Estimating Emission Rates For a Retrofitted SCR-Based Locomotive Emission Control System Using PEMS

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Background

- Since 2008, measured locomotive emissions in rail yard and over-the-rail using Portable Emission Measurement Systems (PEMS)
- Have compared a GlobalMRV Axion and SEMTECH-DS
- Developed Axion bias corrections for NO to NO_x and HC to THC
- The CATI Montana system, a predecessor to the GlobalMRV Axion, has been compared to chassis dynamometer measurements for light duty vehicles.
- Axion has not been benchmarked to a reference system for locomotive applications.

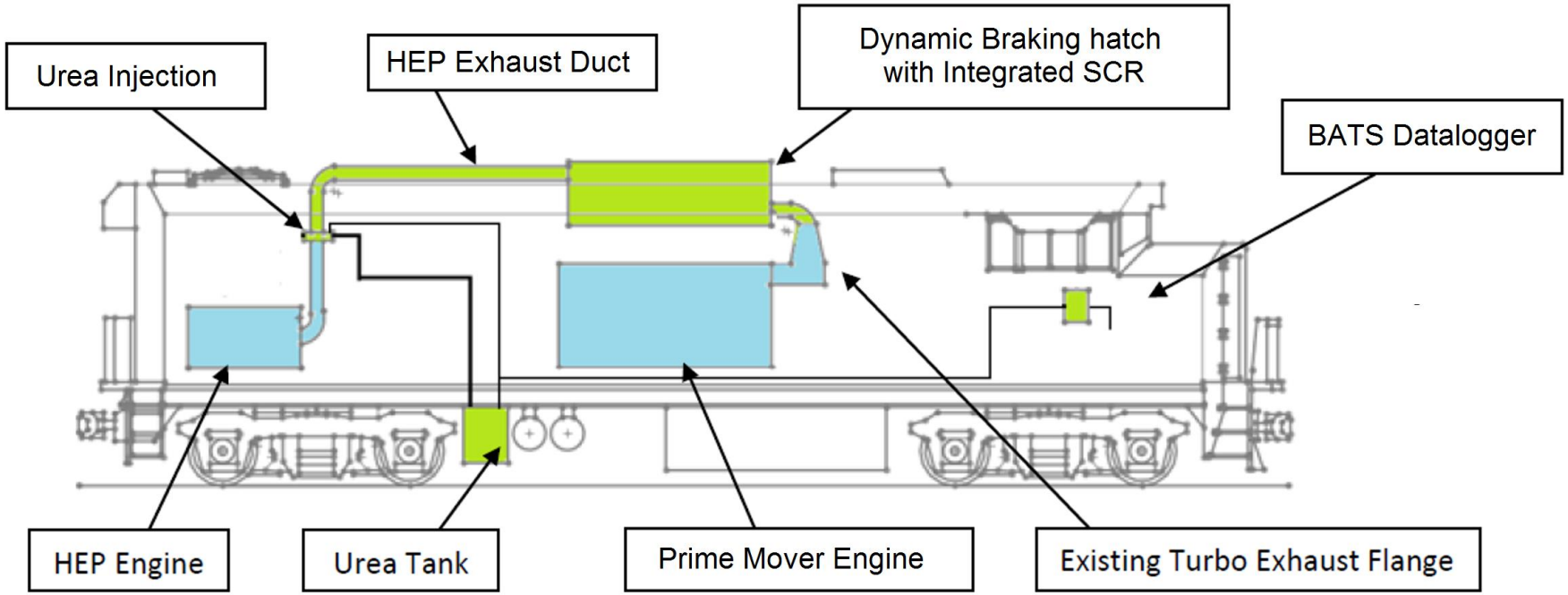
Purpose

- To assess the validity of the Axion compared to a reference system for locomotive engines
- To demonstrate a method for in-use testing of locomotive emissions using PEMS measurements

Locomotive Measurement Scenario

- North Carolina Department of Transportation (NCDOT) owns locomotives and rolling stock
- Operated by Amtrak for passenger rail service between Raleigh and Charlotte
- NCDOT wants to lower locomotive emissions
- Since 2008, NCSU has measured emissions after locomotive rebuilds and for biodiesel fuel
- Further reductions are sought using a retrofitted Selective Catalytic Reduction (SCR) system
- In September 2016, an SCR system was retroffited and “zero hour” measurements made

Blended After Treatment System



Developed by Rail Propulsion Systems (RPS)
Engine Fuel and Emissions Engineering (EF&EE)
Clean Train Propulsion (CPT)

Comparison of Axion to Reference System

- Simultaneously measured BATS outlet exhaust
  - Axion PEMS measurements by NCSU
  - EF&EE Locomotive Emission Measurement System (LEMS), based on the Ride-Along Vehicle Emissions Measurement (RAVEM) system
  - EF&EE Measurements performed by Chris Weaver
  - Measurements at NCDOT Capital Rail Yard in Raleigh, NC

Portable Emissions Measurement System

Axion system by Clean Air Technologies International, Inc.

- Non-dispersive infrared (NDIR) for CO_2, CO, HC
- Electrochemical sensor for NO, O_2
- Light scattering particulate matter measurement

Portable Emission Measurement System

- Axion PEMS manufactured by Global MRV
- Electrochemical cell for NO
  - Does not measure NO_2
  - Does not measure NO_x ($NO + NO_2$)
- Non-dispersive infrared (NDIR) CO_2, CO and HC
  - Accurate for CO_2 and CO
  - NDIR less responsive to aromatics and long chain alkenes/alkynes
- Laser light scattering for PM measurements
  - Typically biased low by a factor of 5 for diesel PM

PEMS comparison

- Previous Axion PEMS model correlated with dynamometer facility for light duty gasoline vehicles
  - coefficients of determination (R^2) exceeded 0.86 for all pollutants
  - Slopes of parity plots for CO_2, CO and NO ranged from 0.92 to 1.05
- NO_x/NO and THC/HC ratios for locomotive exhaust
  - Compared to SEMTECH-DS PEMS (40 CFR 1065 compliant)
  - bias correct Axion PEMS measured NO and HC
  - Diesel exhaust: typically 95 % NO
  - THC/HC ratio: ~ 2.5-5 for diesel exhaust, varies with engine load

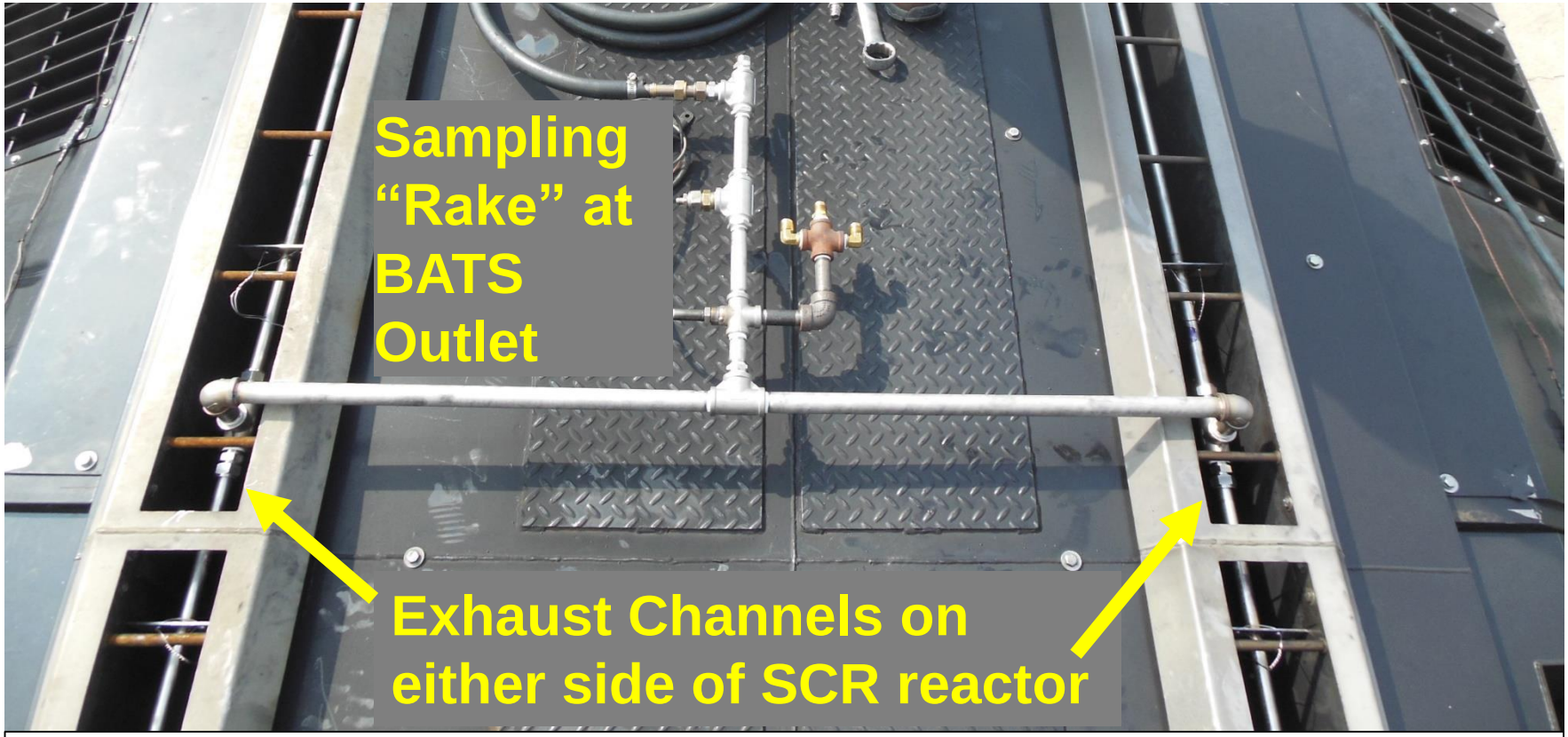
EF&EE's Ride-Along Vehicle Emission Measurement (RAVEM) System

- Manufactured by Engine Fuel and Emissions Engineering (EF&EE)
- 40 CFR 1065 complaint measurements
- NDIR for CO_2 and CO measurements
- Chemiluminescent analysis for NO_x
- Heated Flame Ionization Detection (HFID) for THC
- Gravimetric filter based measurements for PM
- Reference system for comparing PEMS

Measurements: Test Locomotive

- Two engines:
  - 3,000 hp Prime Mover Engine (PME) for traction
  - 900 hp Head End Power (HEP) engine (hotel services)
- PME operates at discreet power levels:
  - Idle
  - Dynamic Braking
  - Notch 1
  - Notch 2
  - Notch 3
  - Notch 4
  - Notch 5
  - Notch 6
  - Notch 7
  - Notch 8
- HEP engine load depends upon number of passenger cars

Measurements: BATS Outlet Exhaust Concentrations



BATS Outlet: Two channels release exhaust to atmosphere
Composite sample drawn from two channels for PEMS

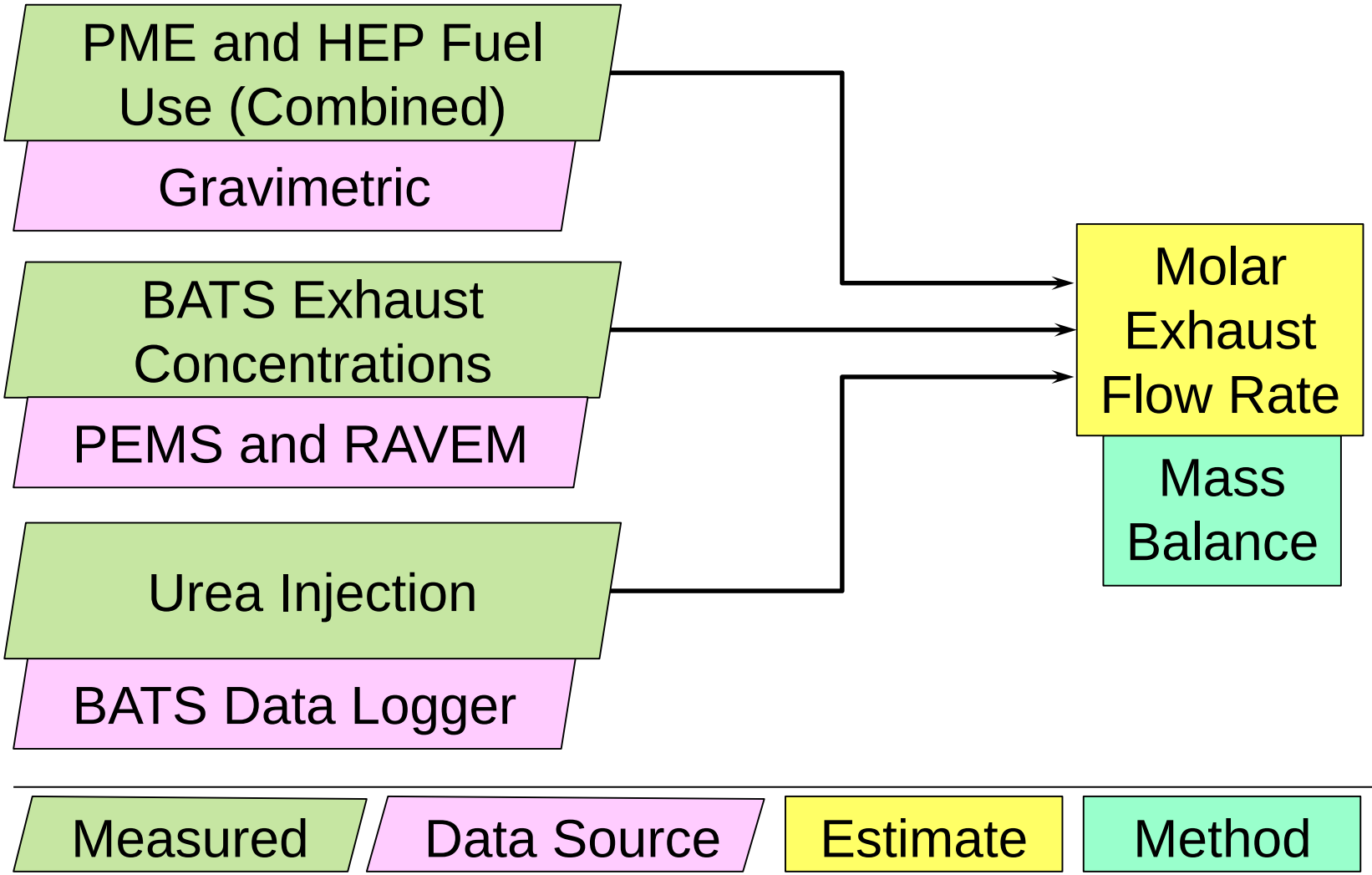
Measurements: Combined PME and HEP Engine Fuel Use

- EF&EE installed external fuel tank to supply fuel to PME and HEP Engine
- EF&EE conducted gravimetric measurements of fuel use at each notch position
- This setup is not feasible for in-use testing

Measurements: Test Schedule

- Test Schedule
  - HEP engine operated at approximately constant load of 125 kW
  - PME engine operation replicate:
    - 5 minutes at each of: idle, dynamic braking and notches 1 through 7
    - 10 minutes at Notch 8
    - 10 engine load settings per test replicate
- 4 replicate measurements on same test schedule
- Urea injection rate varied

Fuel Use Method: Rail Yard Tests



Results: Example PEMS Measurements at BATS Outlet

PME at Notch 5 and HEP Engine at Load 125 kW

CO_2	4.92 vol. %	
NO_x	45 ppm	
PM	0.8 mg/m^3	
CO	0.0 vol. %	(Below detection limit)
HC	0 ppm	(Below detection limit)
O_2	13.98 vol. %	
Urea Injection	0.044 gmol/s	
Fuel Use	78 gal/hr	

EF&EE only reported mass emission rates of CO_2, CO, HC, NO_x and PM. Measured concentrations were not reported

Results: Example Emission Rates- Fuel Use Method

- CO_2 emission rate at BATS outlet

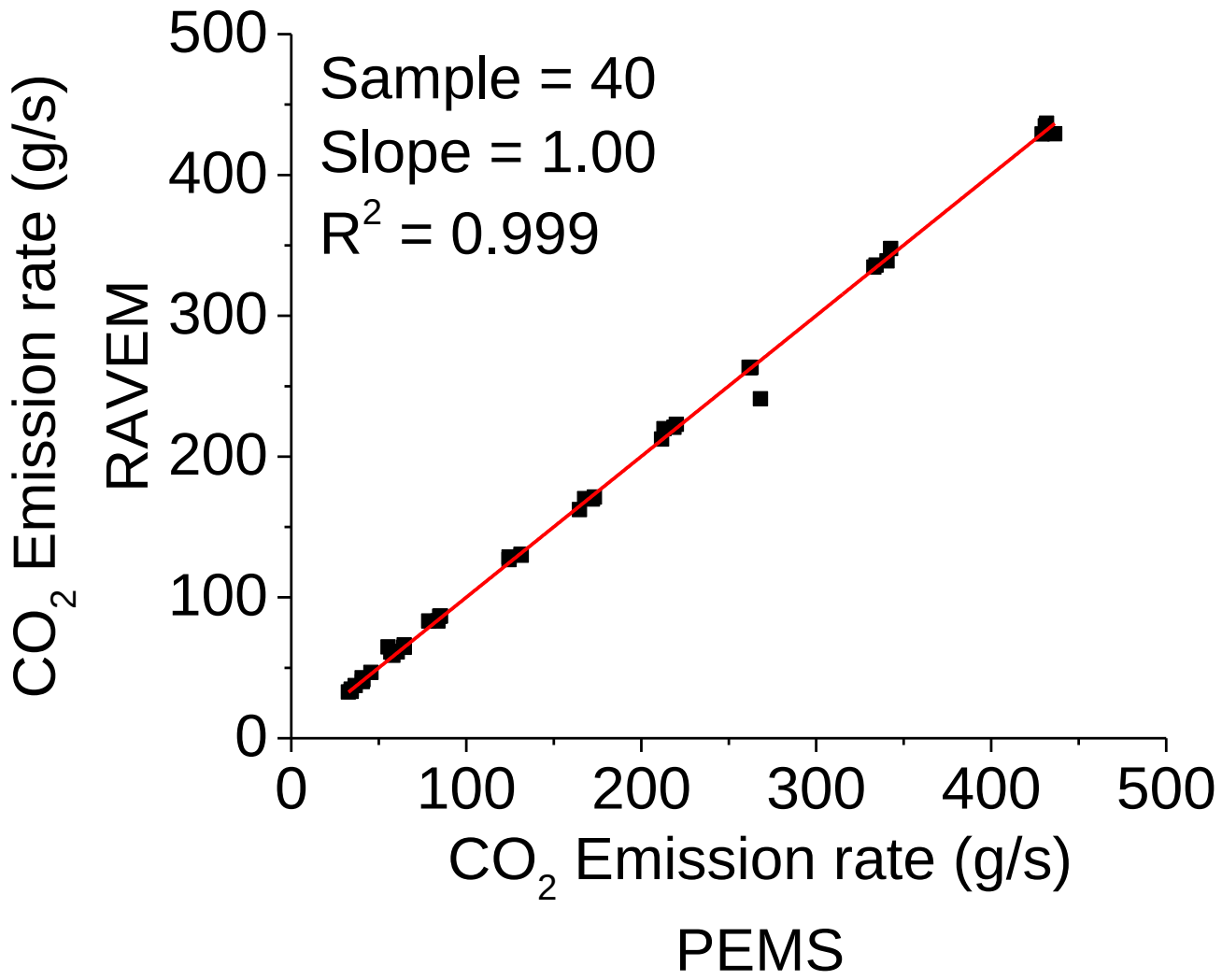
PEMS	216 g/s
RAVEM	219 g/s

- NO_X emission rate

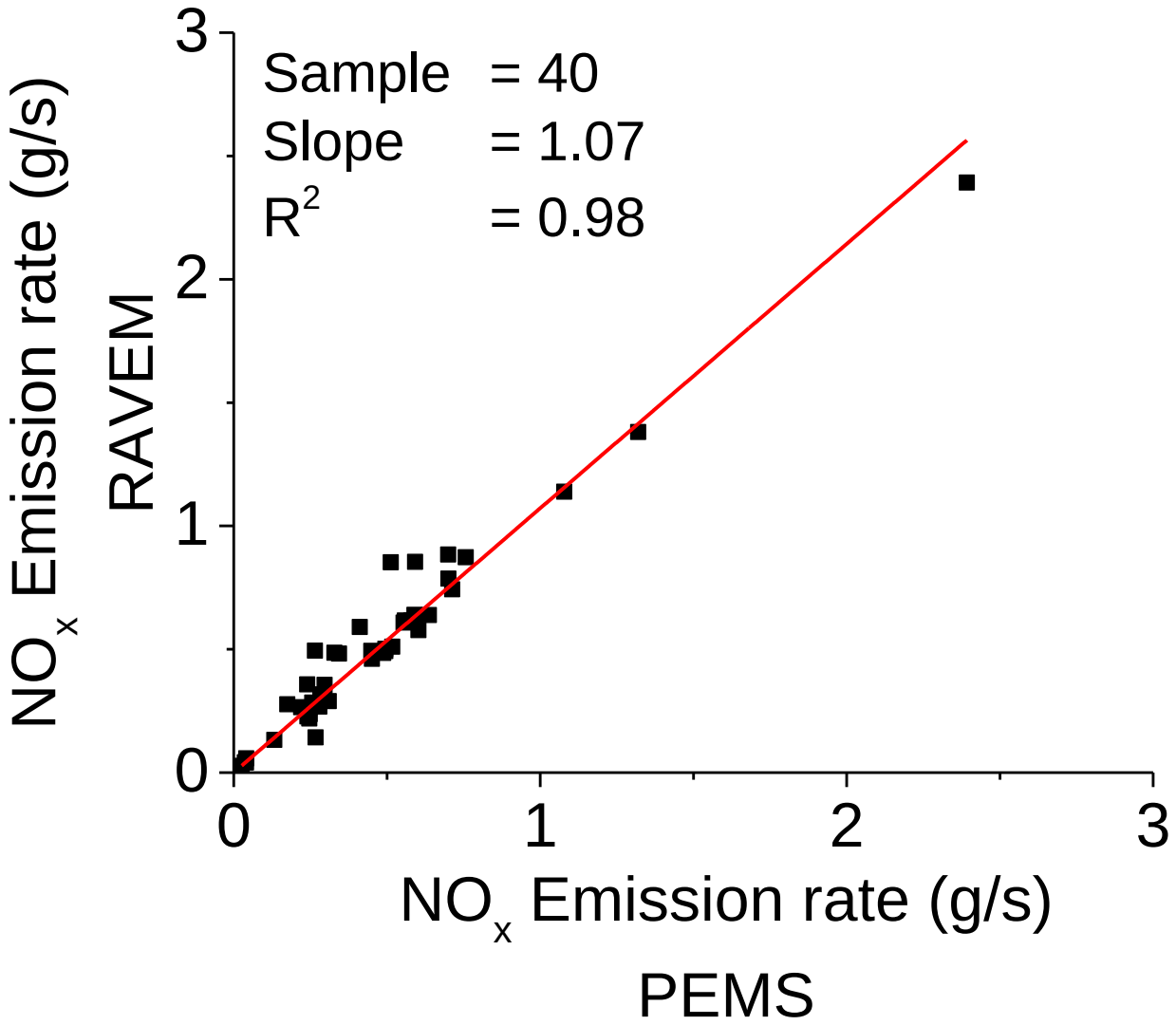
PEMS	0.30 g/s
RAVEM	0.36 g/s

- HC and CO were mostly below the detection limit of PEMS
- Axion PM was correlated to gravimetric filter results, but sample loss need to be mitigated in future tests.

Comparison of CO_2 Emission Rate



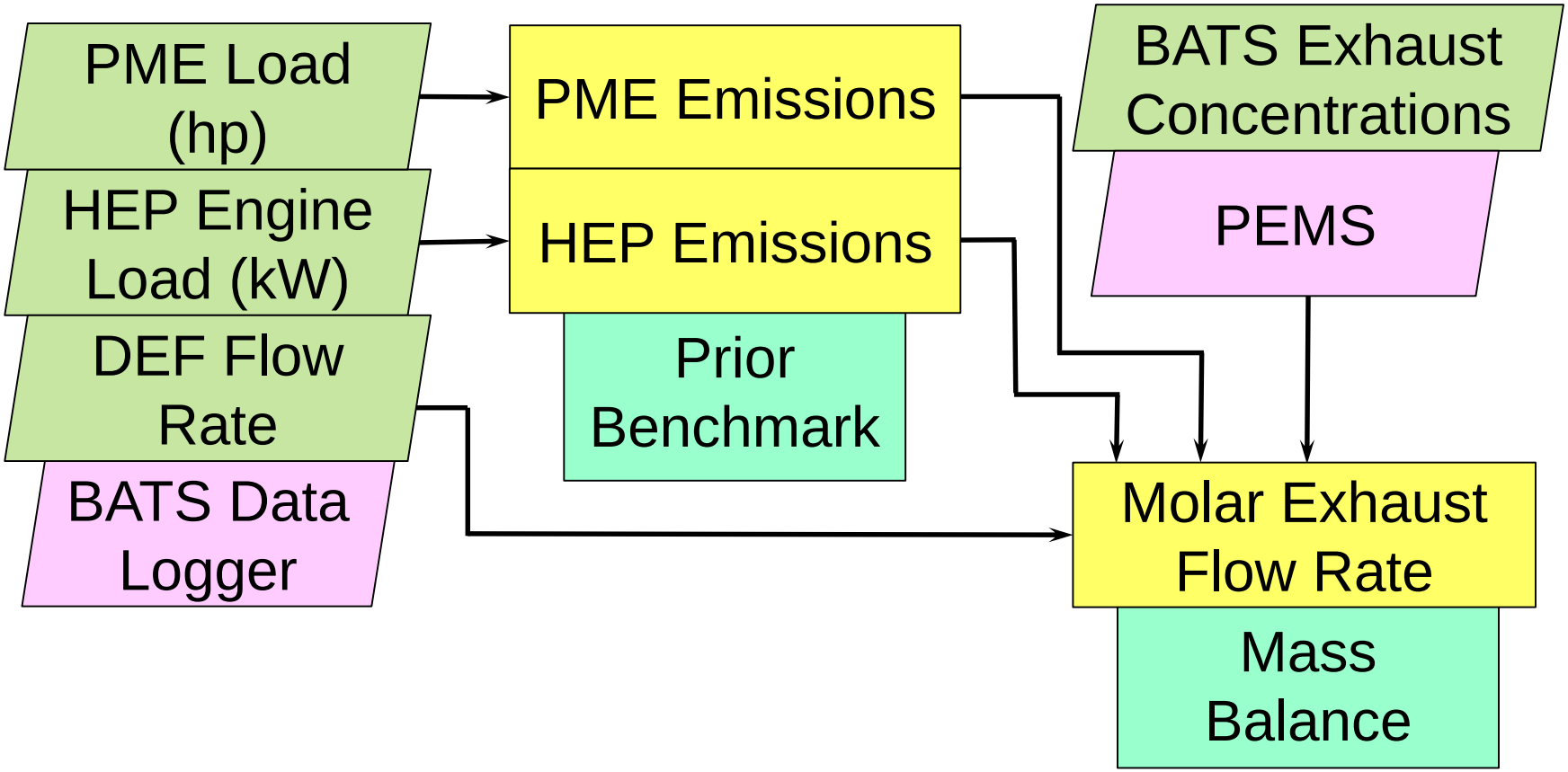
Comparison of NO_x Emission Rate



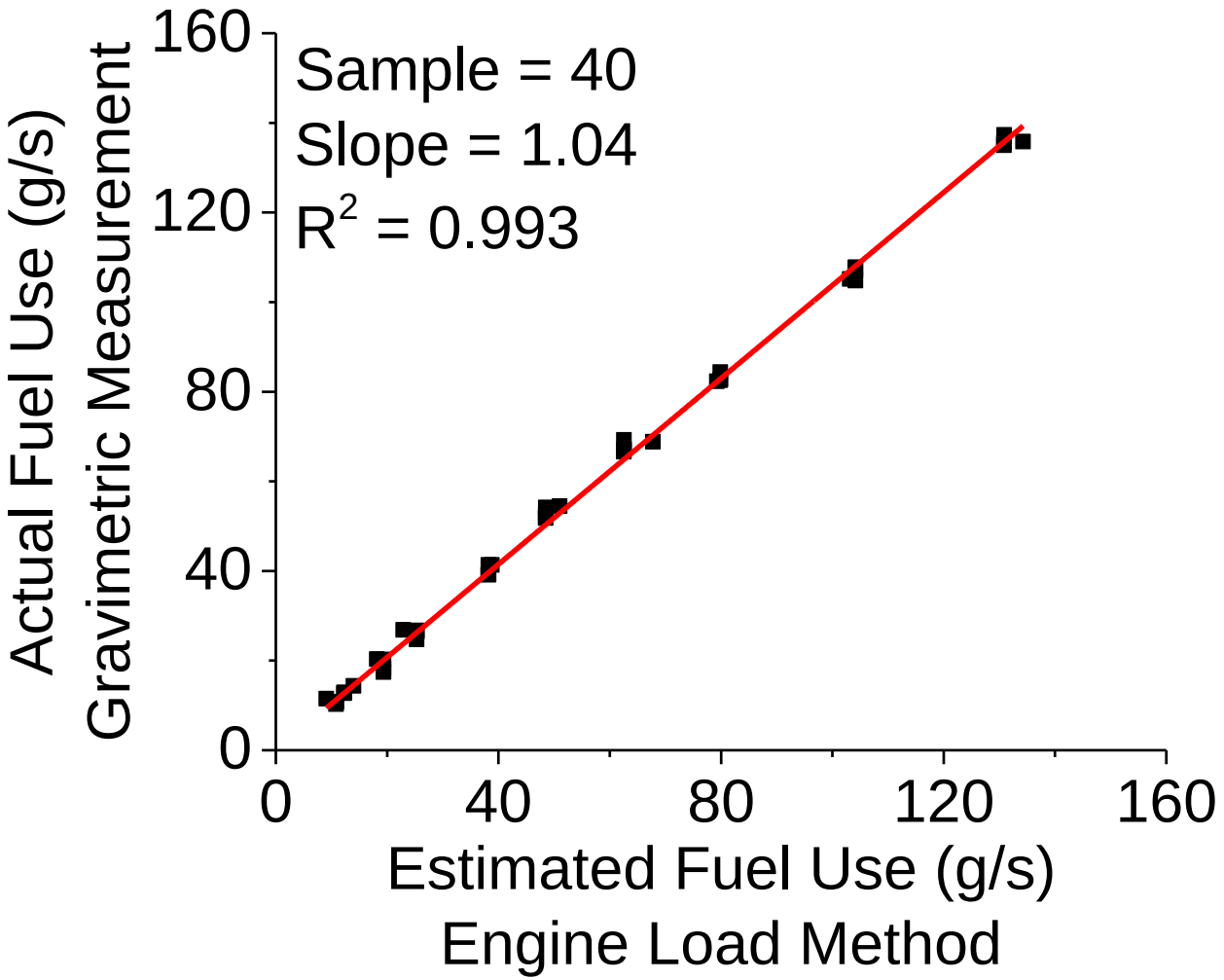
Engine Load-Based Approach for In-use Measurements

- For future over-the-rail measurements, gravimetric fuel use measurement is not feasible.
- Comparison of emission rates estimated from PEMS with “engine load” based approach to fuel-based results from RAVEM

Engine Load Method



Compare PEMS In-use Method to Reference System



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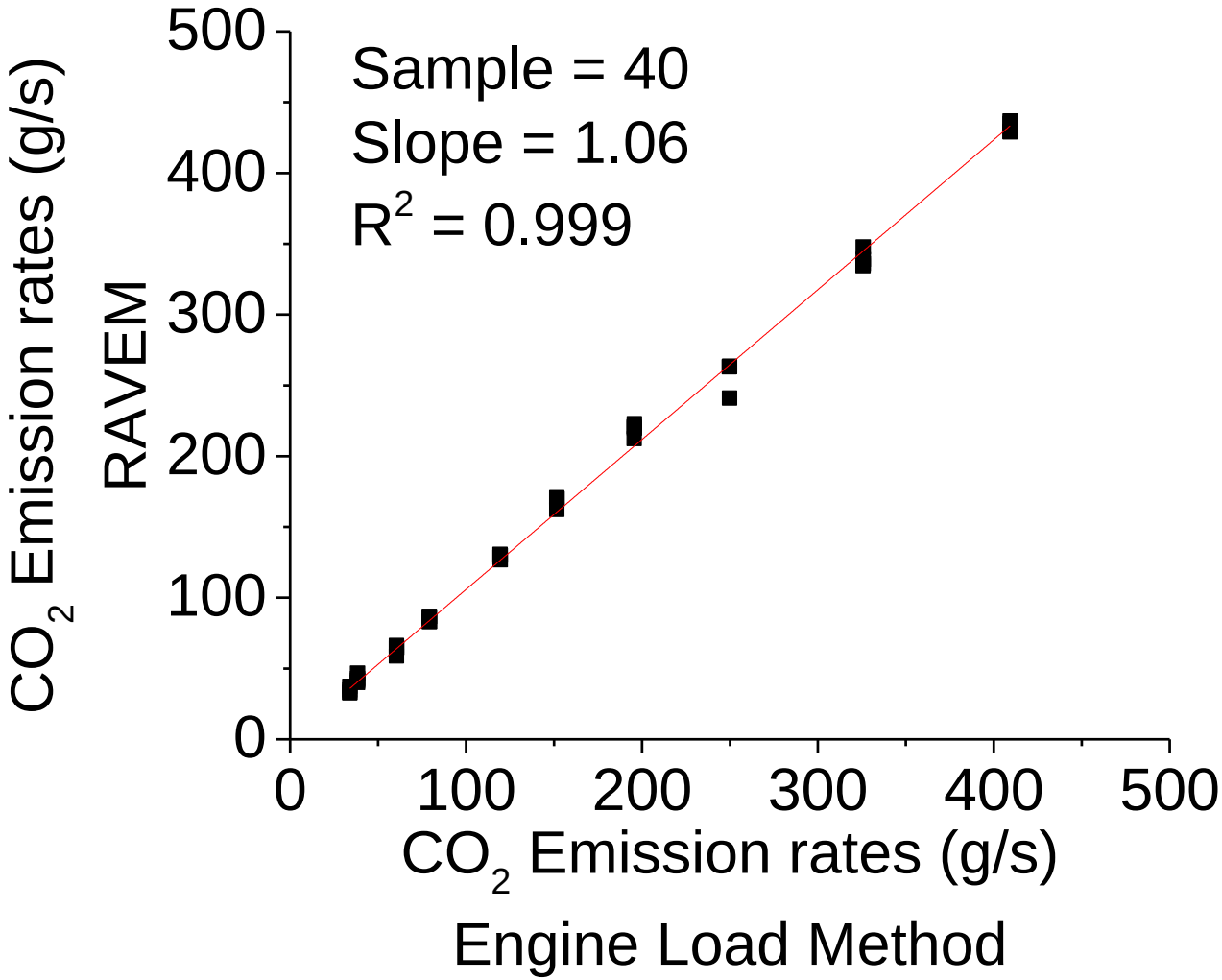

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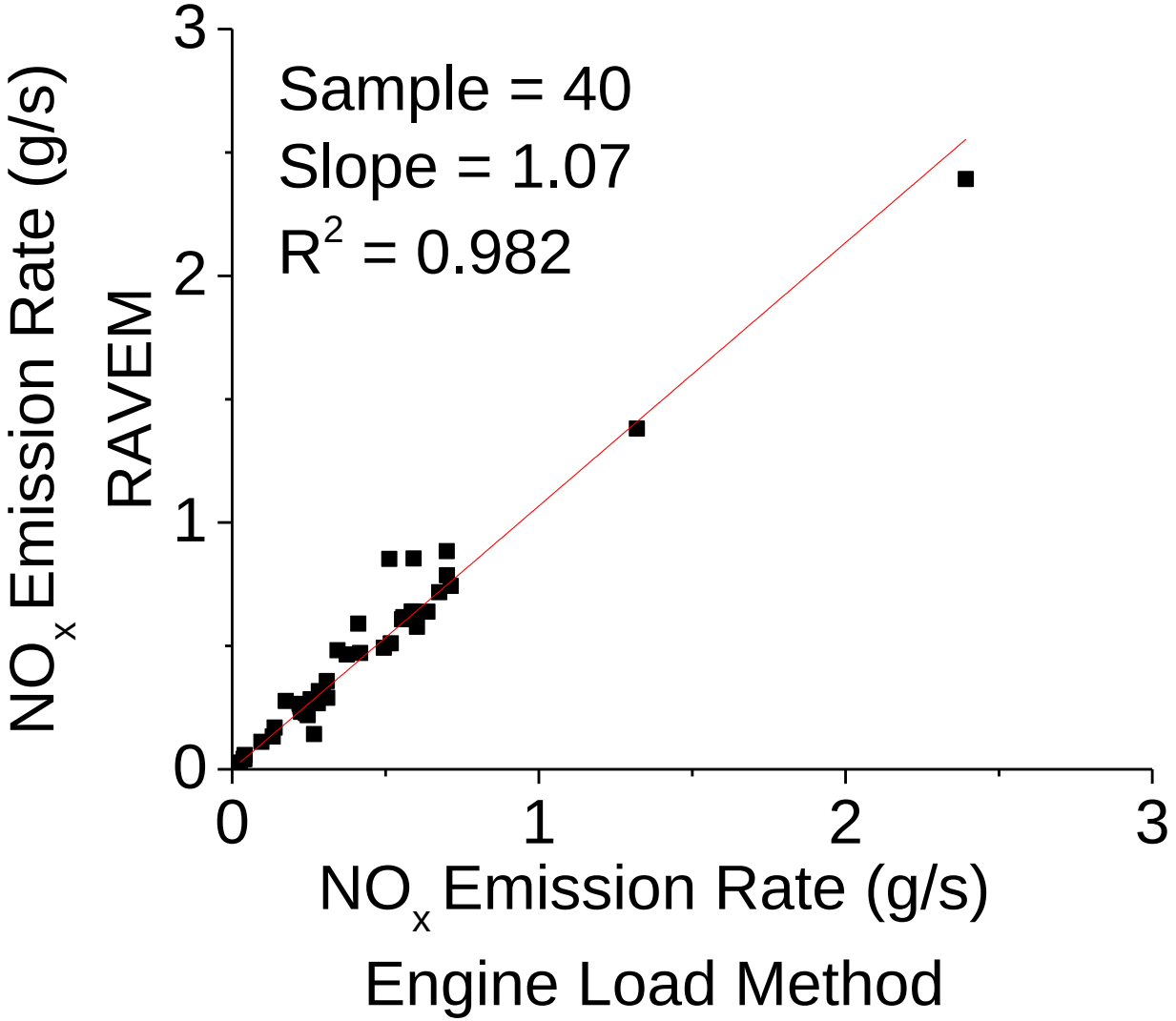

Conclusions

- PEMS based CO_2 and NO_x emission rates were highly correlated with RAVEM
- Results match well based on gravimetric fuel use
- Results also match well based on indirect fuel estimation and PEMS vs. gravimetric fuel measurement & RAVEM
- CO and HC were mostly below the detection limit of PEMS, hence no correlation with RAVEM
- PEMS based PM emission rates will be assessed in future
- PEMS measurements provide reliable estimates of CO_2 and NO_x emission rates
- Will repeat rail-yard measurements with multiple PEMS
- Indirect fuel use estimation method will be used in future over-the-rail measurements.

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