for comparison
  - Longer term: follow actual in-use conditions
- Gases monitored by ISO/EPA methods
  - NO_x Chemiluminescence detector
  - CO, CO_2 Non dispersive infrared
  - HCs GC/FID
  - SOx Calculate from fuel
- Particulate matter (PM)
  - Use ISO 8178-1 partial dilution method for mass
  - Other methods used for PM speciation.
- Emission factor determined from power setting, calculated mass flow & emission concentration.

PM Measurements of Diesel Exhaust is Complex



Schneider, J, E. S.&T.2005, 39,6153-6161

Emission Measurement System



DAF: Dilution Air Filter

VN: Venturi

SP: Sampling Probe

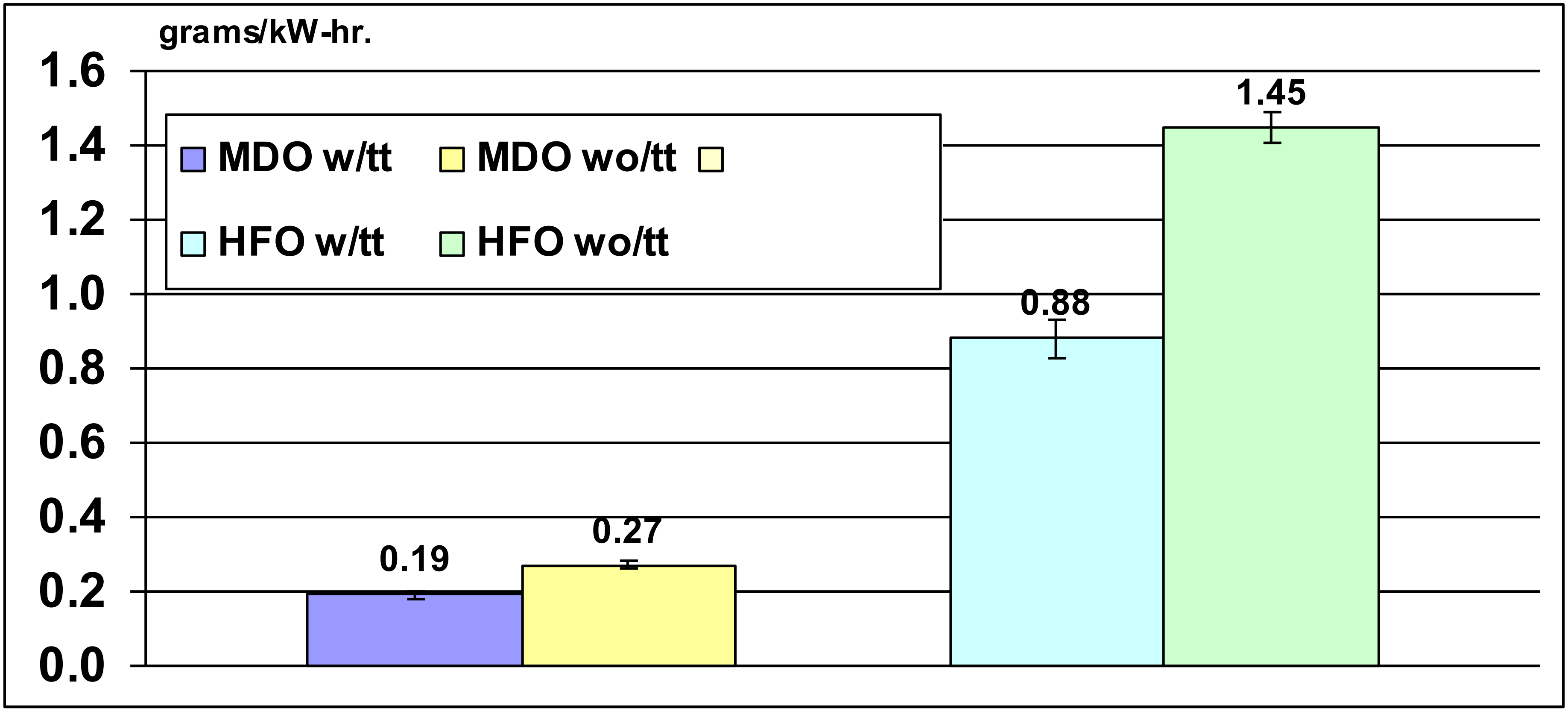
EGA: Exhaust Gas Analyzer

CFO Critical Flow Orifice

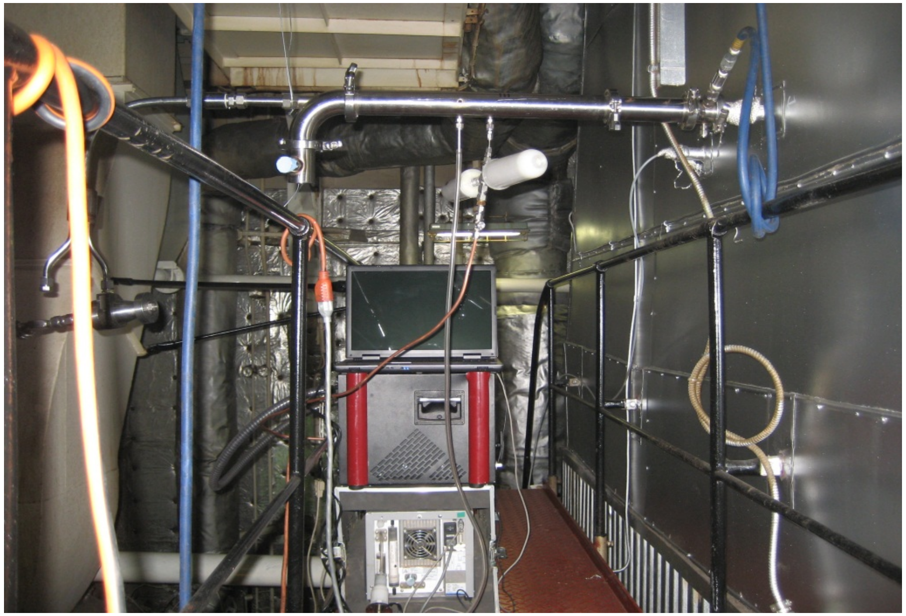
PUF: Poly Urethene Foam

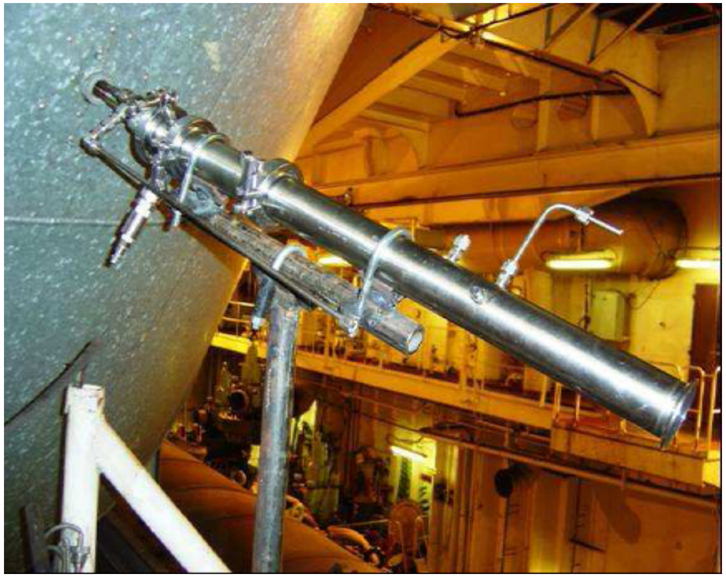
Based on ISO 8178-1 Protocol

Learned Lesson : Measure PM without a Transfer Tube




STATION
8
PPE FOR
I.G FAN
WASHING





Study 1: Test Engines for Ocean Going Vessel

- Main Engine (ME)
  - Sulzer 6RTA72
  - 21000 hp, ~90 rpm
  - Displacement: 1,018 liters/ cylinder X 6 cylinders
- Auxiliary Engine (AE)
  - Wartsila Vasa 6R22/26
  - 900 kW, ~ 1500 rpm
  - Displacement: 9.88 liters/ cylinder X 6 cylinders
- Boiler
  - ADM 707
  - Dry weight: 70.2 ton

Test at Loads of International Standard Cycles

- Test Cycle for Main Engines

ISO 8178 -E3

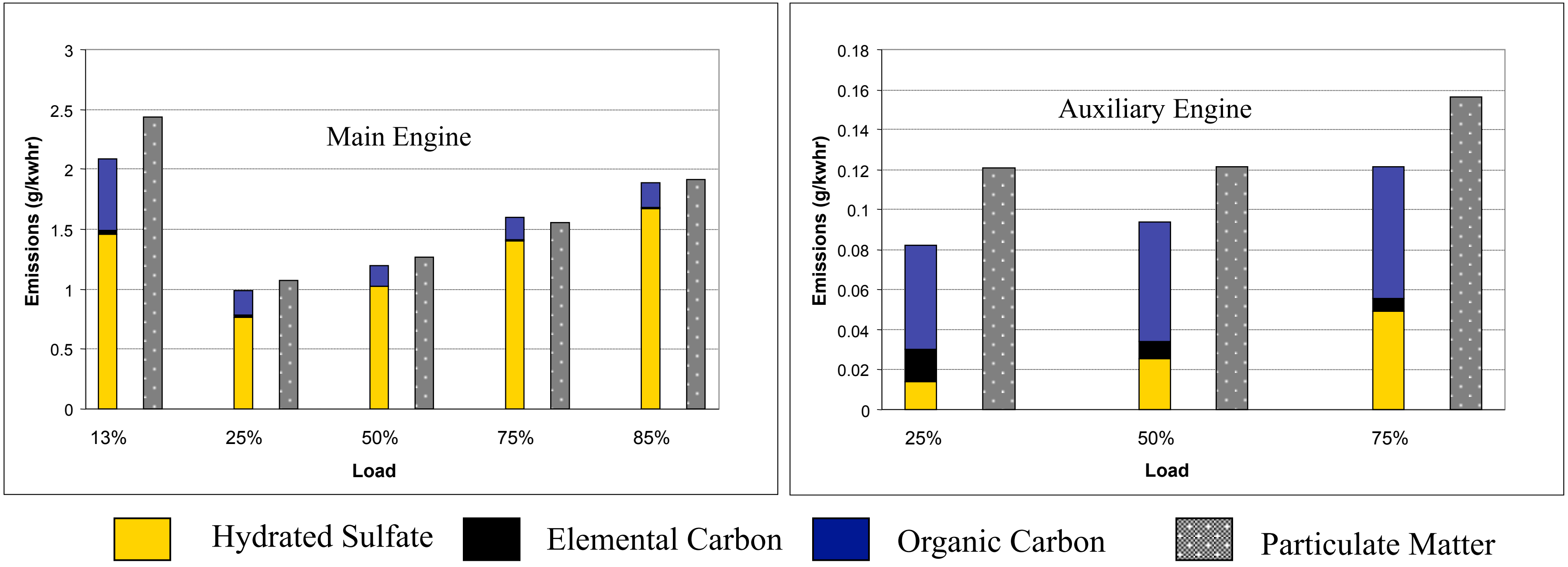
Mode	1	2	3	4
Power (%)	100	75	50	25
Speed (%)	100	91	80	63
Weighting Factor	0.2	0.5	0.15	0.15

- Test Cycle for Auxiliary Engines

ISO 8178 - D2

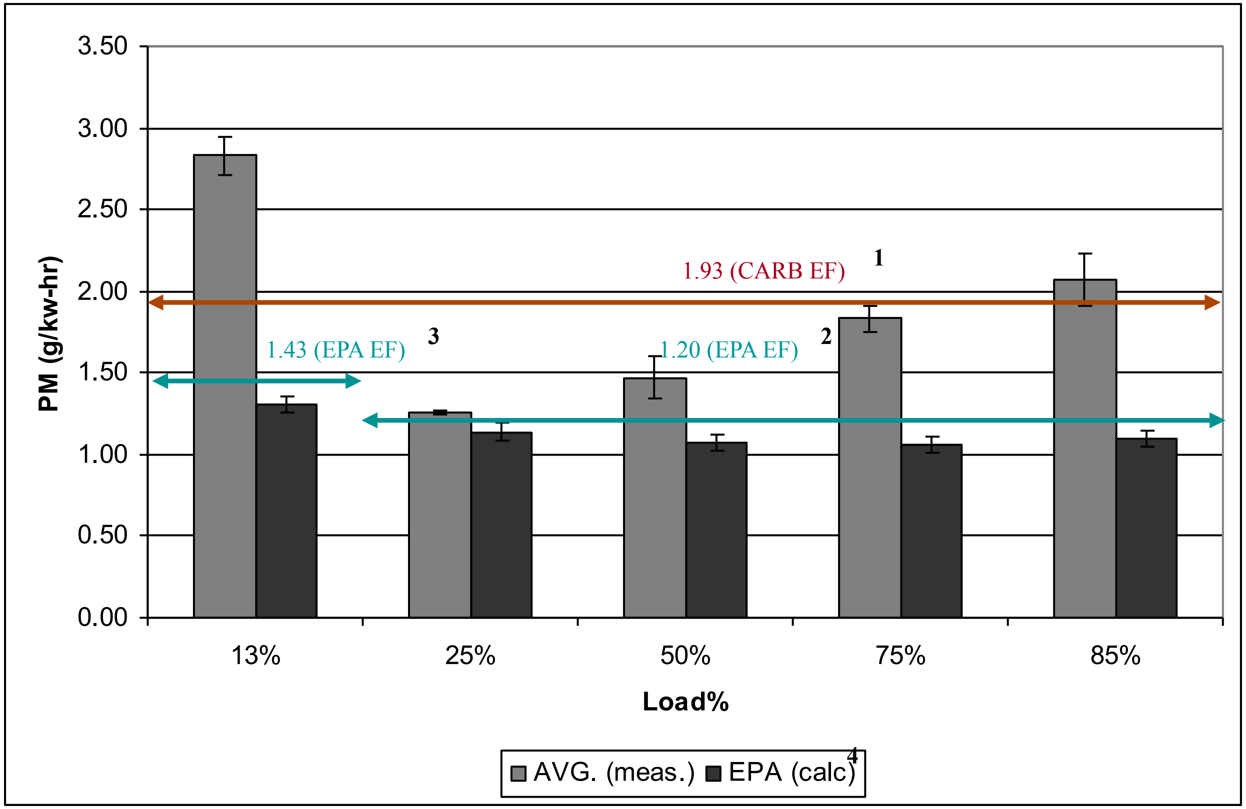
Mode number	Engine Speed	Observed Torque (rpm)	Minimum time in mode (min)	Weighting factors
1	Rated	100	5.0	0.05
2	Rated	75	5.0	0.25
3	Rated	50	5.0	0.30
4	Rated	25	5.0	0.30
5	Rated	10	5.0	0.10

Ship Emission Factors: PM Fractions



- Hydrated sulfate (75%) + EC (5%) + OC (25%) ≈ PM
- Sulfur from fuel to Sulfate Conversion
  - Main Engine : 1.4% to 5% as engine load increased from 25% to 75%
  - Auxiliary Engine : 1.9% to 3.9% as engine load increased from 25% to 85%

Compare PM Emission Factor: Measured vs. Estimated



[1] from CARB "Emissions Estimation Methodology for Ocean-Going Vessels," October, 2005 (transit/maneuvering modes, corr. from 2.5 wt. % to 2.85 wt.% S fuel)
2 from US EPA "Current Methodologies and Best Practices in Preparing Port Emission Inventories," January, 2006 (corr. from 2.7 wt.% to 2.85 wt.% S fuel)
3 from reference (2), corr. to 13% load
4 from Environ/EPA calculation based on brake-specific fuel consumption and 2.85 wt. % S fuel

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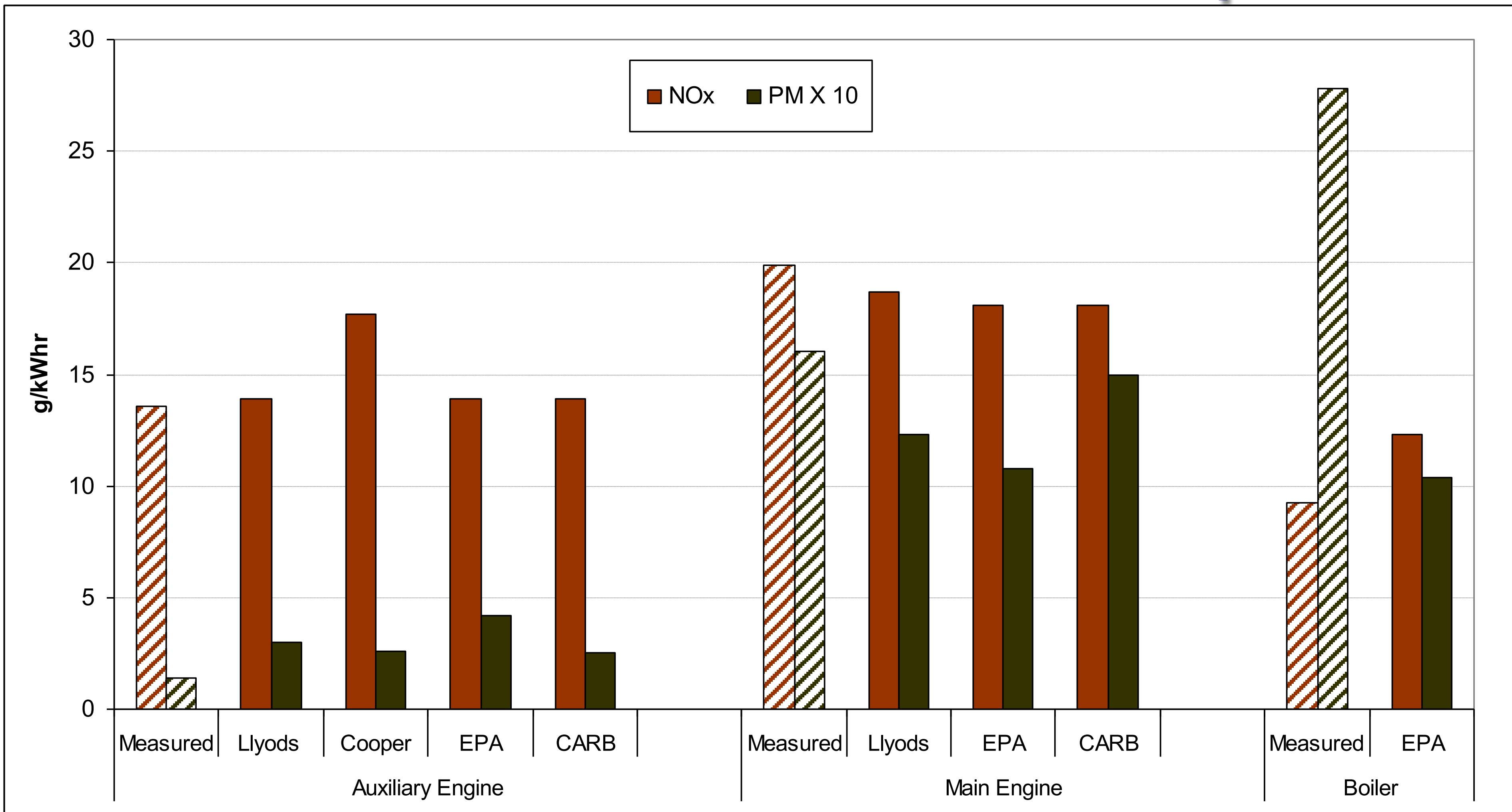
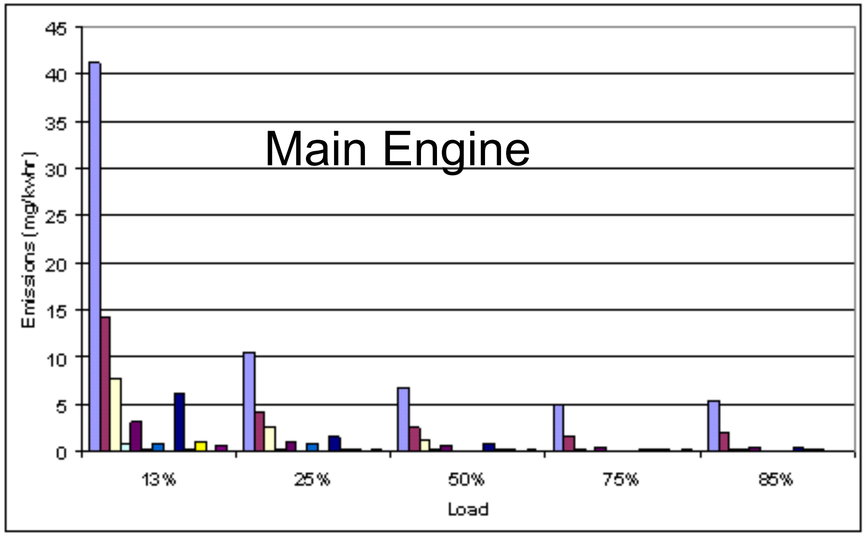
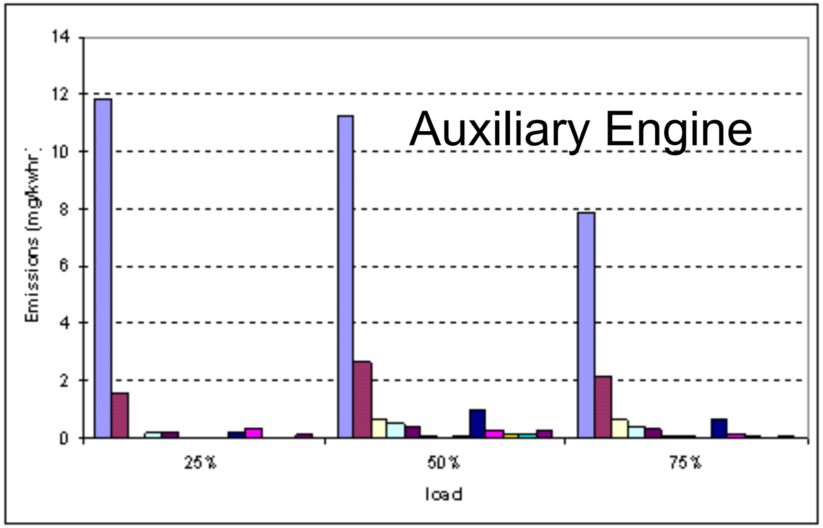
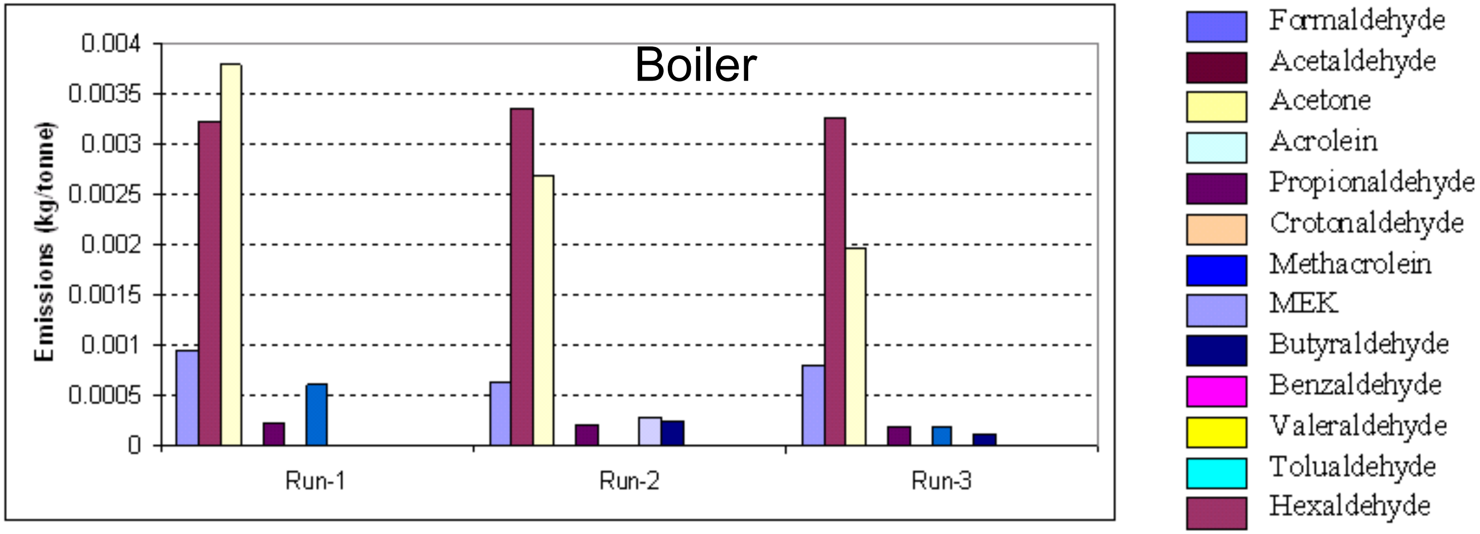
Compare: Measured & Reported Emission Factors for Ships



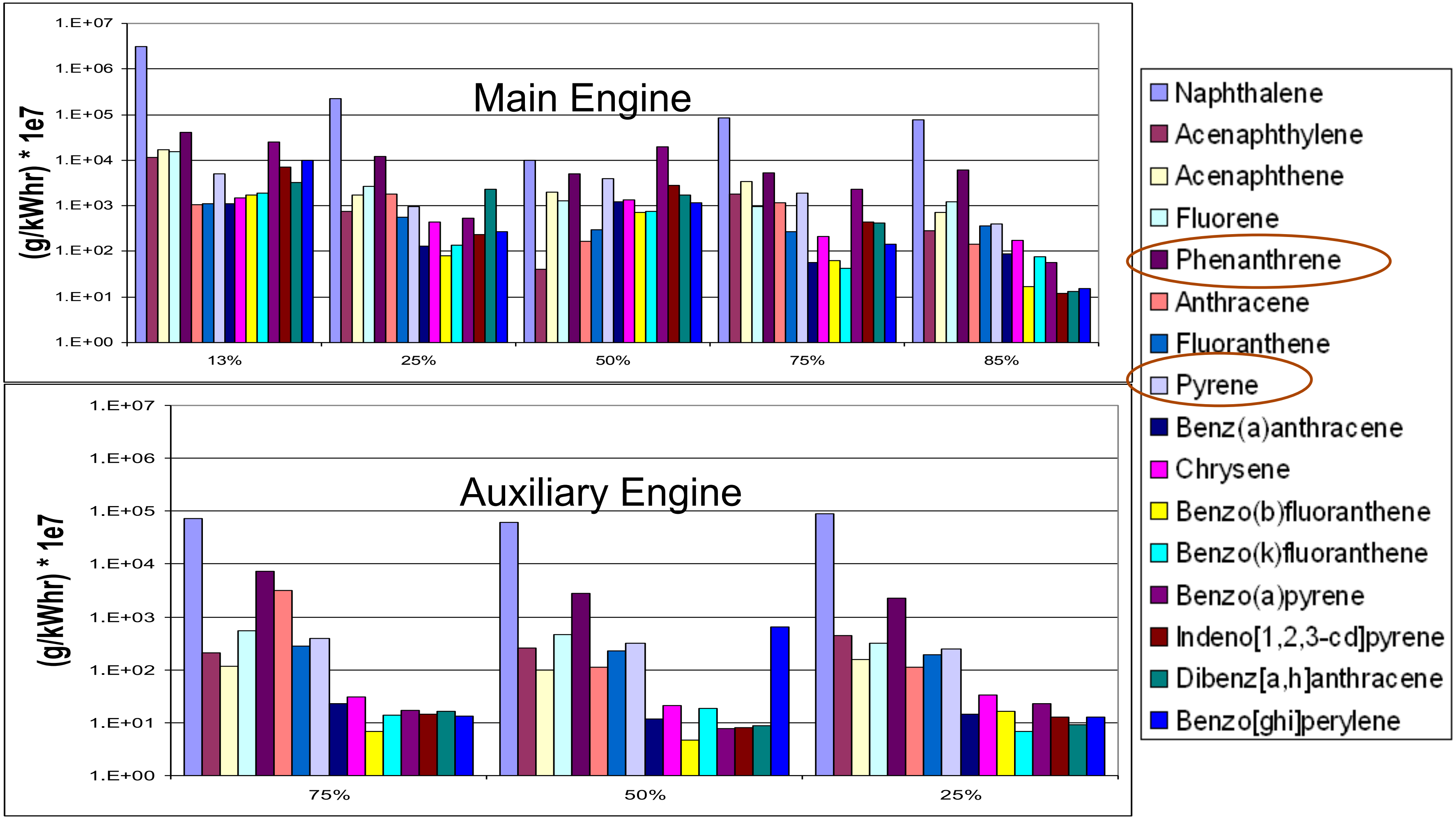
Emission Factors: Aldehydes & Ketones







Ship Emission Factors: PAHs

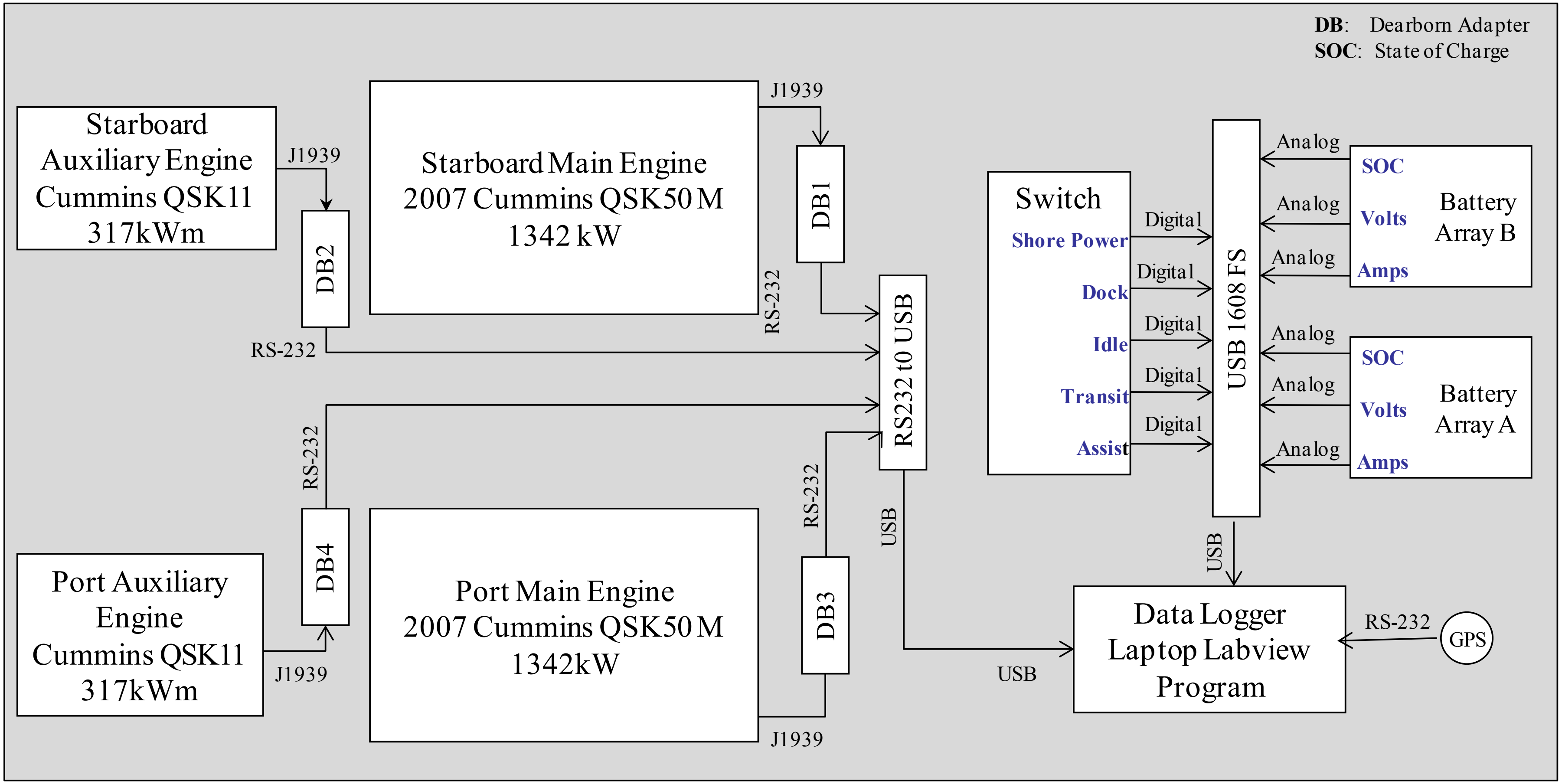


PAH distribution is similar to heavy-duty trucks burning conventional diesel fuel

Study 2: Benefits of Hybrid Tug

- Operating Modes
  - Shore Power
  - Dock
  - Standby
  - Transit
  - Ship Assist
  - Barge Move

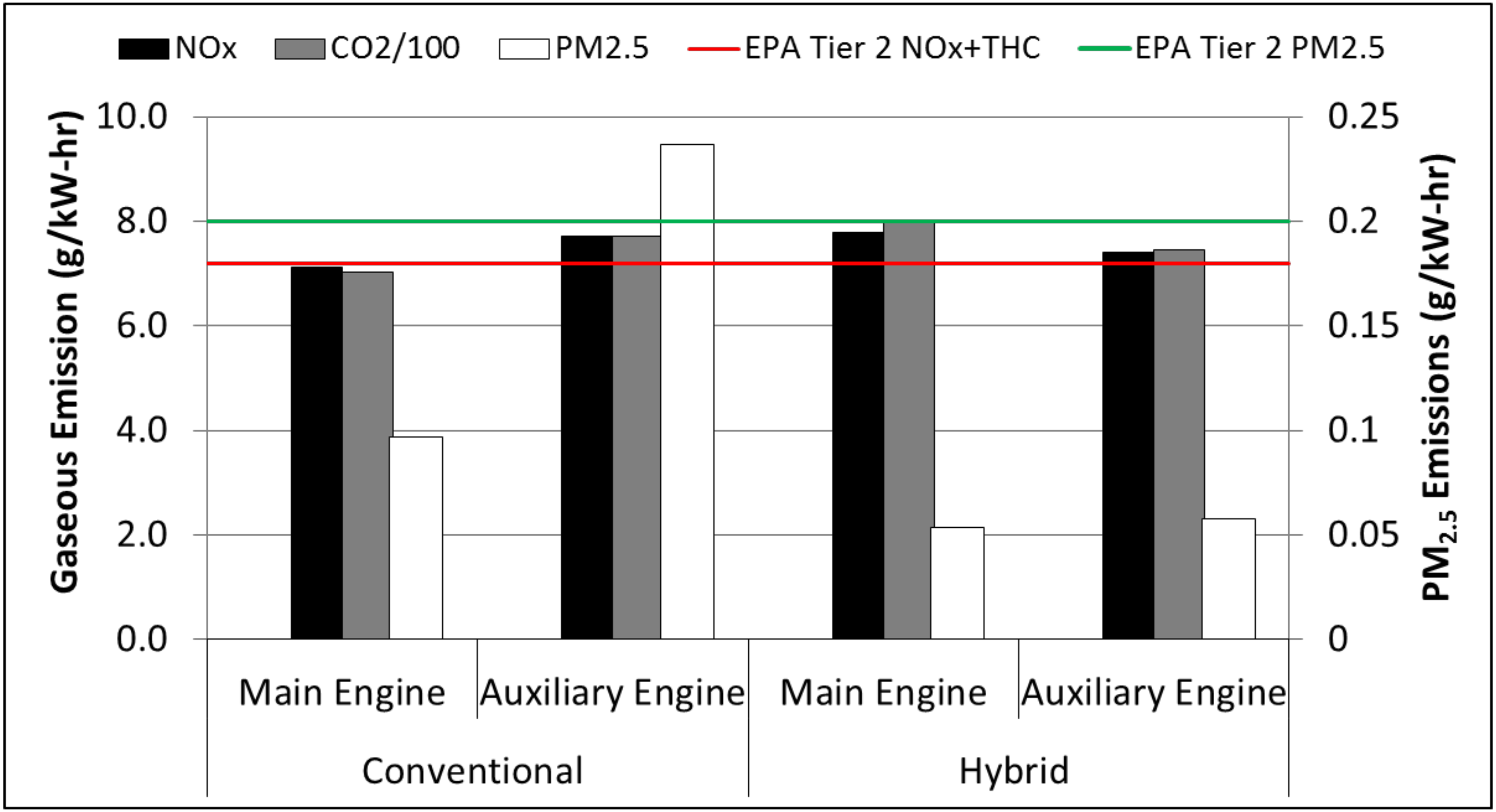
Goal 1: Measure Activity via Data Logging an Operating Hybrid Tug



Total Sample Time ~46 days including a 1.5 days (~10 Ship Assists) of data logging **without use of a Battery**.

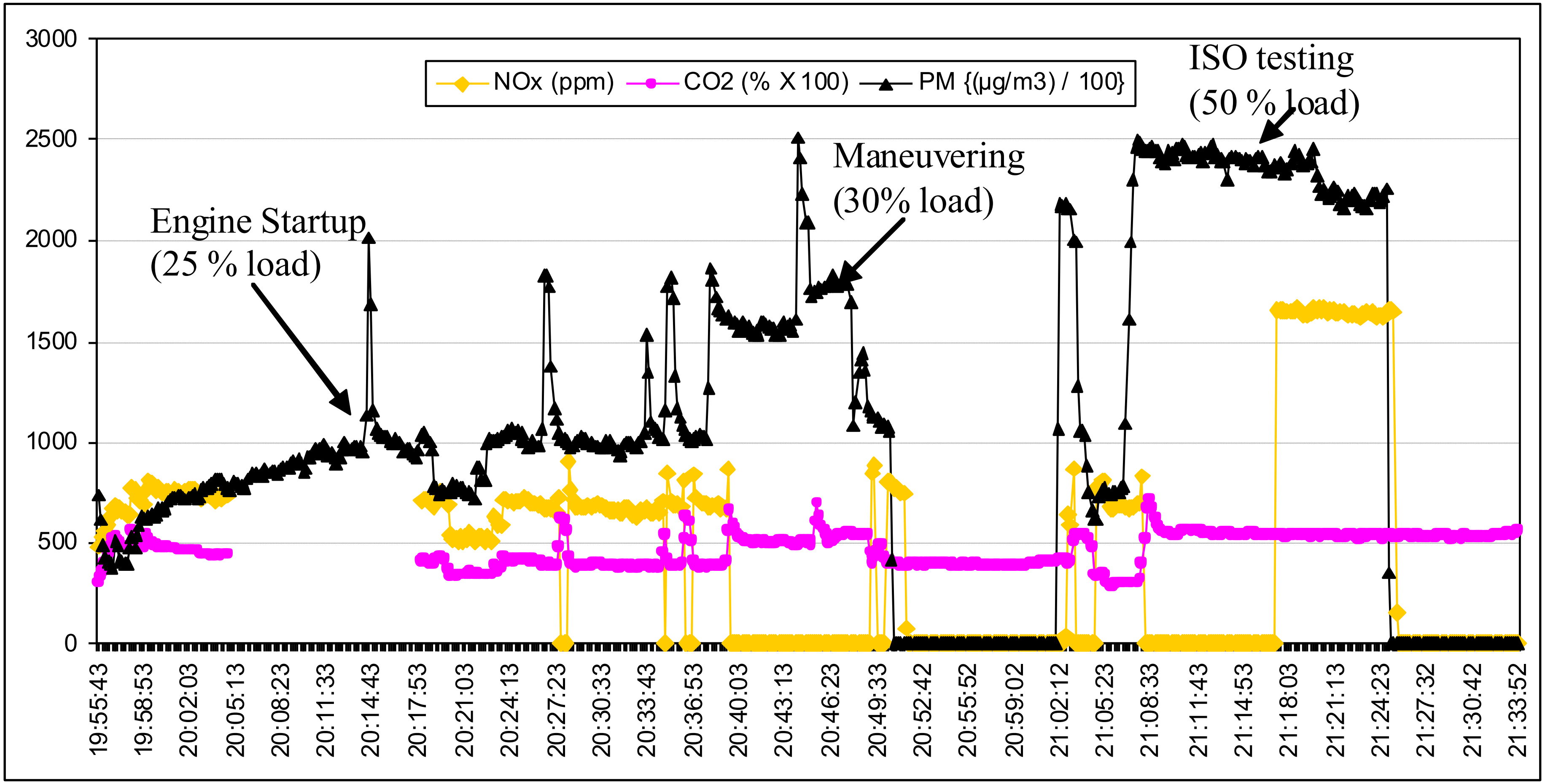
Goal 2: Measure Emissions of Tug Engines

Emission Factors for Certification Cycle

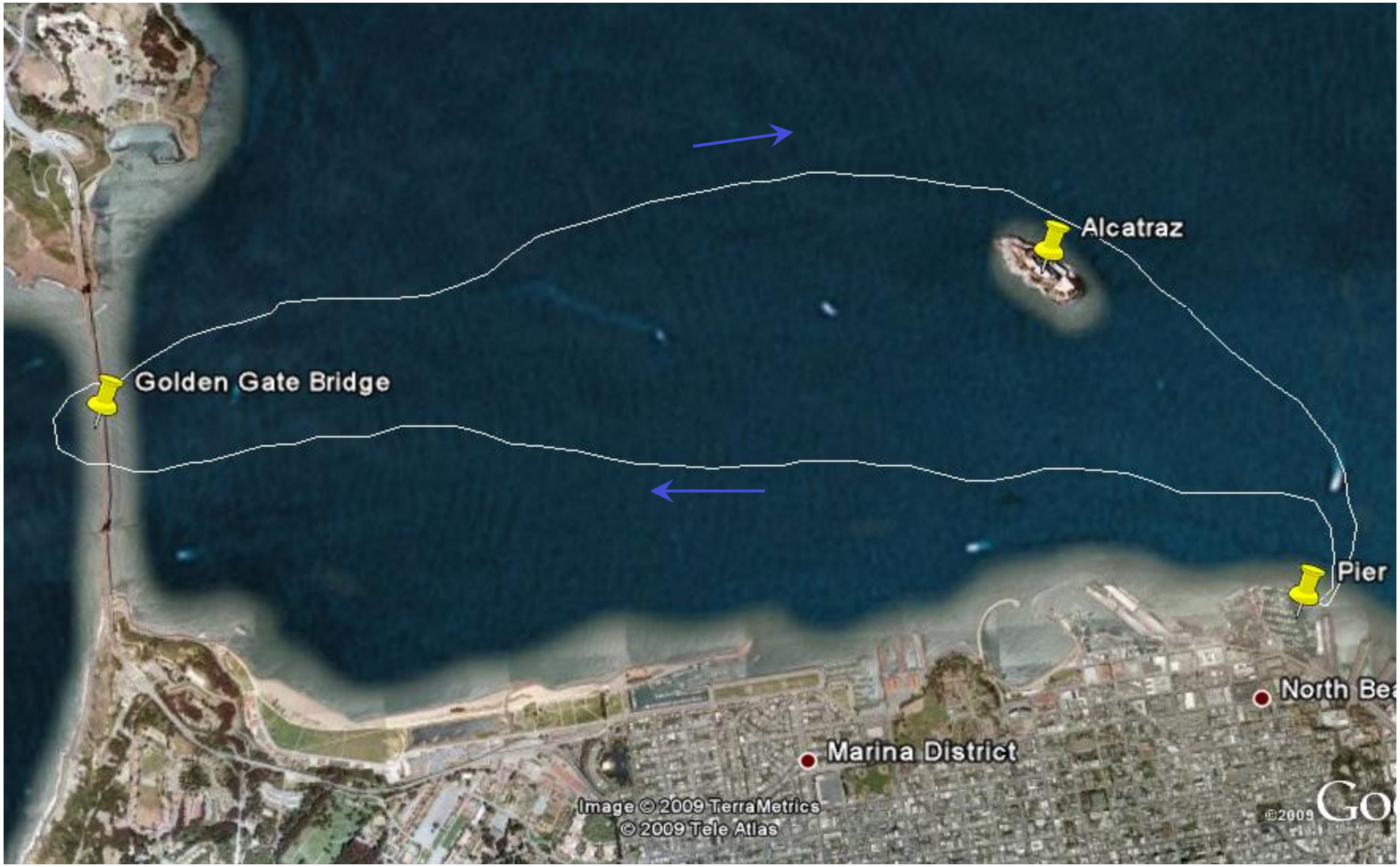


In-use or Real-world Testing

Study 3: In-use Gas & PM Emissions Main Propulsion Engine (OGV)



Study 4: Emissions for Ferry on Biodiesel



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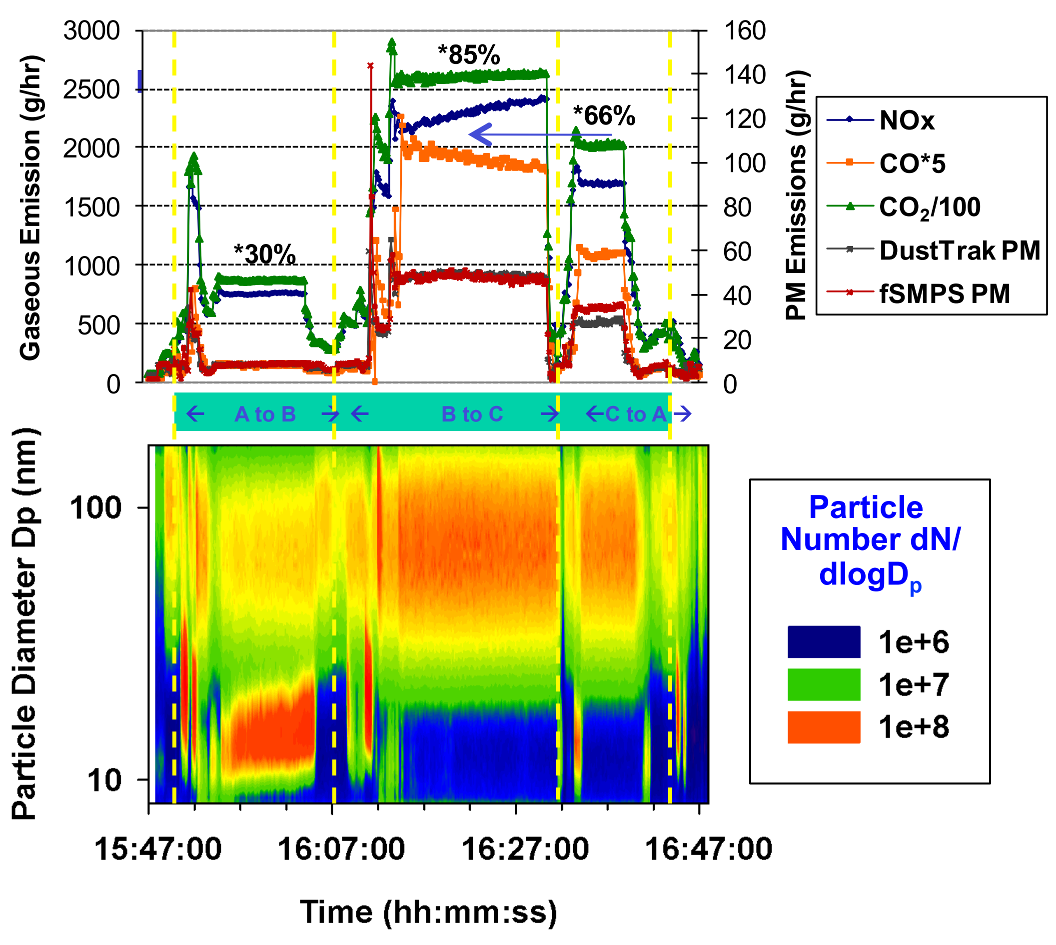
In-Use Emissions for Biodiesel



*Engine Load, A- Pier, B-Bridge, C-Alcatraz

Going into tidal & river flow of a bay increases emissions for vessel at constant speed.

3-fold NO_x ↑

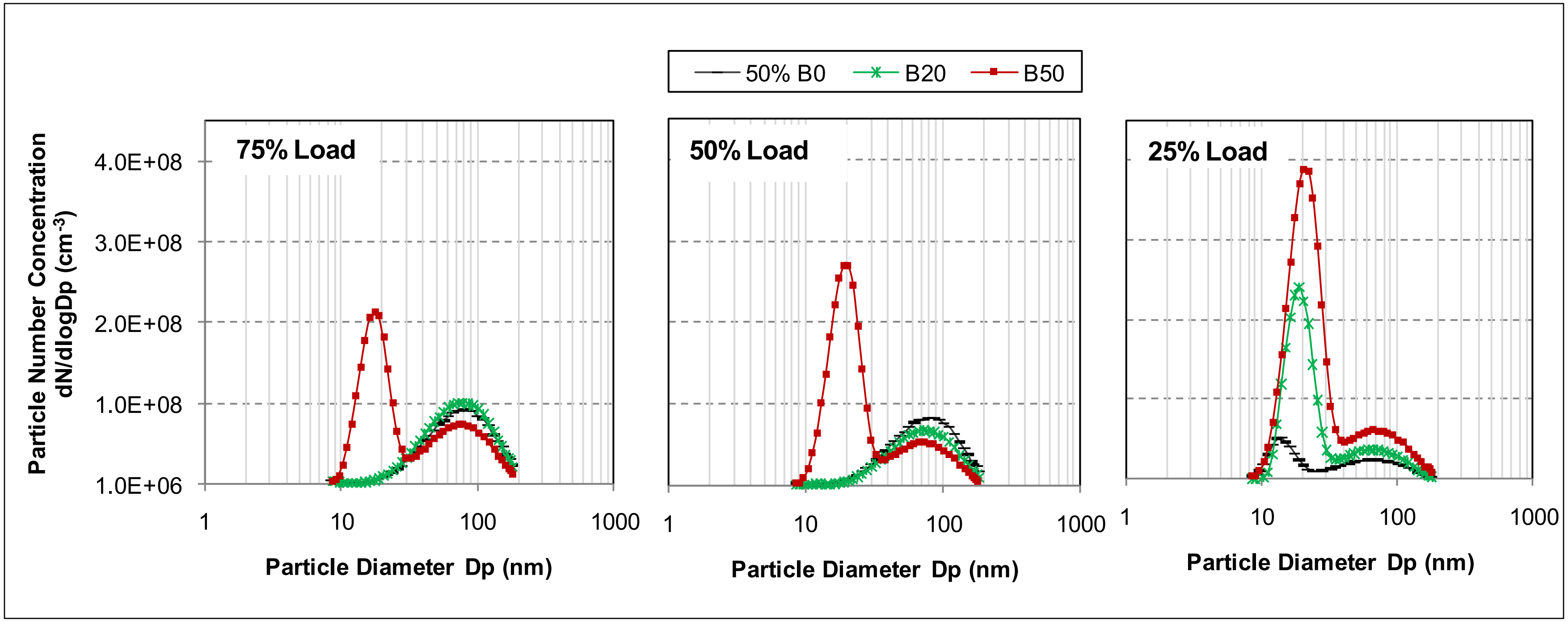
3-fold CO_2 ↑

6-fold $PM_{2.5}$ ↑

With increasing load, ultrafine particles disappear

Biodiesel

Particle Size Distribution



Biodiesel facilitates formation of nucleation mode particles

B0 and B20 OC/EC ratios: ~ 2.5 @ 25% load, ~1.0 @ other loads

B50 OC/EC ratio: ~4.5 @ 25% load, ~1.4 @ other loads

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Study 5: Simultaneous Ship & Airborne Emission Measurements

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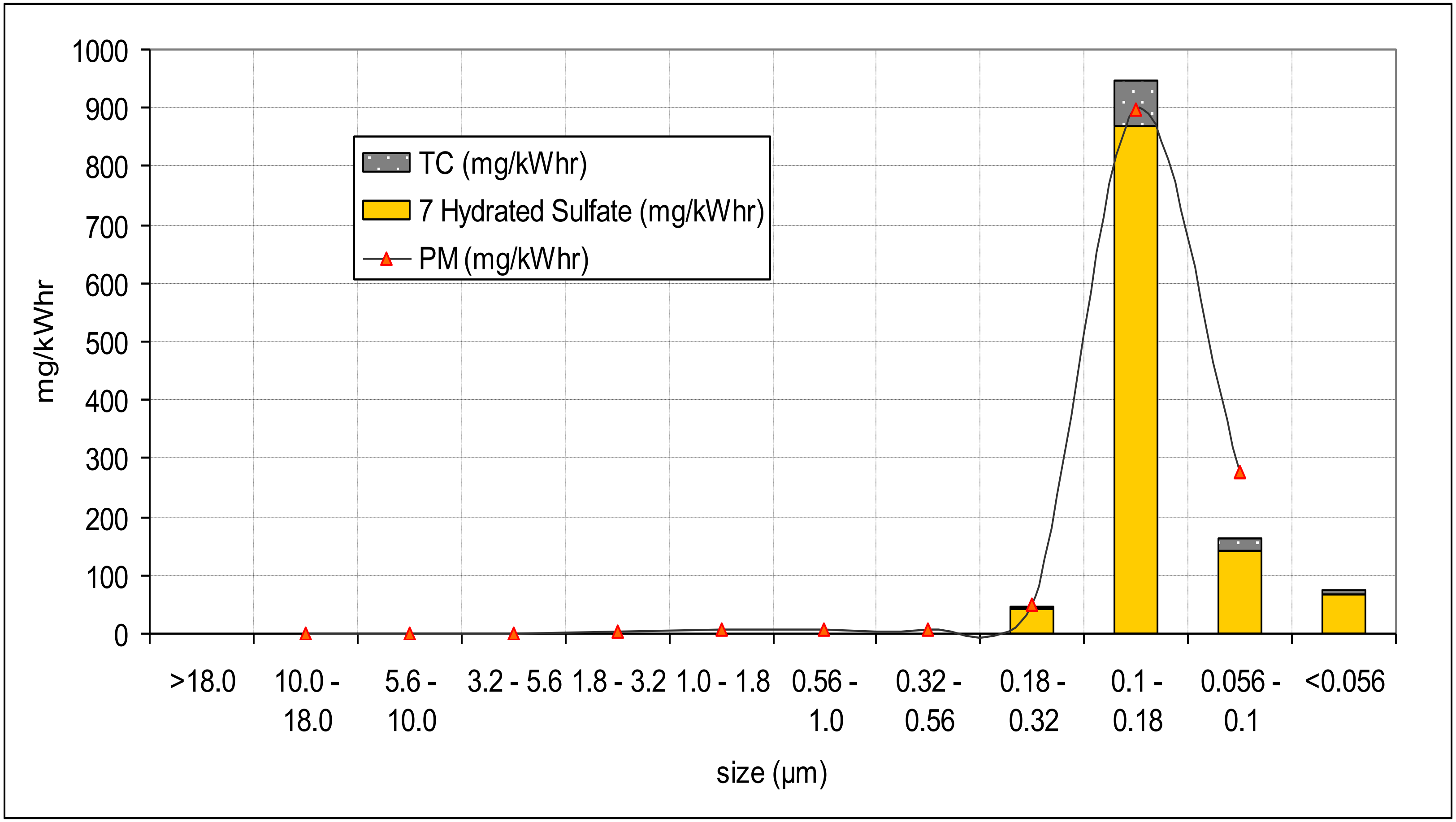
Size Segregated Speciated PM



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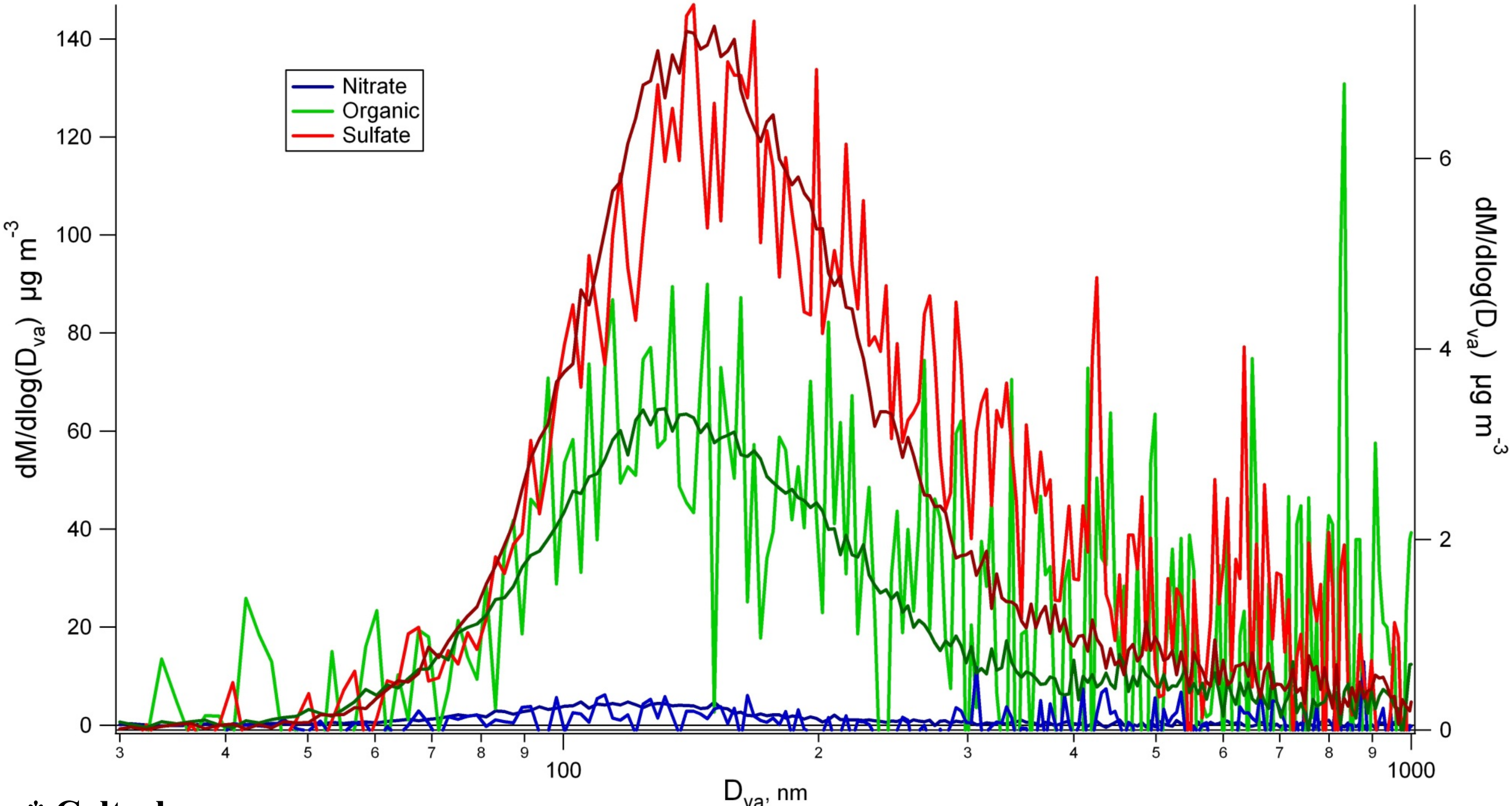
Chemically Resolved Mass Distribution for Ship Exhaust Aerosol*



* Caltech

Summary

- Findings to date:
  - Developed gaseous and PM monitoring equipment suitable for marine vessels.
  - Gaseous and PM emission factors in the field are repeatable and match manufacturer values.
  - Exploratory research on in-use emissions is promising.
- Future work:
  - Carry out more real-time/in-use measurements.
  - Measure emissions related to climate change
  - Develop projects with health experts

Take Home Ideas

- Pre-test inspection and meeting is essential
  - Discuss proposed test matrix with operating crew
  - Identify sampling ports and utilities
- Anticipate difficulty
  - Operational and safety concerns may limit testing
  - Have back up plans for critical equipment
- Maximize sampling opportunities
  - Rare opportunity with important source
  - Minor incremental cost of extra sample media and instruments
- Look to new trends
  - New fuels, black/brown carbon, aftertreament

Thank You; Any Questions?