UNIQUE FINDINGS FROM ON ROAD DATA FOR VARIOUS VEHICLE TYPES USING REMOTE SENSING IN SCOTLAND

J. Stewart Hager, PhD, HEAT
Andrew Burnette, infoWedge

PEMS 2018 INTERNATIONAL CONFERENCE AND WORKSHOP AT CE-CERT, March 21-23, 2018

Hager Environmental & Atmospheric Technologies
H.E.A.T.

Outline of Presentation

- Introduction to HEAT
- Description of EDAR technology
- Description of pilot study
- Summary of results

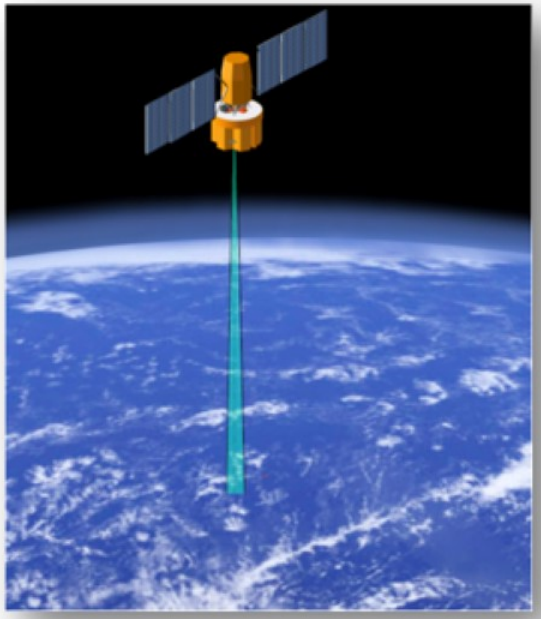
Hager Environmental & Atmospheric Technologies
H.E.A.T.

Genesis of HEAT's Technology: EDAR

- HEAT's Remote Sensing Technology named EDAR is based on NASA's ASCENDS Satellite's platform
- Dr. Stewart Hager, EDAR's inventor, worked with NASA Langley in the development of the ASCENDS Satellite

- Most recently, NASA recognized EDAR as one of their SPINOFF Technologies in their journal published in January 2017

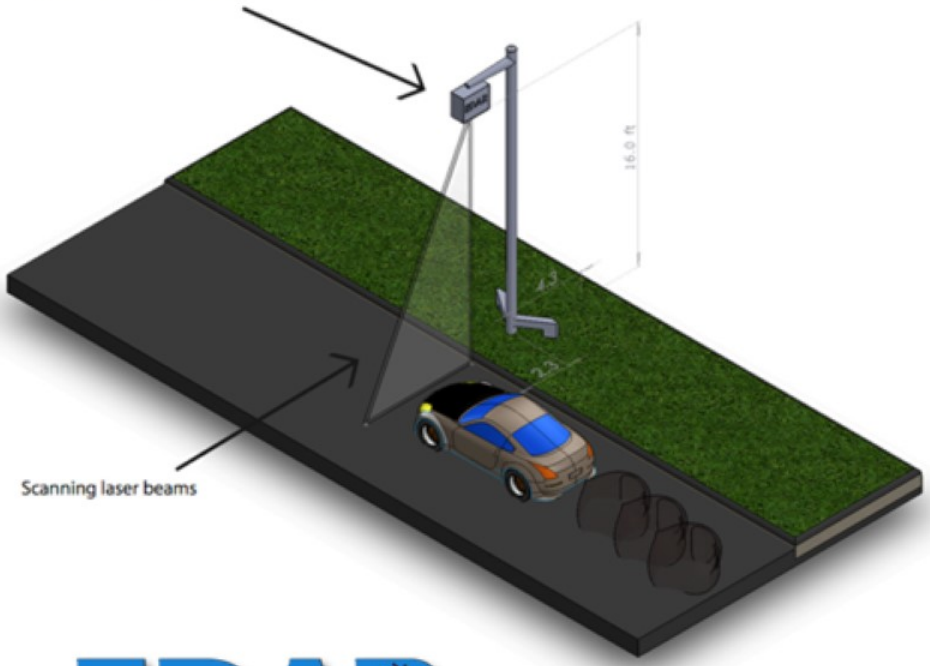
- EDAR began in 2009 and was commercialized then introduced to the North American Market in 2014



Hager Environmental & Atmospheric Technologies
H.E.A.T.

What is EDAR?

EDAR system includes:
- License plate Recognition Camera
- Speed & Acceleration Detector
- Laser Remote Sensing of Vehicle Exhaust



EDAR
Emission Detection And Reporting

The Emissions Detection And Reporting (**EDAR**) System detects **real world emissions**

Measures & quantifies **CO2, CO, NO, NO2, HC** and **$PM_{2.5}$** for both gasoline and diesel vehicles

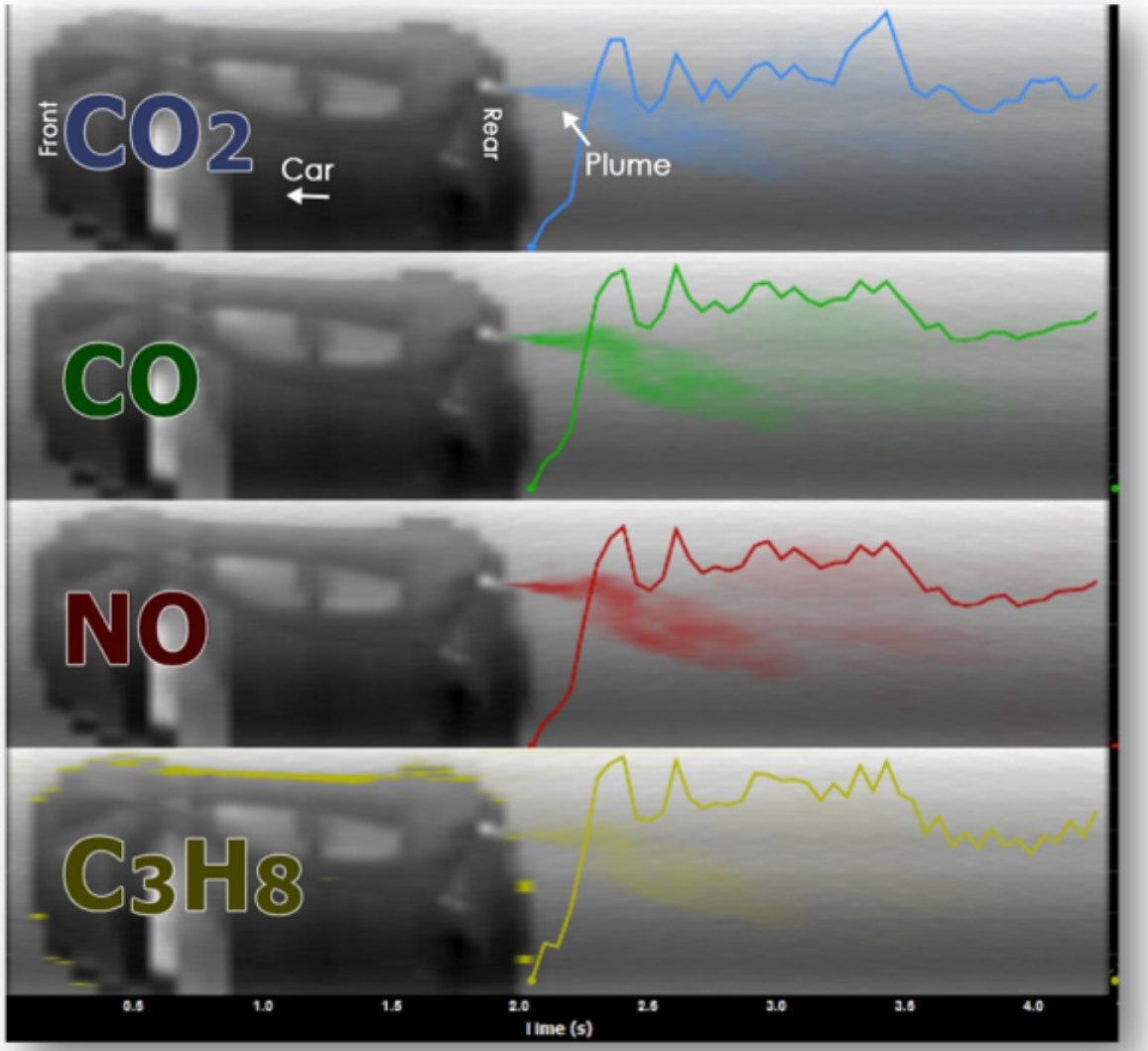
Remote sensing monitors 24 hours a day, 7 days a week, 365 days a year unmanned

Intelligent retroreflector design enables data collection in light rain and mist

Hager Environmental & Atmospheric Technologies
H.E.A.T.

Pollution of Vehicles is No Longer Invisible

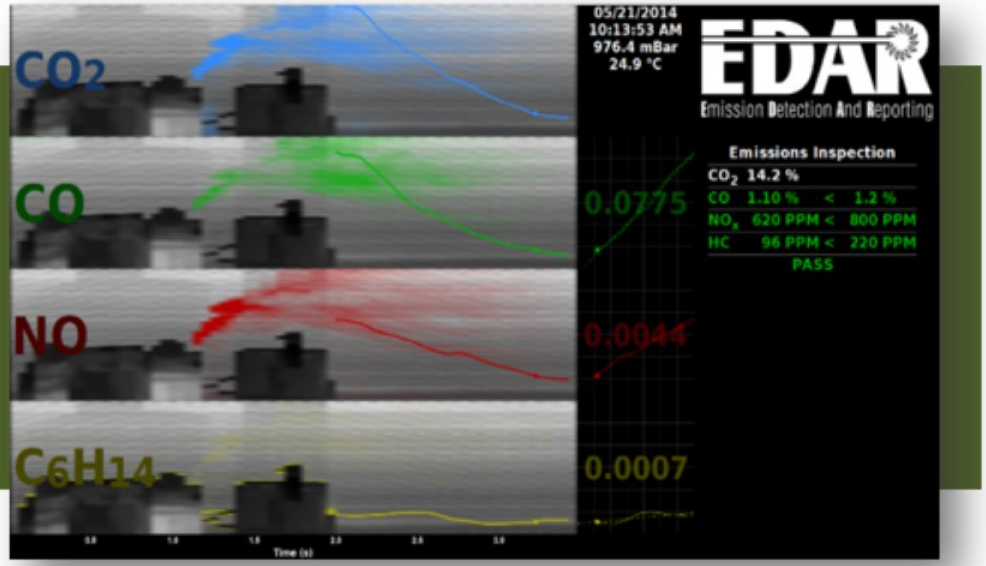
EDAR can Detect All Vehicles on Road and Image the Plume in Real Time as Vehicles Drive Under Normal Driving Conditions

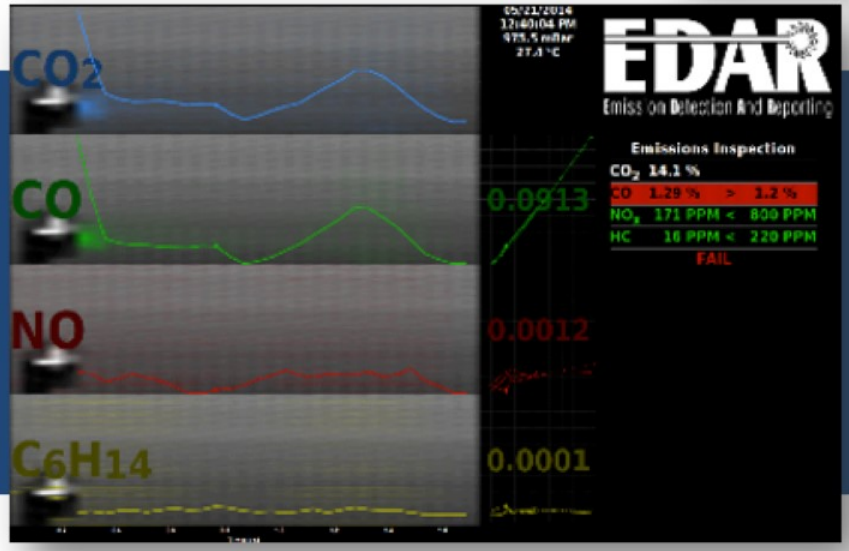


Hager Environmental & Atmospheric Technologies
H.E.A.T.

Trucks and Motorcycles

Image of a Truck Pulling a Trailer

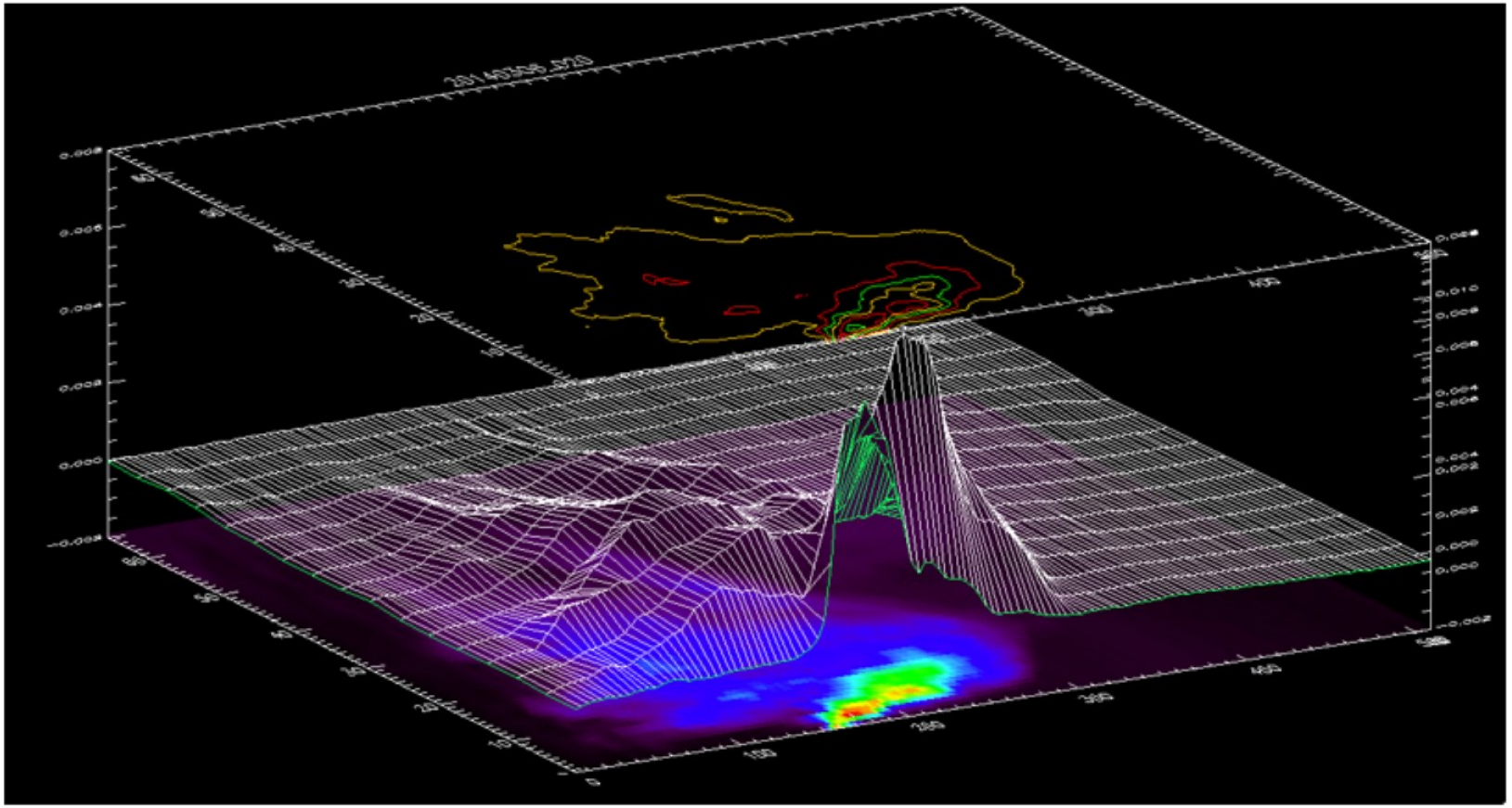




Two Dimensional Image of a Motorcycle

Hager Environmental & Atmospheric Technologies
H.E.A.T.

What we see with EDAR: One of 3-D multi-spectral images of entire exhaust plume



EDAR makes 512 measurements per scan per gas per second

Hager Environmental & Atmospheric Technologies
H.E.A.T.

Description of Pilot Study

- **Reason**
  - Scotland is developing regulations to reduce air pollution "hot spots" – especially in the centers of four large cities (i.e., Low Emission Zones).
  - On road information is being collected to make regulatory decisions.
  - In light of "Diesel gate" it was clear that there is a relative lack of empirical, on-road emissions data.
- **Funding**
  - East Central Scotland Vehicle Emissions Partnership
  - Scottish government
- **Approach**
  - HEAT for vehicle remote sensing device (RSD) system data collection and reporting
  - HEAT's remote sensing system, EDAR was deployed for emissions (CO_2, NO, NO_2 and $PM_{2.5}$) and vehicle data (speed, acceleration, license plate and exhaust temperature)
  - Characterize fleet and vehicles with collected on road data

Hager Environmental & Atmospheric Technologies
H.E.A.T.

Pilot Deployment

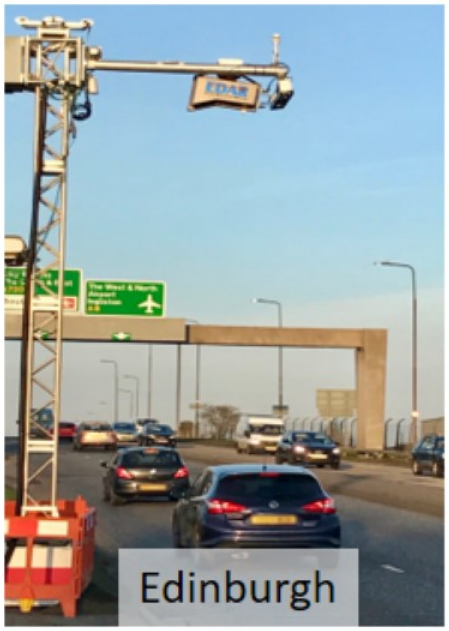
Three locations

- Coatbridge in North Lanarkshire (not yet published)
- Edinburgh
- Broxburn in West Lothian (between)

Hager Environmental & Atmospheric Technologies
H.E.A.T.

Test Site Setup

The same unmanned, mobile truss system for all three sites



Hager Environmental & Atmospheric Technologies
H.E.A.T.

Data Collection and Processing

EDAR Measured the Following:

- CO2, NO, NO2 & PM2.5
- Record of ambient conditions (wind speed, wind direction, humidity and ambient temperature)
- Vehicle speed and acceleration
- Automatically read (OCR) the plate number.
- Detected entire plume
- Interfering Plumes
- Determine exhaust temperature.
- Calculated vehicle specific power (VSP)

Processing

- Match to registration database and determine vehicle characteristics.
- Combine databases of emissions/conditions with vehicle characteristics.
- Quality assure the resulting database
- Perform analyses
- Report Results

Hager Environmental & Atmospheric Technologies
H.E.A.T.

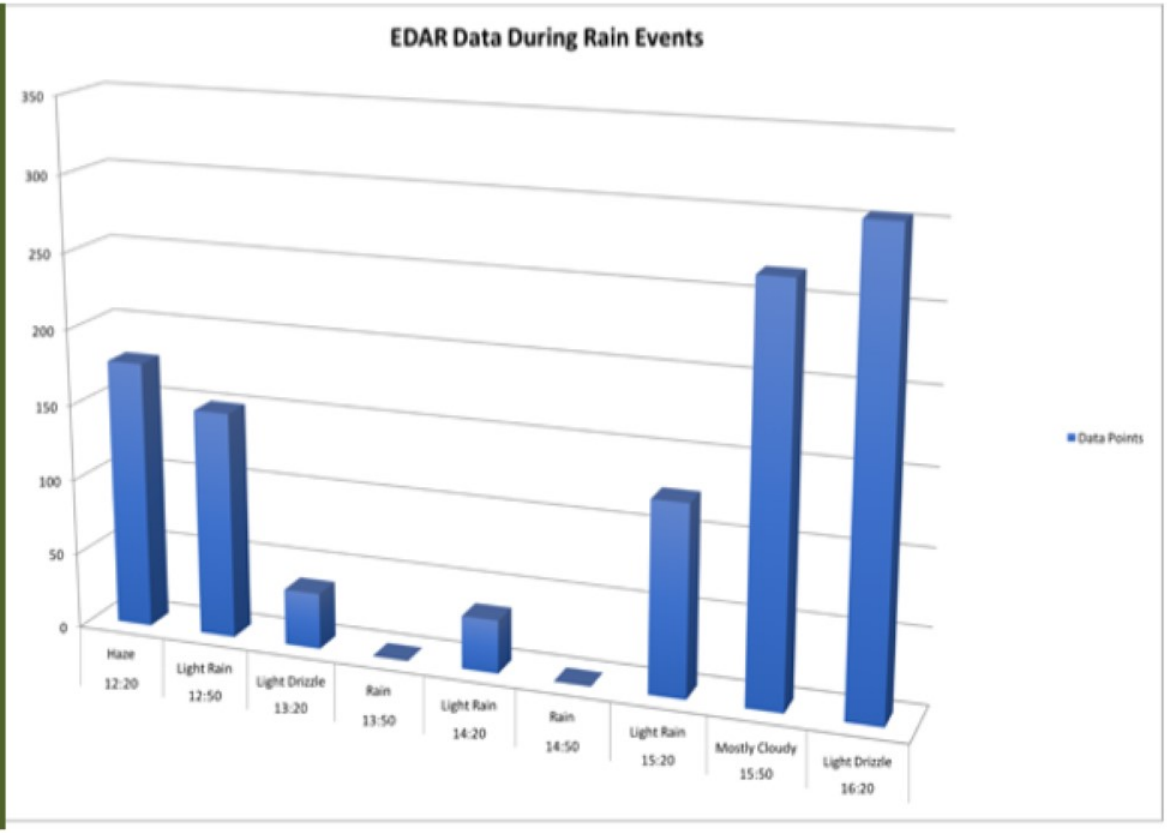
Published Data Overview

Overview	
Measurement Sites	2
Measurement Days	13
Attempted Measurements	81240
Valid Measurements (minus unreadable plates, interfering plumes, registered outside of country, etc)	74316
Valid Measurements Matched to Registration (minus unmatched plate numbers)	70318
Unique Vehicles Validly Measured & Matched (not including repeat measurements)	46882

Hager Environmental & Atmospheric Technologies
H.E.A.T.

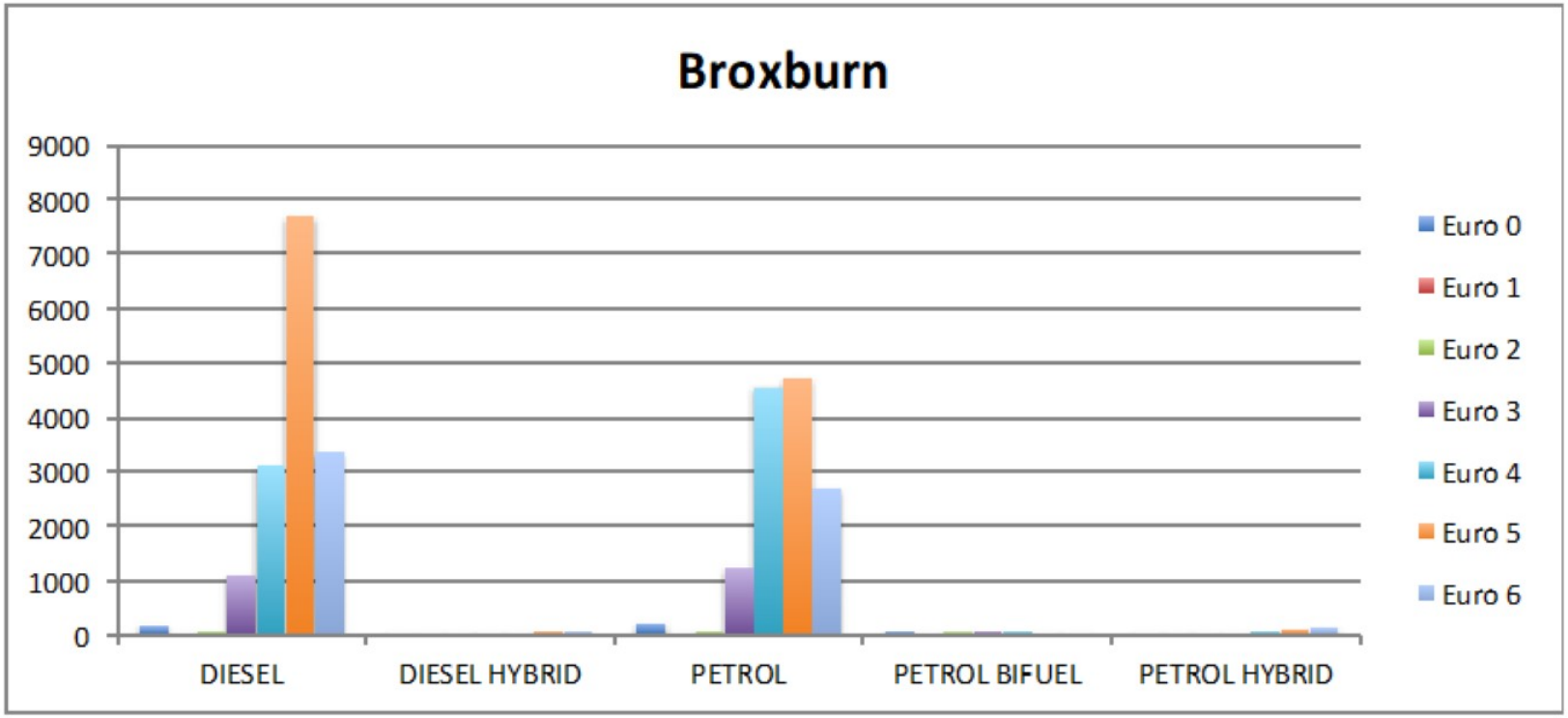
All Weather Application

- Directly below each EDAR an intelligent retroreflective strip was installed in the roadway.
- The reflector is deployed by securing it into a narrow transverse channel cut in the carriageway (in a similar manner to traffic sensor loops).
- When placed in position it is hidden and undetectable to road users.
- The reflector significantly increased data capture during light rain and mist due to increased albedo, and after heavy rain due to the reduction of spray from tires during the surface drying period.



Hager Environmental & Atmospheric Technologies
H.E.A.T.

Typical Sample Distribution by Fuel and Euro Standard



Hager Environmental & Atmospheric Technologies
H.E.A.T.

Exhaust Temperature (i.e., Fully Warmed Up?)

Vehicle Type	Fuel	* Total Vehicles	Engine Not Warm	% Engine Not Warm
Car	Petrol	33614	5477	16%
	Diesel	26038	4179	16%
Taxi	Diesel	704	153	22%
Van	Diesel	8273	1982	24%
Bus	Diesel	273	49	18%
OGV	Diesel	1329	411	31%

*Note, for this calculation:
All vehicles in this category are included, not just those with catalysts.

Hager Environmental & Atmospheric Technologies
H.E.A.T.

The Euro Emissions Standards

Light Duty Emissions Standard	Year Introduced	Heavy Duty Emissions Standard	Year Introduced
Euro 1	1992	Euro I	1992
Euro 2	1996	Euro II	1996
Euro 3	2000	Euro III	1999
Euro 4	2005	Euro IV	2005
Euro 5	2009	Euro V	2008
Euro 6	2014	Euro VI	2013

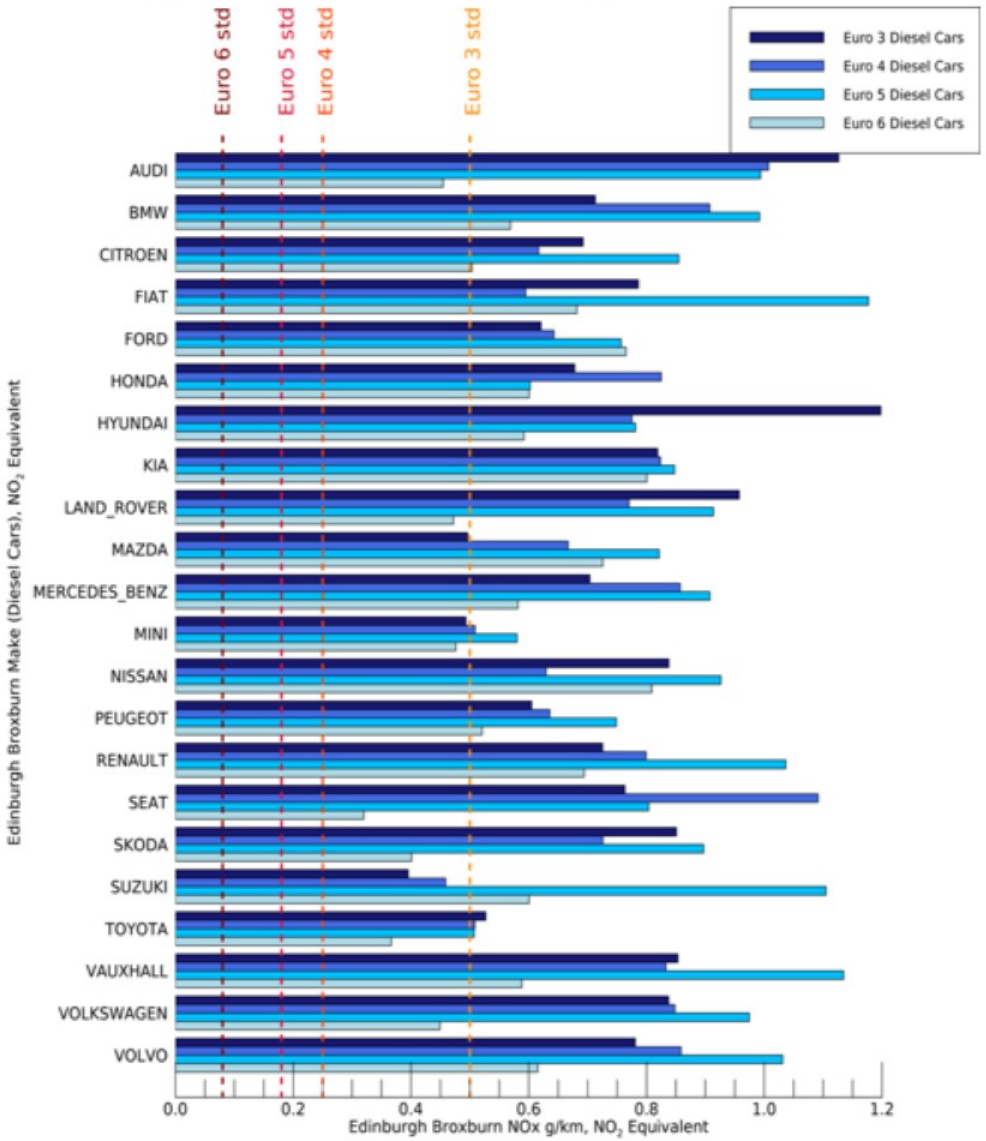
Vehicle Type	Emission Rate	Equivalent Euro Standard
Cars (g NOx/km)	0.08	Euro 6 Diesel Euro 4 Petrol
Light Goods Vehicles (g NOx/km)	0.105	Euro 6 Diesel Euro 4 Petrol
Heavy Duty Vehicles (g NOx/kWh)	0.40	Euro VI

	Euro Standards			
Passenger car / small LGV type (g NOx/km)*	Euro 3/III	Euro 4/IV	Euro 5/V	Euro 6/VI
Petrol	0.15	0.08	0.06	0.06
Diesel	0.5	0.25	0.18	0.08
Large LGV type (g NOx/km*)				
Petrol	0.18	0.1	0.075	0.075
Diesel	0.65	0.33	0.235	0.105
Heavy Duty Vehicles (g NOx/kWh)				
Rigid	5	3.5	2	0.4
Articulated	5	3.5	2	0.4
Buses and Coaches	5	3.5	2	0.4

*Euro standards before Euro 3/III are not presented as by 2020 they are an insignificant portion of the fleet

Hager Environmental & Atmospheric Technologies
H.E.A.T.

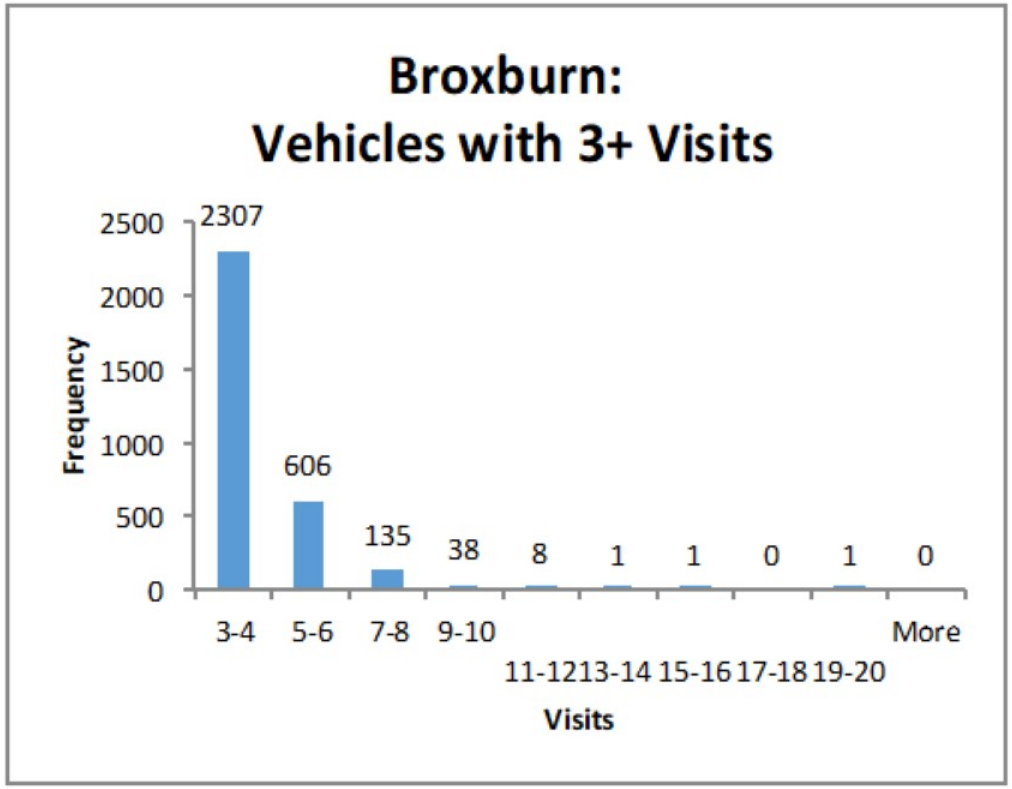
Comparison to the Euro Standards (by Make-Average at Both Sites)



Hager Environmental & Atmospheric Technologies
H.E.A.T.

Repeat Measurements

- Maximize single measurements to characterize the fleet.
- Maximize repeat measurements to characterize individual vehicles



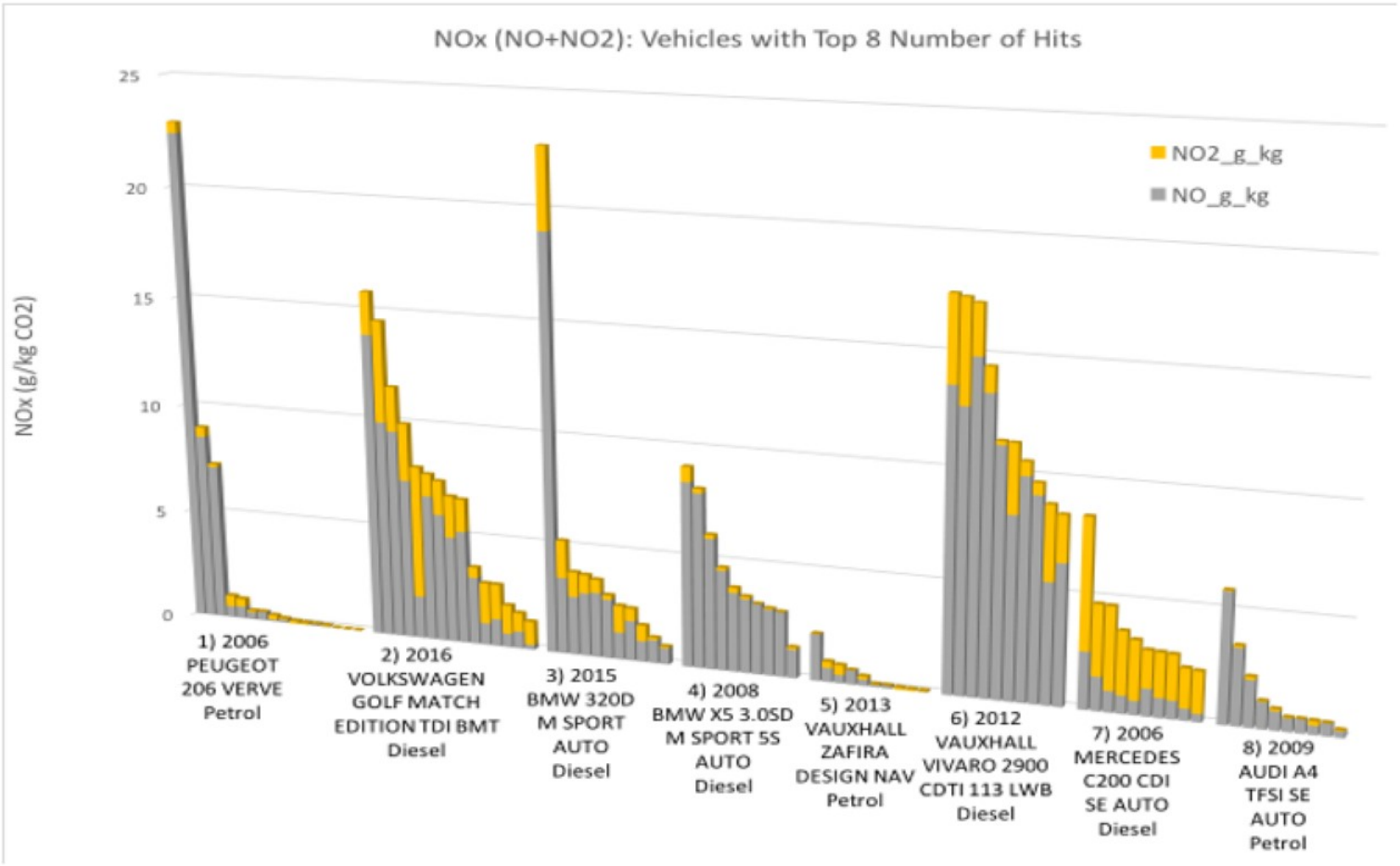
Hager Environmental & Atmospheric Technologies
H.E.A.T.

Advantages of Continuous Monitoring and Multiple Readings Per Vehicle

- Characterizing emissions using replicate measurements
- Finding Probable High Emitters
- Finding anomalies among the fleet
- Setting Rules and Regulations to alleviate congestion
- Allowing for Valid Clean Air Zones

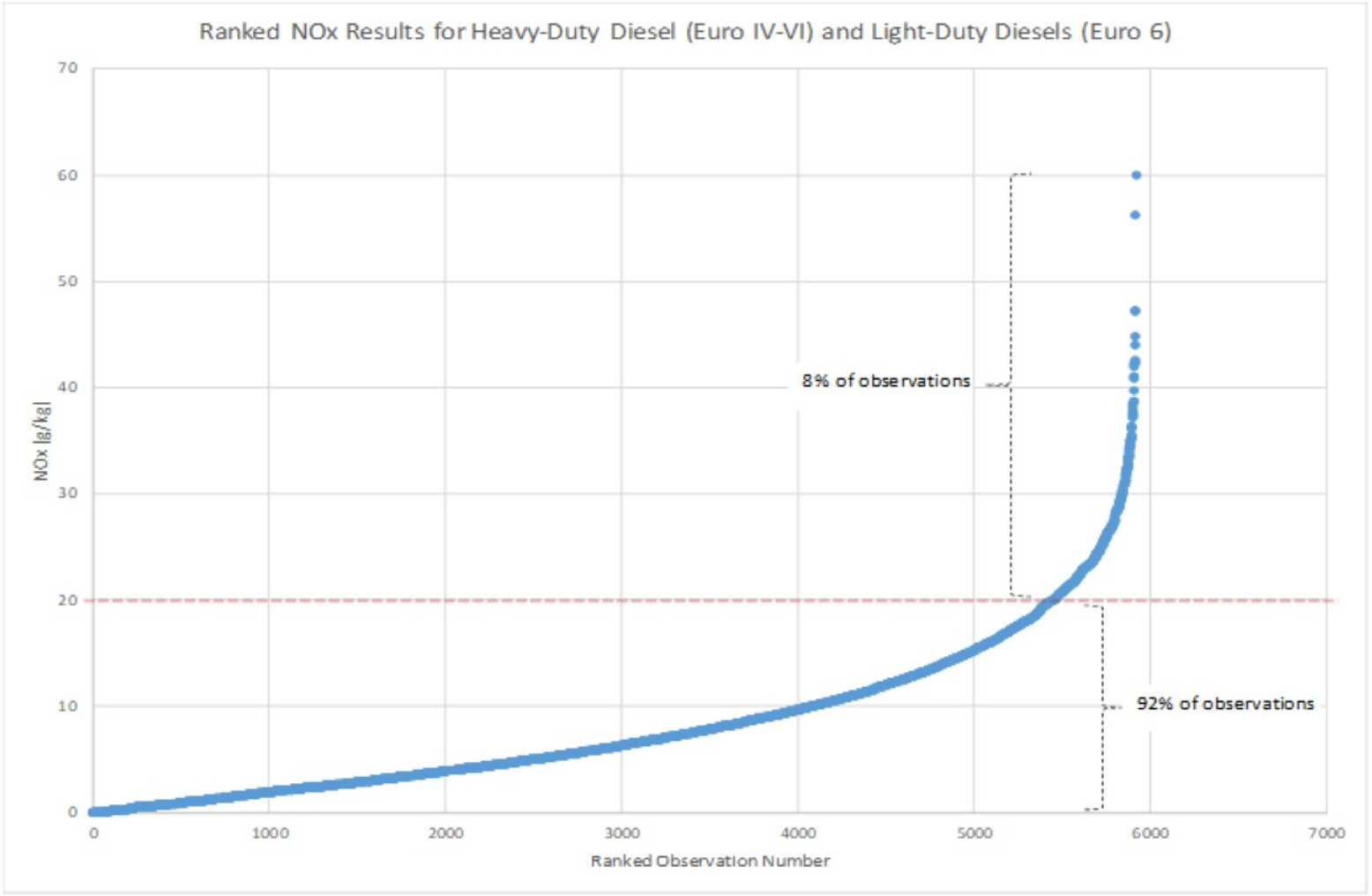
Hager Environmental & Atmospheric Technologies
H.E.A.T.

Top Eight Repeat Measurements from Both Sites - NOx



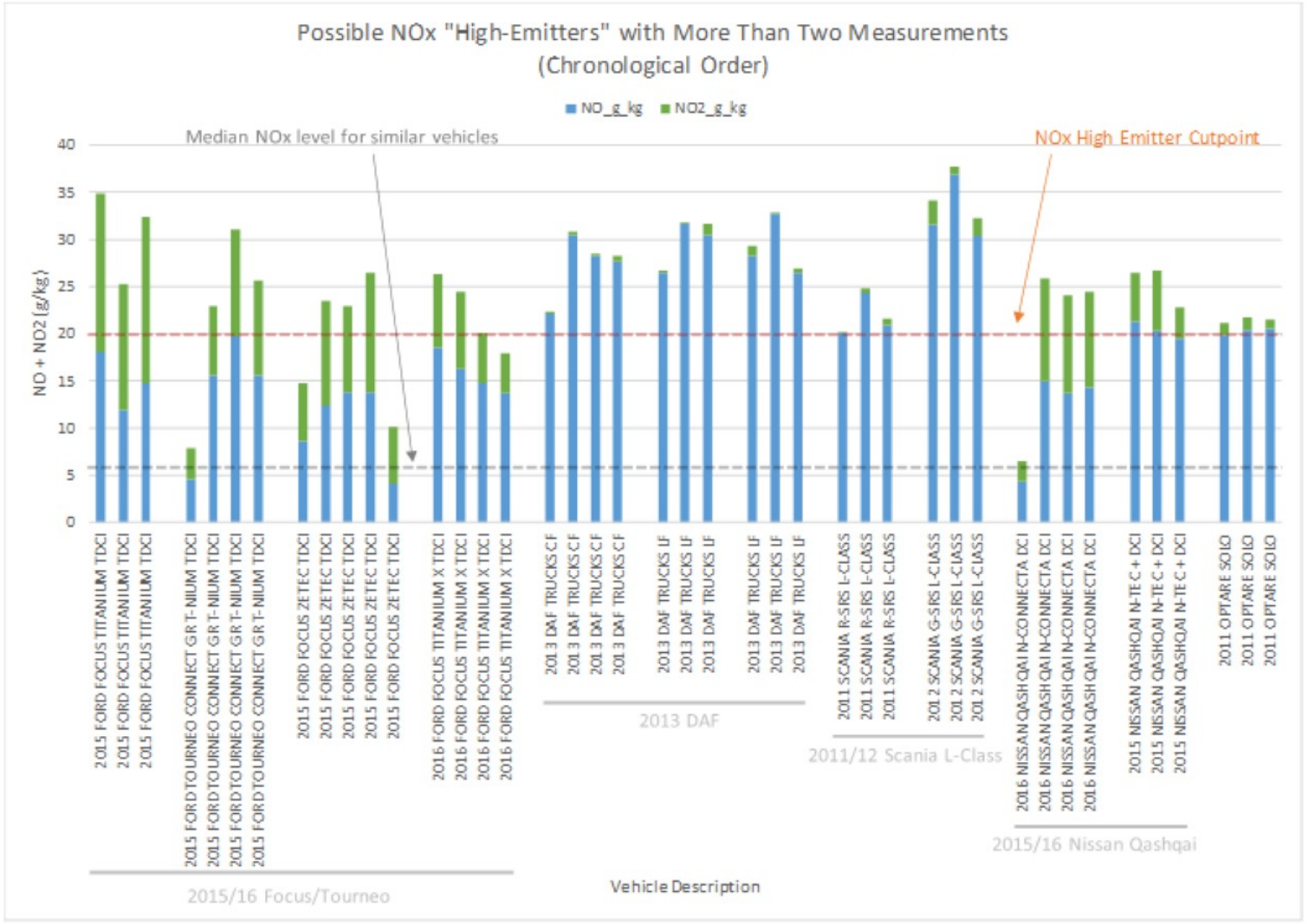
Hager Environmental & Atmospheric Technologies
H.E.A.T.

Ranking Emitters to Target the Highest - Both Sites - NOx



Hager Environmental & Atmospheric Technologies
H.E.A.T.

Probable High NOx Emitters from Both Sites



Hager Environmental & Atmospheric Technologies
H.E.A.T.

Summary

- The proposed method for excluding vehicles from Low Emissions Zones by using the Euro Standard will not produce Valid Clean Air Zones
- Euro 6 is not a proxy for "low emitter" in the real world
- Identifying actual clean vehicles requires real world emissions tests
- Buses retrofitted with aftermarket emissions controls should be monitored for pattern failures and faster than anticipated deterioration
- The evidence of pattern failures and emissions system design deficiencies in the Scottish fleet was found to be noteworthy
- Vehicles should be proven worthy of admission to an LEZ using actual measurements

Hager Environmental & Atmospheric Technologies
H.E.A.T.

The Authors Thank

East Central Scotland Vehicle Emissions Partnership

For conceiving and sponsoring the pilot

Lochwynd

For help with site permits and setting up the Portable Truss System at each site

The Scottish Government

For direct funding

Hager Environmental & Atmospheric Technologies
H.E.A.T.

Q? ➔ A!

Contact:

J. Stewart Hager, PhD
stewart@heatremotesensing.com
865-288-7890

Andrew Burnette
andrew.burnette@infowedge.com
916-760-8474