Diesel Locomotive Emissions Upgrade Kit Demonstration Project

Fuel Efficiency, Emissions & Noise Testing

Presentation of Project & Results 10/03/16

Natalie Roberts
Managing Director – ABMARC
0438 352 530 nroberts@abmarc.com.au

Contents

1. About ABMARC

2. Project Overview

3. Testing & Results

ABOUT ABMARC

ADVANCED | BENCHMARKING | REPORTING | CONSULTING

SENIOR STAFF

NATALIE ROBERTS – Managing Director

Principal of ABMARC, a business Natalie established in 2010, specialising in fuels, environment, automotive, transport, mining and energy business development and strategic marketing.

In 2012, Natalie became an Ian Potter Foundation Fellow, receiving the Fellowship to research Portable Emissions Measurement Systems (PEMS) in Europe and the USA from a regulatory and systems perspective. In 2015, ABMARC brought the first [and only] PEM system into Australia and has been conducting emissions and fuel consumption testing for research and policy development in the locomotive and heavy commercial vehicle sectors.

Holding a Bachelor of Engineering (Aerospace), Natalie first worked for GM (Holden) in powertrain calibration, before accepting a position with Toyota, leading strategic planning and research for the Australian and Middle Eastern vehicle markets. Additionally, Natalie is approved by VicRoads under their Vehicle Assessment Signatory Scheme.

ANDREA WINKELMANN – Engineering Director

Beginning her automotive career in Germany and completing her engineering degree in the UK, Andrea has worked across the heavy and light vehicle sectors for more than 25 years. Andrea immigrated to Australia in 2005, first working at Ford and then GM Holden.

Andrea is Engineering Director at ABMARC, where she is responsible for delivering customer test and engineering projects across all mobility sectors. Specifically focusing on engines, emissions and fuels and testing with a Portable Emissions Measurement System, capable of Euro 6 measurements on customer sites or on mobile applications.

Andrea has been awarded the ISSI – Eddy Dunn Endowment International Fellowship to research the Impact of International Heavy Duty Vehicle OBD Regulation Amendments (2013 onwards) on the Service and Repair Industry in Australia and will be traveling early 2016.

ABOUT ABMARC

ADVANCED | BENCHMARKING | REPORTING | CONSULTING

ENGINEERING, RESEARCH & CONSULTING

REAL WORLD ECONOMY & EMISSIONS

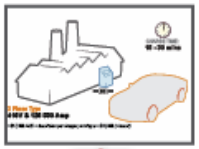
Australia's only Portable Emissions Measurement System compliant to EPA 1065 2007 & EC 595 2009
On road or in field emissions & fuel consumption measurement
Development of engines & exhaust after treatment systems
Gaseous & particulate emissions
Laboratory quality emissions data from the real world

RESEARCH, BENCHMARKING & MARKETING

Market insight & product demand studies
Product planning
Policy development for regulation or corporate
Alternative fuels
Vehicle & engine technologies
Benchmarking & competitor analysis

VEHICLE & FLEET ENGINEERING SERVICES

Durability & environmental [hot weather] test programs
Captured fleet programs
Telematics & analytics for validation & certification
Dynamic vehicle testing
Forensic engineering



TECHNICAL WRITING & ILLUSTRATIONS

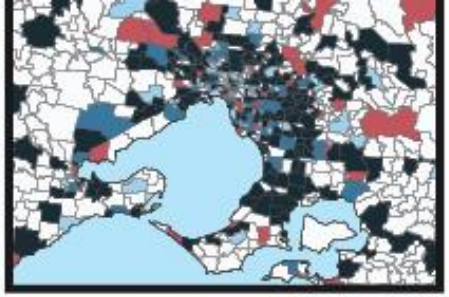
Sales materials for Automotive suppliers selling to OEMs
Editing & illustration
Maintenance and service manuals
Reports
Job procedures

OUR CUSTOMERS

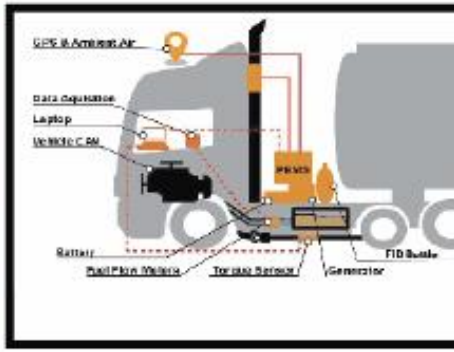
CALTEX
ELGAS
AUSTRALIA POST
RACV
NRMA
AUSTRALIAN AUTOMOBILE ASSOCIATION
RMIT UNIVERSITY
Rail Technology International
RACQ
VACC
ADFA
Kleenheat Gas
ERGON ENERGY
AGL
Gas Energy Australia
ASA
Mercedes-Benz
Ford
TOYOTA
United
HYUNDAI
7 ELEVEN
SAE AUSTRALASIA

+ MANY MORE.









GPS & Ambient Air
Data Aquisition
Laptop
Vehicle CAN
Battery
Fluid Flow Meters
Torque Sensor
Generator
FID Bunsle












Contents

1. About ABMARC

2. Project Overview

3. Testing & Results

Test Overview & Locomotives

The objective of the Diesel Locomotive Emission Upgrade Kit Demonstration project was to determine the emissions, fuel efficiency and noise impact of fitting Tier 0+ emission upgrade kits to two EMD locomotives, relative to the same locomotives rebuilt to their original standard.

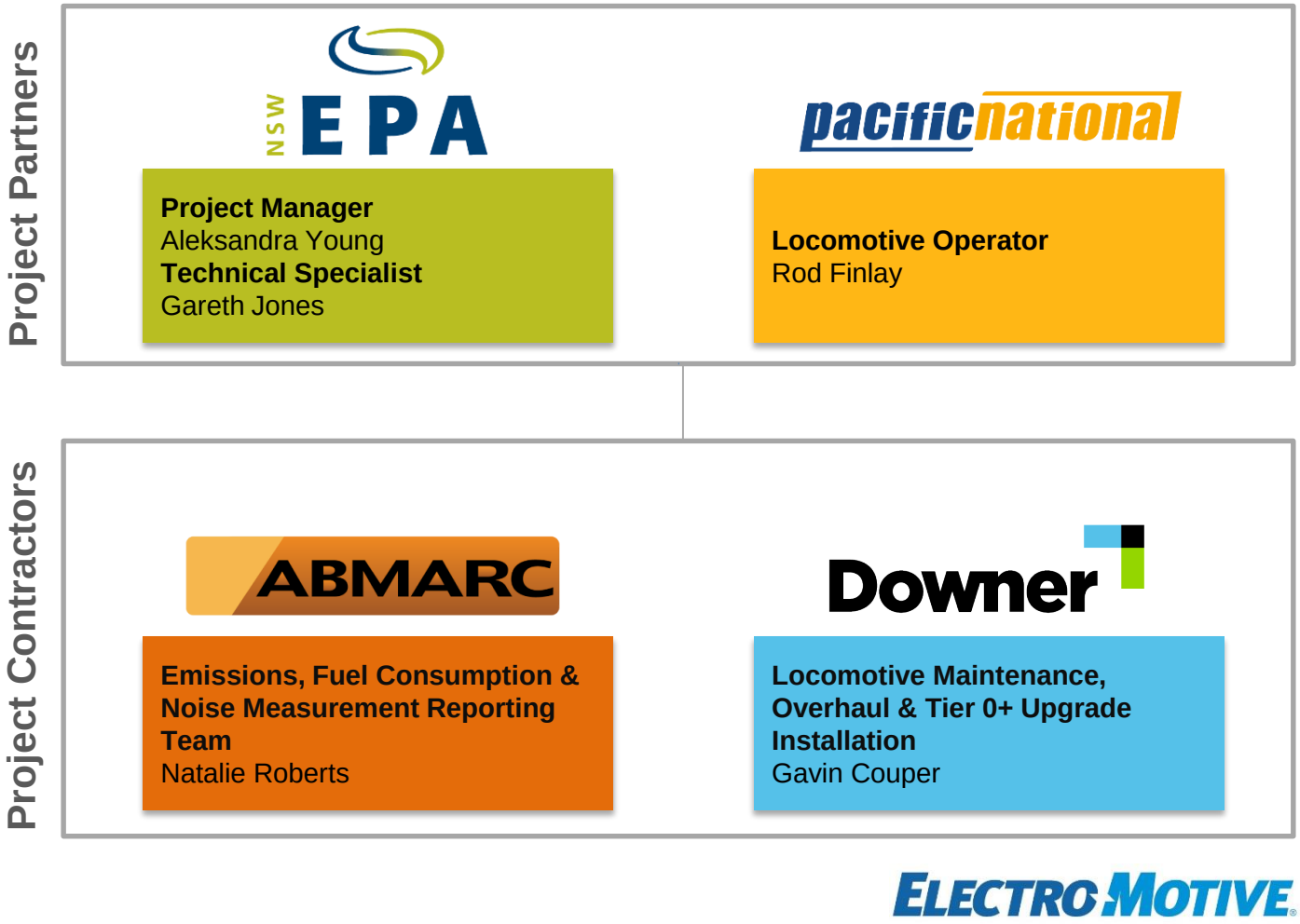
- Stage 1, Pre Upgrade Test – After standard rebuild
- Stage 2, Post Upgrade [Tier 0+] Test – After Tier 0+ rebuild

EMD16-645 E3B engine ~ 2,460 kW

EMD 16-710 G3A engine ~ 3,030 kW

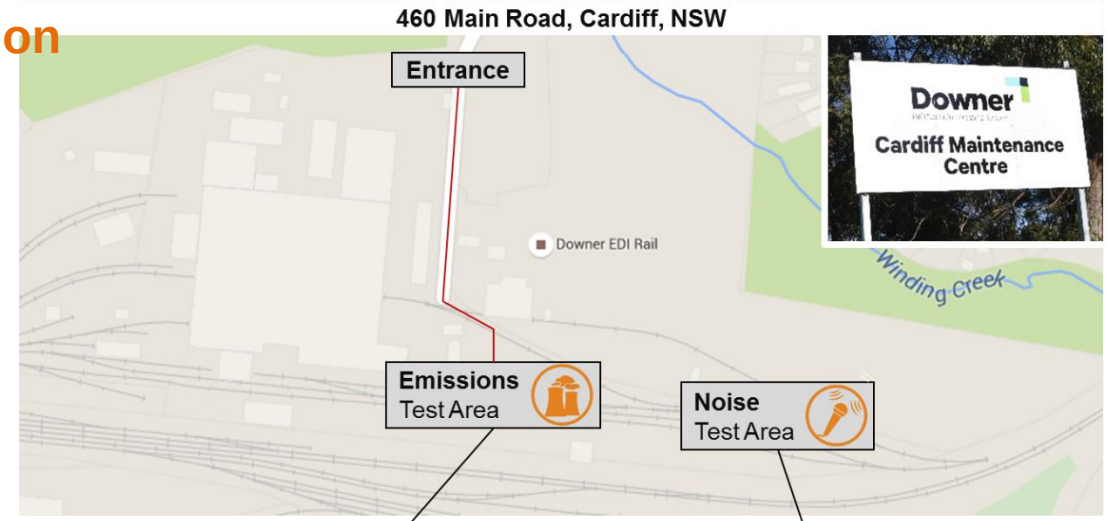
Two locomotives. Two configurations. Two tests per configuration. Emissions measured with PEMS.

Project Stakeholders



ABMARC engaged AECOM for noise testing and partnered with AVL [emissions equipment manufacturer] for first test. EMD provided Pacific National with emissions kit and supported Downer Edi with the installation.

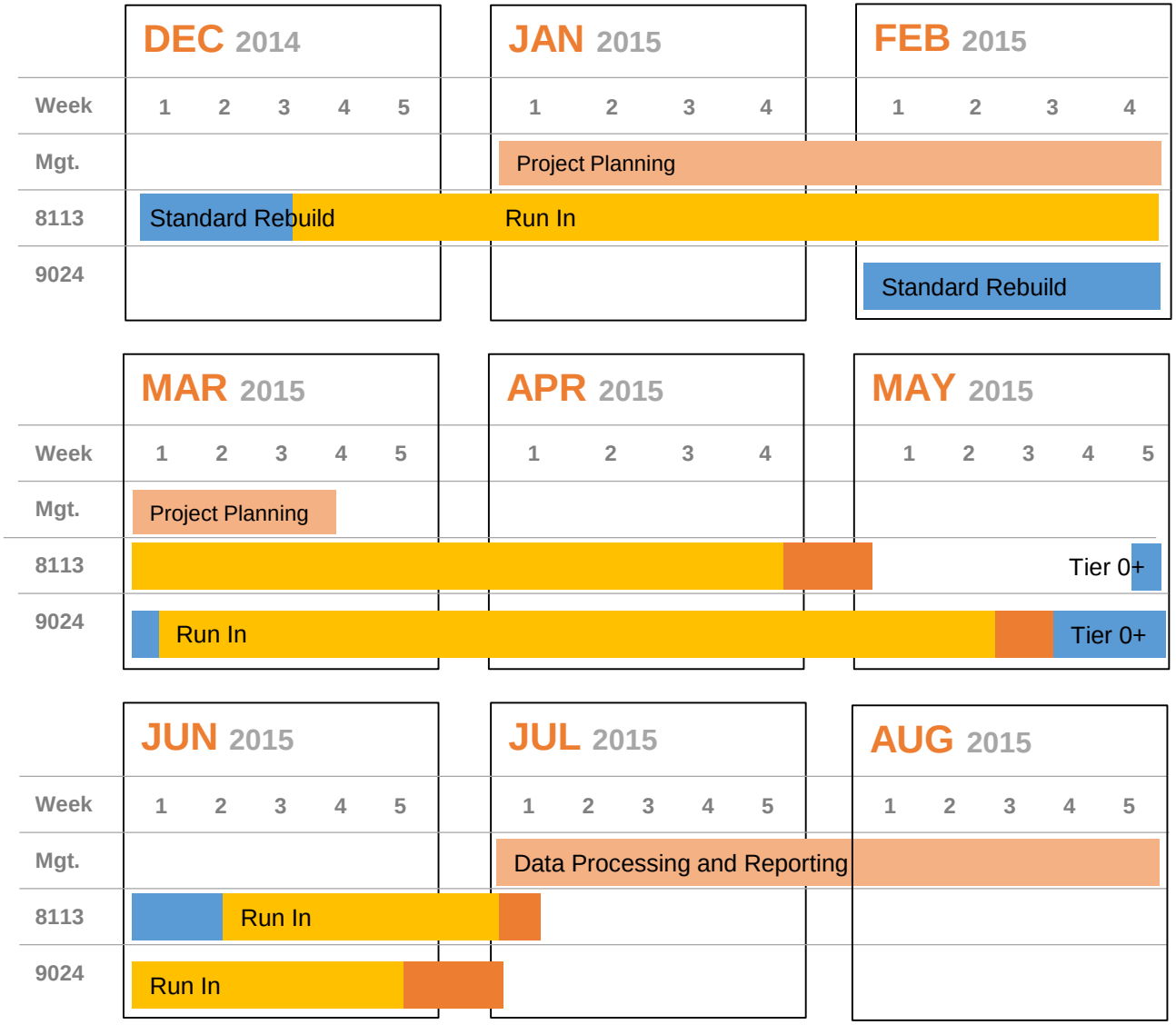
Test Location



PROJECT OVERVIEW

ADVANCED | BENCHMARKING | REPORTING | CONSULTING

Project Timing

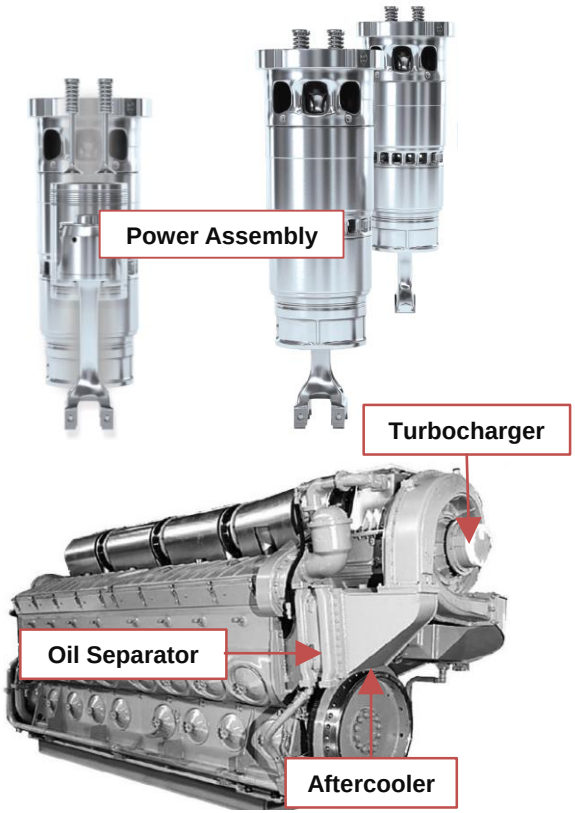


- Project management and reporting
- Emissions, fuel consumption and noise testing
- Locomotive rebuild or kit installation (as specified)
- Run In – to stabilise emissions and fuel consumption

Example Schedule For All Tests

Day	ITEM
1	Set Up
2	Emissions and Fuel Consumption Test
3	
4	Instrumentation Decommission
5	Noise Test
6	PM Filters Weighed
7	Fuel Sample Analysed

Emissions Upgrade Kit Overview



Ultra Low Lube Oil Power Assembly - The introduction of a hardened upper bore liner with specially designed bore profile and piston crown with improved piston ring design results in a claimed reduction in oil consumption by 50%.

Oil Separator – The Tier 0+ kit includes an improved oil separator to reduce the amount of crankcase oil mist that is carried over to the intake air, leading to further reduction in PM emissions.

Four Pass Aftercooler –Improved aftercoolers for more effective cooling of the combustion air from the turbocharger.

Ecotip Injectors – The Tier 0+ injectors drip less fuel and have an improved spray pattern to improve combustion efficiency, reduce PM, NO_x and other emissions along with improving fuel consumption. Additionally the Tier 0+ kit includes an adjustment of the injection timing to aid in reducing NO_x emissions to below the Tier 0+ limit.

Key Performance Benefits
Fuel consumption reduced by 2% to 5%
PM and NO_x reductions below Tier 0+
Reduce oil consumption by 50%.

PROJECT OVERVIEW

ADVANCED | BENCHMARKING | REPORTING | CONSULTING

Measurements

Emissions

Measured with Portable Emissions Measurement System [PEMS]. Providing repeatability of 1% or better and complying with US EPA and ECE regulations.

- Particulate Matter: Collected on gravimetric filter and weighed
- Soot: Second by second
- Gaseous: THC, CO, CO2, NO, NO2

Fuel consumption

Accuracy to 0.2% and repeatability to 0.02%.
Measured from positive displacement [volume] fuel flow meters [inc temp measurement].

Engine power

Measured across all motors and calculated instantaneously from the voltage and current outputs. Engine power is calculated from generator efficiencies.

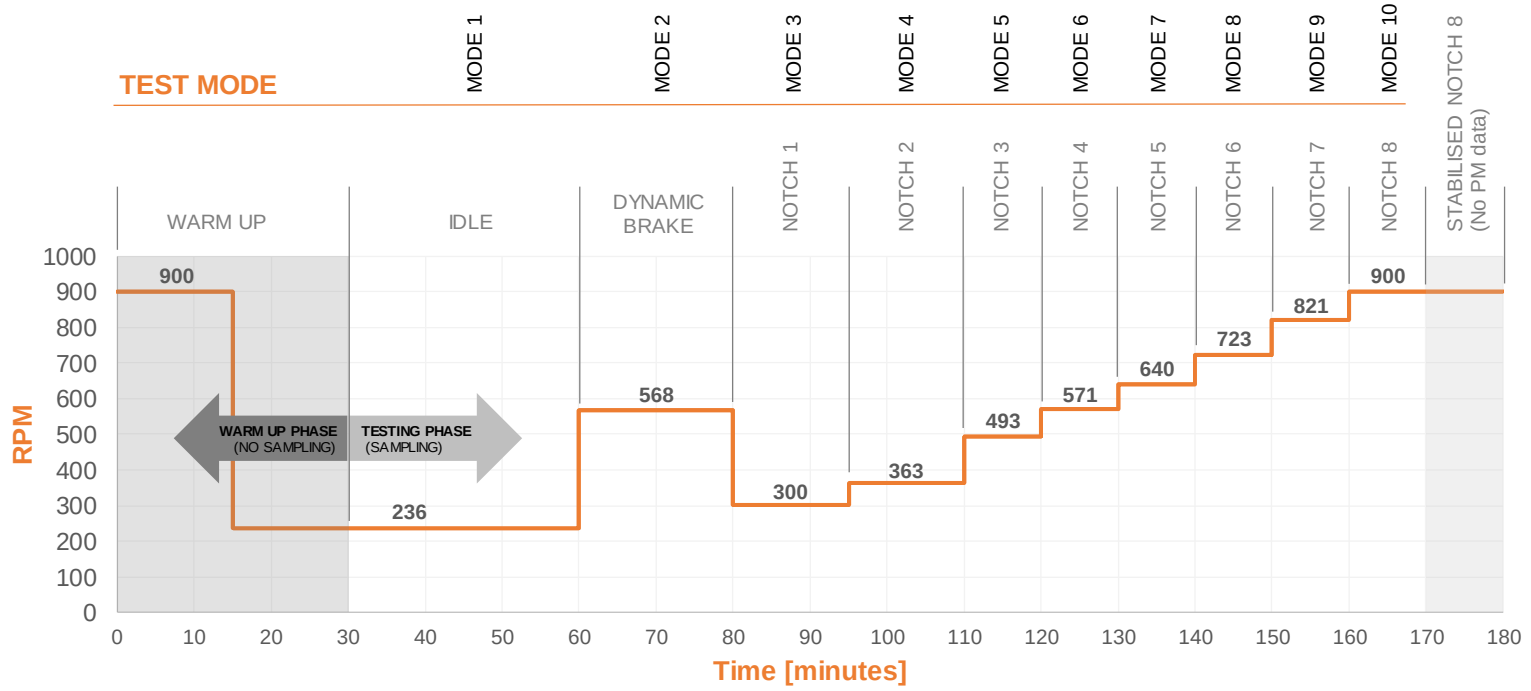
Noise

Measured according to AS2377-2002.

Outputs

- Grams [g] of emissions per unit of work [kW.hr]
- In Litre/hr and Grams [g] of fuel burned per unit of work [kW.hr]
  Also known as Brake Specific Fuel Consumption (BSFC) [g/kW.hr]
- Noise [dB]

Locomotive Test Procedure



Notch setting	Normal Idle	Dynamic Brake	Notch 1	Notch 2	Notch 3	Notch 4	Notch 5	Notch 6	Notch 7	Notch 8
Test mode	Mode 1	Mode 2	Mode 3	Mode 4	Mode 5	Mode 6	Mode 7	Mode 8	Mode 9	Mode 10
Weighting Factors	0.38	0.125	0.065	0.065	0.052	0.044	0.038	0.039	0.03	0.162

Emissions and fuel consumption testing and calculations were conducted according to US EPA CFR Title 40, Volume 33, Part 1065 and 1033.

PROJECT OVERVIEW

ADVANCED | BENCHMARKING | REPORTING | CONSULTING

Test Standards [Emissions & Fuel Efficiency]

Pre-Test

Filter conditioning and weighing
40 CFR 1065.590

Temp, humidity, pressure sensors
40 CFR 1065.915

Environmental Conditions
Temperature: 5°C to 43°C *(emission test)*
Humidity: Max 95% at 25°C *(emission test)*
Wind Speed: ≤10m/s *(noise test)*
Background Noise Levels: 10dB below A or C weighted locomotive SPL *(noise test)*

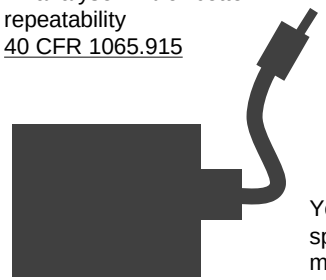
Test

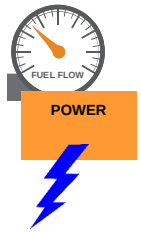
Calibration

Span gases
1% accuracy
40 CFR 1065.750

Testing

AVL Gaseous & PM PEMS –
All analyser 1% or better repeatability
40 CFR 1065.915





Yokogawa power analyser – as specified by locomotive manufacturer

Kral fuel flow meter x 2
0.2% accuracy combined, repeatability to 0.02% combined.
Calibration
40 CFR 1065.320

Noise tested to
AS2377-2002

PEMS emissions and fuel test to 40 CFR 1065.201 - 395

Post - Test

PEMS Analyser Drift Verification
40 CFR 1065.550

Filter conditioning and weighing
40 CFR 1065.595

Fuel samples tested to
ASTM D4052 & D240

Density & calorific value used for emissions and fuel consumption calculations.

Calculations performed to
40 CFR 1065 subpart G

$$f(x)$$

With EMD specified BSFC correction factors

Report and data to EPA

Accuracy of PEMS

Gas PEMS Module

Photo-acoustic sensor

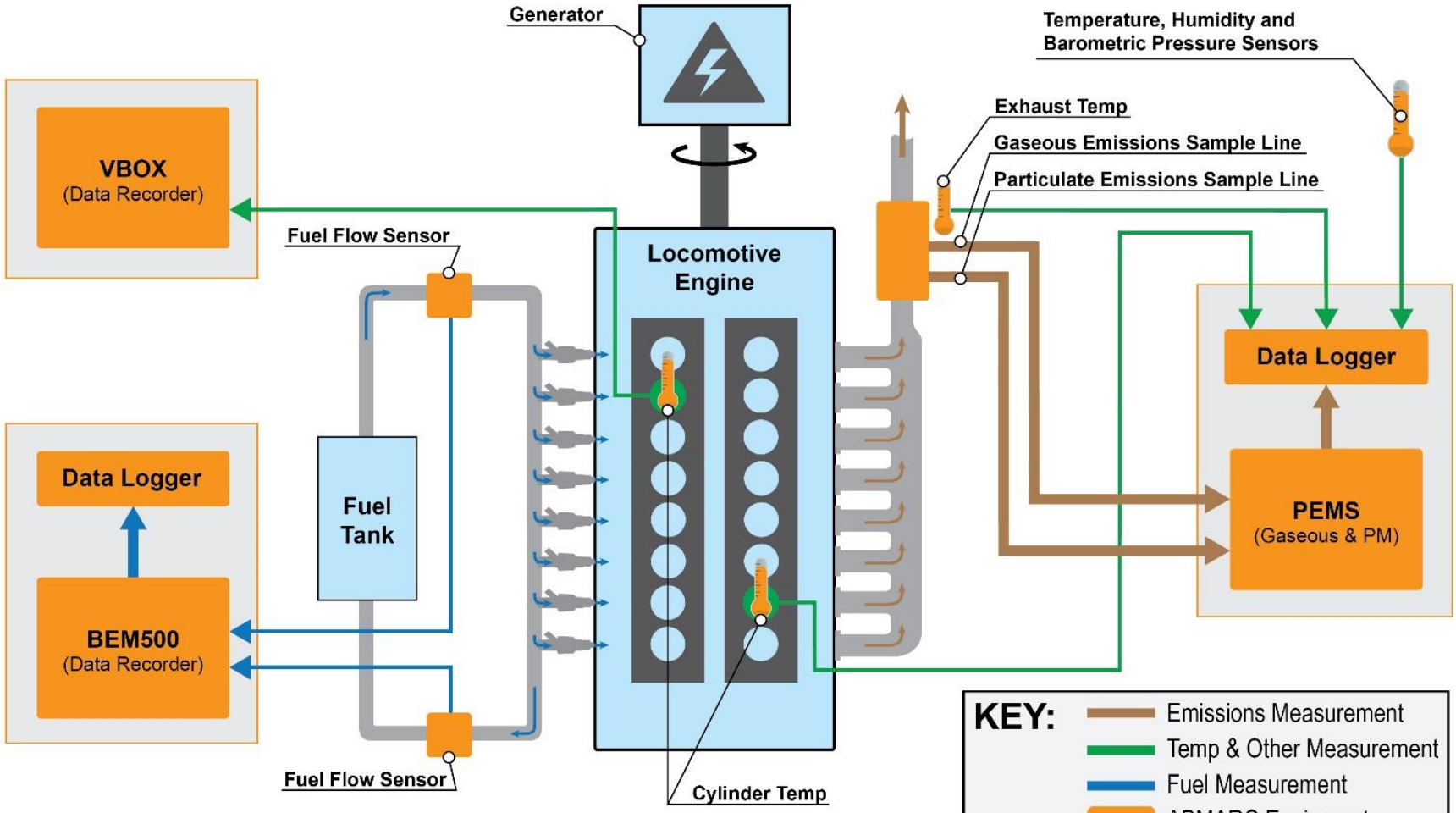
Gravimetric Filter Module

PM PEMS Modules

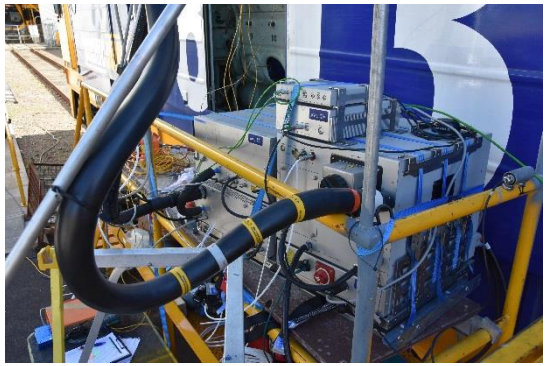
Attribute	UNEC Reg. 49 Annex 4		AVL PEMS & Fuel Flow Meters	
	Accuracy	Repeatability	Accuracy	Repeatability
Fuel Flow (Combined)	≤2%	≤1%	±0.2%	±0.02%
CO/CO_2	≤2%	≤1%	±2%	±1%
THC	≤2%	≤1%	±2%	±0.5%
$NOx (NO/NO_2)$	≤2%	≤1%	±2%	±0.5%
PM (Gravimetric)	≤2%	≤1%	Satisfied	Satisfied

PEMS provides laboratory accuracy and repeatability on the road and in the field.

Instrumentation for Emissions and Fuel



Instrumentation for Emissions and Fuel



PEM system and
emissions sample lines

Exhaust stack and emissions
sample probes on 8113

PEMS setup on 9024

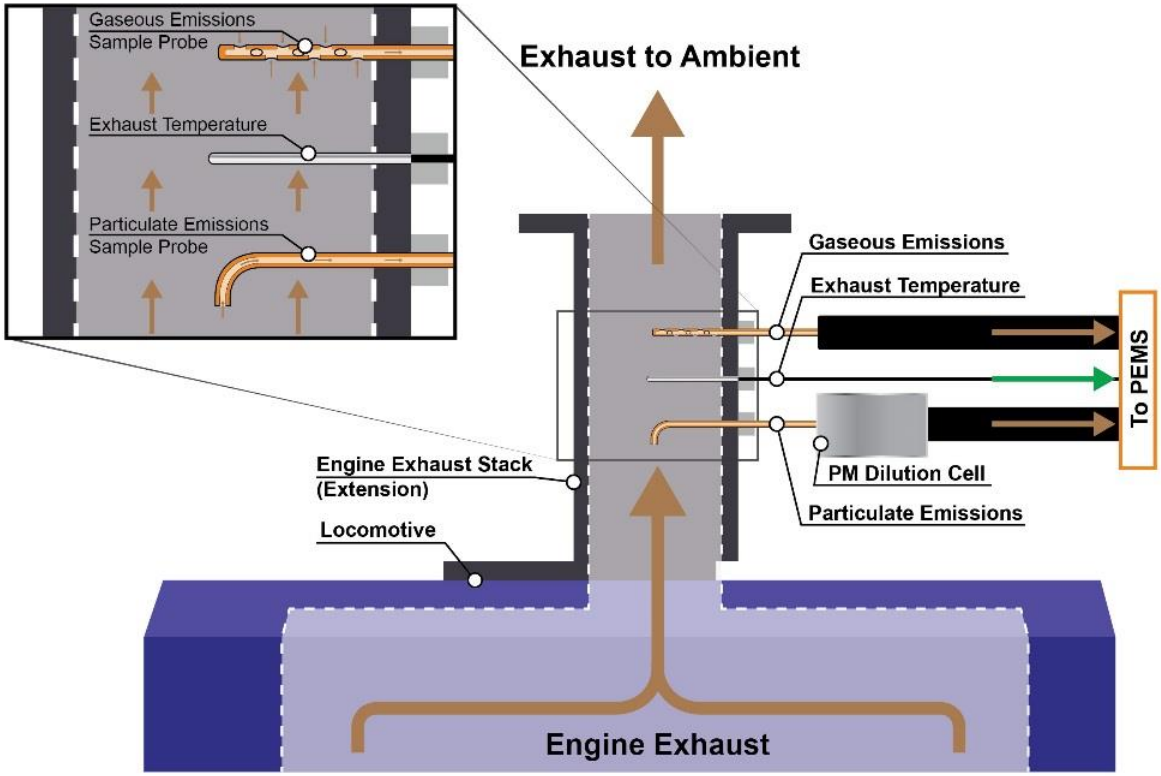
High precision fuel flow
meter on delivery line

High precision fuel flow
meter on return line

9024 In-Cabin data monitoring of all
measurement Items

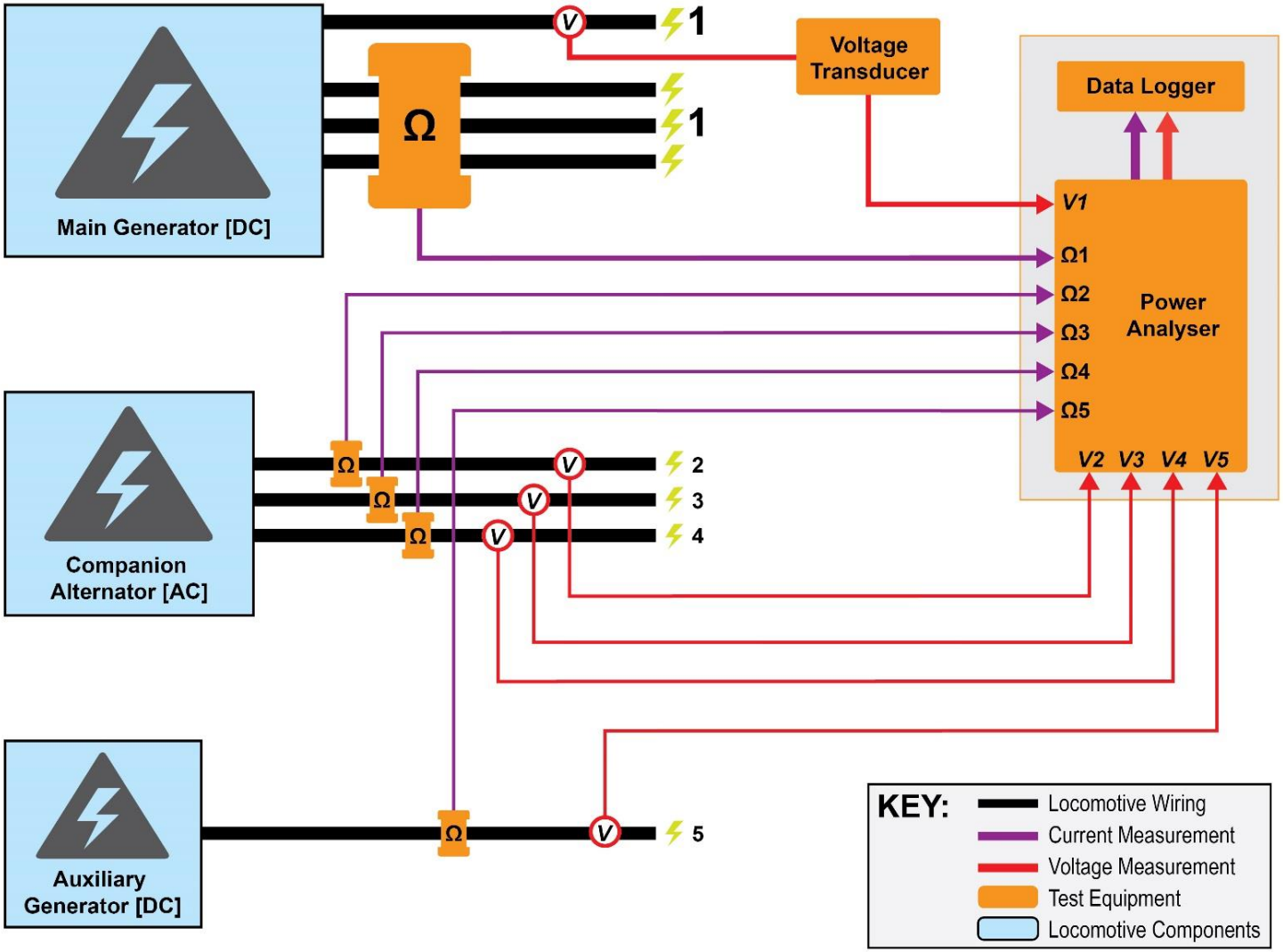
Instrumentation for Emissions and Fuel

Emissions Sampling

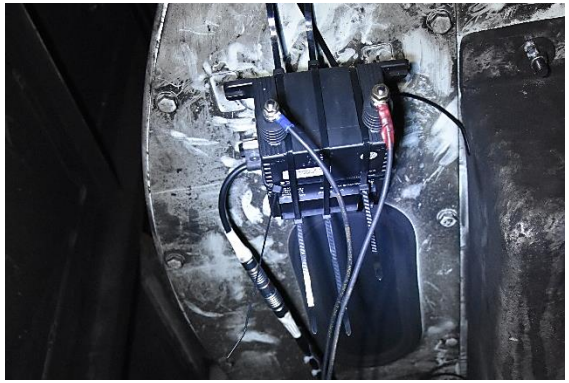


Emissions Sampling

Power (from Motors)



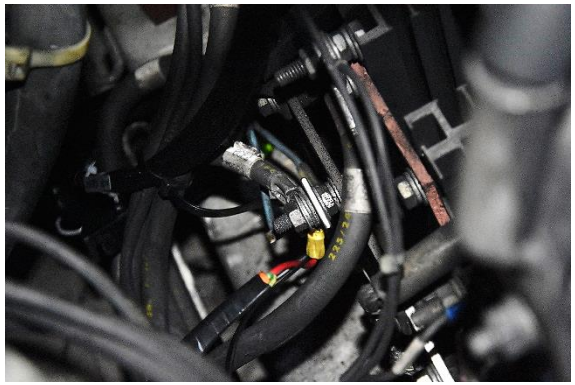
Power Measurement



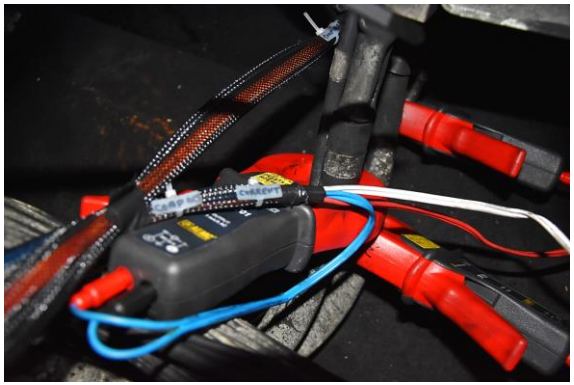
Voltage transducer on main DC generator

Current transducer on main DC generator

Power measurement device installed in-cabin

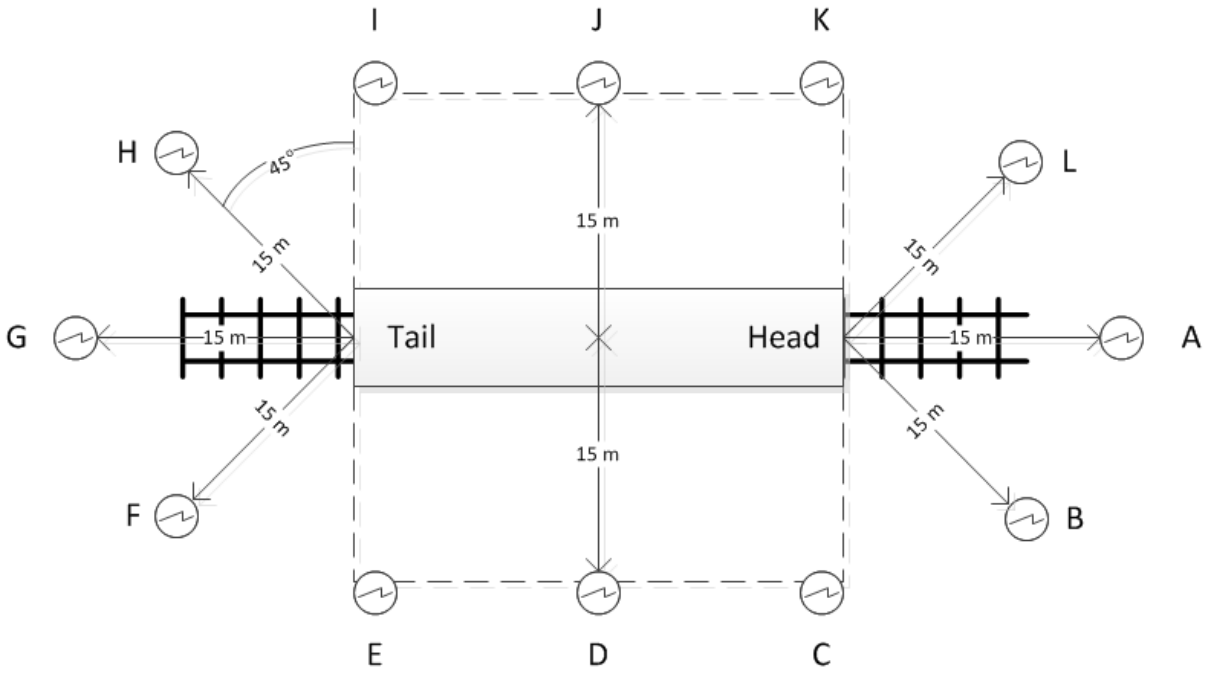


Voltage connections for auxiliary DC generator



Current clamps on companion AC alternator cables

Noise Test Procedure AS 2377-2002



Environmental Condition	Limit
Wind speed	≤10m/s
Background noise levels	10dB below A or C weighted SPL of locomotive
Precipitation	None

Acoustic values were recorded in all locomotive operating modes, from idle to notch 8.

Noise Testing

Cirrus

Bruel and Kjaer

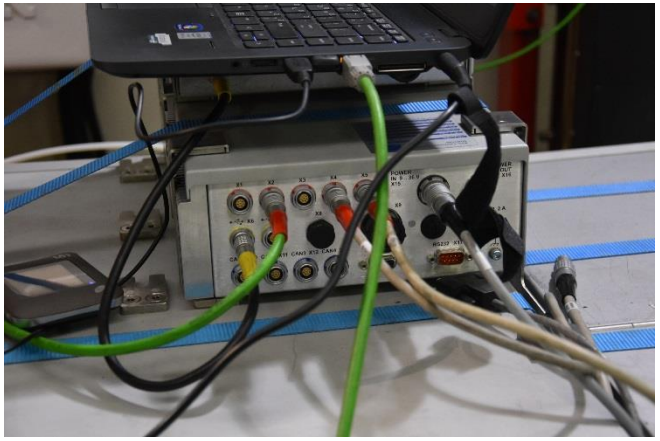
Contents

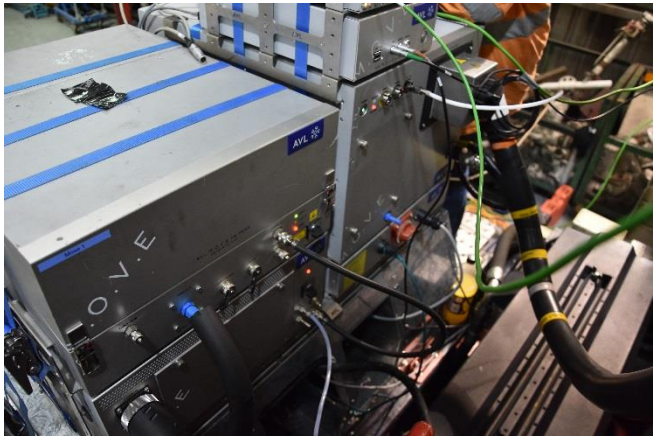
1. About ABMARC

3. Project Overview

3. Testing & Results

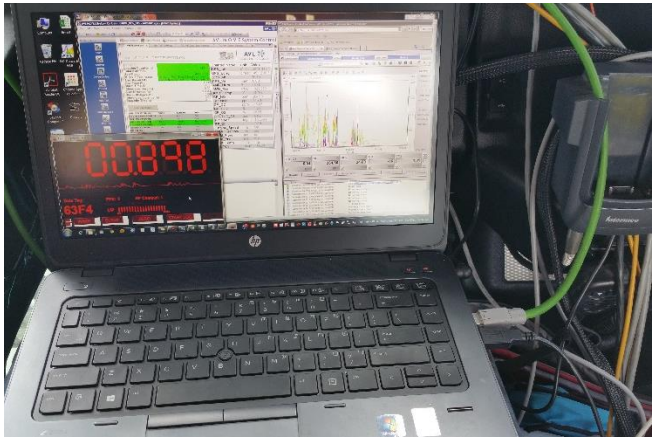
PEMS Warm Up

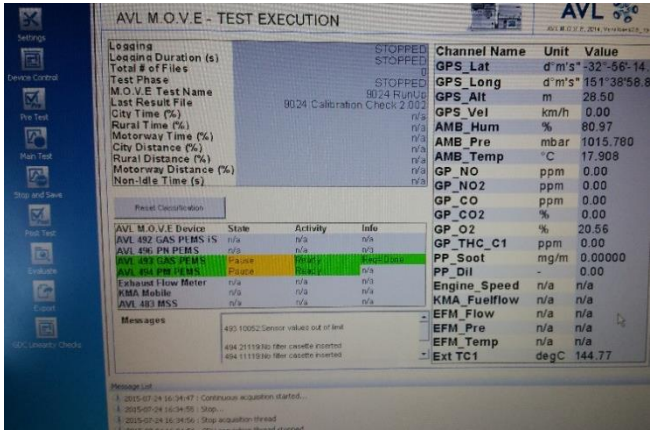




Warm up PEMS before calibration and test. Approx 60 minutes. Gaseous sample line to 191°C and PM sample line to 52°C.

PEMS Calibration



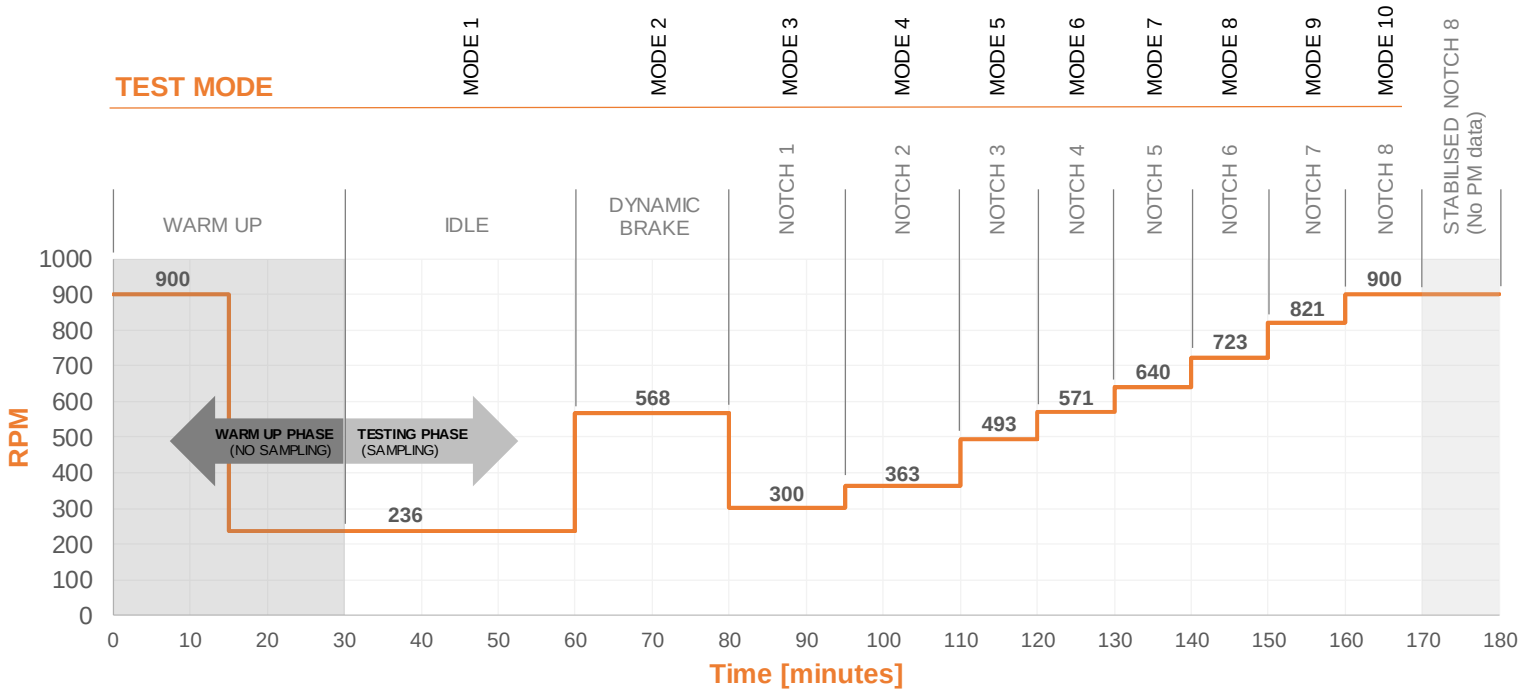


PEMS calibration includes a leak check, gaseous calibration with certified gas and data check.

Filters

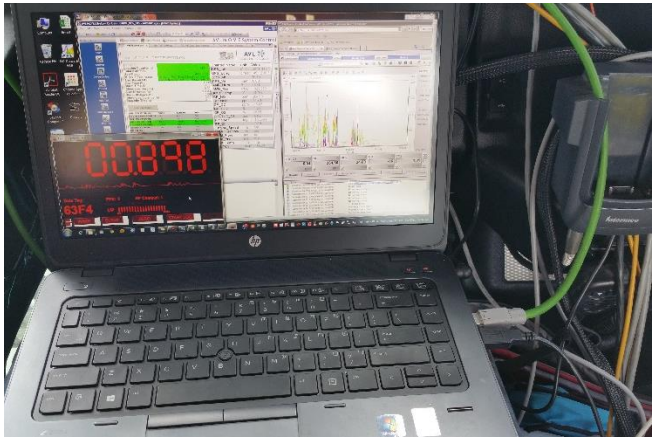
New filter for each test mode [10 per test]

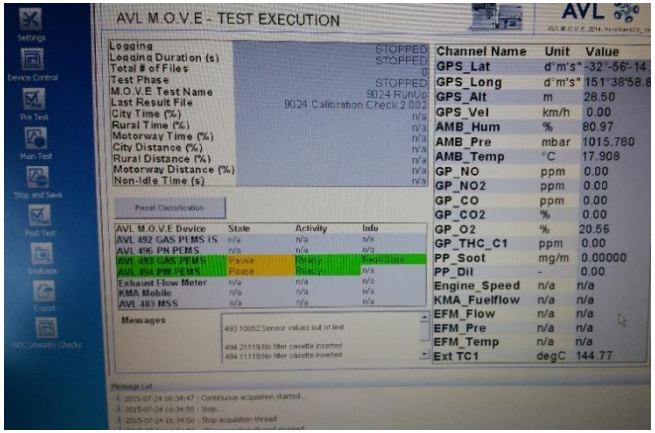
Locomotive Test Procedure



Emissions and fuel consumption testing and calculations were conducted according to US EPA CFR Title 40, Volume 33, Part 1065 and 1033.

Finish Test



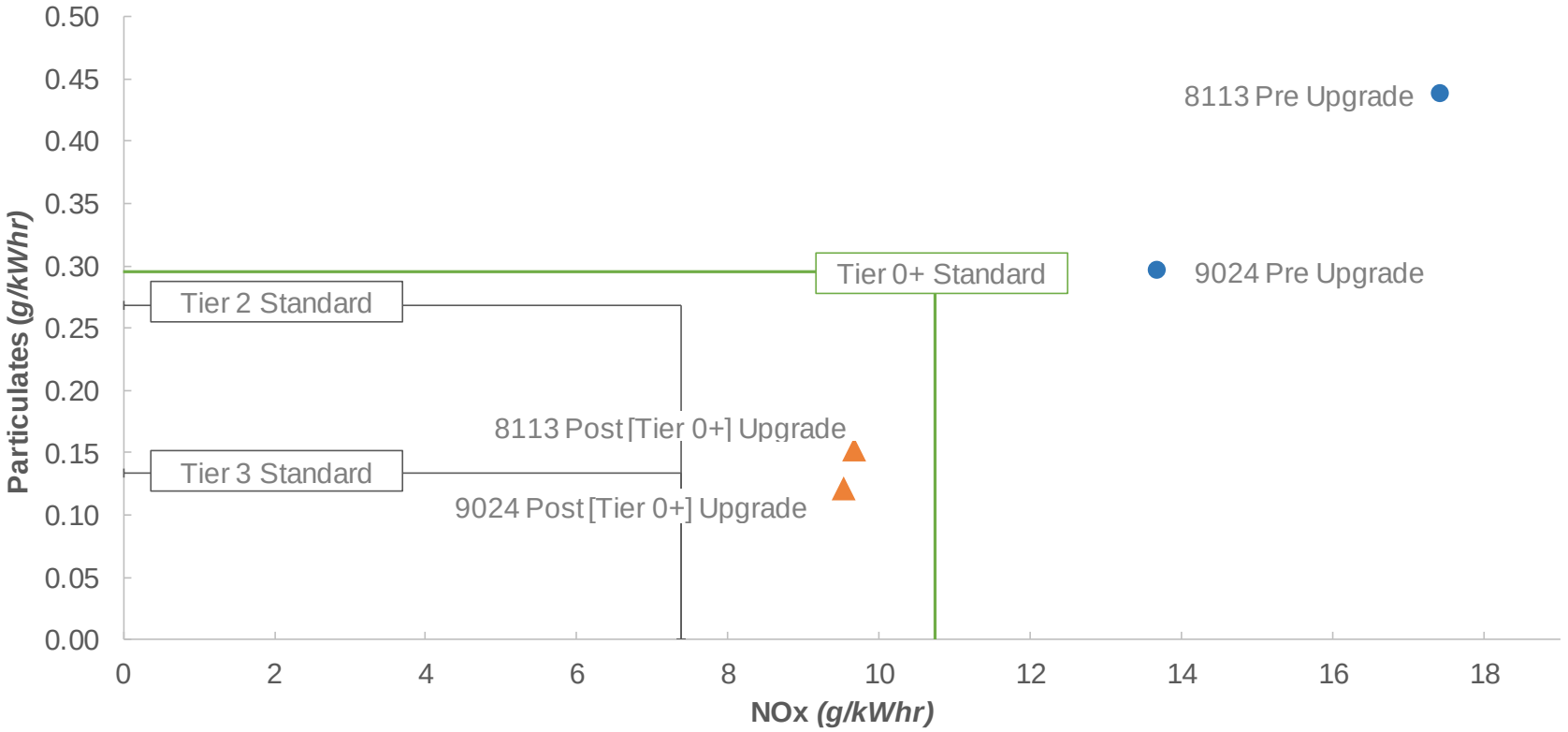


PEMS analyser drift check, leak check and data check.

Finish Test

Send diesel fuel sample and gravimetric filters for analysis.

Results both Locomotives – Summary PM & NOx

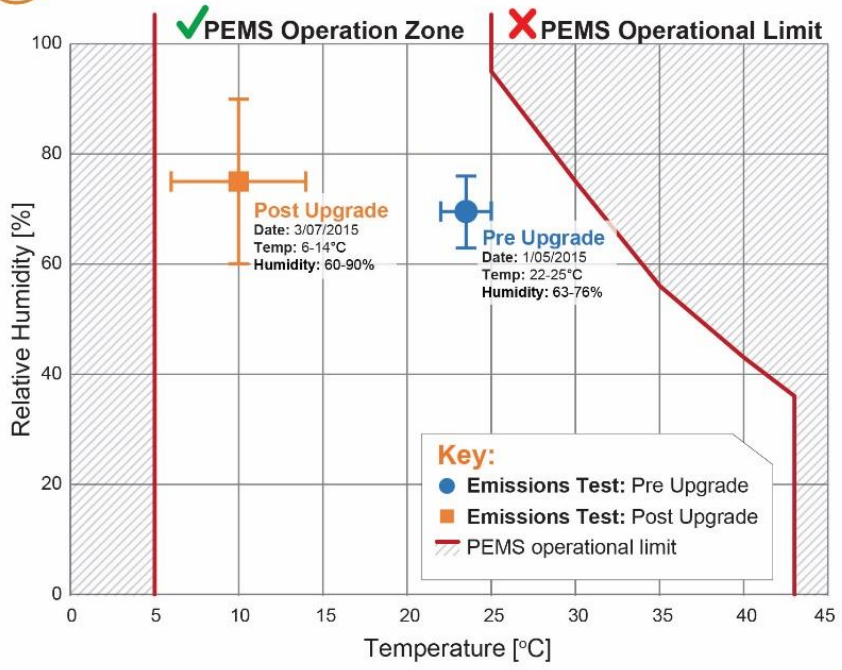


When compared to the Tier 0+ emissions limits, 8113 achieved reductions of 48.3% and 9.95% for PM and NOx respectively, whilst 9024 achieved reductions of 59.1% for PM and 11.2% for NOx.

8113 – Summary Results

8113 – Ambient Test Conditions

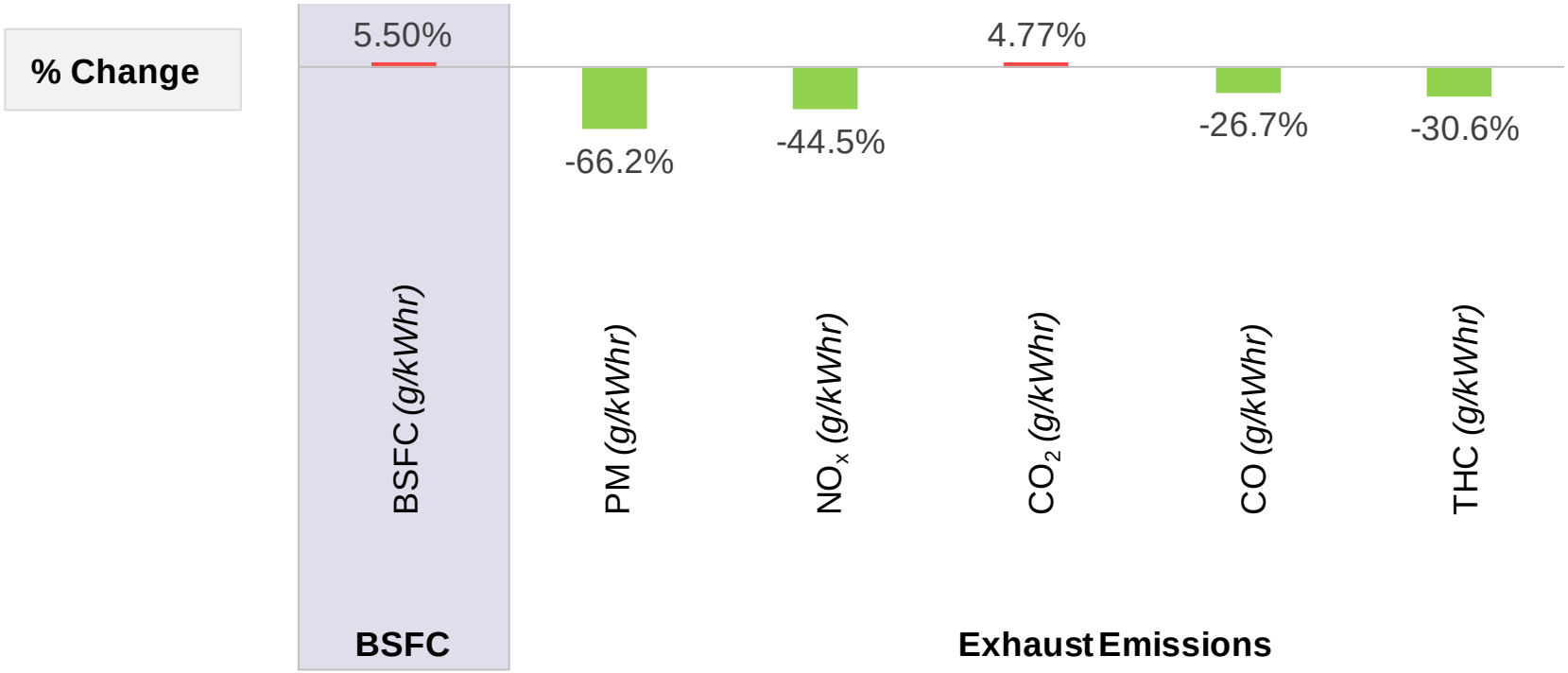
Emissions Testing



Noise Testing

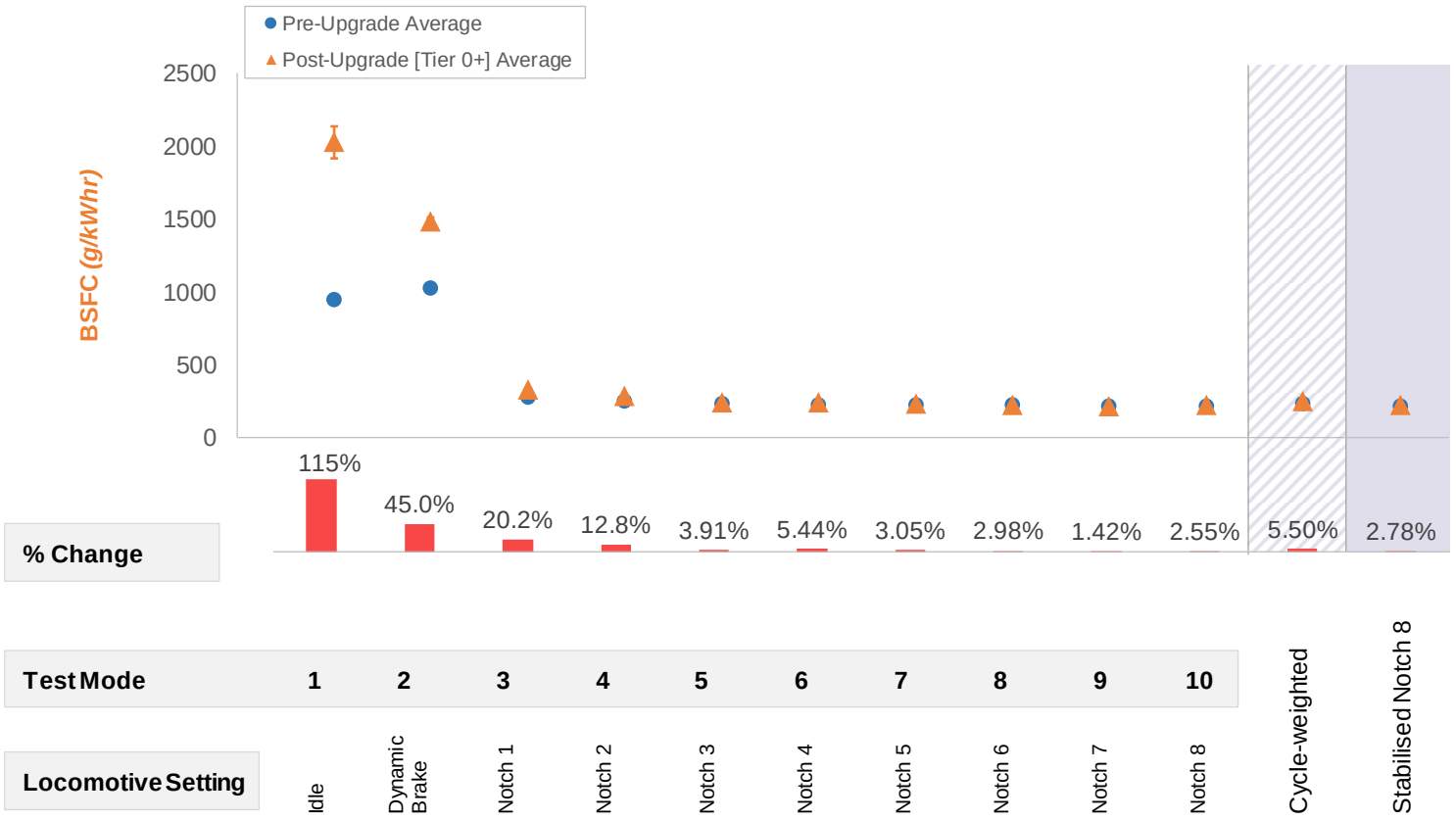
Pre Upgrade	Post Upgrade
Date: 4/05/2015 **Temp:** 19°C **Humidity:** 82%	**Date:** 3/07/2015 **Temp:** 6-14°C **Humidity:** 60-90%
Weather Condition:	**Weather Condition:**
Rainfall: 0 mm	**Rainfall:** 0 mm
Wind Direction & Speed: SW 5.6m/s	**Wind Direction & Speed:** SW 6.1m/s

8113 – Cycle Weighted Summary Results



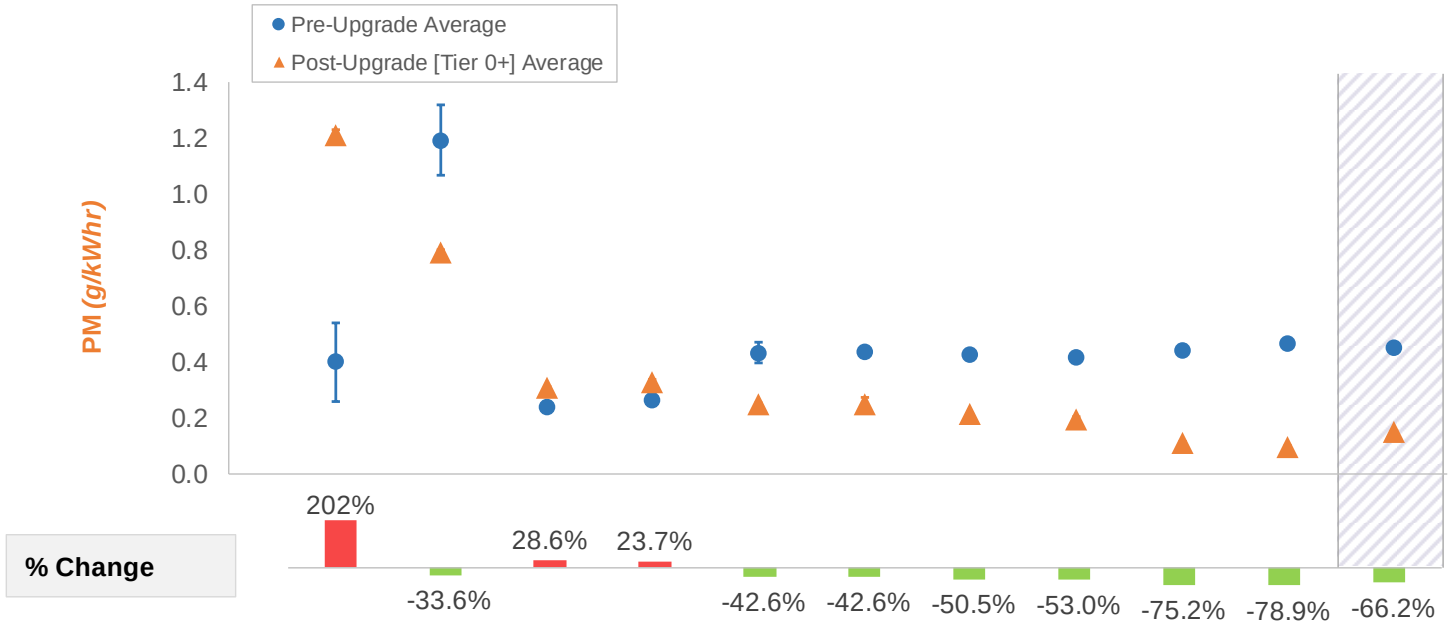
Significant reductions in particulate and regulated gaseous emissions were achieved in the cycle weighted emissions results after the installation of the Tier 0+ engine emissions kit. BSFC results have been corrected for temperature and humidity as per the Association of American Railroads (AAR) practice, whereas emissions results are uncorrected. For this reason, there is a difference between the percentage change in BSFC and CO2 presented within the report.

8113 – Brake Specific Fuel Consumption



The change in BSFC between test configurations was lowest in the higher notches. Percentage change in BSFC ranged between 1.42% in notch 7 to 115% in idle. The test to test repeatability in both pre and post emissions upgrade configurations was excellent, and within 1%, with the exception of modes 1 and 2 which varied between 1.78% and 10.4%.

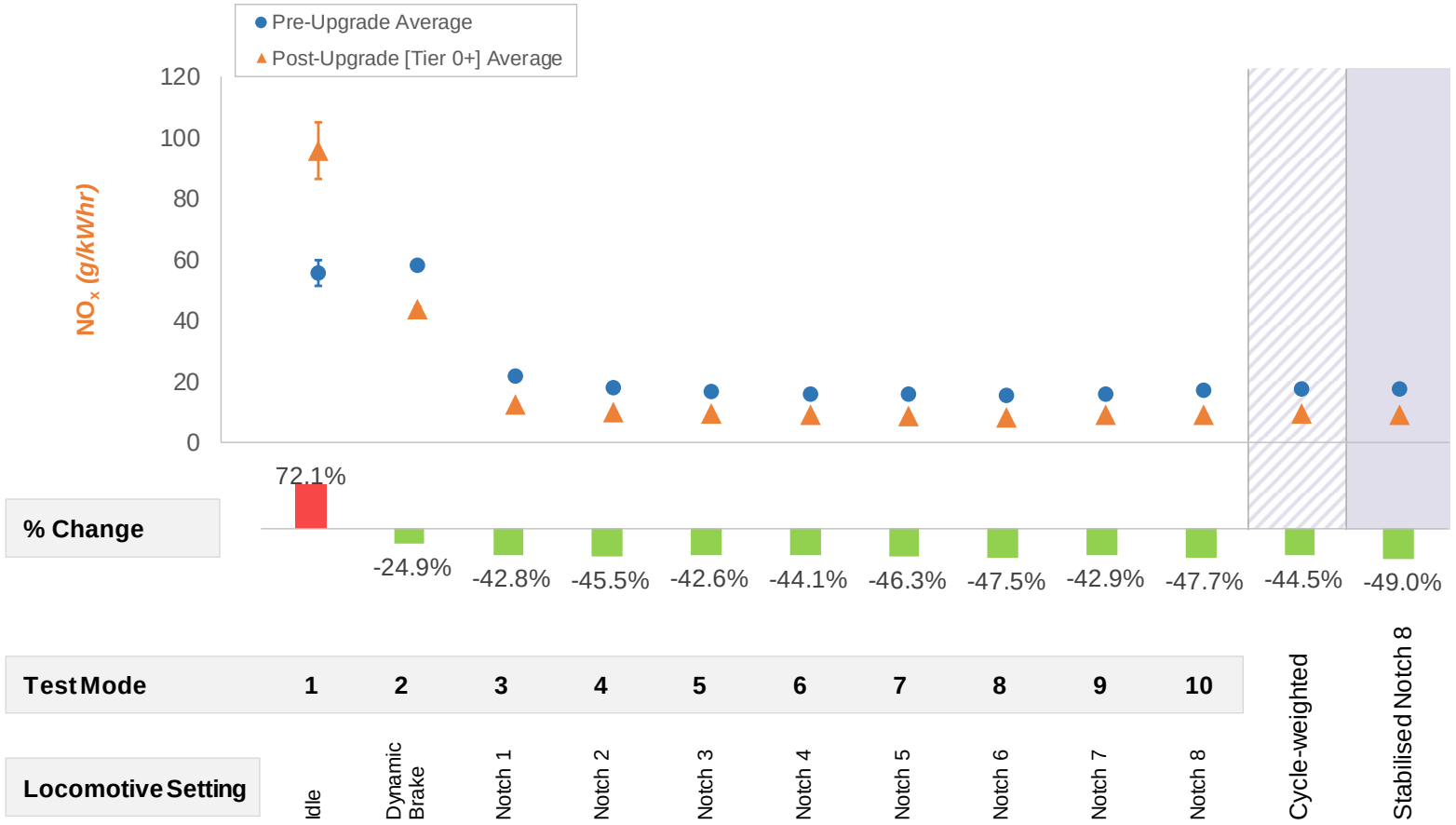
8113 – PM



Test Mode	1	2	3	4	5	6	7	8	9	10	
Locomotive Setting	Idle	Dynamic Brake	Notch 1	Notch 2	Notch 3	Notch 4	Notch 5	Notch 6	Notch 7	Notch 8	Cycle-weighted

PM emissions increased after installation of the emissions upgrade kit in modes 1, 3 and 4, by 23.7% to 202%. In all other modes, PM was significantly reduced by between 33.6%, in dynamic brake and 78.9%, in notch 8 when compared to the standard engine rebuild results.

8113 – NOx



NOx emissions increased after installation of the emissions upgrade kit only in mode 1 (idle), by 72.1%. In all other modes, NOx was significantly reduced by between 24.9%, in dynamic brake and 47.7%, in notch 8 when compared to the standard engine rebuild results. Test to test repeatability was excellent, typically within 1%, with the exception of testing in mode 1.

8113 – Noise

Idle - Change in Maximum Level	
Measurement	**Change**
LAmax, *dB(A)*	- 1
LAeq,T, *dB(A)*	0

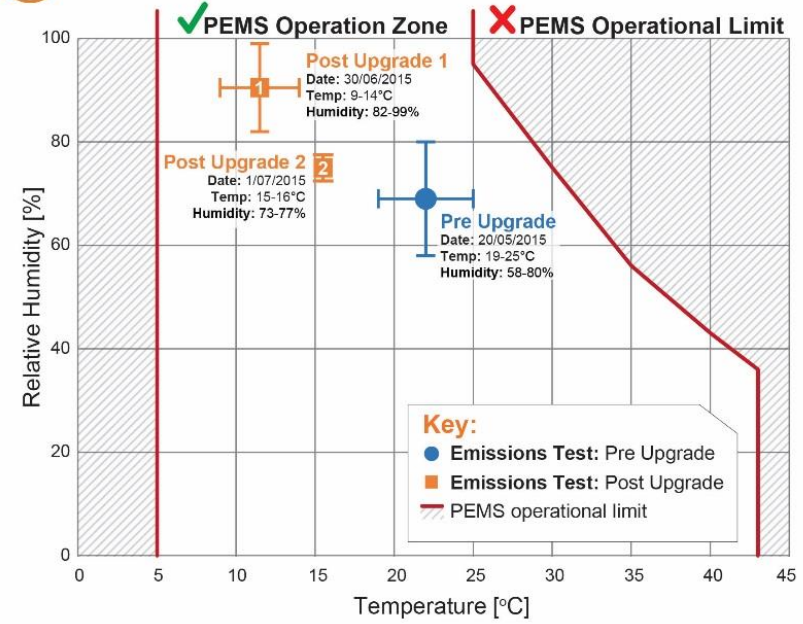
Notch 1 to 8 - Change in Maximum Level	
Measurement	**Change (dB)**
LAmax, *dB(A)*	- 7
LZmax, *dB*	- 4
LAeq,T, *dB(A)*	- 7
LZeq,T, *dB*	- 3

The A weighted measurements filter the noise by frequencies to which the human ear is most sensitive, representing how a person will likely hear sounds. The maximum measured A weighted noise level change was 7.20 dB(A) lower. A change of this magnitude provides a noticeable noise reduction.

9024 – Summary Results

9024 – Ambient Test Conditions

Emissions Testing

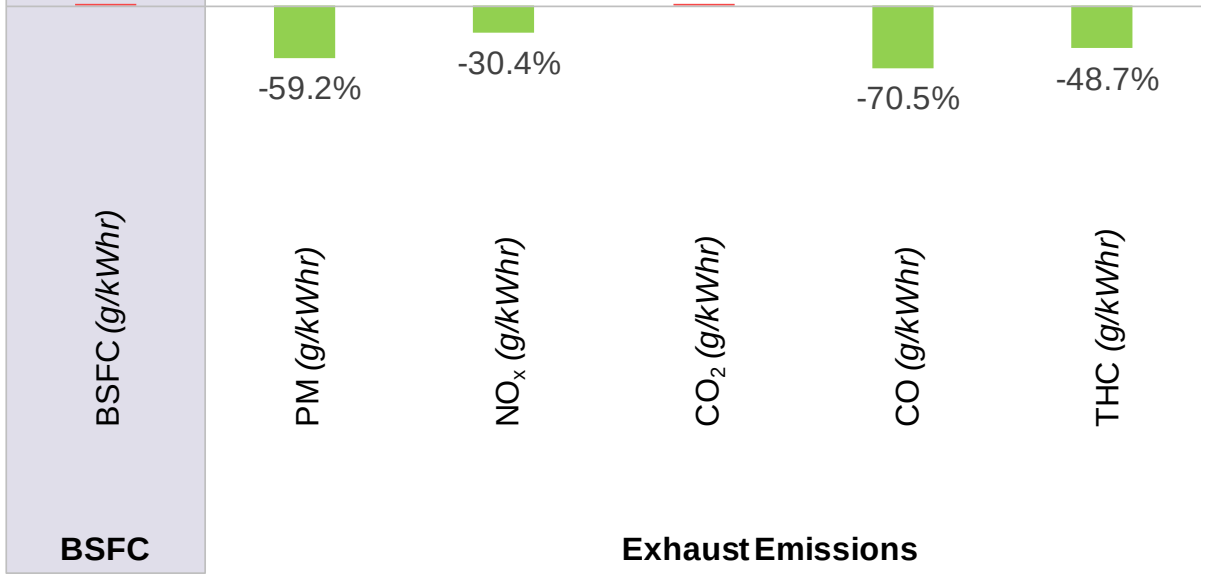


Noise Testing

Pre Upgrade	Post Upgrade
Date: 21/05/2015 **Temp:** 18°C **Humidity:** 77%	**Date:** 3/07/2015 **Temp:** 6-14°C **Humidity:** 60-90%
Weather Condition:	**Weather Condition:**
Rainfall: 2.2 mm	**Rainfall:** 0 mm
Wind Direction & Speed: NW 3.6m/s	**Wind Direction & Speed:** SW 6.1m/s

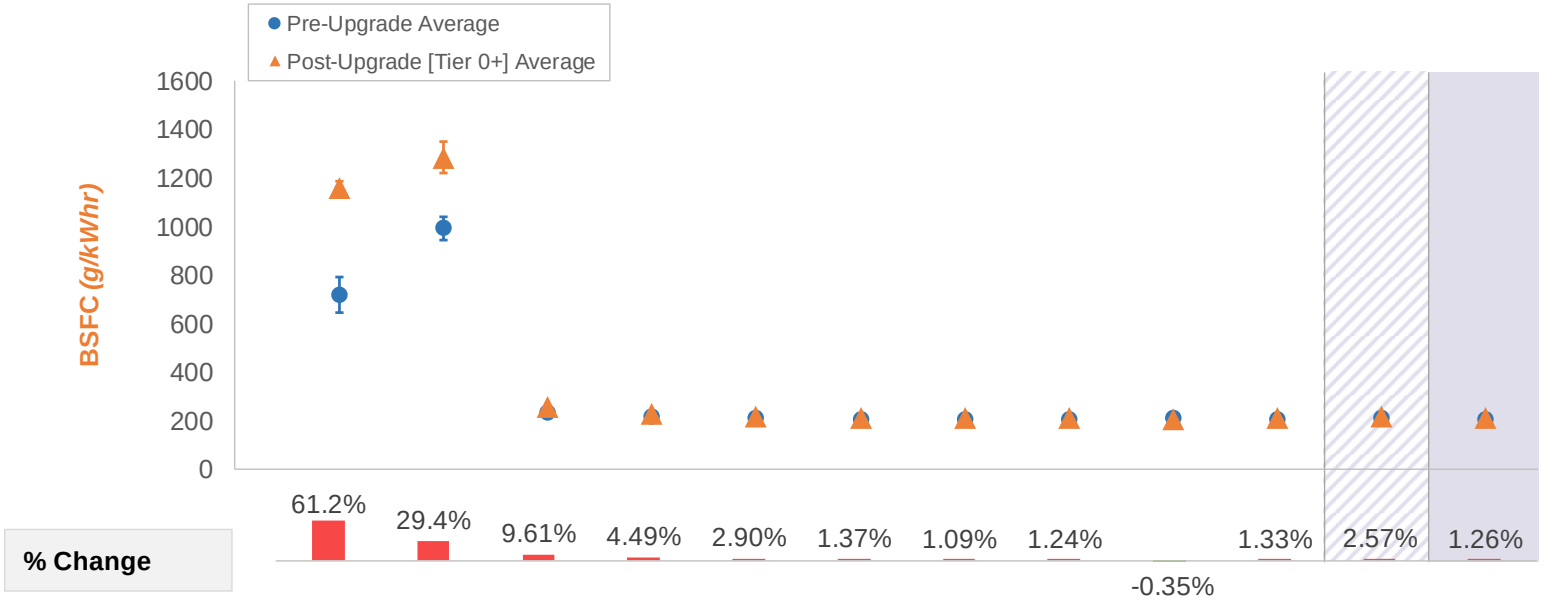
9024 – Cycle Weighted Summary Results

	BSFC	PM	NO_x	CO_2	CO	THC
Pre-Upgrade	212	0.296	13.7	661	2.01	0.343
Post-Upgrade [Tier 0+]	217	0.121	9.52	674	0.592	0.176
% Change	2.57%	-59.2%	-30.4%	1.93%	-70.5%	-48.7%



Significant reductions in particulate and regulated gaseous emissions were achieved in the cycle weighted emissions results after the installation of the Tier 0+ engine emissions kit. An increase in the BSFC with the upgrade kit installed, indicates lower engine efficiency.

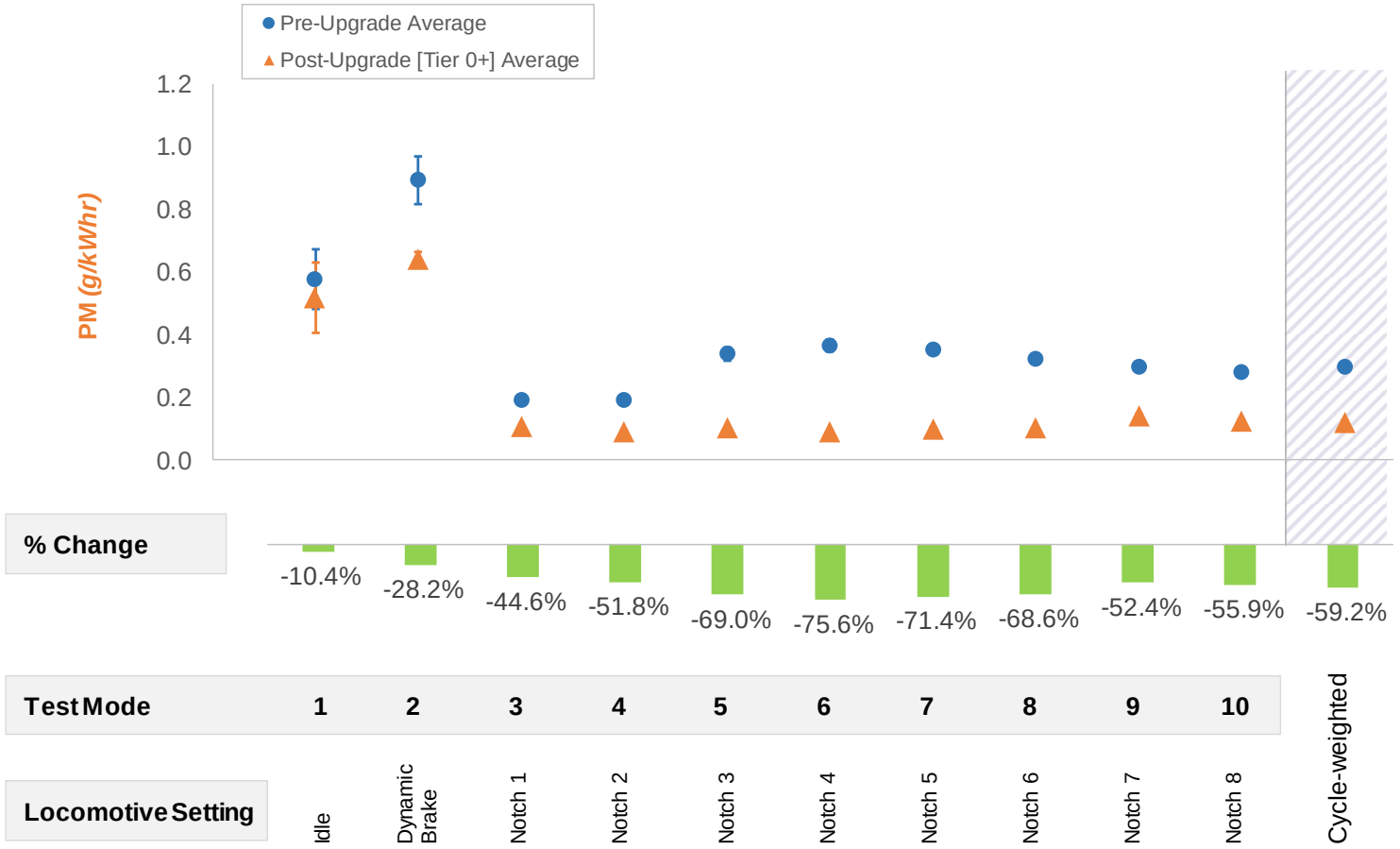
9024 – Brake Specific Fuel Consumption



Test Mode	1	2	3	4	5	6	7	8	9	10	Cycle-weighted	Stabilised Notch 8
Locomotive Setting	Idle	Dynamic Brake	Notch 1	Notch 2	Notch 3	Notch 4	Notch 5	Notch 6	Notch 7	Notch 8		

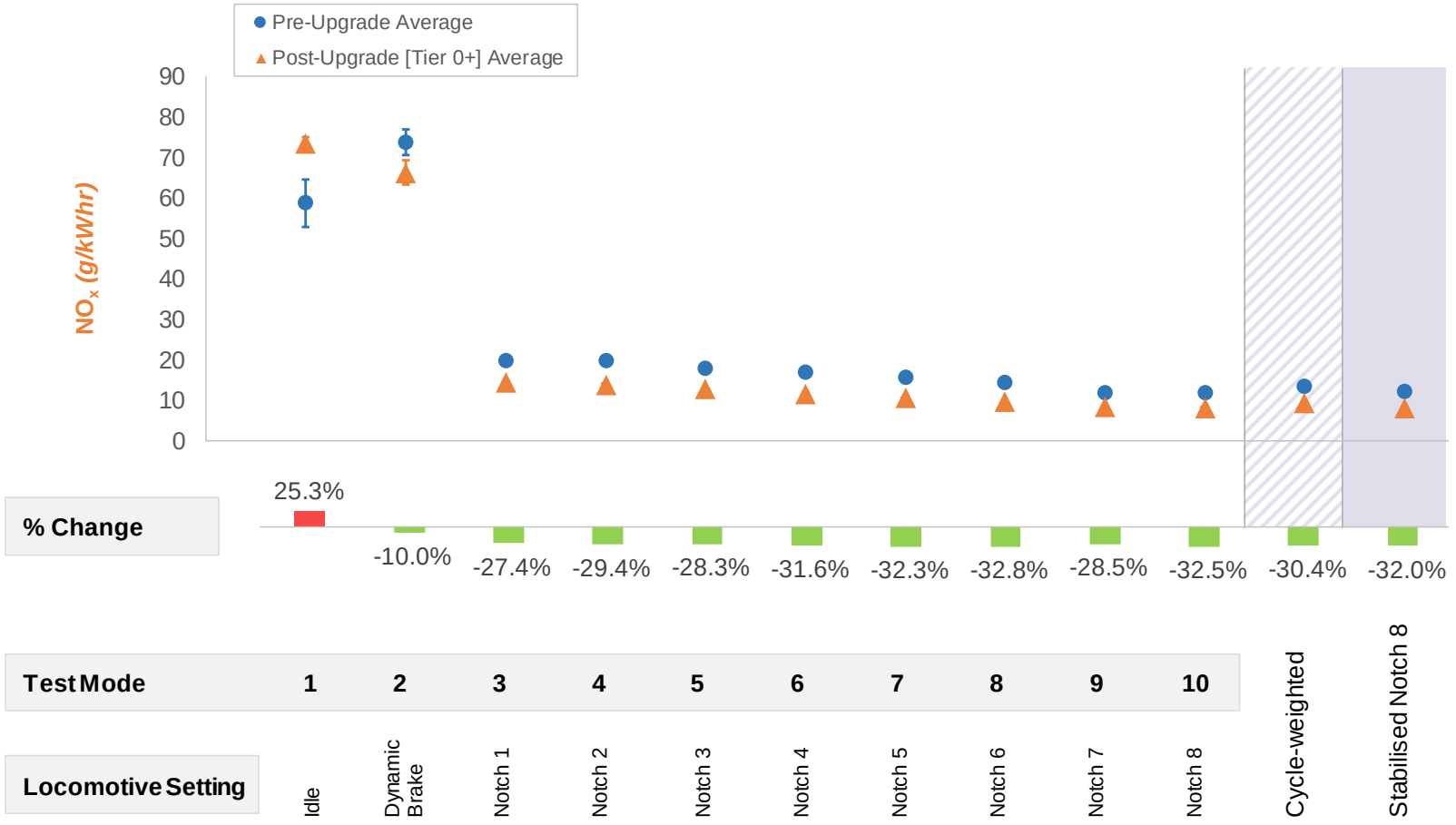
The change in BSFC was lowest in the higher notches. Percentage change in BSFC ranged between 1.09% in notch 5 to 61.2% in idle. Overall, the test to test repeatability in both pre and post emissions upgrade configurations was very good.

9024 – PM



In all modes, PM was significantly reduced by between 10.4%, in idle and 75.6%, in notch 4 when compared to the standard engine rebuild results. The greatest improvements in PM emissions were measured in notch 3 to 5.

9024 – NOx



NOx emissions improved significantly after the installation of the upgrade kit with cycle weighted NOx emissions reducing by 30.4%. NOx was significantly reduced by between 10.0% in dynamic brake and 32.8% in notch 6 when compared to the standard engine rebuild results.

9024 – Noise

Idle - Change in Maximum Level	
Measurement	**Change**
LAmax, *dB(A)*	2
LAeq,T, *dB(A)*	1

Notch 1 to 8 - Change in Maximum Level	
Measurement	**Change**
LAmax, *dB(A)*	- 1
LZmax, *dB*	- 4
LAeq,T, *dB(A)*	0
LZeq,T, *dB*	- 1

The A weighted measurements filter the noise by frequencies to which the human ear is most sensitive, representing how a person will likely hear sounds. The maximum A weighted noise level increase at idle was 2.32 dB(A). At this level, it would be difficult for the human ear to distinguish.

Thank-you!

Natalie Roberts
Managing Director – ABMARC
0438 352 530 nroberts@abmarc.com.au