DIESEL LOCOMOTIVE
Emissions Upgrade Kit Demonstration Project

Fuel Efficiency, Emissions & Noise Testing

Prepared for NSW EPA

ABMARC

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REPORT

For NSW EPA

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PROJECT OVERVIEW:

This project comprised the testing of exhaust emissions, fuel efficiency and noise on two locomotives pre and post installation of an EMD Tier 0+ emissions upgrade kit. Emissions testing was conducted in accordance with USA CFR 1065 and 1033, noise to AS2377-2002, and occurred in the first half of 2015 in Cardiff, NSW.

PROJECT BACKGROUND:

Non-road emissions, including those from diesel locomotives, are unregulated in Australia. In response to environmental and health concerns, the NSW Government is working with industry with the aim to reduce exhaust emissions from locomotives. The NSW Environment Protection Authority (EPA) has commissioned the testing in this project to determine the effect on locomotive exhaust emissions, fuel efficiency and noise of the installation of Tier 0+ emission upgrade kits to existing diesel locomotives operating in NSW. The project is a part of a broader "Diesel and Marine Emissions Management Strategy", to progressively control and reduce emissions from priority diesel non-road and marine sectors, including locomotives.

Pacific National partnered with NSW EPA on this project. Pacific National funded; the locomotive emissions kit upgrade, maintenance processes to fit the kits, the fitment and removal of test equipment, the costs of fuel and technical personnel to support the test program and made the locomotives available for testing.

MEASUREMENTS:

Emissions
Emissions were measured with a Portable Emissions Measurement System (PEMS), providing repeatability of 1% or better and complying with US EPA and ECE regulations.

- **Particulate Matter (PM):** Collected on gravimetric filter
- **Gaseous:** Total Hydrocarbons (THC), Carbon Monoxide (CO), Carbon Dioxide (CO_2), Nitric Oxide(NO) and Nitrogen Dioxide (NO_2)

The exhaust gas sample was taken from probes in an exhaust stack extension and transferred via heated sample lines to the gaseous analysers and gravimetric filter.

Fuel Consumption
Fuel consumption was measured from high precision fuel flow meters with a combined accuracy of 0.2%.

Fuel properties were determined to correct Brake Specific Fuel Consumption (BSFC) and emissions to standard fuel data.

Power
Electrical power generated was calculated instantaneously from voltage and current measurements across all locomotive generators with combined accuracy better than 2%.

Total engine shaft power was the sum of the main generator, companion alternator and the auxiliary generator power with generator efficiency and mechanical load factors provided by EMD applied.

Noise
Noise was measured according to the Australian Standard, AS2377-2002.

OUTPUT:

In each test mode the following was measured and has been reported:

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

LOCOMOTIVES AND TEST SEQUENCE

One 90 class, 9024 (EMD 16-710 G3A engine ~ 3,030 kW) and one 81 class, 8113 (EMD16-645 E3B engine ~ 2,460 kW) were tested according to the following:

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

These locomotive classes were selected due to:

- The wide use by industry of both locomotive and/or engine type.
- Their age, being older type locomotives, and the high opportunity for potential emissions improvements.
- Commercial availability of US EPA certified emission kits.

EMISSIONS TEST PROCEDURE:

The test cycle was conducted in accordance with US EPA Title 40 CFR part 1033.515. The procedure shown in Figure 1 represents the test cycle for locomotive 8113. Engine RPM varies between the 81 and 90 class locomotives in each notch.

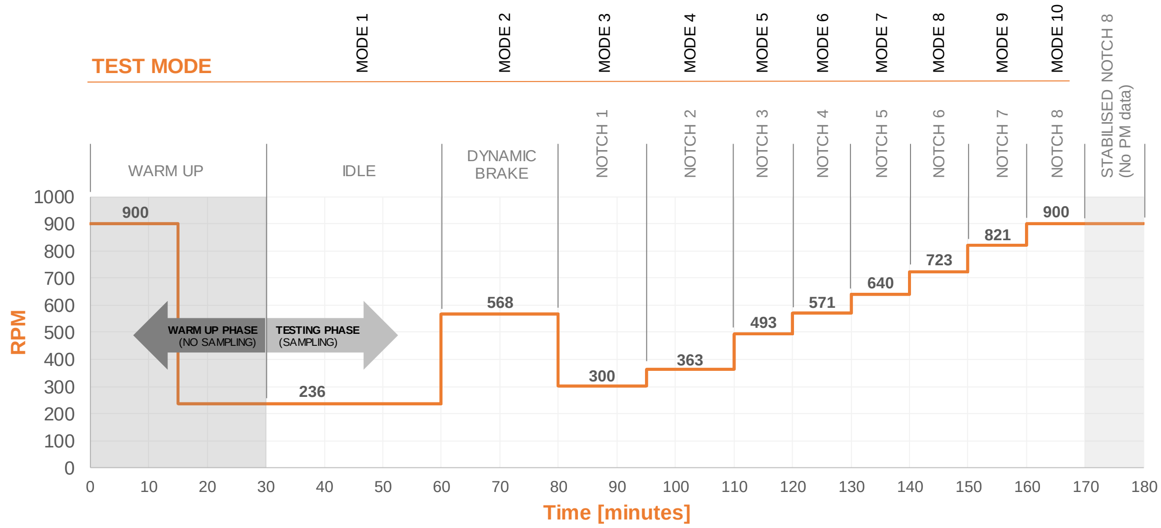

Figure 1 - Test Cycle Example

EMISSIONS RESULTS:

Overall, all US EPA regulated emissions were significantly reduced on both locomotives after the installation of the EMD Tier 0+ emissions kit relative to the pre-upgrade test results. Regulated emissions being: PM, NO_x, CO and THC.

Brake specific fuel consumption (BSFC) increased on both locomotives, by 5.50% on the 81 class and 2.57% on the 90 class after installation of the emissions upgrade kit. Consequently, an increase in CO_2 was also measured across both locomotives. The increase in BSFC is contrary to the benefits claimed by the OEM kit manufacturer, EMD, and warrant further investigation.

Engine RPM hunting was observed during both tests post Tier 0+ kit installation on locomotive 8113, primarily in test modes 1 through to 4 (refer to Appendix C). The impact of this on the Tier 0+ test results from 8113 is unknown.

81 Class: Cycle Weighted Results

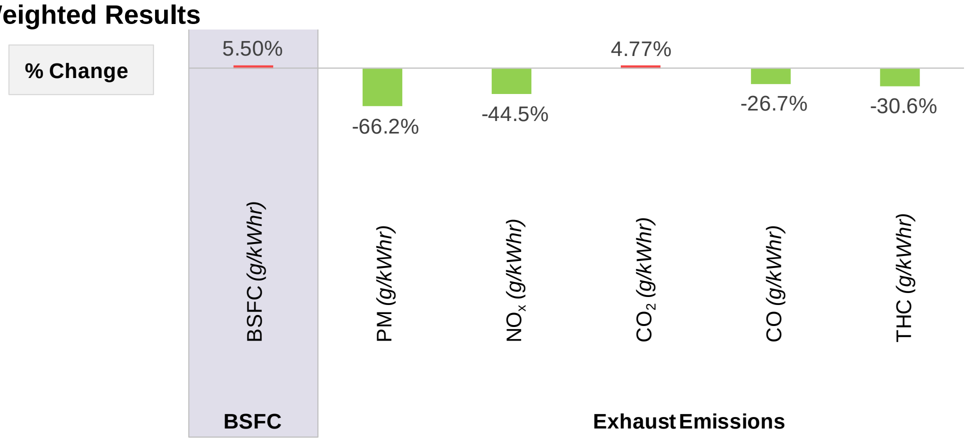

Figure 2 – 8113 Cycle Weighted Results

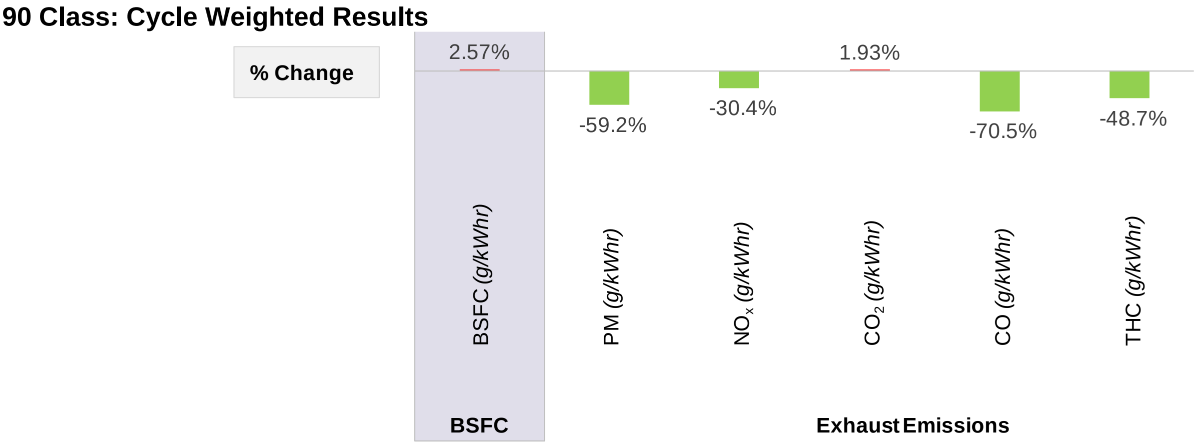

Figure 3 - 9024 Cycle Weighted Results

After installation of the Tier 0+ emissions kit, all US EPA regulated emissions measured on locomotive 8113 and 9024 were below Tier 0+ levels.

When compared to the Tier 0+ standards, 8113 was below by 48.3% and 9.95% for PM and NO_x respectively, whilst 9024 was below by 59.1% for PM and 11.2% for NO_x. The average results from testing are shown in Chart 1.

PM exhaust emissions measured with the emissions kit installed achieved better than the Tier 2 regulations on 8113 and better than Tier 3 in the case of 9024.

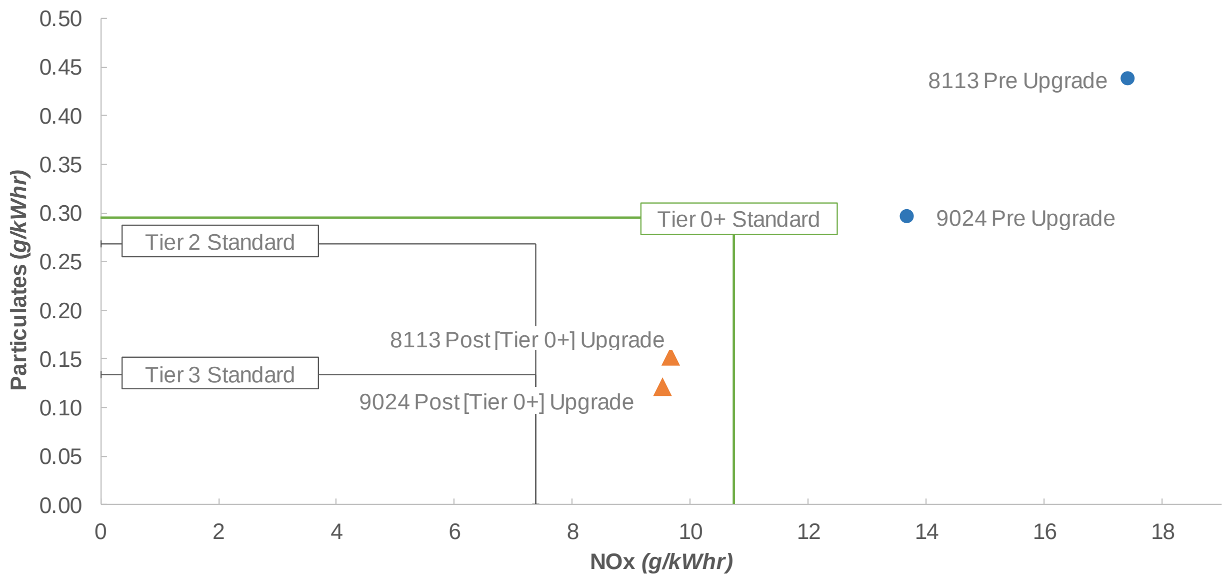

Chart 1 – Emissions Results and US EPA Tier 0+ Standard

NOISE RESULTS:

There was a general trend of minor noise reduction on both locomotives except whilst 9024 was at idle. The increase in noise at idle on 9024 is considered insignificant as it would be difficult for the human ear to distinguish the change in noise level between the two configurations. On 8113, the maximum A weighted noise level decreased by 7 dB(A). At this level, it would be noticeable as a noise reduction.

CONCLUSION:

This test program has demonstrated that the installation of EMD's Tier 0+ emissions upgrade kits on the EMD 16-710 G3A and EMD 16-645 E3B series engines significantly reduces US EPA regulated emissions, however adversely impacts fuel efficiency and increases CO_2. As the manufacturer claims these kits should provide a fuel consumption improvement in the order of 2% to 5%, further investigation into the possible causes is warranted. There was no significant change to noise levels and the general trend was a small decrease.

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ACRONYMS

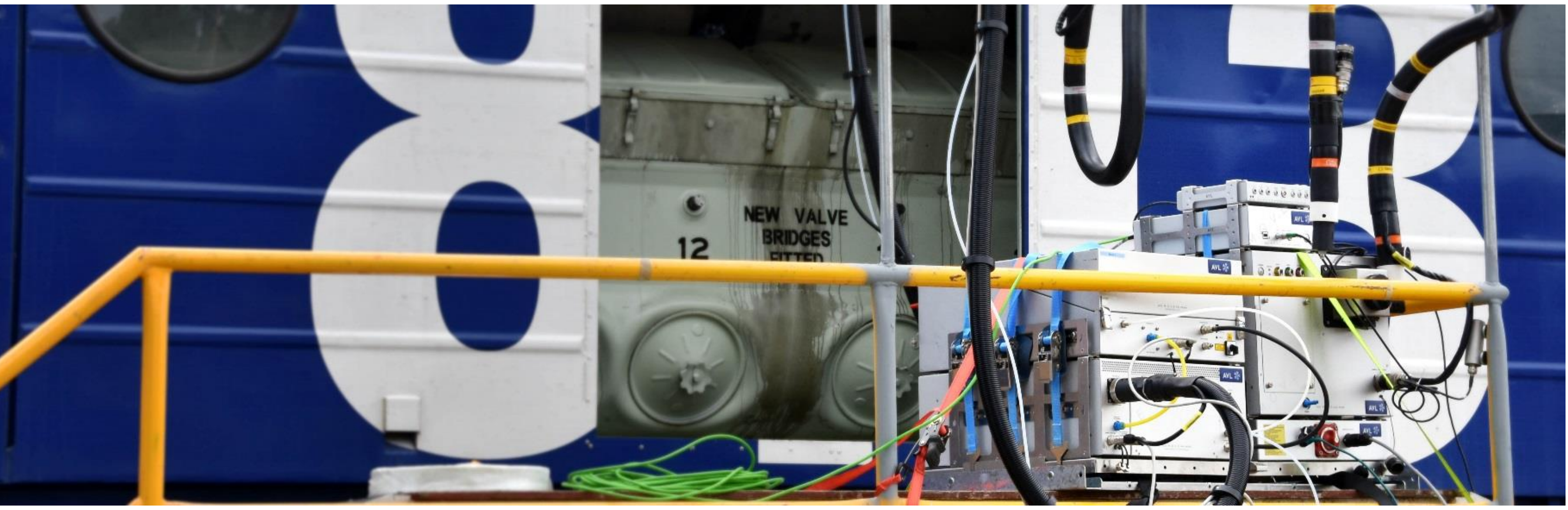
AAR	Association of American Railroads
AC	Alternating Current
AS	Australian Standards
ASTM	American Society for Testing and Materials
AUX	Auxiliary
avg	Average
BSFC	Brake Specific Fuel Consumption
CFR	Code of Federal Regulations (United States of America)
CO	Carbon Monoxide
CO_2	Carbon Dioxide
CSIRO	Commonwealth Scientific and Industrial Research Organisation
DC	Direct Current
EMD	Electro-Motive Diesel
EPA	NSW Environment Protection Authority
EU	European Union
FID	Flame Ionization Detector
GFM	Gravimetric Filter Module
HEPA	High Efficiency Particulate Air
N/A	Not Applicable
NATA	National Association of Testing Authorities, Australia
NDIR	Non-Dispersive Infrared
NDUV	Non-Dispersive Ultra-Violet
NO	Nitric Oxide
NO_X	Oxides of Nitrogen
NO_2	Nitrogen Dioxide
NSW	New South Wales
OEM	Original Equipment Manufacturer
PEMS	Portable Emissions Measurement System
PM	Particulate Matter
PPM	Parts Per Million
RPM	Revolutions Per Minute
SPL	Sound Pressure Level
Temp.	Temperature
THC	Total Hydrocarbons
US	United States of America
UTEX	Unit Exchange
UV	Ultra Violet
WHO	World Health Organisation
8113	Locomotive 8113 – 81 Class
9024	Locomotive 9024 – 90 Class

GLOSSARY OF TERMS

Baseline Test: Used to establish reference value(s).
Charge Air: Intake air. Charge air temperature measured just prior to entry to cylinders.
Dilution Air: Conditioned and filtered air used to dilute the exhaust sample entering the particulate matter emissions measurement device.
Particulate Matter Dilution Ratio: Ratio of dilution air to exhaust gas sample that is used for particulate matter measurement.
Drift: Drift is the slow change in the response of a measurement instrument over time.
Dynamic Brake: A mode of operation of the propulsion system in which braking is provided through the use of traction motors as generators, converting the kinetic energy of the locomotive into electrical energy.
Fire Face Cracking: The firing face is the bottom of the cylinder head.
Gaseous Emissions: Engine emissions in gaseous form. Includes oxides of nitrogen, carbon monoxide, carbon dioxide and total hydrocarbons.
Hunting: Periodic oscillation of engine RPM about its set point
Injector Timing: The points at which the start and end of fuel injection occurs, often reported in the number of degrees before or after the piston reaches top dead centre.
Notch: Locomotive throttle control position.
Particulate Emissions: Also referred to as Particulate Matter (PM). A complex mixture of small solid and liquid particles suspended in the exhaust gas, often visible as soot and smoke being ejected from the exhaust. In emission standards for internal combustion engines, PM is defined as the material collected on a filter when the exhaust gas is diluted to a temperature of not more than 52°C and passed through a filter.
Payback Period: The length of time required for an investment to recover its initial outlay in terms of profits or savings.
Remanufacture: Remanufacture in the context of US locomotive emissions standards refers to a scheduled major engine overhaul.
Injector Timing Retard: Refers to the start of injection being retarded (occurring later) relative to the piston reaching top dead centre.
Run In: The period of time to bed in/stabilise new components installed on the locomotive engine.
Span Gas: A gas of known composition used to calibrate the emissions testing devices.
Tier #: The US EPA emissions standards for oxides of nitrogen, hydrocarbons, carbon monoxide, particulate matter and smoke for newly manufactured and remanufactured locomotives.

ABBREVIATIONS

A	Ampere - Electric Current
ºC	Degrees Celsius
dB	Decibel (noise level)
g	Gram
g/bhp-hr	Grams Per Brake Horsepower Hour
g/kWhr	Grams Per Kilowatt Hour
J	Joule
J/L	Joule/litre
L	Litre
L/min	Litre Per Minute
LAmax	Linear A weighted – Maximum level over measurement period
LZmax	Linear Z weighted – Maximum level over measurement period
LAeq,T	Linear A weighted – Equivalent continuous sound level
LZeq,T	Linear Z weighted – Equivalent continuous sound level
m	Metre
m^3	Cubic Metre
min	Minute
m/s	Meters Per Second
N	Newton
Nm	Newton Metre
Pa	Pascal
ppm	Parts Per Million
RPM	Revolutions Per Minute
s	Seconds
V	Voltage
W	Watt
Wh	Watt Hours



TEST OVERVIEW

PROJECT OVERVIEW

The "Diesel Locomotive Upgrade Kit Demonstration Project – Fuel Efficiency, Emissions and Noise Testing" was undertaken to inform the NSW Environment Protection Authority's (EPA) strategy to progressively control and reduce diesel non-road and marine emissions from priority sectors, including locomotives.

The project involved the testing of two locomotives to US EPA test methods, in two configurations; after a standard engine rebuild, and after installation of an emissions upgrade kit targeting US EPA Tier 0+ standards. In each configuration, the locomotive was tested twice.

Background

This project was undertaken to inform the NSW Environment Protection Authority's (EPA) strategy to progressively control and reduce diesel non-road and marine emissions from priority sectors, including locomotives. The industry practice of rebuilding locomotives during their long lifetime may afford the opportunity to reduce emissions through the retrofitting of emissions upgrade kits to the engines at their scheduled engine rebuild periods. The testing conducted in this project was commissioned to inform the EPA's investigation into the feasibility of applying emissions control technologies to locomotives to reduce emissions.

Emissions from non-road diesel vehicles and equipment, including those from diesel locomotives, are unregulated in Australia and non-road diesel engines are the largest unregulated source of $PM_{2.5}$ emissions in the NSW Greater Metropolitan Region[1]. Particle emissions are of primary health concern as they contribute to respiratory and cardiovascular disease and are linked with premature death. Diesel exhaust was classified by the World Health Organisation in 2012 as a human carcinogen. Current health evidence indicates that no lower threshold exists below which particle emissions have no impact, so all particle exposure reductions have positive health outcomes.[2]

Regulations governing new and in-service diesel locomotive exhaust emissions were introduced in the US from 2000 and in the European Union (EU) from 2006. Regulations in the USA were revised in 2008 to tighten the requirements for new and in-service locomotives. The revised standards for in-service locomotives compelled the development of engine emission upgrade kits that would reduce the emissions of locomotives built from 1973 onwards. In the US, locomotives with engines remanufactured after 2010 must meet the applicable US Tier+ standards.

In response to these environmental and health concerns, the NSW Government is working with industry with the aim to reduce exhaust emissions from locomotives. To achieve this, NSW EPA is utilising emission upgrade kits for this demonstration project that have been developed by the Original Equipment Manufacturer (OEM) in the USA to meet the US EPA remanufacture standards.

In Australia, the two largest locomotive engine OEMs are Electromotive Diesel (EMD) and General Electric (GE). EMD have developed US Tier 0+ emission upgrade kits for diesel-electric locomotives powered by their 645 and 710 series engines. As these series of engines are widely used in NSW and Australia, they have been chosen for the demonstration project. In addition to reducing emissions, the kits are claimed to reduce fuel consumption and oil consumption by the manufacturer, EMD (see Appendix H). The claimed improvement in fuel efficiency could provide an attractive payback period and offer a win-win outcome for locomotive operators and the NSW EPA by reducing both operating costs and emissions to ambient air.

The objective of the Diesel Locomotive Emission Upgrade Kit Demonstration project is 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.

Emissions and fuel consumption testing was conducted according to US CFR Title 40, Volume 33, Part 1065. The results are presented in this report. One 90 class (EMD 16-710 G3A engine ~ 3,030 kW) and one 81 class (EMD16-645 E3B engine ~ 2,460 kW) were tested according to the following:

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

Noise testing was conducted according to the Australian Standard AS 2377-2002, to ensure that no adverse impacts to locomotive noise levels occurred as a result of the emissions upgrade kit installation.

[1] NSW EPA Diesel and Marine Emissions Management Strategy, 2015

[2] ibid

US Locomotive Emissions Standards

The US EPA introduced locomotive emission standards in 2000, starting with Tier 0 to Tier 2, with Tier 0 applying retrospectively to in-service locomotives built since 1973, applicable at time of major engine overhaul (remanufacture). These were updated in 2008 to more stringent Tier 0+, Tier 1+ and Tier 2+ standards, accompanied by the introduction of Tier 3 and 4 for new locomotives. Regulations for diesel locomotive emissions were also introduced in the European Union (EU) from 2006.

The US EPA emissions regulations apply to locomotives when they are first manufactured or re-manufactured. For remanufactured locomotives, this requires that they must comply with the applicable Tier +, Tier 3 or 4 standard as represented in Table 1 based on the model year.

US EPA regulated Line-Haul locomotive PM and NO_x emission limits are shown in Chart 2. Note that locomotives must also comply with the applicable switch locomotive emissions limit where applicable. The more stringent Tier+, 3 and 4 standards apply to locomotives first manufactured or remanufactured after 2010.

These standards compelled the development of emissions upgrade kits to reduce the emissions of in-service locomotives when remanufactured, in order to comply with the regulatory limits.

Emission Limit	Model Year	NOx *(g/kWhr)*	Particulates *(g/kWhr)*
Tier 0	1973 - 2001	13	0.80
Tier 1	2002 - 2004	9.9	0.60
Tier 2	2005 or later	7.4	0.27
Tier 0+	1973 - 1992	11	0.30
Tier 1+	1993 - 2004	9.9	0.30
Tier 2+	2005 - 2011	7.4	0.13
Tier 3	2012 - 2014	7.4	0.13
Tier 4	2015 or later	1.7	0.04

Table 1 - US EPA Line Haul Locomotive Emissions Standards by Model Year of Manufacture

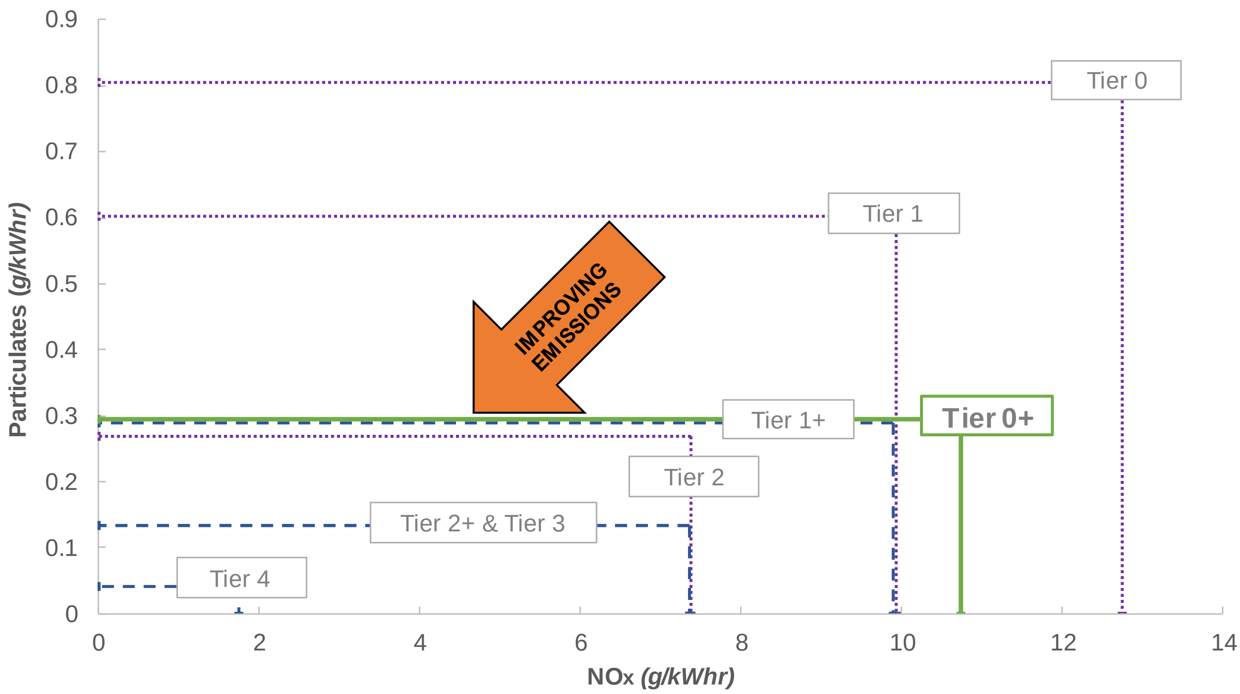


Chart 2 - US EPA Line Haul Locomotive Emissions Limits

TEST PROGRAM OVERVIEW

NSW EPA partnered with Pacific National to carry out the project "Diesel Locomotive Upgrade Kit Demonstration Project – Fuel Efficiency, Emissions and Noise Testing." Locomotive rebuilds and upgrades were completed by Downer EDi and the testing and reporting was conducted by ABMARC. The project took place over the period January to August 2015 with testing carried out at Cardiff, NSW.

Project Partners and Contractors

NSW EPA partnered with Pacific National to carry out the project "Diesel Locomotive Upgrade Kit Demonstration Project – Fuel Efficiency, Emissions and Noise Testing." NSW EPA engaged ABMARC to conduct the testing and reporting on two Pacific National locomotives to quantify the changes in fuel efficiency, emissions and noise after installation of the EMD manufactured Tier 0+ emissions kit, relative to the same locomotives rebuilt to their original standard.

Pacific National funded the locomotive emissions kit upgrade, maintenance processes to fit the kits, making the locomotives available for testing, the fitment and removal of equipment and the costs of fuel and technical personnel to support the test program.

Downer EDi maintain the EMD locomotives in Pacific National's locomotive fleet and installed both the standard rebuild and Tier 0+ emissions kit in addition to providing technical support for the test program.

Installation of test equipment was performed by both ABMARC and Downer EDi personnel. The locomotive was operated by a Downer EDi staff member and all testing occurred at the Downer EDi site in Cardiff, NSW.

An overview of the project participants is shown in Figure 4.

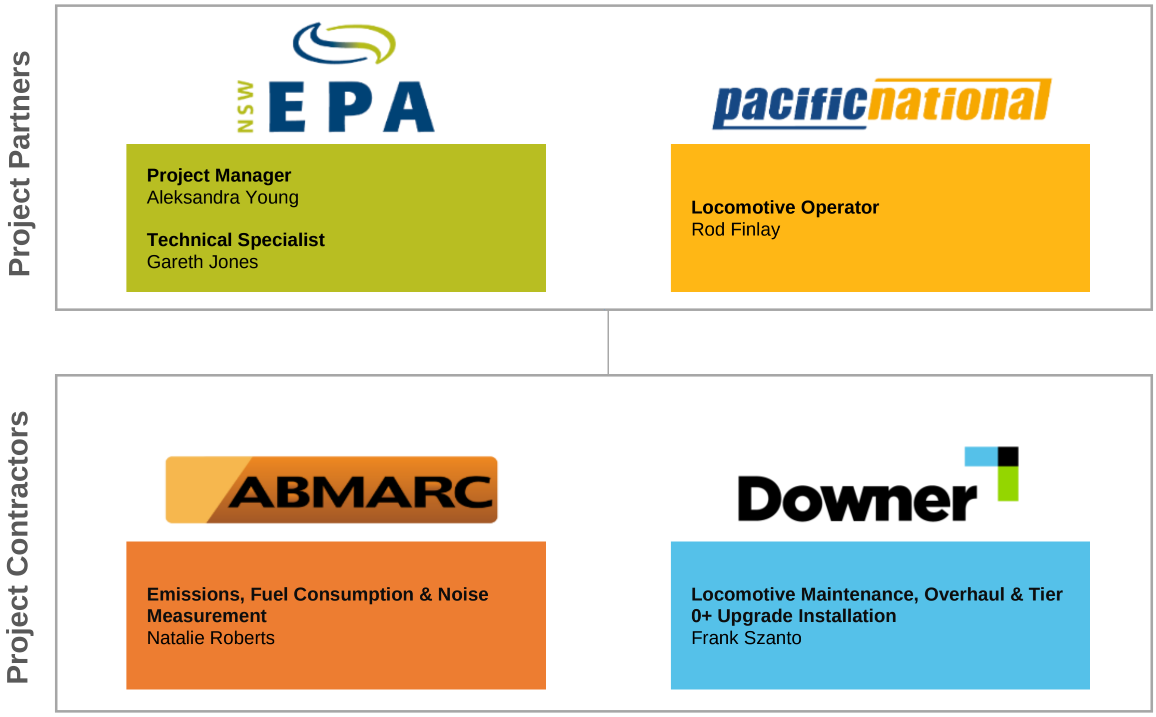


Figure 4 – Project Partners and Contractors

Project Timing

Each locomotive required a run in period of a minimum two weeks operation post rebuild and emissions kit upgrade to stabilise emissions and fuel consumption.

Locomotive 8113 was the first to be rebuilt to standard configuration in December 2014, after which it underwent a run in period of approximately 23,000 kilometres, prior to testing during the week of the 4th of May.

On locomotive 9024, the standard rebuild occurred during February 2015, after which it underwent a run in period of approximately 20,000 kilometres, prior to the first test in the week of the 21st of May.

The locomotives were consecutively upgraded to the Tier 0+ emissions kit at the end of May and start of June 2015, and run in before the final emissions, fuel efficiency and noise testing occurred back to back during the first two weeks of July.

An overview of the project timing is shown in Figure 5.

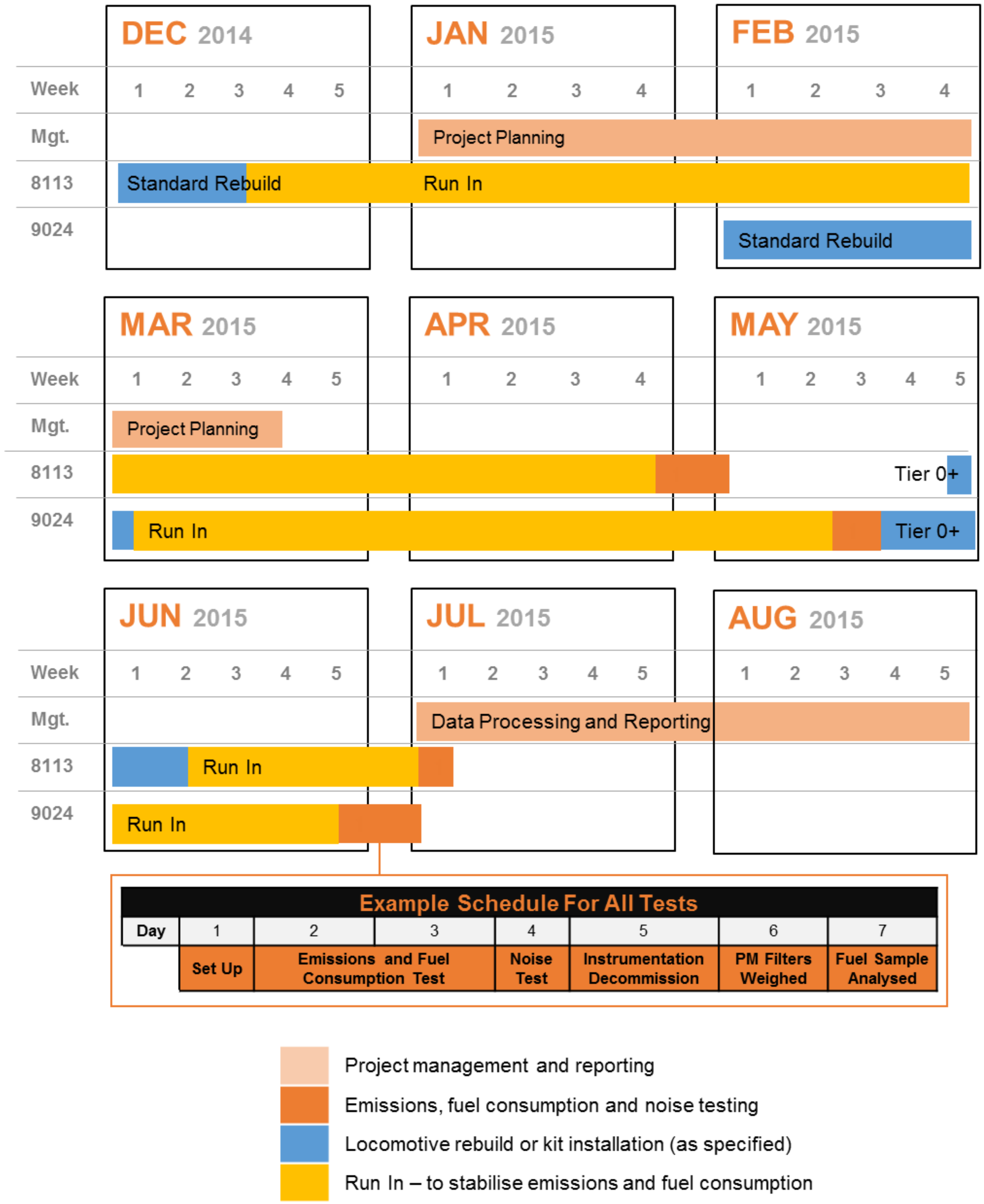


Figure 5 – Project Timing

LOCOMOTIVE AND UPGRADE KIT OVERVIEW

Two locomotives were tested, being 8113 and 9024. These locomotive classes were selected due to their wide use by industry of both locomotive and or engine type and their age, being older type locomotives and the high opportunity for potential improvements.

The locomotive engines were rebuilt to standard configuration and run in prior to baseline testing. Subsequently, they were upgraded with the EMD Tier 0+ emissions kit and run in again prior to final testing. The EMD Tier 0+ upgrade kit is claimed to reduce emissions and oil consumption whilst also improving fuel efficiency in the order of 2% to 5%. The main Tier 0+ upgrade components consist of; new power assemblies, cylinder heads, oil separator, aftercooler and injectors.

Locomotive Specifications and Tested Condition

Introduced in 1982, the 81 class diesel electric locomotive was manufactured in Australia by Clyde Engineering (now Downer EDi). The two-stroke 16 cylinder turbocharged EMD 16-645 E3B powered locomotive produces 2,460kW. Originally, the 81 class performed Hunter Valley coal haulage. It has since been moved to a wide variety of work, from bulk operations, including grain and mineral freight within regional NSW to port and other facilities in the Greater Metropolitan Region.

Locomotive 8113, built in 1985 and operated by Pacific National was selected as the test locomotive to evaluate the Tier 0+ kit on the 16-645 E3B engine type.

8113

Project Phase	Date Completed	Operational Kilometres	Run-In Kilometres
Standard Rebuild	18/12/2014	189,242	
Pre Upgrade Test	4/05/2015	212,240	22,998
Tier 0+ Upgrade Kit Installation	11/06/2015	217,664	
Post Upgrade [Tier 0+] Test	3/07/2015	219,465	1,801

The 90 class locomotive was introduced in 1994, and was built in Canada by General Motors Electro-Motive Diesel. The two stroke 16 cylinder turbocharged EMD 16-710 G3A powered 90 class locomotive produces 3,030kW. The 90 and 82 classes replaced the 81 class locomotives in the Hunter Valley carrying coal. (The 82 class is powered by the 12 cylinder 710 G3A engine.) Being specifically designed for this purpose, the Pacific National owned and operated 90 class continues its role hauling coal, exclusively on the Hunter Valley network.

Locomotive 9024, built in 1994 and operated by Pacific National was selected as the test locomotive to evaluate the Tier 0+ kit on the 16-710 G3A engine type.

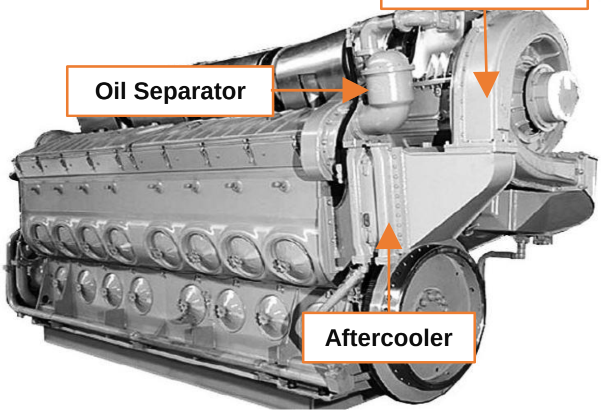
9024

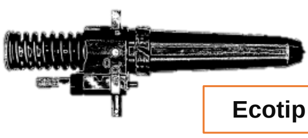
Project Phase	Date Completed	Operational Kilometres	Run-In Kilometres
Standard Rebuild	3/03/2015	235,672	
Pre Upgrade Test *(locomotive stayed on site for installation of Tier 0+ upgrade kit)*	21/05/2015	255,439	19,767
Tier 0+ Upgrade Kit Installation	29/05/2015	255,440	
Post Upgrade [Tier 0+] Test	3/07/2015	260,433	4,993

EMD Tier 0+ Emissions Upgrade Kit – Manufacturer Information

The major components of the EMD Tier 0+ emissions upgrade kit include the complete power assembly, comprising of the piston, cylinder liner/barrel and cylinder head, an increased capacity four pass counter flow aftercooler, fuel injectors, and an upgraded oil separator.

The key claimed performance benefits are emissions and lubrication reductions and fuel efficiency improvements.





Ultra Low Lube Oil Power Assembly – EMD combines its hardened upper bore liner with a specially engineered bore profile and ring design. 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%. The improved design of the cylinder head claims to eliminate fire face cracking.

Cylinder Head – The new 'maximum life' cylinder head features improved coolant flow, coupled with improved flat head exhaust valve and valve rotators resulting in greater durability and reliability for longer life.

Oil Separator – EMD two stroke engines use a closed crankcase ventilation system, keeping the crankcase under vacuum and directing crankcase gases back into the engine intake air. 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 – The improved aftercoolers provide more effective cooling of the combustion air from the turbocharger. The new four pass counterflow aftercoolers pass the water in the opposite direction to airflow through the aftercooler four times. The layout enables combustion air to pass the coolest water at the exit of the heat exchanger, resulting in the most efficient cooling of combustion air. This results in lower NOx emissions and improved engine efficiency for lower fuel consumption.

Ecotip Injectors – The Tier 0+ injectors have a reduced sac volume and 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.

EMD Claimed Benefits

Key Performance Benefits
Fuel consumption reduced by: 81 Class – 3% to 5% 90 Class – 2% to 3%
PM and NO_x reductions below Tier 0+
Reduce oil consumption by 50%.

Benefits to Engine Life
Eliminate fire face cracking
Minimise gasket failures (cylinder head to liner)
Reduce valve and valve seat wear

TEST PROCEDURES & SITE LOCATION

Emissions and fuel consumption testing and calculations were conducted according to US CFR Title 40, Volume 33, Part 1065 and 1033 according to the following configurations:

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

Noise testing was conducted according to the Australian Standard AS 2377-2002, to ensure that no adverse impacts to locomotive noise levels occurred as a result of the emissions upgrade kit being fitted.

The locomotives were tested two times in each configuration.

Locomotive Test Procedure

The test mode duration and procedure was conducted according to the US EPA CFR 40 part 1033.515. The test procedure requires that emissions, power and fuel consumption are measured in each engine operating mode, including idle and dynamic brake. Engine RPM and mode duration is shown in Chart 3 and Chart 4 for the 81 and 90 class locomotives respectively.

The time in each mode was established based on the CFR and the requirement to load the Gravimetric Particulate Filter with a suitable amount of particulate matter. The RPM information displayed in Chart 3 and Chart 4 reflects the actual measured average values recorded during testing.

Gaseous emissions, power and fuel flow were sampled continuously for the duration of each test. Gravimetric filters were replaced at the end of each test mode. The gravimetric filters were subsequently weighed at CSIRO's automated weighing facility in North Ryde, NSW.

An additional test was conducted at the end of mode 10 [notch 8], for the purpose of recording stabilised fuel consumption and gaseous emissions in notch 8, the highest power setting. The stabilised notch 8 data did not include PM measurements.

Each locomotive was tested two times in each of the following configurations:

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

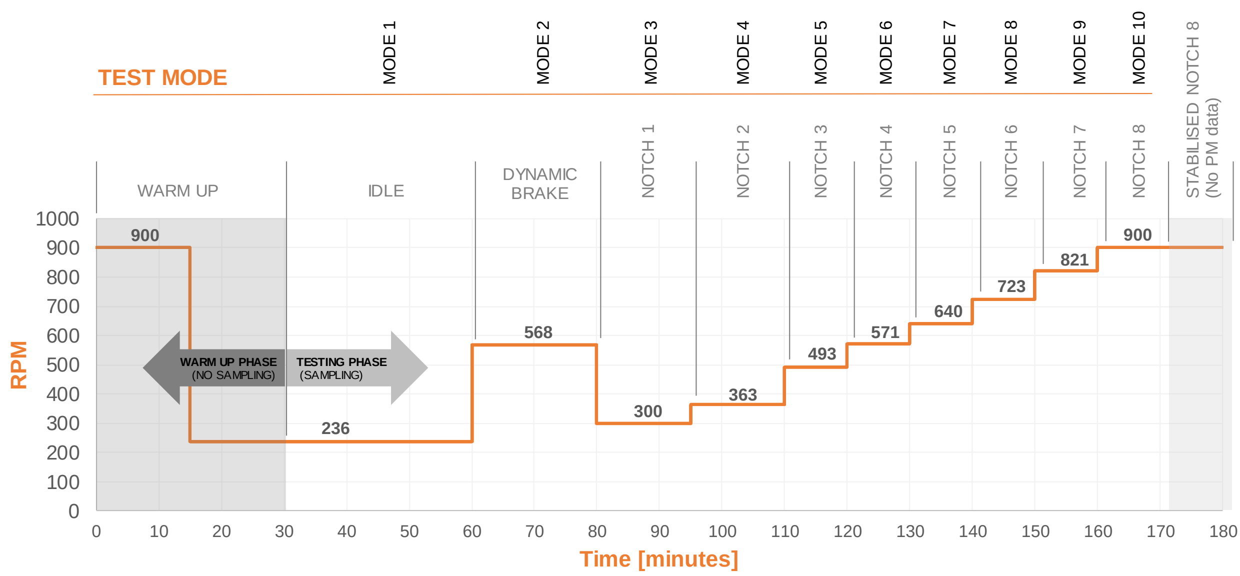


Chart 3 - 81 Class Locomotive Test Procedure

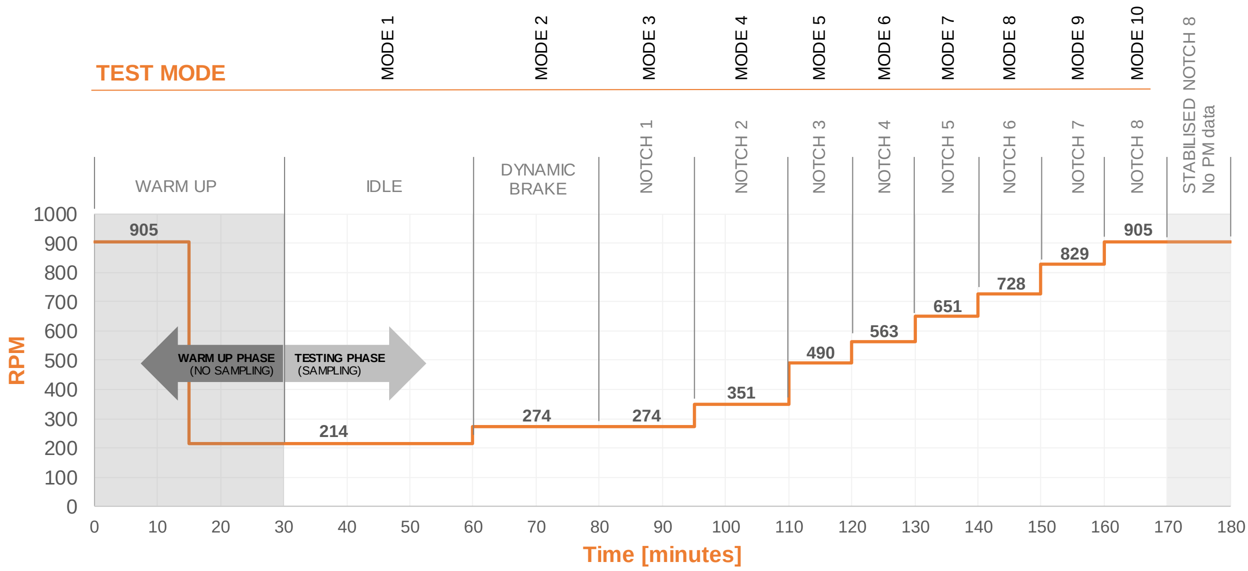


Chart 4 - 90 Class Locomotive Test Procedure

US EPA Cycle Weighting Factors

To calculate cycle-weighted average emission rates, locomotive operating duty cycles are specified by the US EPA in 40 CFR part 1033.530. The line haul locomotive weighting factors are shown in Table 2.

The US EPA defines different duty cycles for line haul and switch locomotives in order to represent the actual operating conditions based on locomotive type. Line-haul locomotives are defined as locomotives powered by an engine with a maximum rated power (or a combination of engines having a total rated power) greater than 2300 HP or 1716 kW.

Both 8113 and 9024 are classified as line-haul locomotives.

It is noted that the actual operating cycles of the 8113 and 9024 locomotives vary substantially to the US EPA averages. This is due to NSW network requirements, freight loading characteristics and their operational deployment. The operating cycle differences will result in the actual emissions and fuel consumption observed on these locomotives varying from the US EPA cycle weighted average results presented in this report.

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

Table 2 - Cycle Weighting Factors for Line Haul Locomotives

Fuel Consumption & Emissions Test Standards

Testing to the US EPA CFR 40 part 1033.515 requires specific procedures to be followed pre-test, during testing and post-test and specifies the measurement equipment that can be used.

These requirements relate to:

- Equipment specification and calibration
- Handling of filters pre and post test
- Environmental conditions of the test
- Test methodology
- Calculations

BSFC results have been corrected for temperature and humidity as per the Association of American Railroads (AAR) practice. Refer to Appendix F for fuel calculations.

40 CFR Part 1065 has more stringent requirements than 40 CFR part 92. The Gaseous PEMS meets instrumentation requirements for laboratory testing as specified in 40 CFR part 1065 subpart C. This is particularly important for testing fuels or technologies to quantify a small improvement in emissions or fuel efficiency.

An overview of the test standards followed is shown in Figure 6.

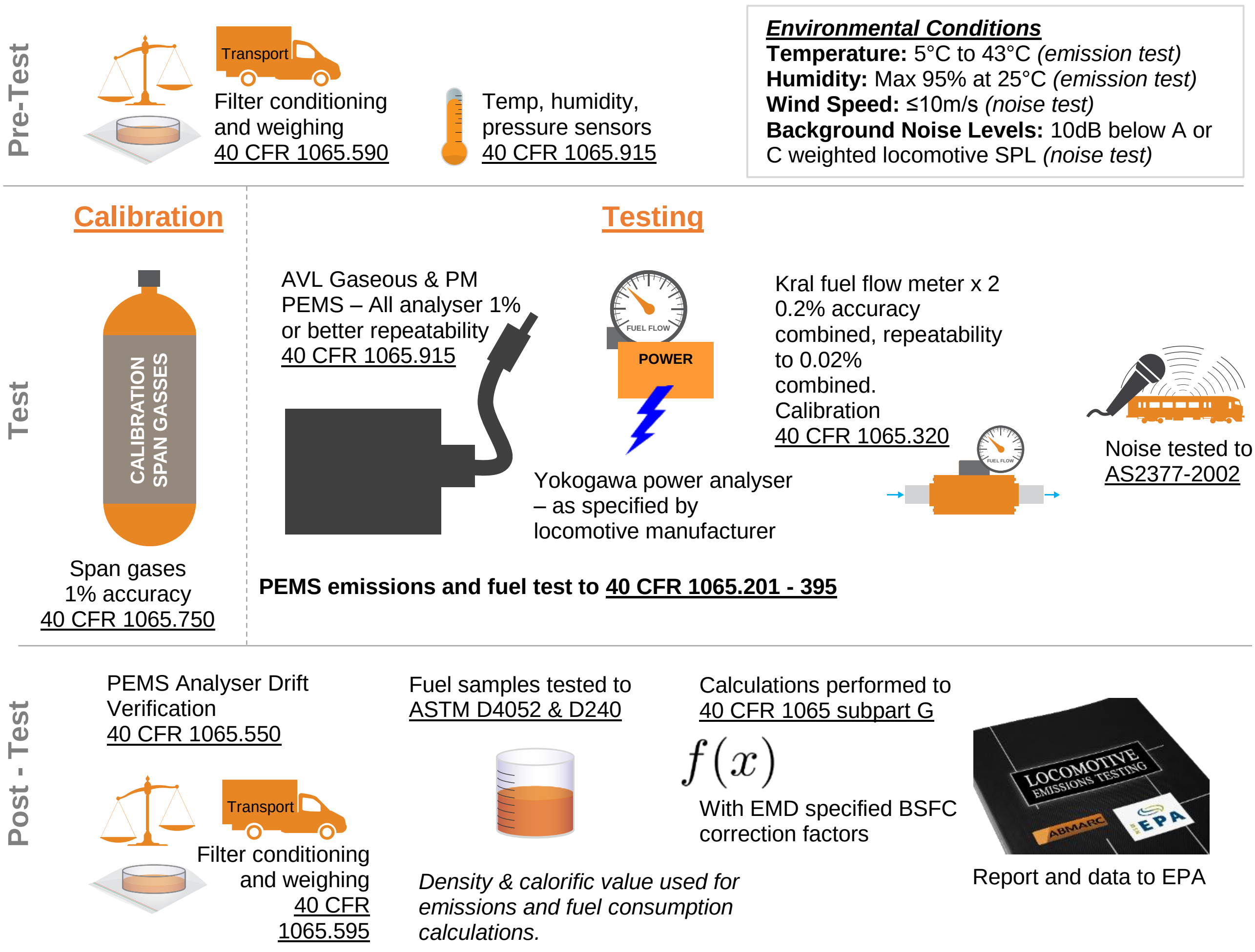


Figure 6 – Fuel and Emissions Test Standards

Noise Test Procedure

The noise test was performed to ensure no adverse effects to noise levels result from the Tier 0+ emissions kit installation.

The test was conducted by AECOM in accordance with AS 2377-2002, using sound level meters compliant with the specifications of the Australian Standard, Part 1: Non-integrating, AS 1259.1-1990.

The noise test measurements were conducted at 12 points, indicated from A to L around the locomotive. Each point at a distance of 15 meters from the locomotive, as shown in Figure 7, and height of 1.5m +/- 0.2 meters above the rail head height.

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

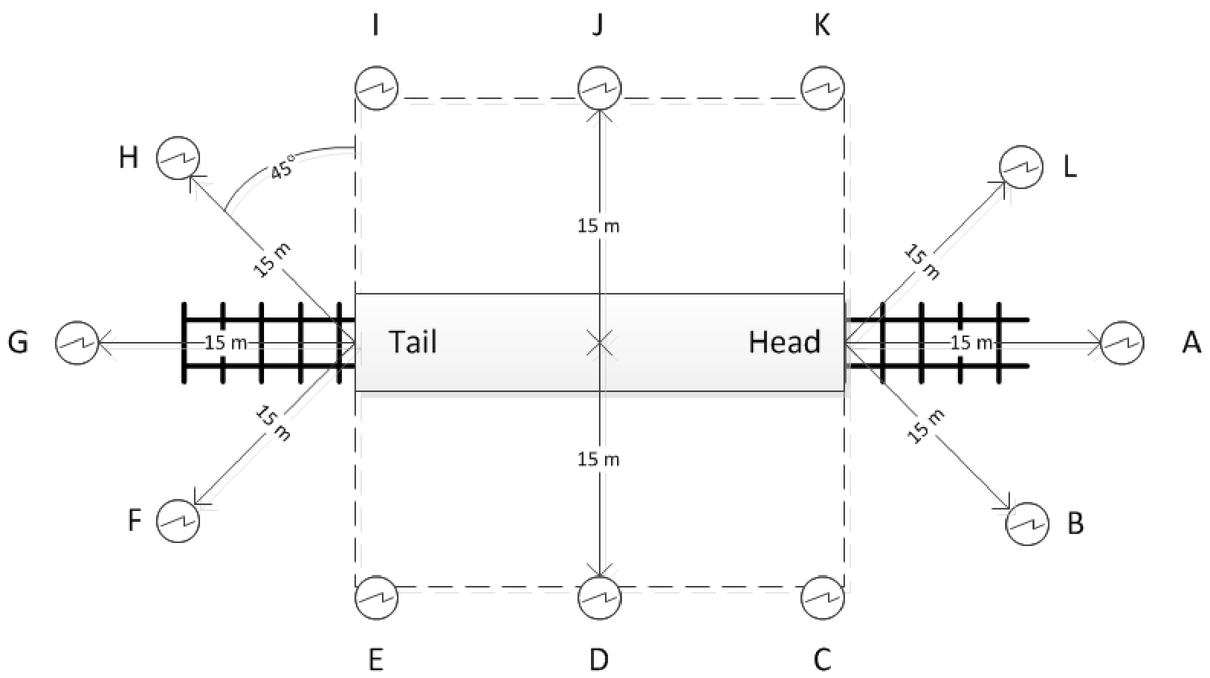


Figure 7 – AS 2377-2002 Noise Test Measurement Locations

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

Table 3 – Noise Test Environmental Limits

Measured Acoustic Values

- L_{Amax} Linear A weighted – Maximum level over measurement period
- L_{Zmax} Linear Z weighted – Maximum level over measurement period
- $L_{Aeq(T)}$ Linear A weighted – Equivalent continuous sound level
- $L_{Zeq(T)}$ Linear Z weighted – Equivalent continuous sound level

Test Site Location

All testing was conducted at Downer's facilities in Cardiff, NSW. Emissions, fuel efficiency and noise testing was conducted in the open air in the locations indicated in Figure 8.

Noise testing was conducted in the open space rail yard to ensure minimal sound reflection from objects, as per AS 2377-2002, and to keep background noise to a minimum.

Figure 8 – Emissions, Fuel Consumption and Noise Test Sites

INSTRUMENTATION

Four significant areas were measured, being; emissions, fuel consumption, power and noise. This section provides an overview of the instrumentation that was used, their installation and use.

Emissions and Fuel Consumption Measurement Instrumentation

Emissions measurements were performed utilising an AVL Portable Emissions Measurement System (PEMS). The PEM system consists of gaseous analysers for NO, NO_2, CO and THC contained in an environmentally controlled chamber and a gravimetric filter for PM measurements. A continuous sample of exhaust gas was taken from two probes located in the exhaust stack extension with the sample lines temperature controlled to 191ºC (gaseous) and 52ºC (PM) as required by the CFR. More information regarding the operation of the PEM system can be found in Appendix G.

The ambient conditions; pressure, temperature and humidity were recorded by the PEM system.

Fuel flow measurements were performed with high accuracy fuel flow meters that correct for fuel temperature. The fuel system is a return type, and two flow meters were utilised; one on the delivery line and one on the return line. The difference in fuel flow between the meters is fuel consumption.

All measurements were performed at 1 Hz or greater.

All test equipment is calibrated under 40 CFR part 1065 specifications to the appropriate NIST or equivalent standard. The equipment exceeds many of the CFR requirements for repeatability, refer Table 4.

An overview of the instrumentation setup can be seen in Figure 9.

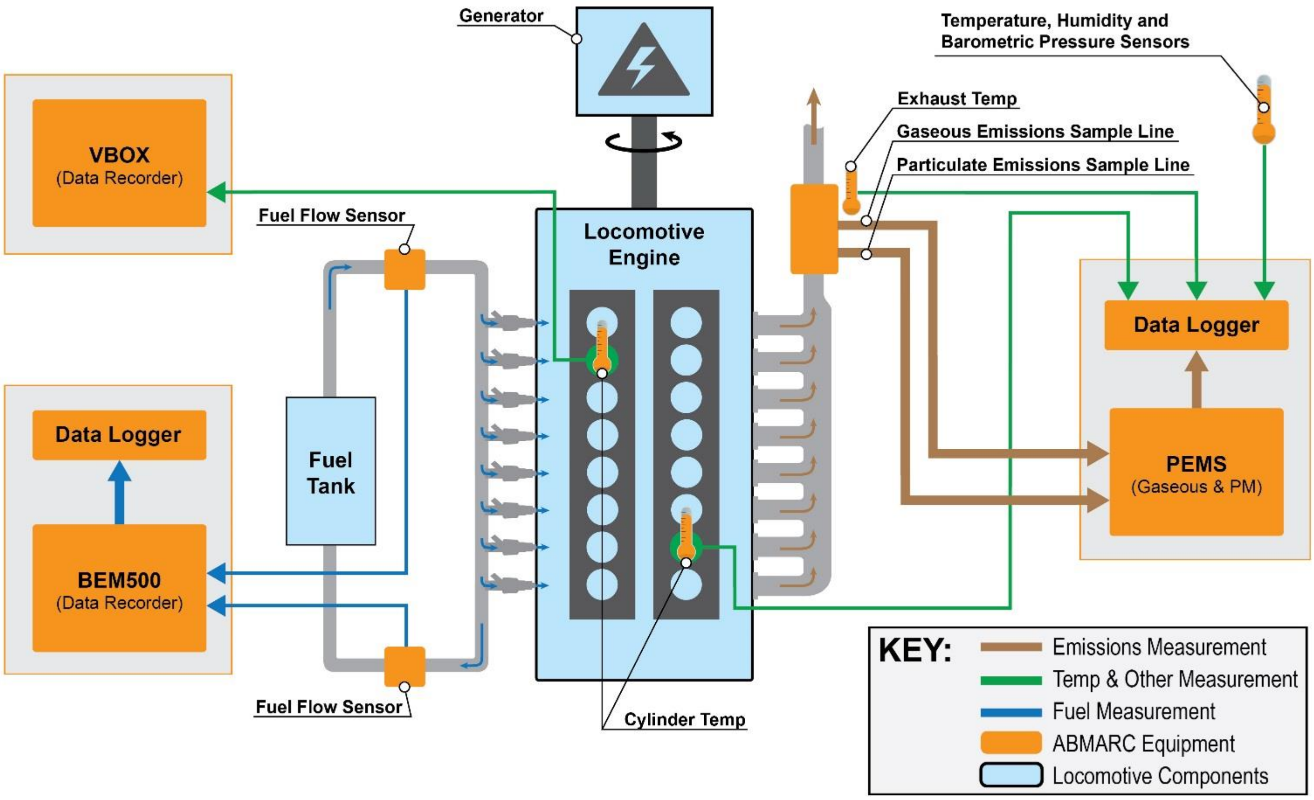


Figure 9 – Emissions and Fuel Consumption Instrumentation

Attribute	CFR 40 Part 1065 requirement		AVL PEMS & Fuel Flowmeter	
	Accuracy	Repeatability	Accuracy	Repeatability
Fuel flow (combined)	± 2% pt	± 1% pt	± 0.2%	± 0.02%
	± 1.5% of max	± 0.75% of max		
CO/CO_2	± 2%	± 1%	± 2%	± 1%
Hydrocarbons	± 2%	± 1%	± 2%	± 0.5%
NOx (NO_2/NO)	± 2%	± 1%	± 2%	± 0.5%
PM (Gravimetric)	See 1065.790 / 2%	0.5 micro grams / 1%	Satisfied	Satisfied

Table 4 – Accuracy and Repeatability of Emissions and Fuel Consumption Instrumentation

PEMS setup on 9024

9024 In-Cabin data monitoring of all measurement Items

PEM system and emissions sample lines

Exhaust stack and emissions sample probes on 8113

High precision fuel flow meter on delivery line

High precision fuel flow meter on return line

Exhaust Stack and Emissions Sampling

An exhaust stack extension was manufactured for each locomotive. The exhaust stack extension provides a well-mixed exhaust flow to the exhaust sample probes and was designed to prevent dilution of the sample with ambient air. The sample probes were installed according to CFR 1065. The probe configuration is shown in Figure 10, with two sample probes installed, one for gaseous and one for PM emissions, located in the centre of the exhaust stream.

The PM probe comprises a 90 degree bend with a single opening orientated into the exhaust stream. The raw PM sample gas was diluted with filtered and dried ambient air within 250mm of the sample point at a constant dilution ratio of 5. The diluted PM exhaust sample was transferred to the gravimetric filter and soot sensor modules via a transfer line heated to 52°C.

The gaseous probe comprised a closed end probe with a number of inlet holes along its length to draw the sample gas in. The raw exhaust gas was passed to the emissions analysers via a sample line heated to 191°C.

An exhaust gas temperature sensor was located between the PM and gaseous sample probes.

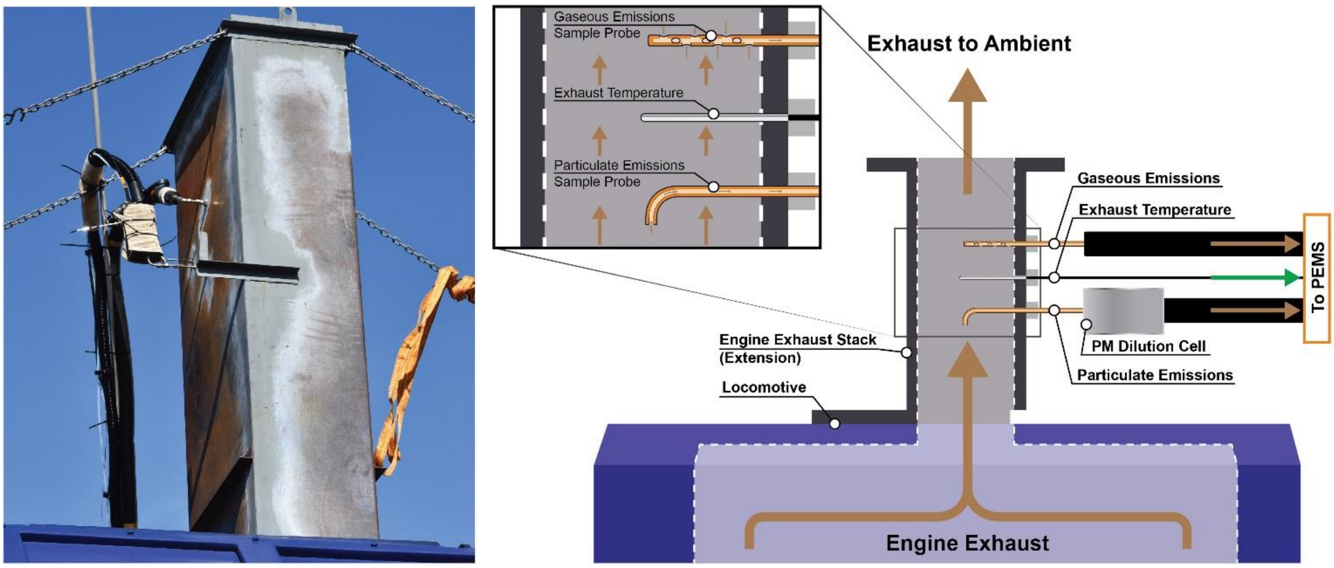


Figure 10 – Exhaust Stack and Emissions Sample Probes

Installing exhaust stack extension

Gaseous heated sample entry to PEMS

Power Measurement Instrumentation

The engine on each locomotive drives two generators, the main and auxiliary, and a companion alternator in addition to a range of mechanically driven accessory loads.

Instantaneous measurement of current and voltage across each generator / alternator was taken to determine the electric power. High accuracy current clamps or transducers were installed around the power cables from the generators and alternator and the voltage was measured directly, with the exception of the main generator voltage, which was measured via a 0-10V transducer. This setup is shown in Figure 11. Current and voltage signals were input to a laboratory grade power analyser. All test equipment is calibrated under 40 CFR part 1065 to the appropriate NIST or equivalent standard.

Electric power was calculated for all generators from the voltage and current outputs with total combined accuracy better than 2%.

Engine shaft power was then calculated as the sum of the main generator, companion alternator and the auxiliary generator power measured with efficiency and mechanical load factors provided by EMD applied.

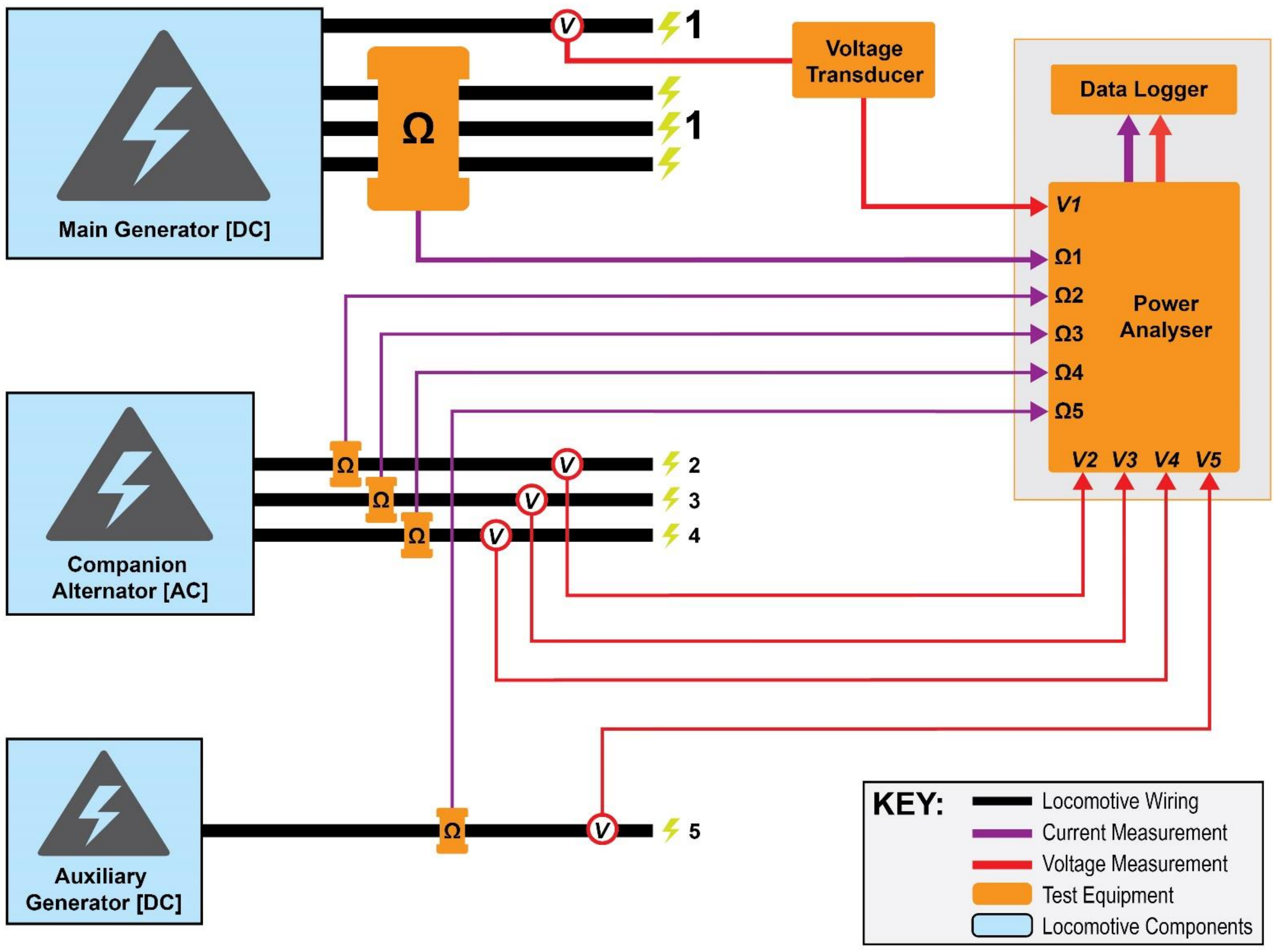
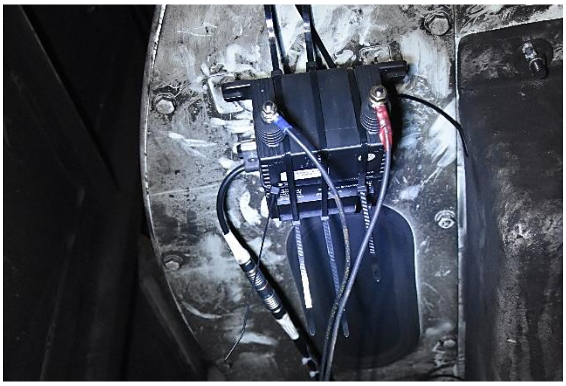
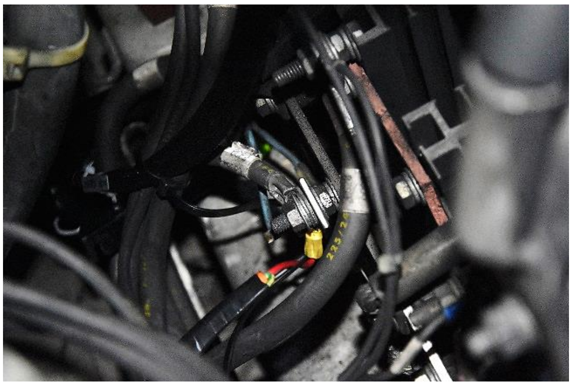


Figure 11 – Power Measurement Instrumentation

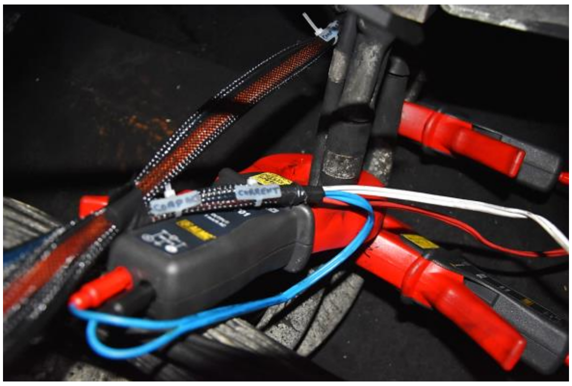


Voltage transducer on
main DC generator

Current transducer on
main DC generator



Voltage connections for
auxiliary DC generator



Current clamps on
companion AC alternator
cables

Power measurement
device installed in-cabin

Noise Measurement Instrumentation

Two brands of sound level meters were used, *Cirrus*, and *Bruel and Kjaer.* These were calibrated prior to noise measurements being taken and the drift measurement was not to exceed +/- 0.5dB. All equipment was within current NATA certification. The sound level meters were setup to the acoustic values shown with “P” and “M” in AS 2377-2007

Cirrus

Bruel and Kjaer

81 CLASS LOCOMOTIVE RESULTS

TEST RESULTS

This section outlines the results from testing of locomotive 8113.

The environmental conditions of each test were in accordance with the relevant specifications of 40 CFR 1033 and were within the test equipment environmental operational limits.

The average emissions and fuel consumption data from each test configuration (pre and post emissions kit upgrade) is presented in both table and chart formats. Test to test variation in each test configuration is represented on each emissions chart with test variation bars. Significantly, the test to test repeatability observed was excellent and the test to test variation bars are not visible for most test points. Noise results are presented as the variation, pre upgrade to post upgrade, in maximum sound pressure level (SPL), when the locomotive is operating in idle and when operating from notch 1 to 8.

After installation of the Tier 0+ emissions upgrade kit, significant reductions in PM, NO_x, THC and CO were measured, whilst BSFC and CO_2 increased, indicating a lower engine efficiency. Overall, a minor reduction in SPL's were measured, some of which would be detectable to the human ear. The maximum measured A weighted noise level change was 7 dB(A) lower.

Engine RPM hunting was measured during both post upgrade tests and was most significant in modes 1, 3 and 4, refer to Appendix C. The impact of this on the test results of the post emissions kit upgrade is unknown.

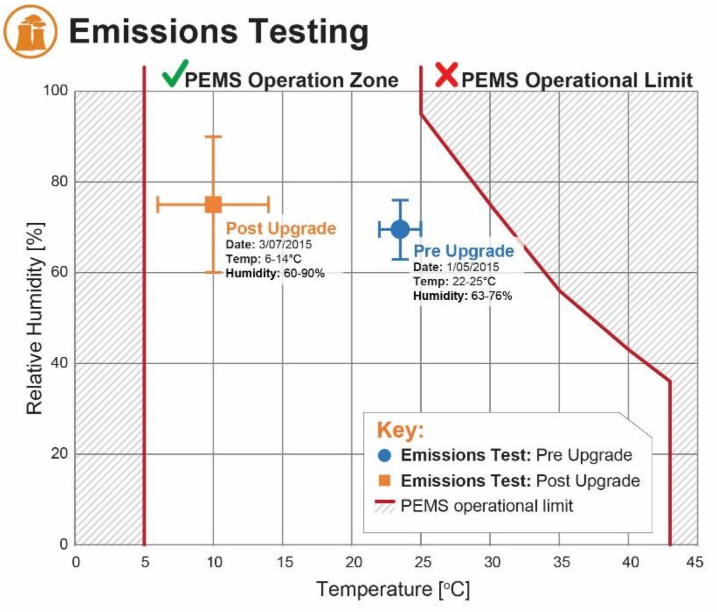
Summary results of all tests can be found in tables in Appendix A.

Ambient Test Conditions

Emissions and fuel consumption testing conformed to the environmental requirements specified by US EPA 40 CFR 1033 and temperature and humidity were within the operational limits specified by test equipment manufacturers.

Noise testing conditions conformed to the AS 2377-2002 standard that specifies no precipitation during measurement and a wind speed below 10 metres per second.

The test environmental conditions are outlined below in Figure 12.



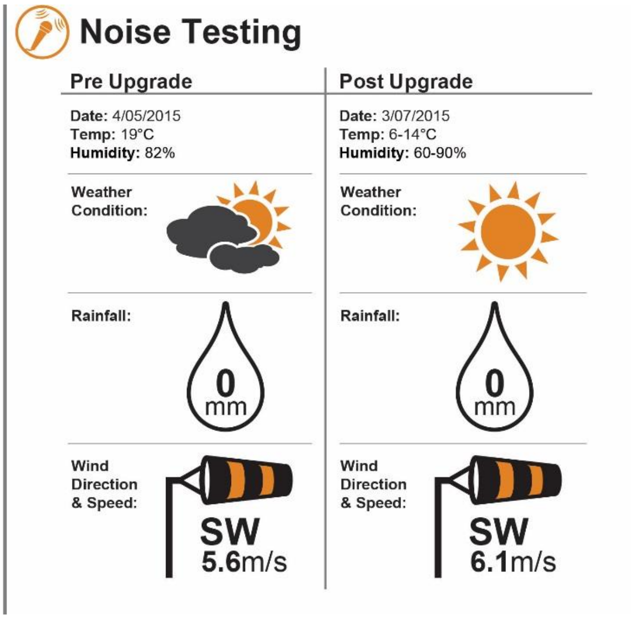


Figure 12 – Environmental Test Conditions

Comparison to Tier 0+ Emissions Limits

After installation of the Tier 0+ emissions kit, all US EPA regulated emissions measured on 8113 were below Tier 0+ limits and significantly below in the case of PM, THC and CO.

The cycle weighted average reductions achieved in PM and NO_x exhaust emissions is equivalent to 48.3% and 9.95% respectively below the legislated Tier 0+ emissions limits as shown in Chart 5. Detailed individual test results can be found in Appendix A.

PM exhaust emissions measured with the emissions kit installed far exceed the requirements of Tier 0+ and achieve better than the Tier 2 limit, as can be seen below in Chart 5.

Emission	Tier 0+ Limit	Post Upgrade Cycle Weighted	% Difference to Tier 0+
Particulates	0.295	0.153	-48.3%
NO_x	10.7	9.66	-9.95%
HC	1.34	0.395	-70.5%
CO	6.71	0.811	-87.9%

Table 5 – Emissions Results Compared to Tier 0+ Limits

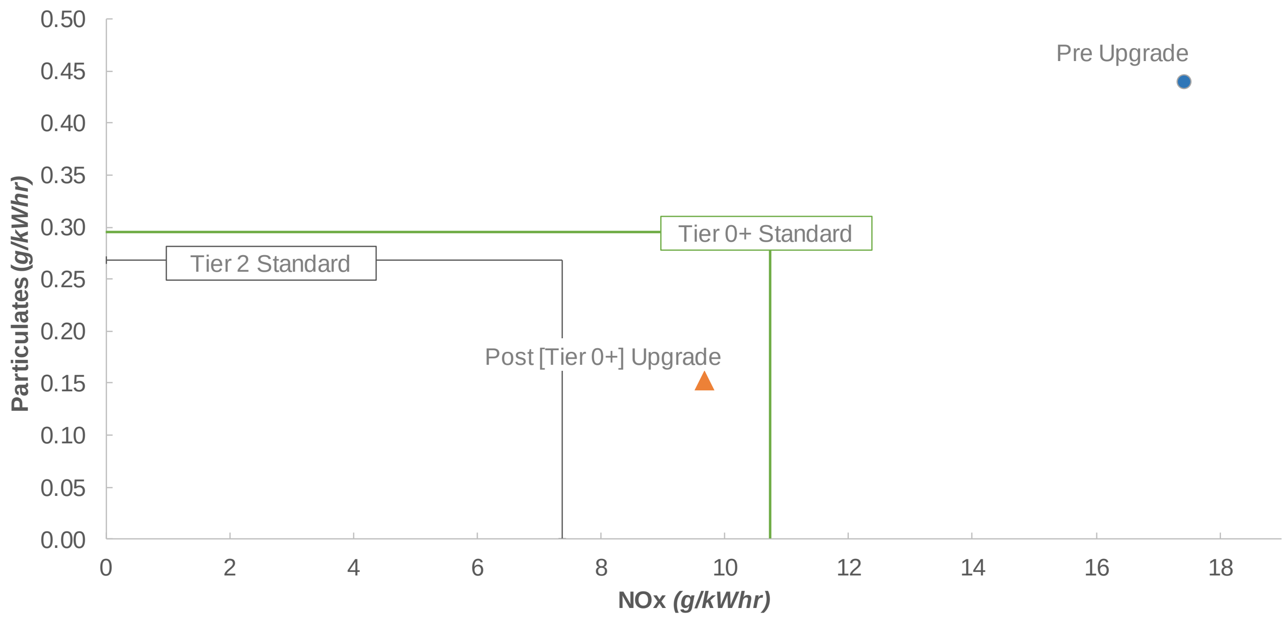


Chart 5 – Emissions Test Results Compared to Tier 0+ NO_x and PM Limits

Cycle Weighted 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.

An increase in the BSFC after installation of the upgrade kit, indicates lower engine efficiency, resulting in higher fuel consumption for the same work output. The cycle weighted emissions are heavily weighted to idle modes, where the largest increase in brake specific fuel consumption was observed. Refer to Figure 13. The increase in BSFC is contrary to the manufacturer claims.

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 CO_2 presented within the report. Refer to Appendix F for BSFC corrections.

	BSFC	PM	NO_x	CO_2	CO	THC
Pre-Upgrade	235	0.452	17.4	731	1.11	0.570
Post-Upgrade [Tier 0+]	248	0.153	9.66	766	0.811	0.395
% Change	5.50%	-66.2%	-44.5%	4.77%	-26.7%	-30.6%

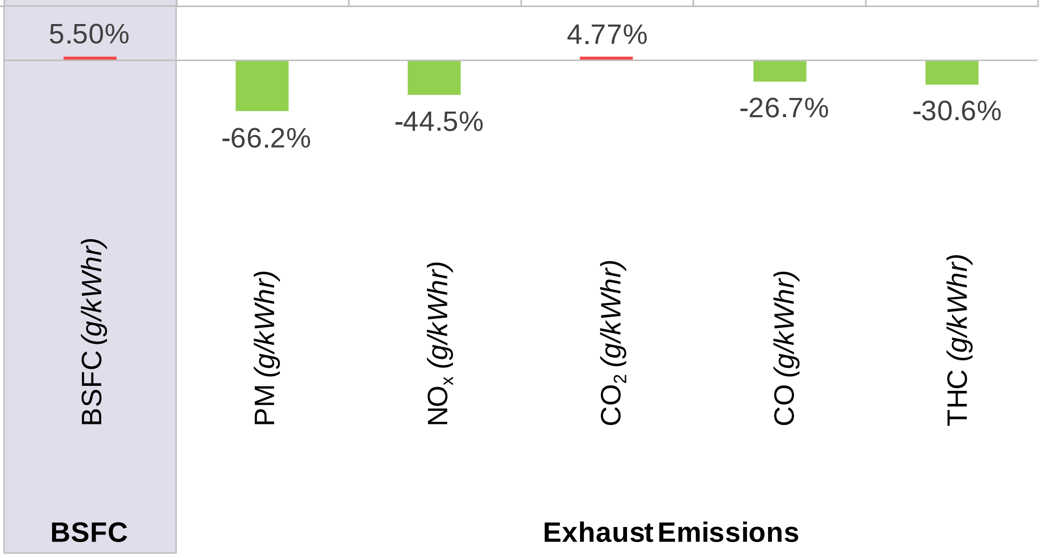


Figure 13 – Cycle Weighted Test Results

Brake Specific Fuel Consumption

Brake Specific Fuel Consumption (BSFC) is an indicator of engine efficiency, with the units g/kWhr being: grams of fuel burned per unit of work.

Brake specific fuel consumption increased after the installation of the emissions upgrade kit. Cycle weighted brake specific fuel consumption increased by 5.50%. 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.

EMD stated that fuel injection timing is retarded with the Tier 0+ emissions kit. Retardation of injection timing is commonly used to reduce NOx, however typically causes a decrease in fuel efficiency.

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%.

BSFC was normalised according to Appendix F.

Description	Test Mode	1	2	3	4	5	6	7	8	9	10	Cycle Weighted	Stabilised Notch 8
Pre-Upgrade Average	(g/kWhr)	946	1023	278	253	235	229	224	222	217	217	235	217
Post-Upgrade [Tier 0+] Average	(g/kWhr)	2030	1483	334	286	244	242	231	228	220	223	248	223

Table 6 – Brake Specific Fuel Consumption Results

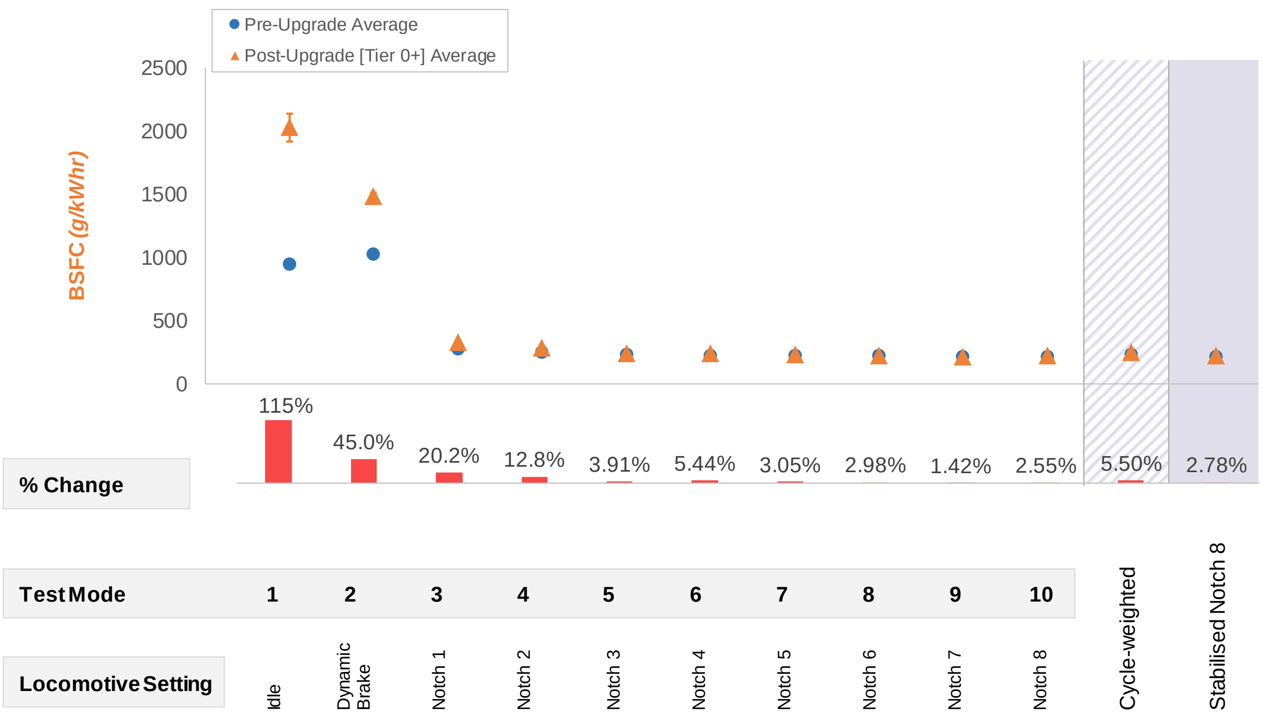


Chart 6 – Brake Specific Fuel Consumption Results

Emissions – Average Brake Specific PM

Often visible as soot and smoke ejected from an exhaust, particulate matter is a complex mixture of small solid and liquid particles suspended in the exhaust gas.

Particulate matter emissions improved significantly after the installation of the upgrade kit with cycle weighted PM emissions reducing by 66.2%, as shown in Chart 7.

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. Greater improvements in PM emissions were measured as the operating mode increased past notch 3.

Overall, the test to test repeatability in both pre and post emissions upgrade configurations was good.

PM emissions were not recorded as part of the stabilised notch 8 data.

Description	Test Mode	1	2	3	4	5	6	7	8	9	10	Cycle Weighted
Pre-Upgrade Average	(g/kWhr)	0.401	1.19	0.239	0.265	0.434	0.439	0.429	0.416	0.444	0.467	0.452
Post-Upgrade [Tier 0+] Average	(g/kWhr)	1.21	0.793	0.308	0.328	0.249	0.252	0.212	0.196	0.110	0.098	0.153

Table 7 – Average PM Emission Results

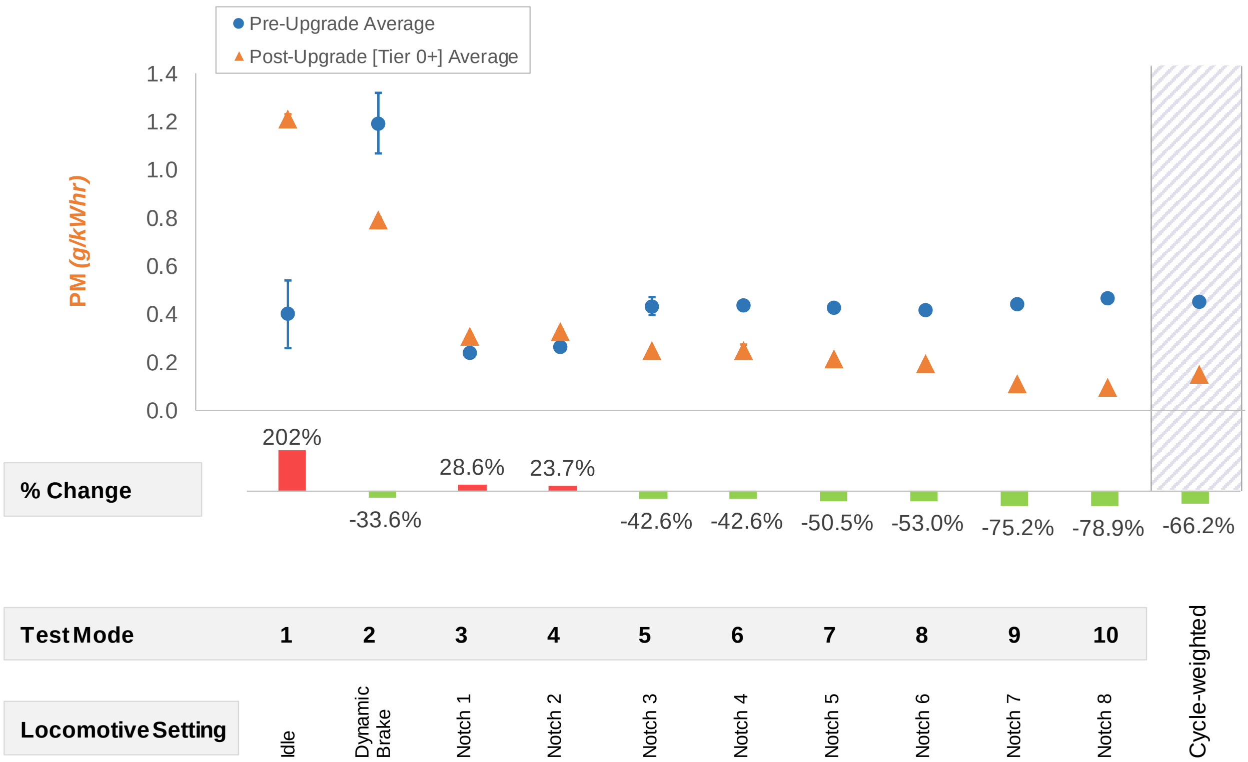


Chart 7 – Average PM Emissions Results

Emissions – Average Brake Specific NO_x

Oxides of nitrogen (NO_x) is the sum of nitric oxide (NO) and nitrogen dioxide (NO_2).

Overall, NO_x emissions improved significantly after the installation of the upgrade kit with cycle weighted NO_x emissions reducing by 44.5%, as shown in Chart 8.

NO_x emissions increased after installation of the emissions upgrade kit only in mode 1 (idle), by 72.1%. In all other modes, NO_x was significantly reduced by between 24.9%, in dynamic brake and 47.7%, in notch 8 when compared to the standard engine rebuild results. Improvements in NO_x emissions mostly ranged between 42% and 48% across the modes.

The test to test repeatability in both pre and post emissions upgrade configurations was excellent, typically within 1%, with the exception of testing in mode 1 for both pre and post emissions upgrade testing which varied by 16.4% and 17.9% respectively.

Description	Test Mode	1	2	3	4	5	6	7	8	9	10	Cycle Weighted	Stabilised Notch 8
Pre-Upgrade Average	(g/kWhr)	55.6	58.2	21.7	18.1	16.6	16.1	15.8	15.4	16.0	17.0	17.4	17.5
Post-Upgrade [Tier 0+] Average	(g/kWhr)	95.7	43.7	12.4	9.85	9.52	8.99	8.47	8.09	9.11	8.89	9.66	8.94

Table 8 – Average NO_x Emissions Results

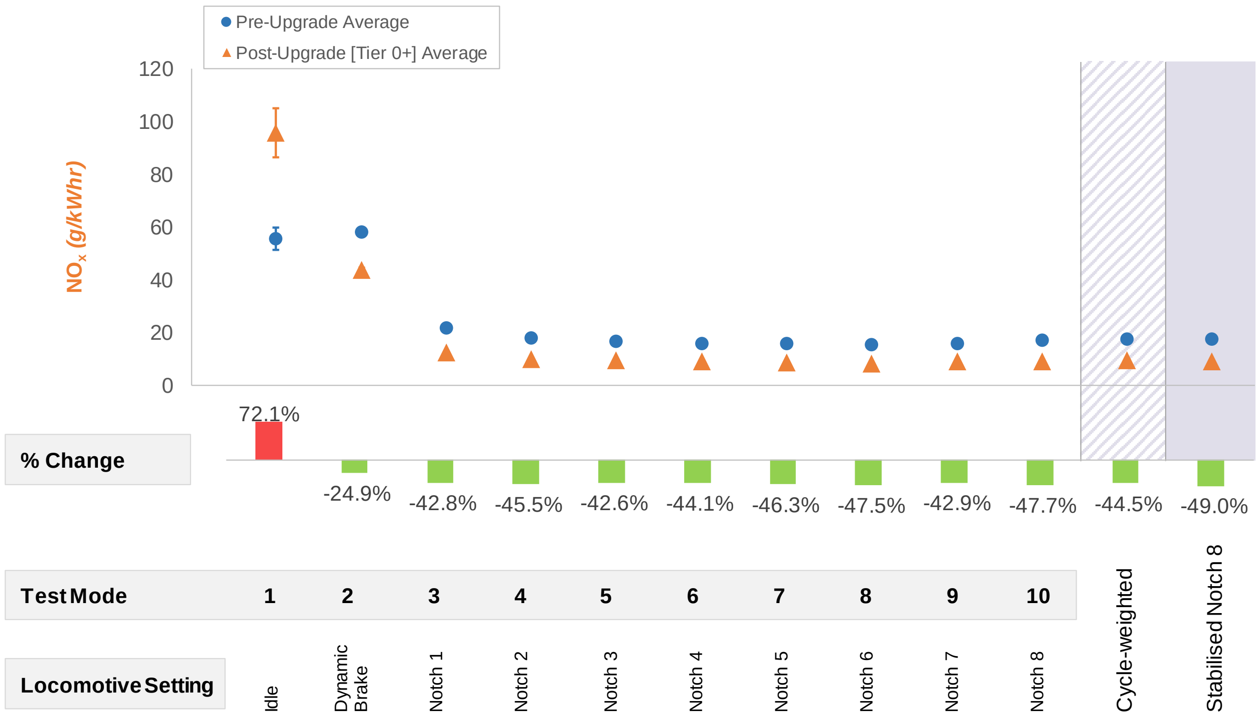


Chart 8 – Average NO_x Emissions Results

Emissions – Average Brake Specific CO_2

Carbon dioxide (CO_2) is not a regulated emission, however is presented due to its contribution to greenhouse gases.

CO_2 increased after the installation of the upgrade kit with cycle weighted CO_2 emissions higher by 4.77%, as shown in Chart 9.

CO_2 emissions were significantly increased by 12.1% to 115% in the post emissions kit configuration in modes 1 through 4. Smaller increases in CO_2 were measured in the higher test modes ranging from 0.59% in mode 9 to 4.71% in mode 6.

The test to test repeatability in both pre and post emissions upgrade configurations was excellent, and within 2%, with the exception of testing in mode 1 and 2 in the post emissions upgrade configuration which varied by 11.7% and 4.49% respectively.

Description	Test Mode	1	2	3	4	5	6	7	8	9	10	Cycle Weighted	Stabilised Notch 8
Pre-Upgrade Average	(g/kWhr)	2883	3149	862	787	734	715	701	693	677	676	731	675
Post-Upgrade [Tier 0+] Average	(g/kWhr)	6213	4571	1030	882	757	749	717	707	681	688	766	689

Table 9 – Average CO_2 Emissions Results

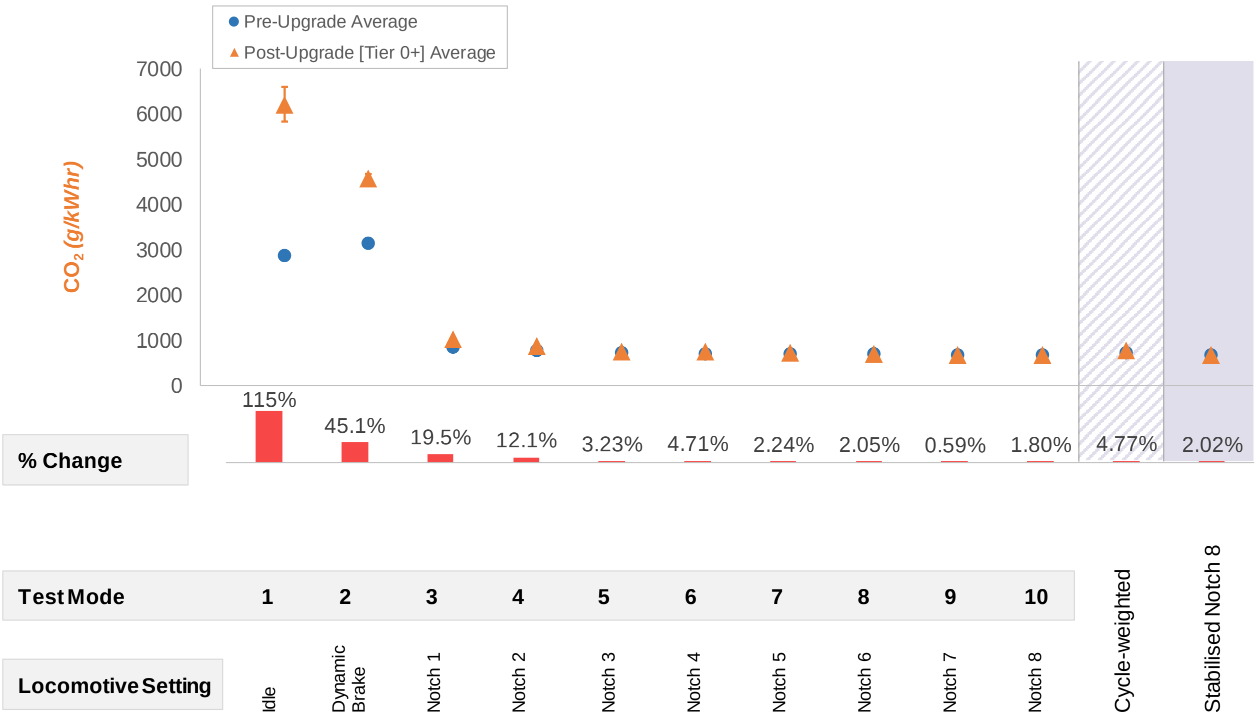


Chart 9 – Average CO_2 Emissions Results

Emissions – Average Brake Specific CO

CO emissions improved after the installation of the upgrade kit with cycle weighted CO decreasing by 26.7%, as shown in Chart 10.

CO emissions increased after installation of the emissions upgrade kit in mode 7 and 8 by 7.32% and 78.0%, however measured values were very small.

CO was reduced by between 1.65% in mode 9 and 57.3% in mode 2 when compared to the standard engine rebuild results.

The test to test repeatability in both pre and post emissions upgrade configurations showed some variation, see Appendix A for individual results.

Overall, measured CO emissions were relatively small in both the pre and post emissions kit upgrade tests with some measurements within the instrumentation error.

Description	Test Mode	1	2	3	4	5	6	7	8	9	10	Cycle Weighted	Stabilised Notch 8
Pre-Upgrade Average	(g/kWhr)	30.9	21.4	2.39	1.74	0.852	0.752	0.583	0.559	0.534	0.612	1.11	0.536
Post-Upgrade [Tier 0+] Average	(g/kWhr)	25.0	9.11	2.31	1.40	0.579	0.515	0.625	0.996	0.525	0.492	0.811	0.496

Table 10 – Average CO Emissions Results

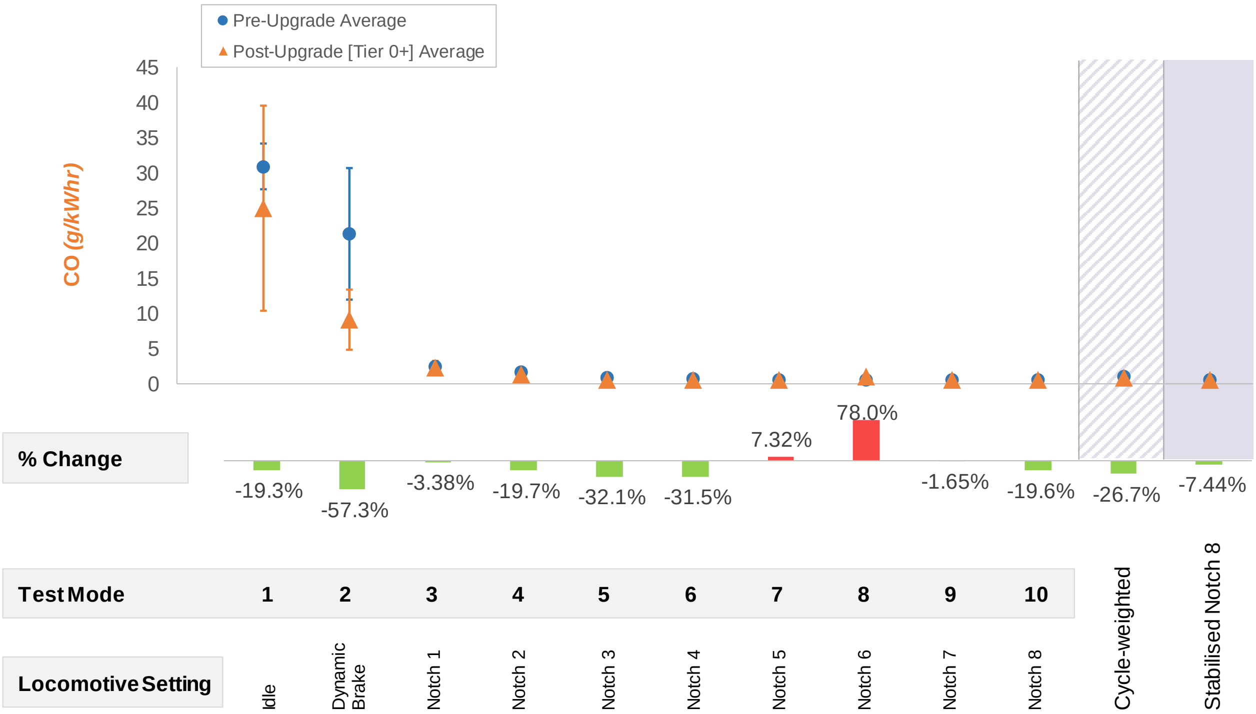


Chart 10 – Average CO Emissions Results

Emissions – Average Brake Specific THC

Total hydrocarbons (THC) represents unburnt and partially burnt fuel.

THC emissions improved significantly after the installation of the upgrade kit with cycle weighted THC emissions reducing by 30.6%, as shown in Chart 11.

THC increased after installation of the emissions upgrade kit in mode 1 through to 4 by between 19.8% and 102%. In all other modes, THC was significantly reduced by between 27.4% in mode 5 and 52.2% in mode 10 when compared to the standard engine rebuild results. Greater improvements in THC emissions were measured as the operating mode increased past notch 3.

Overall, the test to test repeatability in both pre and post emissions upgrade configurations was very good.

Description	Test Mode	1	2	3	4	5	6	7	8	9	10	Cycle Weighted	Stabilised Notch 8
Pre-Upgrade Average	(g/kWhr)	8.02	4.98	0.805	0.601	0.453	0.388	0.367	0.369	0.431	0.497	0.570	0.499
Post-Upgrade [Tier 0+] Average	(g/kWhr)	16.2	6.85	1.10	0.719	0.329	0.238	0.204	0.180	0.211	0.238	0.395	0.245

Table 11 – Average THC Emissions Results

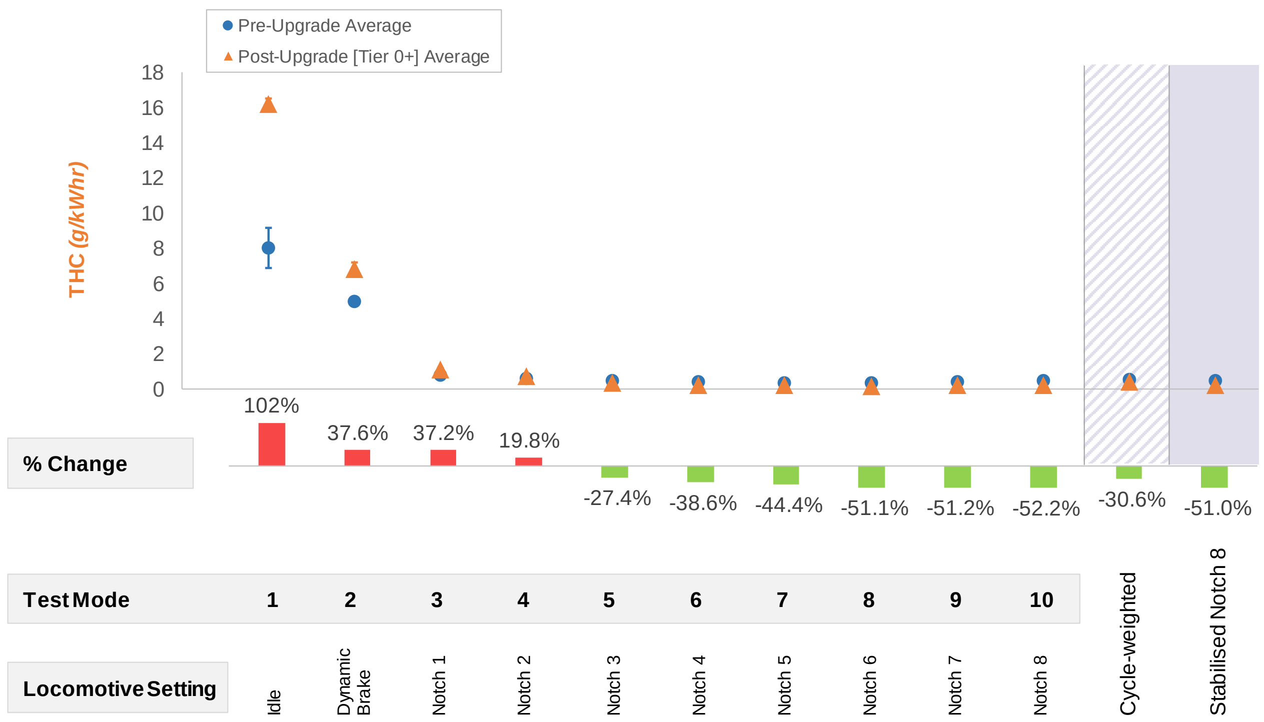


Chart 11 – Average THC Emissions Results

Operating Temperature – Exhaust

Exhaust temperature was measured in the exhaust stack extension between the gaseous and particulate matter sampling probes.

After upgrade to the Tier 0+ emissions kit, test results showed an increase in exhaust temperature from modes 1 to 8 of around 20 ºC and small decreases of 7 °C in modes 9 and 10, as shown in Table 12 and Chart 12.

It was anticipated that exhaust and combustion temperatures may have been cooler with the installation of the four pass aftercooler.

Temperature data from modes 8, 9, 10 and stabilised notch 8 in the post upgrade configuration test 2 had large amounts of noise, and have been excluded. Only post upgrade test 1 data has been presented for these 4 modes in the data and charts.

It is typical that retarding the fuel injection timing may result in higher exhaust temperatures. Injection timing is retarded as part of the emissions upgrade kit.

Description	Test Mode	1	2	3	4	5	6	7	8	9	10	Stabilised Notch 8
Pre-Upgrade Average Temperature	(°C)	68	75	98	130	182	230	268	309	338	340	341
Post-Upgrade [Tier 0+] Average Temperature	(°C)	92	95	125	156	209	252	287	329	331	333	335
Change in Temperature	(°C)	23	20	27	26	26	22	18	20	-7	-7	-6

Table 12 – Average Exhaust Temperature

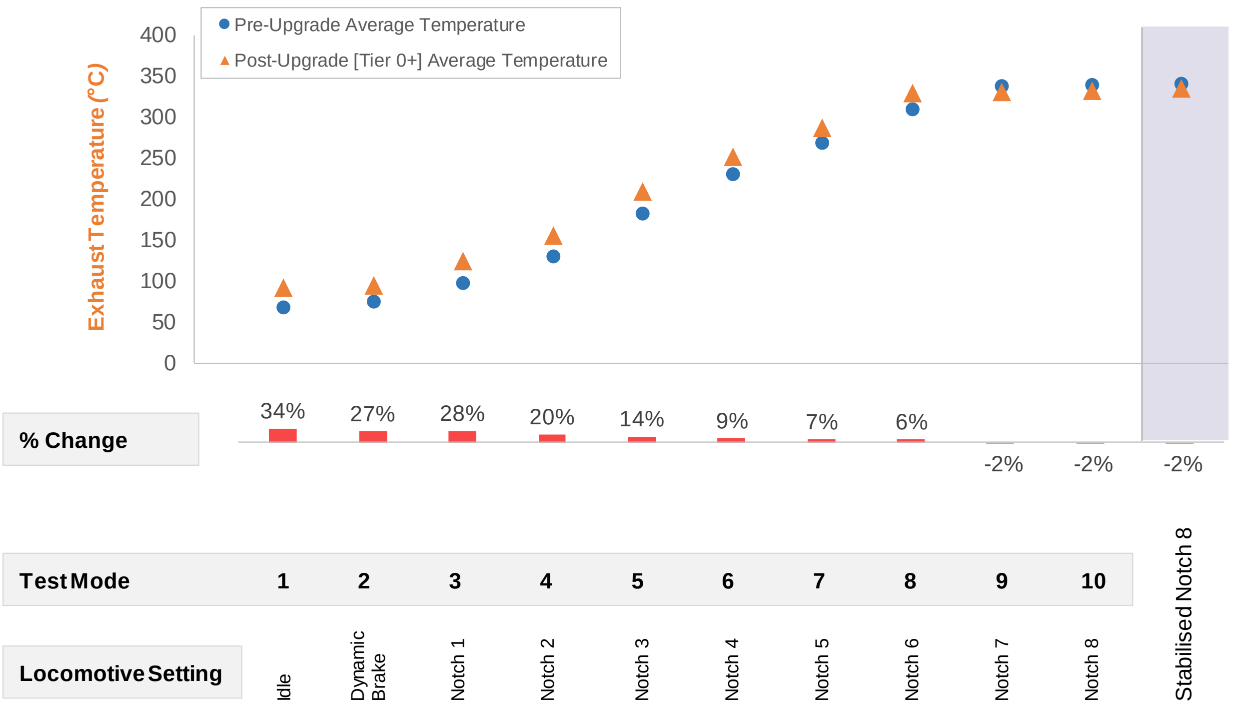


Chart 12 – Average Exhaust Temperature

Operating Temperature – Charge Air

Charge air temperature was measured from the handhole cover over cylinder 10.

With the Tier 0+ emissions kit installed, significant increases of up to 32 °C of charge air temperature were measured during test modes 1 through to 9, as shown in Table 13 and Chart 13, despite cooler ambient test conditions.

It was anticipated that charge air temperature may have been cooler with the installation of the four pass aftercooler.

Description	Test Mode	1	2	3	4	5	6	7	8	9	10	Stabilised Notch 8
Pre-Upgrade Average Temperature	(°C)	38	42	38	39	44	51	57	65	79	93	98
Post-Upgrade [Tier 0+] Average Temperature	(°C)	69	72	70	69	70	71	73	78	85	89	91
Change in Temperature	(°C)	31	30	32	30	26	21	16	13	6	-3	-7

Table 13 – Average Charge Air Temperature

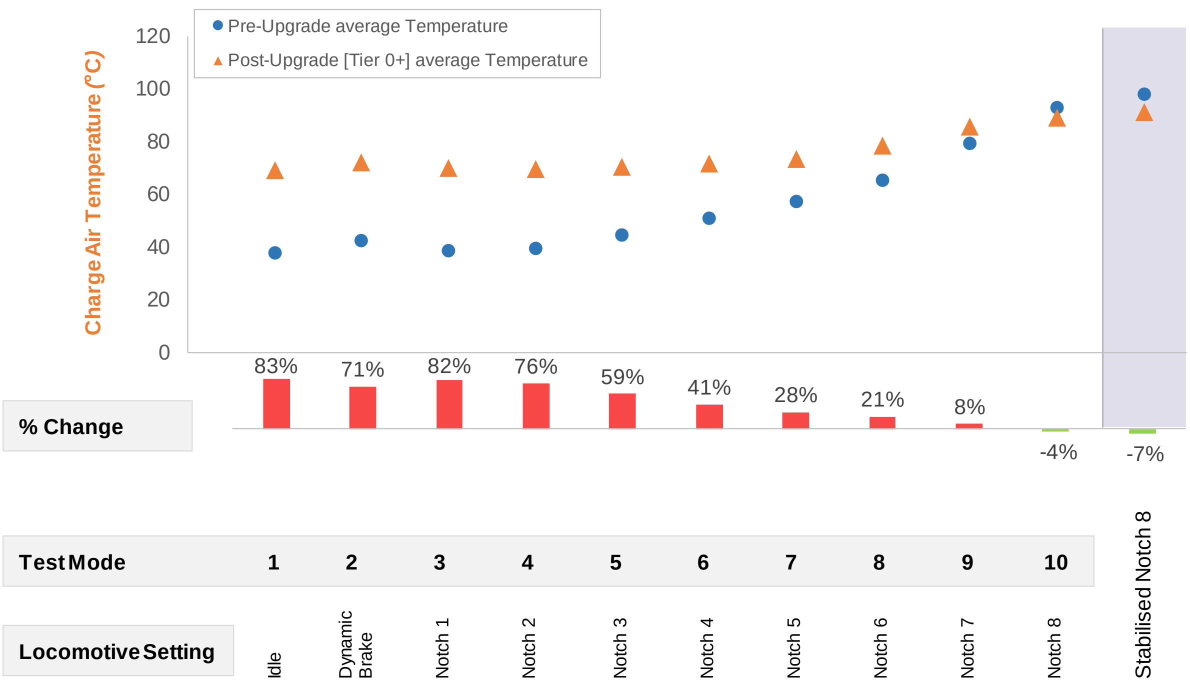


Chart 13 – Average Charge Air Temperature

Noise

A change of 2 dBA or less in broadband noise is difficult for the human ear to distinguish.

The data in Table 24 shows the noise results presented as the variation, pre upgrade to post upgrade, in maximum sound pressure level (SPL), when the locomotive is operating in idle and when operating from notch 1 to 8. The change in maximum noise levels were compared irrespective of the measurement position around the locomotive.

EPA noise regulations for new locomotives set Z-weighted noise level limits for throttle notches 1 to 8, but no Z-weighted limit applies at engine idle. Z-weighted noise levels were measured at idle on both locomotives as part of this testing, however close examination of the idle results for 9024 indicated that they were wind affected. Due to this, Z-weighted noise levels are not reported at idle for either locomotive.

In general, the noise test data showed a consistent trend in noise reduction with the maximum noise level in both idle and notch 1 to 8 decreasing post emissions upgrade. These results are shown in Table 14.

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 decrease was 7 dB(A). At this level, it would be noticeable as a noise reduction.

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

Table 14 – Noise SPL Results

90 CLASS LOCOMOTIVE RESULTS

TEST RESULTS

This section outlines the results from testing of locomotive 9024.

The environmental conditions of each test were in accordance with the relevant specifications of 40 CFR 1033 and were within the test equipment environmental operational limits.

The average emissions and fuel consumption data from each test configuration (pre and post emissions kit upgrade) is presented in both table and chart formats. Test to test variation in each test configuration is represented on each emissions chart with test variation bars. Significantly, the test to test repeatability observed was excellent and the test to test variation bars are not visible for most test points. Noise results are presented as the variation, pre upgrade to post upgrade, in maximum sound pressure level (SPL), when the locomotive is operating in idle and when operating from notch 1 to 8.

After installation of the Tier 0+ emissions upgrade kit, significant reductions in PM, NO_x, THC and CO were measured, whilst BSFC and CO_2 increased, indicating a lower engine efficiency. Overall, a minor reduction in maximum SPL's were measured across all modes and small increases at idle. The maximum A weighted noise level increase at idle was 2 dB(A). At this level, it would be difficult for the human ear to distinguish.

Summary results of all tests can be found in tables in Appendix B.

Ambient Test Conditions

Emissions and fuel consumption testing conformed to the environmental requirements specified by US EPA 40 CFR 1033 and temperature and humidity were within the operational limits specified by test equipment manufacturers.

Noise testing conditions conformed to the AS 2377-2002 standard that specifies no precipitation during measurements and a wind speed below 10 metres per second. Whilst rain fell during the noise test on the 21st of May, measurements were taken between showers.

The test environmental conditions are outlined below in Figure 14.

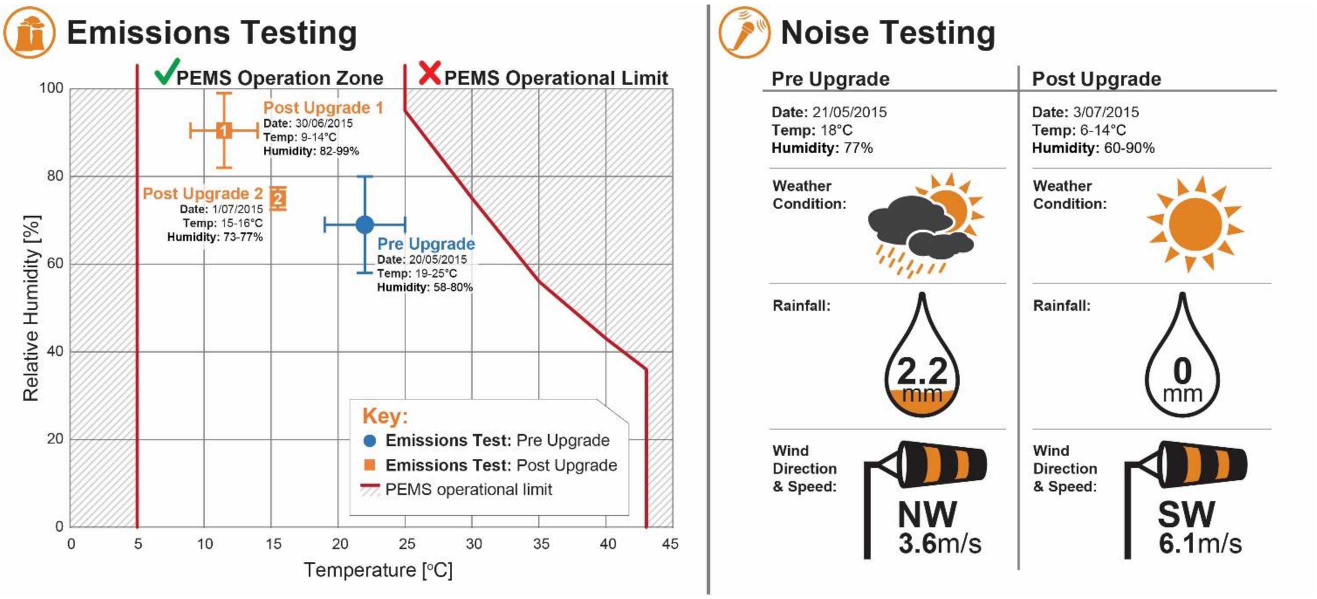


Figure 14 – Environmental Test Conditions

Comparison to Tier 0+ Emissions Limits

After installation of the Tier 0+ emissions kit, all US EPA regulated emissions measured on 9024 were below Tier 0+ limits and significantly below in the case of PM, THC and CO.

The cycle weighted average reductions achieved in PM and NO_x exhaust emissions is equivalent to 59.1% and 11.2% respectively below the legislated Tier 0+ emissions limits, as shown in Table 15 and Chart 14. Detailed individual test results can be found in appendix B.

PM exhaust emissions measured with the emissions kit installed far exceed the requirements of Tier 0+ and achieve better than the Tier 3 limit.

Emission	Tier 0+ Limits	Post Upgrade Cycle Weighted	% Difference to Tier 0+
Particulates	0.295	0.121	-59.1%
NO_x	10.73	9.52	-11.2%
HC	1.34	0.176	-86.8%
CO	6.71	0.592	-91.2%

Table 15 – Emissions Results Compared to Tier 0+ Limits

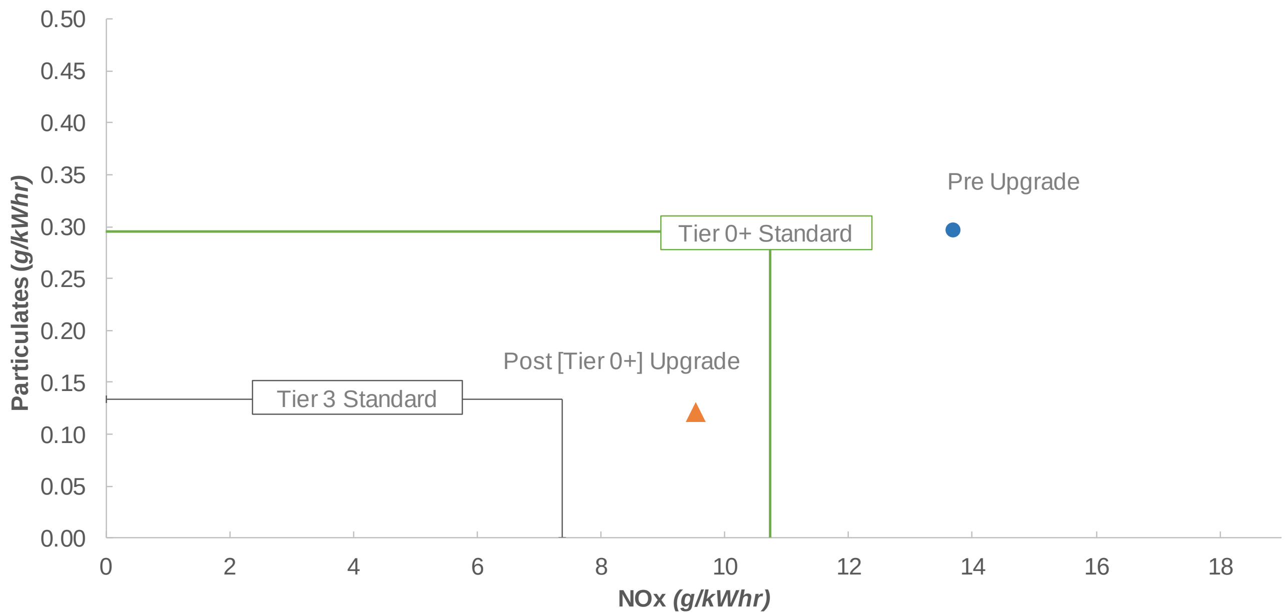


Chart 14 – Emissions Test Results Compared to Tier 0+ NOx and PM Limits

Cycle Weighted 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.

An increase in the BSFC with the upgrade kit installed, indicates lower engine efficiency (resulting in higher fuel consumption). BSFC and CO_2 increased by 2.57% and 1.93% respectively when compared to the pre-emissions kit upgrade configuration, as shown in Figure 15.

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 CO_2 presented within the report. Refer to Appendix F for BSFC corrections.

	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

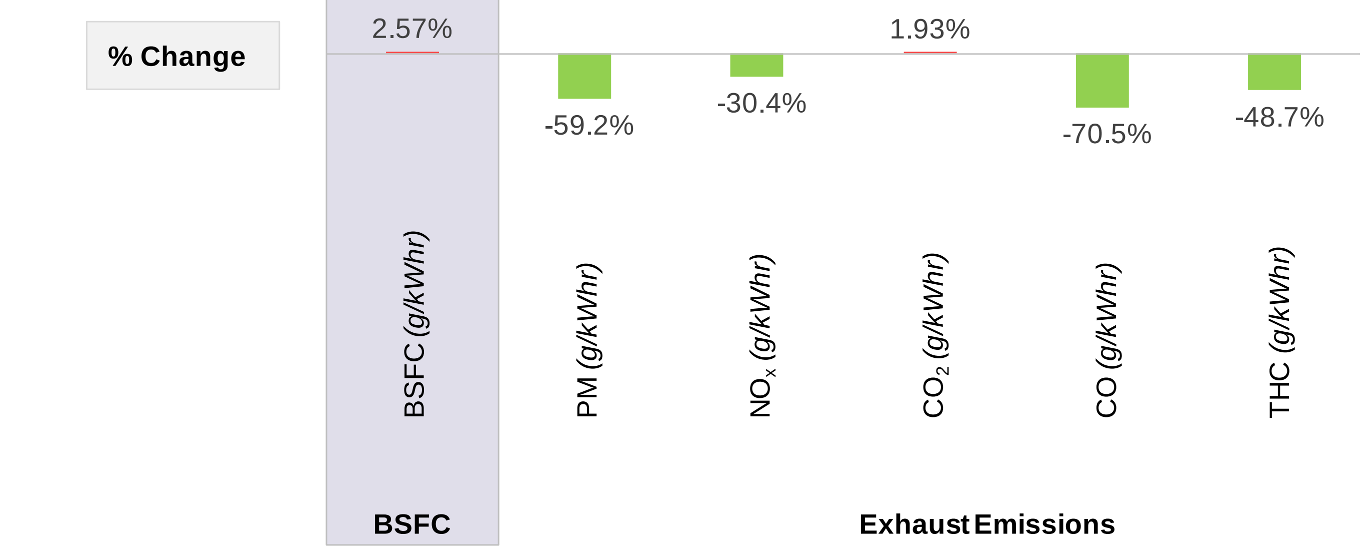


Figure 15 – Cycle Weighted Test Results

Brake Specific Fuel Consumption

Brake Specific Fuel Consumption (BSFC) is an indicator of engine efficiency, with the units g/kWhr being: grams of fuel burned per unit of work.

Brake specific fuel consumption increased after the installation of the emissions upgrade kit. Cycle weighted brake specific fuel consumption increased by 2.57%, as shown in Chart 15.

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. The only notch showing BSFC improvements was notch 7, at 0.35%.

EMD stated that fuel injection timing is retarded with the Tier 0+ emissions kit. Retardation of injection timing is commonly used to reduce NOx, however typically causes a decrease in fuel efficiency.

Overall, the test to test repeatability in both pre and post emissions upgrade configurations was very good.

BSFC was normalised according to Appendix F.

Description	Test Mode	1	2	3	4	5	6	7	8	9	10	Cycle Weighted	Stabilised Notch 8
Pre-Upgrade Average	(g/kWhr)	719	993	235	219	209	207	208	208	209	207	212	207
Post-Upgrade [Tier 0+] Average	(g/kWhr)	1159	1286	258	229	215	210	210	211	208	210	217	209

Table 16 – Brake Specific Fuel Consumption Results

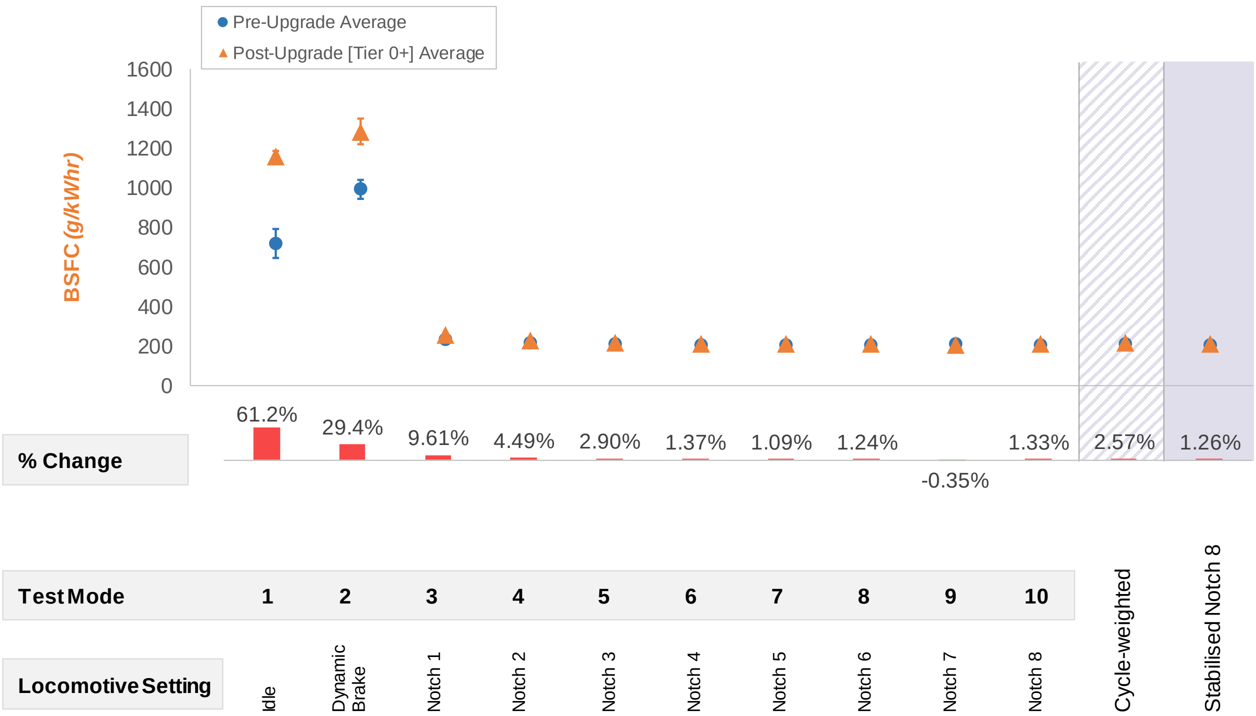


Chart 15 – Brake Specific Fuel Consumption Results

Emissions – Average Brake Specific PM

Often visible as soot and smoke ejected from an exhaust, particulate matter is a complex mixture of small solid and liquid particles suspended in the exhaust gas.

Particulate matter emissions improved significantly after the installation of the upgrade kit with cycle weighted PM emissions reducing by 59.2%, as shown in Chart 16.

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 6.

Overall, the test to test repeatability in both pre and post emissions upgrade configurations was very good.

PM emissions were not recorded as part of the stabilised notch 8 data.

Description	Test Mode	1	2	3	4	5	6	7	8	9	10	Cycle Weighted	Stabilised Notch 8
Pre-Upgrade Average	(g/kWhr)	0.578	0.894	0.193	0.193	0.339	0.367	0.353	0.323	0.297	0.280	0.296	N/A
Post-Upgrade [Tier 0+] Average	(g/kWhr)	0.517	0.642	0.107	0.093	0.105	0.090	0.101	0.101	0.141	0.124	0.121	N/A

Table 17 – Average PM Emission Results

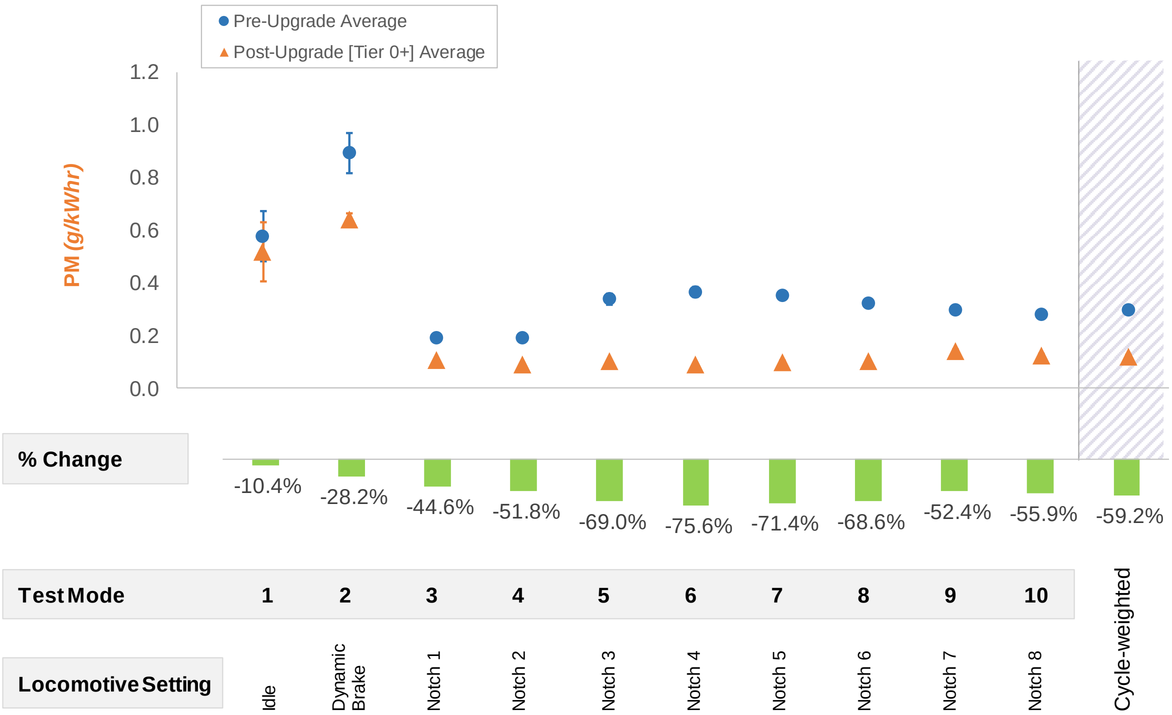


Chart 16 – Average PM Emission Results

Emissions – Average Brake Specific NO_x

Oxides of nitrogen (NO_x) is the sum of nitric oxide and (NO) nitrogen dioxide (NO_2).

NO_x emissions improved significantly after the installation of the upgrade kit with cycle weighted NO_x emissions reducing by 30.4%, as shown in Chart 17.

NO_x increased after installation of the emissions upgrade kit in mode 1 only by 25.3%. In all other modes, NO_x was significantly reduced by between 10.0% in dynamic brake and 32.8% in notch 6 when compared to the standard engine rebuild results. Improvements in NO_x emissions were mostly between 27% and 33%.

Overall, the test to test repeatability in both pre and post emissions upgrade configurations was very good.

Description	Test Mode	1	2	3	4	5	6	7	8	9	10	Cycle Weighted	Stabilised Notch 8
Pre-Upgrade Average	(g/kWhr)	58.8	73.8	19.8	19.8	17.8	17.0	15.7	14.4	12.0	12.1	13.7	12.1
Post-Upgrade [Tier 0+] Average	(g/kWhr)	73.7	66.4	14.4	14.0	12.8	11.6	10.6	9.71	8.58	8.16	9.52	8.24

Table 18 – Average NO_x Emissions Results

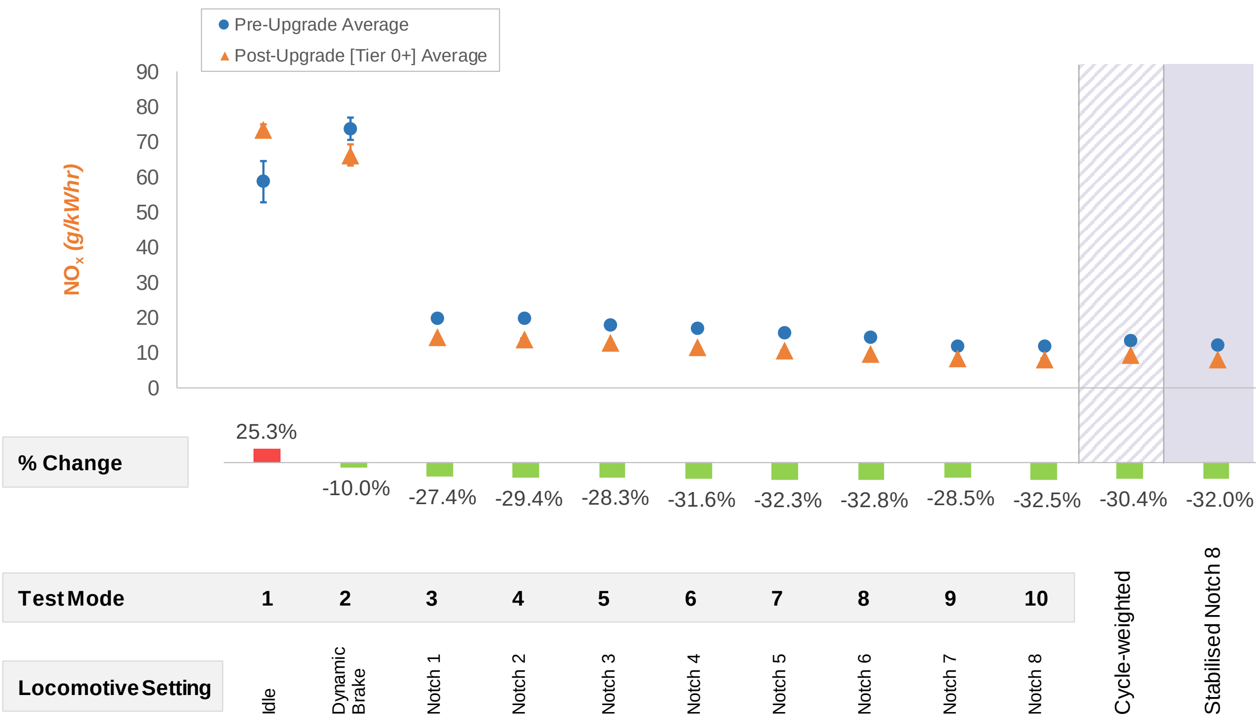


Chart 17 – Average NO_x Emissions Results

Emissions – Average Brake Specific CO_2

Carbon dioxide (CO_2) is not a regulated emission, however is presented due to its contribution to greenhouse gases.

Brake specific CO_2 values increased after the installation of the upgrade kit with cycle weighted CO_2 increasing by 1.93%, as shown in Chart 18.

In the post emissions kit configuration in modes 1 through 3, CO_2 emissions were significantly increased by 8.86% to 60.3%. Smaller increases in CO_2 were measured in higher test modes ranging from 0.20% in mode 7 to 3.67% in mode 4. Mode 9 (notch 7) is the only test mode that showed an improvement at 0.81%.

The test to test repeatability in both pre and post emissions upgrade configurations was excellent, and within 2%, with the exception of testing in mode 1 and 2 for both pre and post emissions upgrade testing which varied by between 21.5% and 4.03%.

Description	Test Mode	1	2	3	4	5	6	7	8	9	10	Cycle Weighted	Stabilised Notch 8
Pre-Upgrade Average	(g/kWhr)	2250	3103	737	686	656	652	655	655	652	645	661	645
Post-Upgrade [Tier 0+] Average	(g/kWhr)	3608	4001	802	712	670	655	656	657	647	650	674	650

Table 19 – Average CO_2 Emissions Results

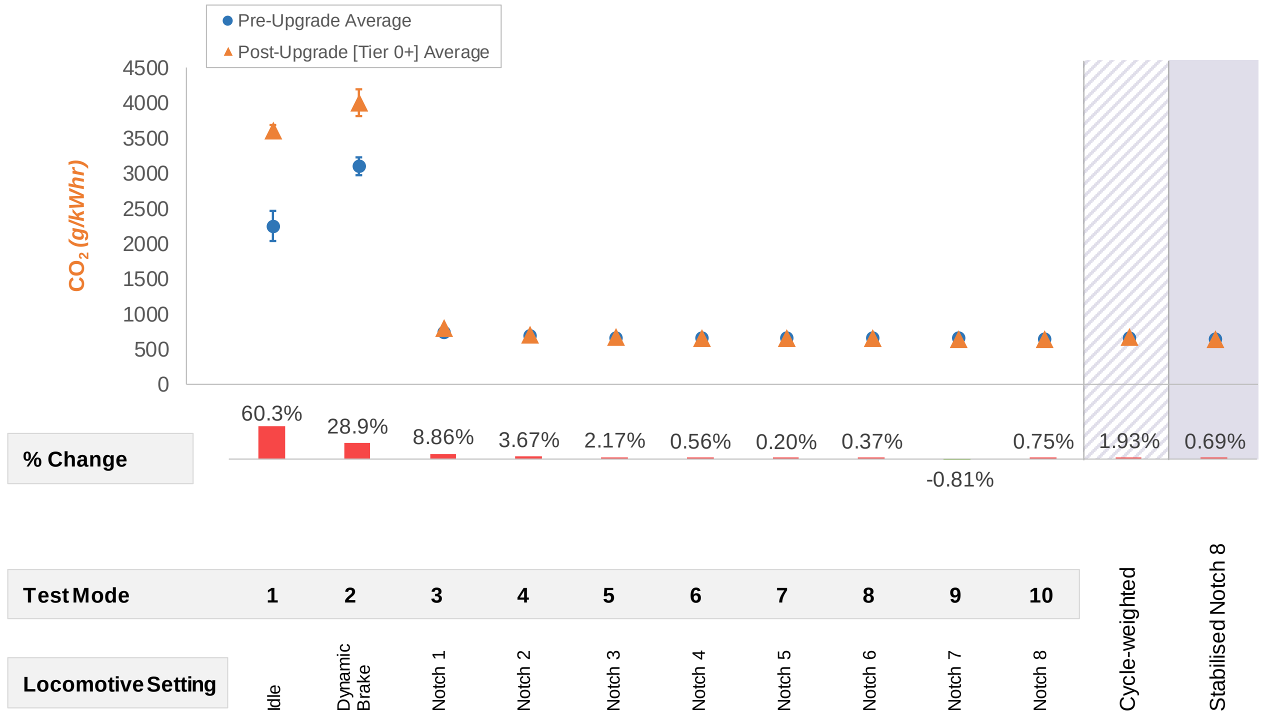


Chart 18 – Average CO_2 Emissions Results

Emissions – Average Brake Specific CO

CO emissions improved after the installation of the upgrade kit with cycle weighted CO emissions decreasing by 70.5%, as shown in Chart 19.

CO was significantly reduced by between 63.6% in notch 7 and 95.9% in notch 5 when compared to the standard engine rebuild results.

Overall, measured CO emissions were very small in both the pre and post emissions upgrade kit tests with some measurements within the instrumentation error, particularly in the post upgrade tests. Small negative values were recorded in both configurations and these have been set to zero as specified by the CFR.

The test to test repeatability in both pre and post emissions upgrade configurations showed some variation, see Appendix B for individual results.

Description	Test Mode	1	2	3	4	5	6	7	8	9	10	Cycle Weighted	Stabilised Notch 8
Pre-Upgrade Average	(g/kWhr)	0.589*	4.16*	0.560*	0.211*	0.632	0.449	0.497	0.771	3.59	2.45	2.01	2.40
Post-Upgrade [Tier 0+] Average	(g/kWhr)	0.000#	0.000#	0.000#	0.000#	0.000#	0.000#	0.020*	0.130	1.31	0.748	0.592	0.673

** One test measurement below detection limits of instrumentation and set to zero as specified by 40 CFR 1065.*
 # Both test measurements below detection limits of instrumentation and set to zero as specified by 40 CFR 1065.

Table 20 – Average CO Emissions Results

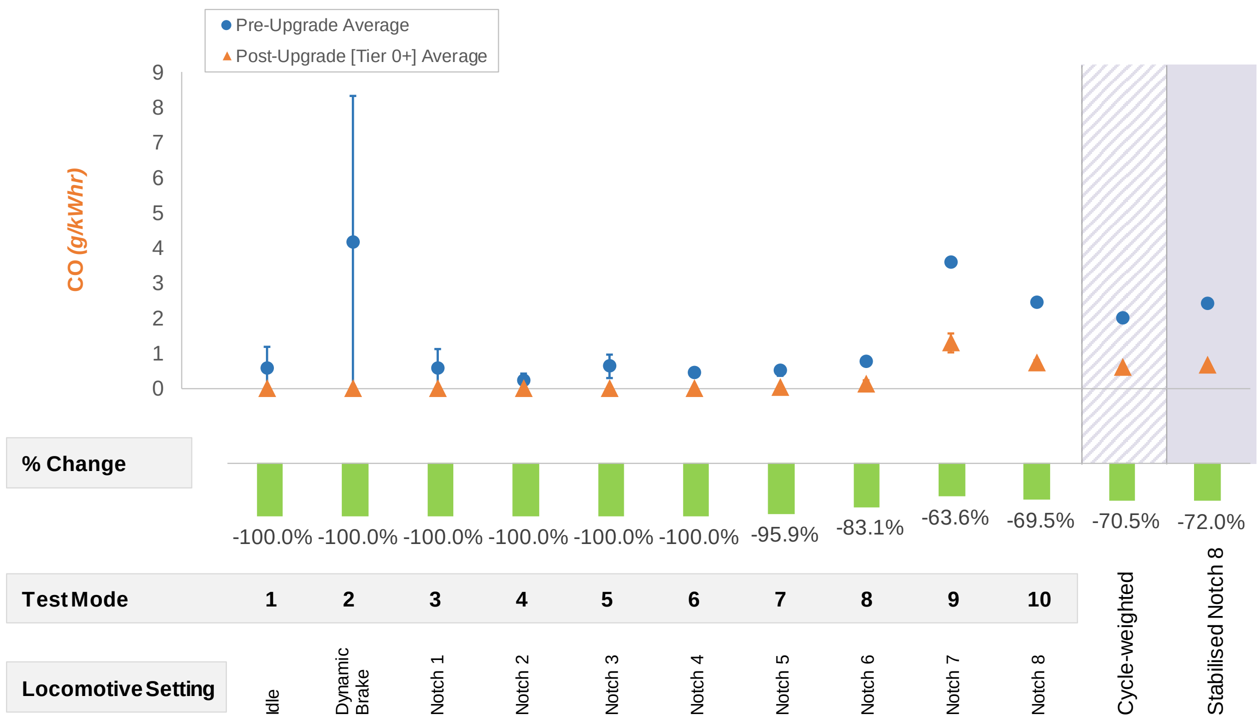


Chart 19 – Average CO Emissions Results

Emissions – Average Brake Specific THC

Total hydrocarbons (THC) represents unburnt and partially burnt fuel.

THC emissions improved significantly after the installation of the upgrade kit with cycle weighted THC emissions reducing by 48.7%, as shown in Chart 20.

THC increased after installation of the emissions upgrade kit in mode 1 and 2 by 33.2% and 1.99% respectively. In all other modes, THC was significantly reduced by between 16.9% in mode 4 and 60.1% in mode 9 when compared to the standard engine rebuild results.

Overall, the test to test repeatability in both pre and post emissions upgrade configurations was very good.

Description	Test Mode	1	2	3	4	5	6	7	8	9	10	Cycle Weighted	Stabilised Notch 8
Pre-Upgrade Average	(g/kWhr)	2.89	3.77	0.445	0.340	0.270	0.231	0.237	0.259	0.345	0.353	0.343	0.367
Post-Upgrade [Tier 0+] Average	(g/kWhr)	3.85	3.85	0.353	0.283	0.210	0.168	0.140	0.138	0.138	0.145	0.176	0.145

Table 21 – Average THC Emissions Results

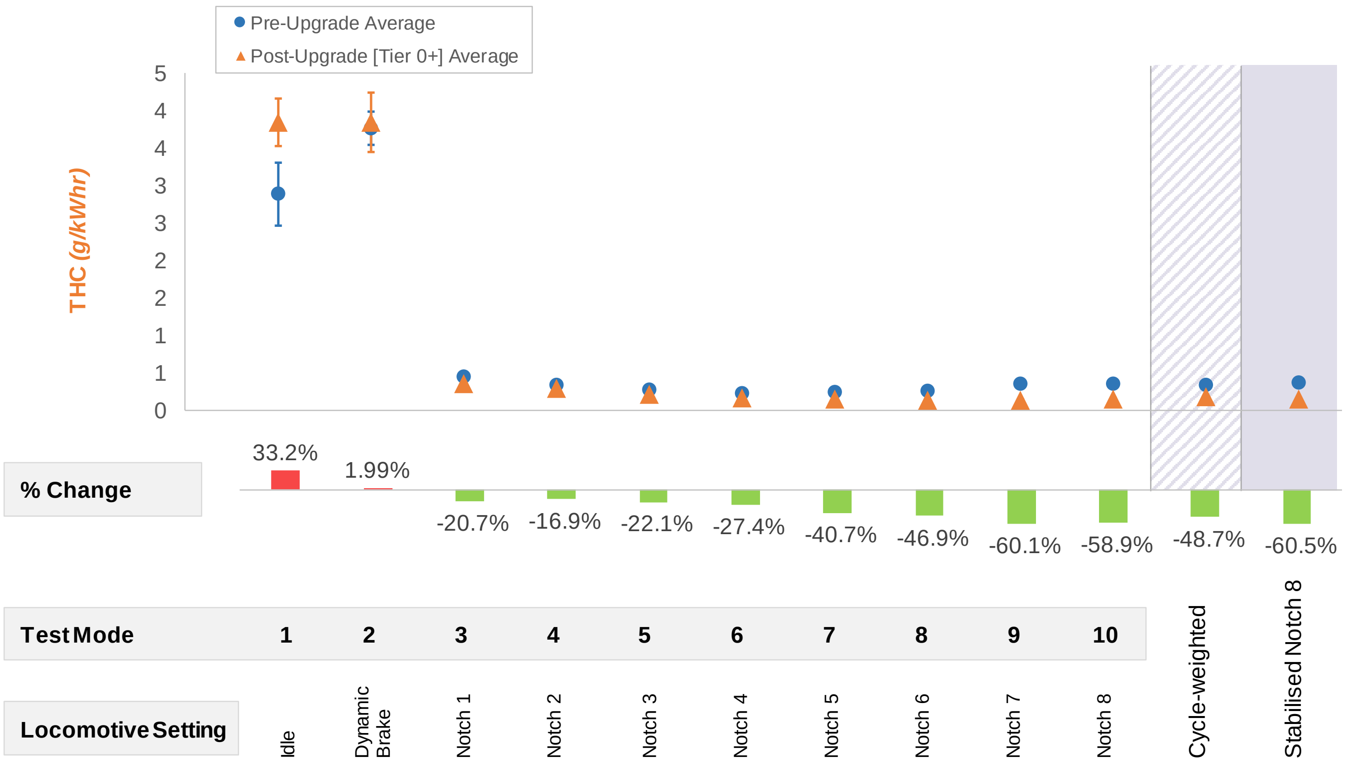


Chart 20 – Average THC Emissions Results

Operating Temperature – Exhaust

Exhaust temperature was measured in the exhaust stack extension between the gaseous and particulate matter sampling probes.

After upgrade to the Tier 0+ emissions kit, test results showed a small decrease of between 6 °C and 31 °C in exhaust temperature across all modes, as shown in Table 22 and Chart 21.

Description	Test Mode	1	2	3	4	5	6	7	8	9	10	Stabilised Notch 8
Pre-Upgrade average Temperature	(°C)	101	88	113	150	203	247	285	314	359	357	357
Post-Upgrade [Tier 0+] average Temperature	(°C)	95	81	104	141	192	235	272	305	328	329	328
Change in Temperature	(°C)	-6	-7	-9	-9	-11	-12	-13	-9	-31	-28	-29

Table 22 – Exhaust Temperature

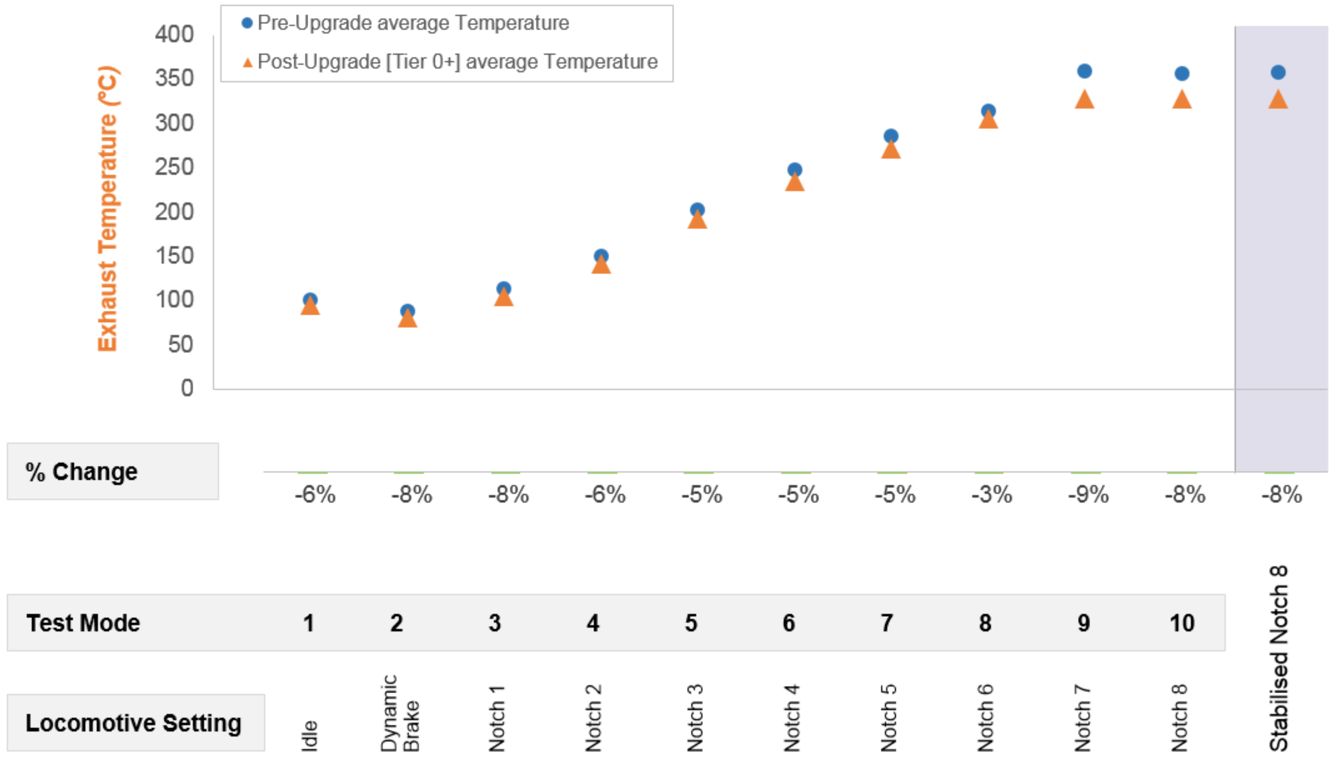


Chart 21 – Average Exhaust Temperature

Operating Temperature – Charge Air

Charge air temperature was measured from the handhole cover over cylinder 10.

Despite ambient air temperatures in the order of 10°C lower in the post Tier 0+ emissions kit testing, only small decreases to the charge air temperature were measured between 1 °C in dynamic brake and 11 °C in notch 7, as shown in Table 23 and Chart 22.

The temperature profiles for each test followed very similar paths, with the exception of post emissions upgrade test 1.

Description	Test Mode	1	2	3	4	5	6	7	8	9	10	Stabilised Notch 8
Pre-Upgrade average Temperature	(°C)	74	74	75	77	79	79	81	83	89	94	95
Post-Upgrade [Tier 0+] average Temperature	(°C)	65	72	70	74	75	74	74	74	78	89	94
Change in Temperature	(°C)	-9	-1	-5	-3	-4	-5	-7	-9	-11	-5	-1

Table 23 – Average Charge Air Temperature

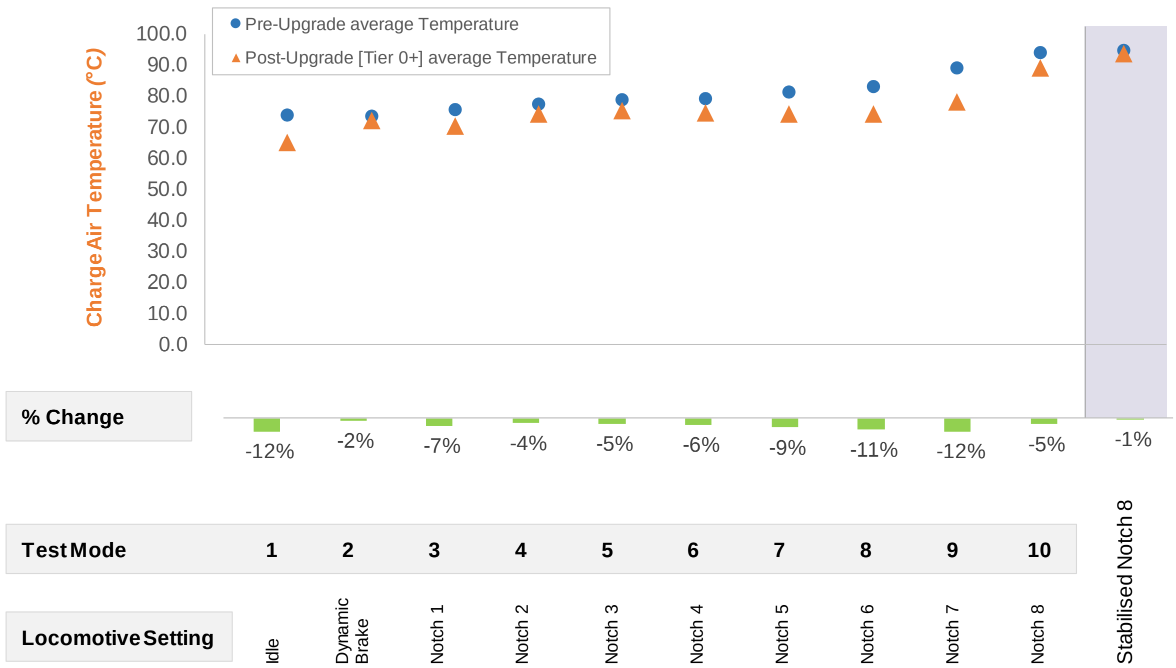


Chart 22 – Average Charge Air Temperature

Noise

A change of 2 dBA or less in broadband noise is difficult for the human ear to distinguish.

The data in Table 24 shows the noise results presented as the variation, pre upgrade to post upgrade, in maximum sound pressure level (SPL), when the locomotive is operating in idle and when operating from notch 1 to 8. The change in maximum noise levels were compared irrespective of the measurement position around the locomotive.

EPA noise regulations for new locomotives set Z-weighted noise level limits for throttle notches 1 to 8, but no Z-weighted limit applies at engine idle. Z-weighted noise levels were measured at idle on both locomotives as part of this testing, however close examination of the idle results for 9024 indicated that they were wind affected. Due to this, Z-weighted noise levels are not reported at idle for either locomotive.

In general, the noise test data showed a consistent trend in noise reduction except for idle where some small increases were measured. These are shown in Table 24.

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 dB(A). At this level, it would be difficult for the human ear to distinguish.

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

Table 24 – Noise SPL Results

APPENDICES

A. 81 CLASS SUMMARY RESULTS

Summary emissions and fuel consumption data from all tests.

Pre Upgrade Average Emissions Comparison

Description		Mode 1	Mode 2	Mode 3	Mode 4	Mode 5	Mode 6	Mode 7	Mode 8	Mode 9	Mode 10	Stabilised Notch 8
PM (g/kWhr)	Test 1	0.261	1.32	0.224	0.246	0.395	0.420	0.428	0.416	0.462	0.473	0.413
	Test 2	0.542	1.07	0.255	0.284	0.474	0.458	0.430	0.416	0.426	0.461	0.411
	% Difference	108%	-18.9%	13.9%	15.1%	19.8%	9.05%	0.331%	0.00%	-7.70%	-2.58%	-0.353%
NOx (g/kWhr)	Test 1	51.4	58.1	21.9	18.0	16.6	16.0	15.7	15.4	16.1	17.0	17.5
	Test 2	59.9	58.3	21.5	18.2	16.6	16.2	15.8	15.4	15.9	17.0	17.5
	% Difference	16.4%	0.199%	-1.67%	0.838%	0.424%	1.15%	0.918%	0.334%	-1.33%	-0.339%	-0.216%
CO2 (g/kWhr)	Test 1	2904	3176	859	786	734	715	701	694	679	678	678
	Test 2	2863	3122	864	787	734	715	701	691	675	673	673
	% Difference	-1.40%	-1.68%	0.570%	0.097%	0.016%	0.058%	0.093%	-0.403%	-0.621%	-0.631%	-0.686%
CO (g/kWhr)	Test 1	34.2	12.0	3.14	2.03	0.706	0.833	0.674	0.613	0.579	0.589	0.479
	Test 2	27.6	30.8	1.64	1.45	0.998	0.671	0.492	0.506	0.489	0.636	0.594
	% Difference	-19.2%	157%	-48.0%	-28.6%	41.3%	-19.4%	-27.0%	-17.5%	-15.7%	8.09%	24.1%
THC (g/kWhr)	Test 1	9.14	5.23	0.801	0.586	0.445	0.385	0.360	0.367	0.445	0.514	0.503
	Test 2	6.90	4.73	0.808	0.616	0.460	0.391	0.374	0.371	0.418	0.481	0.496
	% Difference	-24.5%	-9.54%	0.834%	5.15%	3.36%	1.45%	3.97%	0.844%	-6.09%	-6.46%	-1.33%

Pre Upgrade Average Fuel Consumption Comparison

Description		Mode 1	Mode 2	Mode 3	Mode 4	Mode 5	Mode 6	Mode 7	Mode 8	Mode 9	Mode 10	Stabilised Notch 8
L/hr	Test 1	14.5	65.4	55.1	90.2	179	245	309	400	538	618	617
	Test 2	13.9	64.2	54.6	89.7	178	243	307	399	533	614	613
	% Difference	-4.43%	-1.87%	-0.954%	-0.518%	-0.634%	-0.651%	-0.736%	-0.455%	-1.02%	-0.644%	-0.572%
BSFC	Test 1	955	1026	277	253	235	229	224	222	218	218	218
	Test 2	938	1019	278	253	235	229	224	221	216	216	216
	% Difference	-1.78%	-0.723%	0.436%	0.054%	0.028%	-0.087%	-0.077%	-0.640%	-0.857%	-0.754%	-0.730%

Post Upgrade [Tier 0+]

Post Upgrade [Tier 0+] Average Emissions Comparison

Description		Mode 1	Mode 2	Mode 3	Mode 4	Mode 5	Mode 6	Mode 7	Mode 8	Mode 9	Mode 10	Stabilised Notch 8
PM (g/kWhr)	Test 1	1.20	0.803	0.313	0.340	0.245	0.276	0.217	0.205	0.115	0.099	0.091
	Test 2	1.23	0.783	0.302	0.315	0.254	0.227	0.208	0.186	0.105	0.098	0.090
	% Difference	2.75%	-2.39%	-3.42%	-7.32%	3.50%	-17.7%	-4.22%	-9.69%	-8.12%	-1.62%	-1.49%
NOx (g/kWhr)	Test 1	105	44.7	12.3	9.80	9.47	8.90	8.47	8.11	9.09	8.87	8.88
	Test 2	86.4	42.7	12.5	9.90	9.58	9.08	8.47	8.07	9.14	8.91	8.99
	% Difference	-17.9%	-4.29%	1.05%	0.95%	1.15%	2.05%	0.0767%	-0.446%	0.615%	0.440%	1.30%
CO2 (g/kWhr)	Test 1	6597	4676	1039	889	758	751	719	709	682	689	690
	Test 2	5828	4466	1021	874	757	747	714	704	680	687	688
	% Difference	-11.7%	-4.49%	-1.66%	-1.68%	-0.207%	-0.507%	-0.672%	-0.691%	-0.376%	-0.358%	-0.243%
CO (g/kWhr)	Test 1	10.3	4.80	1.37	0.94	0.293	0.288	0.407	0.953	0.554	0.490	0.468
	Test 2	39.6	13.4	3.25	1.85	0.865	0.742	0.844	1.038	0.497	0.495	0.525
	% Difference	284%	180%	138%	96.7%	196%	158%	108%	8.90%	-10.3%	1.03%	12.1%
THC (g/kWhr)	Test 1	16.5	7.21	1.16	0.725	0.332	0.231	0.211	0.169	0.220	0.238	0.227
	Test 2	15.9	6.49	1.05	0.713	0.325	0.245	0.197	0.192	0.201	0.238	0.262
	% Difference	-3.87%	-9.95%	-9.51%	-1.67%	-1.99%	5.82%	-6.82%	14.1%	-8.59%	0.025%	15.5%

Post Upgrade [Tier 0+] Average Fuel Consumption Comparison

Description		Mode 1	Mode 2	Mode 3	Mode 4	Mode 5	Mode 6	Mode 7	Mode 8	Mode 9	Mode 10	Stabilised Notch 8
L/hr	Test 1	23.5	61.1	64.0	93.8	181	246	305	396	533	623	623
	Test 2	23.5	60.6	63.2	92.9	180	247	306	397	533	622	623
	% Difference	0.237%	-0.724%	-1.20%	-0.967%	-0.625%	0.645%	0.353%	0.314%	0.003%	-0.099%	0.078%
BSFC	Test 1	2141	1511	335	287	244	242	231	229	220	223	223
	Test 2	1919	1456	333	284	245	242	231	228	220	223	223
	% Difference	-10.4%	-3.61%	-0.742%	-0.961%	0.539%	0.053%	-0.136%	-0.237%	0.046%	0.053%	0.188%

Table 25 – 8113 Test 1 and Test 2 Summary

B. 90 CLASS SUMMARY RESULTS

Summary emissions and fuel consumption data from all tests.

Pre Upgrade

Pre Upgrade Average Emissions Comparison

Description		Mode 1	Mode 2	Mode 3	Mode 4	Mode 5	Mode 6	Mode 7	Mode 8	Mode 9	Mode 10	Stabilised Notch 8
PM (g/kWhr)	Test 1	0.482	0.817	0.194	0.192	0.319	0.386	0.356	0.310	0.292	0.266	0.272
	Test 2	0.673	0.970	0.192	0.193	0.360	0.349	0.350	0.335	0.302	0.294	0.305
	% Difference	**39.6%**	**18.8%**	**-1.13%**	**0.427%**	**12.9%**	**-9.70%**	**-1.71%**	**7.98%**	**3.62%**	**10.6%**	**12.0%**
NOx (g/kWhr)	Test 1	53.0	70.6	19.4	19.5	17.8	16.9	15.4	14.4	11.8	12.0	12.0
	Test 2	64.7	76.9	20.3	20.2	17.9	17.1	16.0	14.5	12.2	12.2	12.3
	% Difference	**22.1%**	**8.93%**	**4.96%**	**3.78%**	**0.495%**	**1.50%**	**3.81%**	**0.610%**	**3.97%**	**1.48%**	**2.69%**
CO2 (g/kWhr)	Test 1	2032	2976	731	681	651	648	652	652	649	639	640
	Test 2	2469	3230	743	692	661	655	657	657	655	651	650
	% Difference	**21.5%**	**8.55%**	**1.76%**	**1.70%**	**1.57%**	**1.13%**	**0.845%**	**0.814%**	**0.913%**	**1.89%**	**1.52%**
CO (g/kWhr)	Test 1	0.000	0.000	0.000	0.000	0.975	0.542	0.363	0.740	3.53	2.40	2.48
	Test 2	1.18	8.33	1.12	0.422	0.288	0.356	0.631	0.803	3.65	2.51	2.33
	% Difference	**-**	**-**	**-**	**-**	**-70.4%**	**-34.3%**	**73.8%**	**8.47%**	**3.59%**	**4.50%**	**-5.84%**
THC (g/kWhr)	Test 1	2.47	3.55	0.442	0.340	0.270	0.226	0.232	0.256	0.335	0.341	0.341
	Test 2	3.30	3.99	0.448	0.341	0.269	0.237	0.242	0.262	0.355	0.365	0.393
	% Difference	**33.6%**	**12.5%**	**1.37%**	**0.50%**	**-0.30%**	**5.09%**	**4.08%**	**2.46%**	**5.88%**	**7.02%**	**15.0%**

Pre Upgrade Average Fuel Consumption Comparison

Description		Mode 1	Mode 2	Mode 3	Mode 4	Mode 5	Mode 6	Mode 7	Mode 8	Mode 9	Mode 10	Stabilised Notch 8
L/hr	Test 1	7.04	13.1	43.9	83.0	178	246	332	406	613	726	729
	Test 2	7.37	12.7	45.1	85.0	182	249	337	411	613	735	733
	% Difference	**4.66%**	**-3.31%**	**2.59%**	**2.37%**	**2.12%**	**1.51%**	**1.30%**	**1.29%**	**-0.008%**	**1.31%**	**0.603%**
BSFC	Test 1	645	945	232	216	207	205	206	207	207	204	204
	Test 2	793	1041	239	222	211	209	210	210	211	210	209
	% Difference	**22.9%**	**10.2%**	**2.90%**	**2.70%**	**2.31%**	**1.99%**	**1.86%**	**1.77%**	**1.92%**	**2.94%**	**2.60%**

Post Upgrade [Tier 0+]

Post Upgrade [Tier 0+] Average Emissions Comparison

Description		Mode 1	Mode 2	Mode 3	Mode 4	Mode 5	Mode 6	Mode 7	Mode 8	Mode 9	Mode 10	Stabilised Notch 8
PM (g/kWhr)	Test 1	0.630	0.666	0.106	0.092	0.103	0.088	0.097	0.100	0.146	0.130	0.125
	Test 2	0.405	0.617	0.108	0.093	0.107	0.091	0.104	0.102	0.137	0.117	0.122
	% Difference	**-35.8%**	**-7.24%**	**1.84%**	**0.99%**	**3.60%**	**3.12%**	**7.15%**	**2.11%**	**-6.72%**	**-9.58%**	**-2.89%**
NOx (g/kWhr)	Test 1	75.0	69.3	14.5	14.0	12.8	11.7	10.6	9.66	8.49	8.09	8.24
	Test 2	72.4	63.4	14.3	14.0	12.8	11.6	10.7	9.76	8.68	8.23	8.25
	% Difference	**-3.47%**	**-8.48%**	**-0.886%**	**-0.158%**	**-0.075%**	**-1.57%**	**1.43%**	**1.03%**	**2.21%**	**1.72%**	**0.084%**
CO2 (g/kWhr)	Test 1	3682	4191	801	710	670	655	655	656	646	650	650
	Test 2	3534	3812	803	713	670	656	656	659	647	650	649
	% Difference	**-4.03%**	**-9.03%**	**0.222%**	**0.543%**	**0.073%**	**0.105%**	**0.179%**	**0.412%**	**0.106%**	**0.092%**	**-0.140%**
CO (g/kWhr)	Test 1	0	0	0	0	0	0	0.041	0.236	1.037	0.687	0.662
	Test 2	0	0	0	0	0	0	0.000	0.025	1.579	0.808	0.683
	% Difference	**-**	**-**	**-**	**-**	**-**	**-**	**-**	**-89.6%**	**52.3%**	**17.5%**	**3.19%**
THC (g/kWhr)	Test 1	4.16	4.24	0.363	0.283	0.209	0.169	0.145	0.139	0.142	0.157	0.155
	Test 2	3.53	3.45	0.342	0.283	0.211	0.167	0.136	0.137	0.133	0.134	0.135
	% Difference	**-15.2%**	**-18.6%**	**-6.01%**	**-0.32%**	**1.05%**	**-1.00%**	**-6.54%**	**-1.63%**	**-6.11%**	**-14.6%**	**-13.2%**

Post Upgrade [Tier 0+] Average Fuel Consumption Comparison

Description		Mode 1	Mode 2	Mode 3	Mode 4	Mode 5	Mode 6	Mode 7	Mode 8	Mode 9	Mode 10	Stabilised Notch 8
L/hr	Test 1	11.8	17.6	48.9	87.6	185	251	337	413	628	736	737
	Test 2	11.8	17.5	48.6	87.4	185	250	337	412	627	735	738
	% Difference	**0.000%**	**-0.124%**	**-0.682%**	**-0.202%**	**-0.367%**	**-0.229%**	**-0.195%**	**-0.102%**	**-0.055%**	**-0.100%**	**0.110%**
BSFC	Test 1	1185	1349	258	228	215	210	210	211	208	210	210
	Test 2	1132	1222	258	229	215	210	211	211	208	210	209
	% Difference	**-4.48%**	**-9.41%**	**0.064%**	**0.383%**	**0.000%**	**0.015%**	**0.043%**	**0.271%**	**0.100%**	**0.000%**	**-0.244%**

Table 26 – 9024 Test 1 and Test 2 Summary

C. 8113 RPM DATA

Engine RPM hunting was observed on 8113 in the post emissions kit configuration. Chart 23 shows an RPM comparison to the pre-upgrade test. The large variation in rpm can be seen in the post upgrade test (orange data). The rpm hunting was observed in test modes 1, 3 and 4.

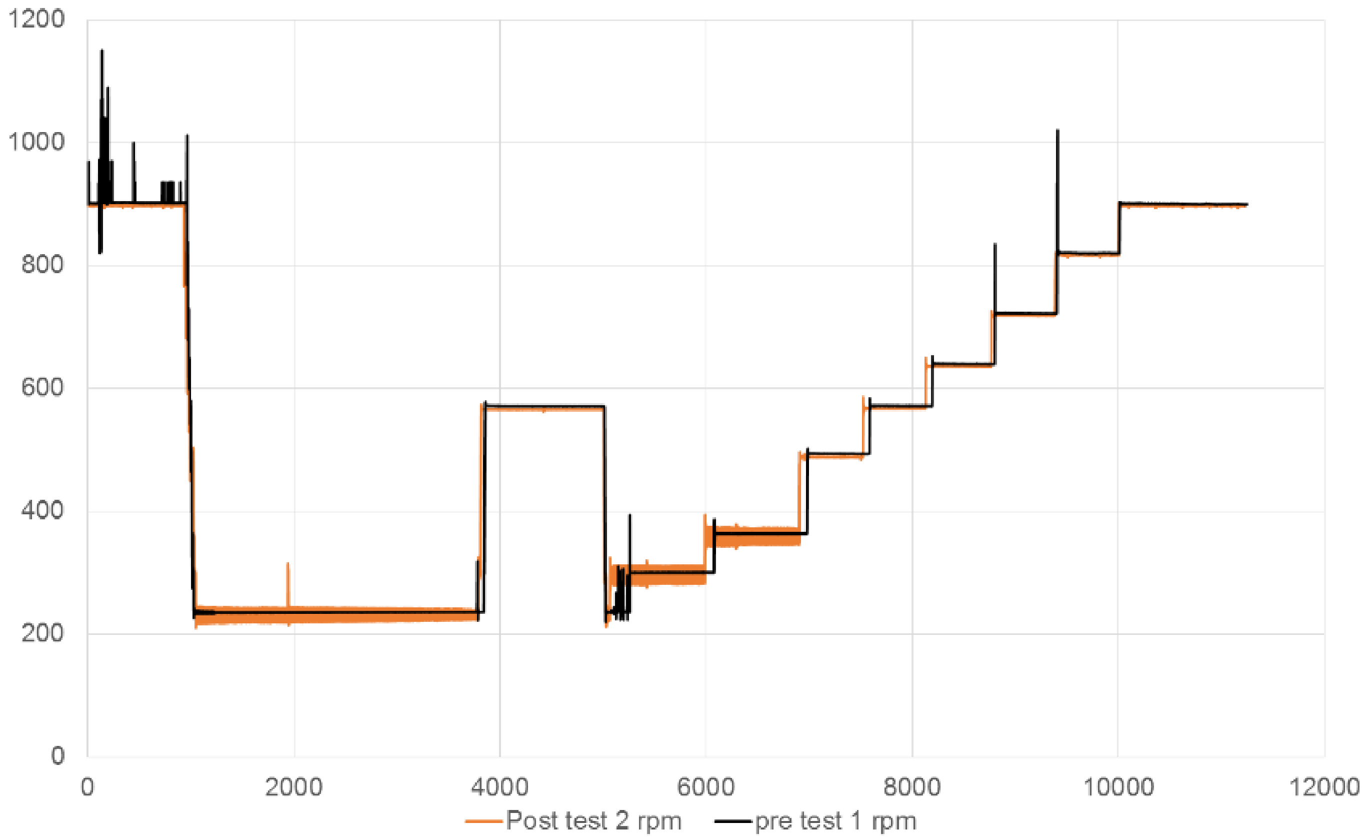


Chart 23 – 8113 rpm Data Chart

D. CORRECTION FACTORS

This section outlines key calculations and correction factors applied to measurement values that have not been specified elsewhere within this report.

- No thermophoresis particulate loss correction has been applied.
- Dry/Wet correction of raw emission concentrations have been performed as per ISO 16183.
- Brake Specific Fuel Consumption was corrected according to equations in Appendix F.
- Fuel properties applied for calculations and data analysis are shown in Figure 16.
- Fuel consumption corrected for density and calorific value for each test. Test results of fuel sample analysis are shown in Table 27.

Post Processor Fuel Properties				
H:C	1.85		Mass fraction H	13.30
C:C	1.00		Mass fraction C	86.60
S:C	0.0		Mass fraction S	0.0
N:C	0.0		Mass fraction N	0.0
O:C	0.0		Mass fraction O	0.0

Figure 16 – Post Processing Fuel Properties

8113	Density	Calorific Value
	kg/L	MJ/kg
Pre Upgrade Test 1	0.8336	45.89
Pre Upgrade Test 2	0.8336	45.89
Post Upgrade [Tier 0+] Test 1	0.8332	45.7
Post Upgrade [Tier 0+] Test 2	0.8332	45.7

9024	Density	Calorific Value
	kg/L	MJ/kg
Pre Upgrade Test 1	0.8321	45.37
Pre Upgrade Test 2	0.8328	45.915
Post Upgrade [Tier 0+] Test 1	0.8412	45.85
Post Upgrade [Tier 0+] Test 2	0.8412	45.85

Table 27 – Fuel Test Results

E. VARIATIONS TO CFR 40 1065

Testing and data analysis complied with 40 CFR part 1065 except for the following variations:

Item	CFR Specification	Variation
NO_2 span gas	1% accuracy	Within 2%
PM Dilution Ratio	Proportional	Constant dilution ratio of 5 applied
PM PEMS	40 CFR Part 1065 equipment specification	The PM PEM system is designed to exceed all of the latest in-field test requirements of CFR 1065 subpart J and meets the accuracy requirements of 1065 engine emissions testing.

Table 28 – Variations to 40 CFR Part 1065

F. BSFC CORRECTIONS

Fuel rate was measured by temperature corrected volumetric flow meters on the supply and return fuel lines with fuel consumption being the difference between the two flow rates.

1. Fuel volumetric flow rate is measured as FR_{raw} in litres per hour for each flow meter
2. Fuel rate for each flow meter is corrected to 15.0 °C and according to the fuel meter calibration factors, applied internally within the BEM 500 module.
3. Net fuel rate is determined as the difference between the two flow meters:
   $$FR_{Net}(l/hr) = FR_{Corr\_Feed} - FR_{Corr\_Return}$$
4. Fuel rate is converted to mass flow rate using density of test fuel as determined by analytical laboratory
   $$FR_{MassFlow}(kg/hr) = FR_{Net}(l/hr) \times Fuel\ Density_{15^\circ}(kg/l)$$
5. Observed power is taken as measured shaft power (determined using assumed generator efficiency as specified by Downer) plus the auxiliary loads (fans etc); BHP_{obs}
6. Power air temperature correction factor a is calculated as:
   $$a = -0.0004830508 \times Ambient\ Temp(^\circ F) + 1.028983051$$
7. Power atmospheric pressure correction factor b is calculated as:
   $$b = 0.0023141891 \times P_{atmospheric}(''Hg) + 0.93321251$$
8. Fuel HHV correction factor z is calculated as:
   $$z = \frac{HHV_{Test\ Fuel}}{HHV_{Reference\ Fuel}}$$
   where the $HHV_{Reference\ Fuel}$ is taken as 19350 BTU/lb (45.008 MJ/kg)
9. Brake specific fuel consumption, corrected for all factors is calculated as:
   $$BSFC_{Corr} = \frac{FR_{Net} \times z}{\left(\frac{BHP_{obs}}{a \cdot b}\right)} = \frac{FR_{Net}}{(BHP_{obs})} \cdot a \cdot b \cdot z$$

G. PEMS OVERVIEW

The AVL Gaseous PEMS meets instrumentation requirements for laboratory testing as specified in 40 CFR part 1065 subpart C, as well as in-field testing requirements of 40 CFR 1065 subpart J.

The AVL PM PEMS meets the latest in-field test requirements of 40 CFR 1065 subpart J and meets the accuracy requirements for laboratory testing specified in 40 CFR 1065.

The PM PEM System allows time resolved (second by second) PM emissions data from its real-time photo acoustic sensor measurement in conjunction with the gravimetric filter PM mass.

Gas PEMS

All analyzers are mounted inside temperature controlled enclosures to ensure stable conditions and a high accuracy even at changing ambient conditions. Exhaust gas flows at a rate of approximately 3.5 L/min through the 191°C temperature controlled sample line to the analysers. This prevents unaccountable losses of HC and NO_2 through condensation forming in the sample line. For each stage of testing, ABMARC used the same span gases to ensure repeatability was achieved across gaseous emissions.

PM PEMS

The Gravimetric Filter Module provides the dilution air and draws the diluted exhaust gas from the dilution cell, mounted just after the sample probe, through a PM Filter and to the photo-acoustic measurement cell, providing time resolved (second by second) data. The device offers the choice between constant or proportional dilution. A constant dilution ratio of 5 was used for all testing. Ambient air is dried with a water separator and cleaned with a HEPA and carbon filters for dilution air, to remove any contaminants.

Attribute	CFR 40 Part 1065 requirement		AVL PEMS & Fuel Flowmeter	
	Accuracy	Repeatability	Accuracy	Repeatability
Fuel flow (combined)	± 2% pt	± 1% pt	± 0.2%	± 0.02%
	± 1.5% of max	± 0.75% of max		
CO/CO_2	± 2%	± 1%	± 2%	± 1%
Hydrocarbons	± 2%	± 1%	± 2%	± 0.5%
NOx (NO_2/NO)	± 2%	± 1%	± 2%	± 0.5%
PM (Gravimetric)	See 1065.790 / 2%	0.5 micro grams / 1%	Satisfied	Satisfied

Gas Analyser Drift Specifications
THC: Heated FID <1.5ppmC1/8hrs
NO/NO_2: NDUV 2ppm/8hrs
CO: NDIR 20ppm/8hrs
CO_2: NDIR 0.1 vol.%/8hrs

PM Analyser Specifications
Raw sample rate: 6 LPM over filter.
Face velocity: 45cm/sec
PM Filters: 47mm TX40

Gas PEMS Module

PM PEMS Modules

PEMS are used for US EPA heavy-duty in-use testing (HDIUT), in-service conformity testing (ISC) and during the development of engines and exhaust after treatment systems.

The combination of two PM measurement principles (gravimetric and photo-acoustic) were developed to meet US and EU in-use requirements for time resolved measurements. Gravimetric measurement delivers a single value for an entire test. The time-resolved particulate (PM) emissions are calculated by weighing the loaded gravimetric filter after the end of the test and using the time resolved soot signal and the exhaust mass flow as inputs. This enables second by second PM data to be captured during testing.

Gas Analysers

Heated Flame Ionisation Detector (FID)

The AVL Gas PEMS uses a heated FID analyzer for measuring the THC concentrations.
The flame ionization detector measures hydrocarbons through the ionization of carbon atoms in organic compounds when burned in a hydrogen flame. A supply of burner air free of hydrocarbons maintains the flame. Ionized particles are produced using the hydrogen flame to burn hydrocarbons present in the sample gas. This generates an ionization current between the two electrode shells that is directly proportional to the number of organically bound carbon atoms present within the sample gas. This ionization current is amplified electrically and converted into a calibrated voltage signal for data acquisition.

Ultra Violet (UV)

The NO and NO_2 measurement is conducted simultaneously and directly (without the need of a NO_2 to NO converter) using the UV analyzer. The UV Analyser is a dual-component UV photometer with high zero-point and end-point stability. The system reads NO and NO_2 separately, which are then combined to provide NO_x readings.

Non-Dispersive Infra-Red (NDIR)

CO and CO_2 measurements are conducted with the NDIR analyser, specially optimized for high accuracy and resolution of the CO channel at low concentrations. Qualitative and quantitative molecular analysis is performed by infrared spectrometry. The analyser is located in a temperature controlled (±0.5 °C) compartment that is maintained even during rapid changes in ambient temperature. Under these conditions, the NDIR provides stable signals with little to no drift over hours of operation.

Heated Gas Transfer Line

PM Analysers

PM Dilution Cell and Transfer Line

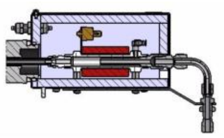
The dilution and exhaust transfer unit consists of the dilution cell at the sample probe, which receives a dilution air supply via an external hose from the Gravimetric Filter Module (GFM). The dilution cell feeds directly into the 52 °C heated transfer tube connected to the GFM.
A dilution ratio of 5 was used for all tests.

Photo-Acoustic Sensor

The flow rate through the photo-acoustic sensor is approximately 2L/min. Time resolved PM emissions are determined by scaling the real-time soot signal to the gravimetric filter reference. The exhaust sample is exposed to modulated light which is absorbed by the soot particles in the exhaust causing periodic warming and cooling of the particles. The resulting expansion and contraction of the carrier gas generates a sound wave that is detected by microphones. Clean air produces no signal. When the air is loaded with soot or exhaust gas, the signal rises proportionally to the concentration of soot in the measurement volume. The soot sensor does not respond to the volatile fractions of the PM.

Gravimetric Filter Module

Filter loading on the PM filter is monitored to avoid overloading. High-performance filter elements are used for filtering particulates. A filter efficiency of 99.995 % is specified for filter elements at the nominal flow rate of 5 L/min through the filter.



PM Dilution Cell

PM and Gas PEMS set up prior to the locomotive arriving

H. EMD TIER 0+ UPGRADE KIT BROCHURES

Manufacturer information on the Tier 0+ emissions upgrade kit. See the following brochures over page.

ELECTRO-MOTIVE

LOCOMOTIVE PRODUCTS

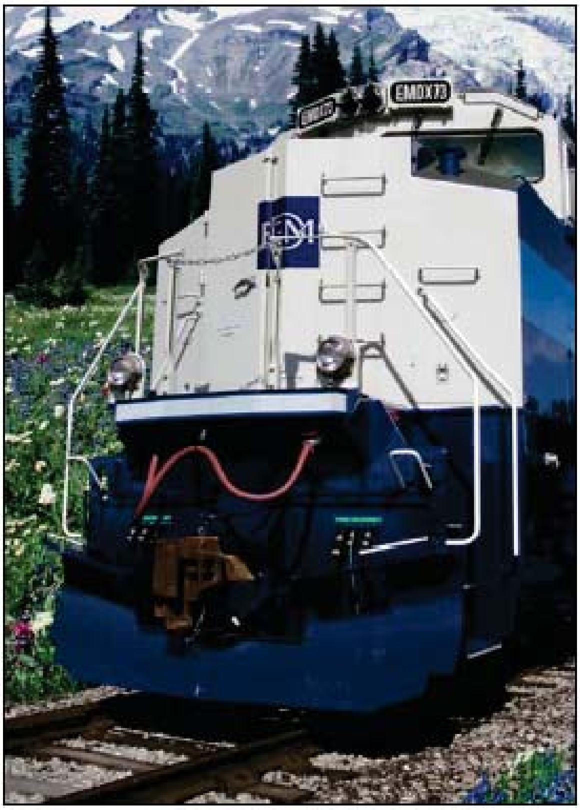
Certified Emissions Kits for EMD Locomotives

Electro-Motive Diesel has provided emissions solutions for its engines for over 25 years and continues to lead the industry in emissions compliance. One of the EPA's guiding principles for the 40 CFR Part 1033 rule was to achieve sizeable reductions in emissions as early as possible. EMD has met this challenge. Its skilled emissions research team has used extensive iterative testing to develop the most advanced emission solutions for locomotive applications using EMD 645 and 710 engines.

System Integration
EMD's complete OEM system knowledge allows for the most reliable and fuel efficient emission kits. Meeting emissions is not a piece-part activity but a finely-tuned balance between emissions compliance and fuel efficiency. Reverse engineered parts lack the proven reliability, systems integration, and support that only the OEM can provide.

EPA Compliance
EPA 40 CFR Part 1033 requires locomotive engines, including all EMD models originally manufactured in 1973 or later, to meet strict particulate matter and NOx standards when overhauled. Installing an EPA certified EMD emissions kit ensures full regulatory compliance with Part 1033 requirements.

Emissions Kit Contents
EMD emissions kits include the following components:
- UL Power Assemblies
- OEM Emission Specification Fuel Injectors
- Aftercoolers and Plumbing (as needed)
- Software Upgrade (as required)
- Oil Separator and Fittings (as needed)
- Engine Emission Label
- Locomotive Emission Label
- Installation Instructions
- Kit Registration Card



EMD Emissions Solution Benefits
- OEM engineered, designed, and tested upgrades, which provide particulate matter and NOx reductions.
- Cuts lube oil consumption significantly.
- Fuel consumption is reduced or maintained at previous levels.
- Application of the kits per EMD Maintenance Instructions achieves full compliance with EPA regulations per 40 CFR Part 1033.

EMD Emissions Kit Availability
Kits are available for all EMD Model 645 and 710 locomotive engines.

The EMD OEM Advantage

EMD replacement parts are the result of extensive development and testing in the same engineering facilities where new EMD engines are designed, built, and tested. This OEM focus ensures the same performance, reliability, and durability for which EMD engines are legendary.

- OEM fuel injectors are fully remanufactured to precise internal specs vs. partially rebuilt retrofits. This ensures sustained fuel economy and emissions performance over their full useful life and avoids the operating penalties and expense of non-compliance.

- Power Assemblies and all emissions critical components are the result of fully integrated OEM design vs. partial substitution of non-optimized third party components.

- Engines and critical subsystems are carefully calibrated to optimize performance, reduce emissions, and minimize fuel consumption.

- EMD emissions kits require no cumbersome catalyst retrofits which can suffer from excessive backpressure, ash fouling, and extreme temperatures.

- EMD has stood solidly behind its products since 1922. As the EPA certificate holder for its engines and kits, their in-use emission compliance and engine performance is covered by the EMD OEM factory warranty.

ELECTRO MOTIVE®

ELECTRO MOTIVE

LOCOMOTIVE PRODUCTS

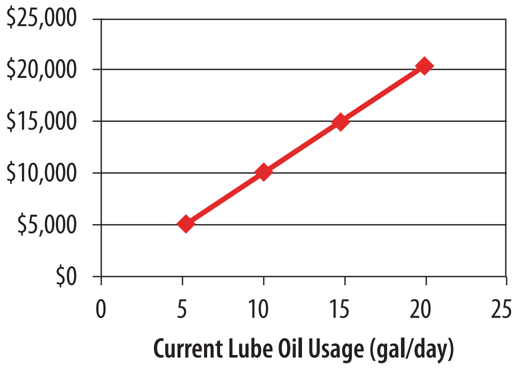
New Ultra Low Lube Oil 645 & 710 Power Assemblies

- ✓ Reduce lube oil consumption by 50%
- ✓ Eliminate fire face cracking
- ✓ Reduce valve and valve seat wear for improved reliability and performance
- ✓ Minimize gasket failures before overhaul

Electro-Motive introduces the newly designed UL™ power assembly that enhances the reliability of its current power assemblies with new low oil consumption features. EMD has combined its hardened upper bore liner with a specially engineered bore profile, and exclusive ring design, to achieve the lowest oil consumption in the industry.

This proprietary system results in up to 50% savings in engine lube oil consumption compared to standard power assemblies.

Annual Lube Oil Savings Per Engine



*Based on a 50% Lube savings and $6.00/gal lube

Maximum Life Cylinder Head

The UL power assembly includes the new Maximum Life™ cylinder head. The ML™ cylinder head is the most advanced cylinder head produced to date, providing unmatched reliability and durability for the most demanding service.

The new ML head casting builds upon the industry leading Diamond 6™ head with improvements in both coolant flow and structural design. Hardened valve seats provide the most durable valve sealing surface which reduces wear and improves valve sealing.

Flat Head Exhaust Valve

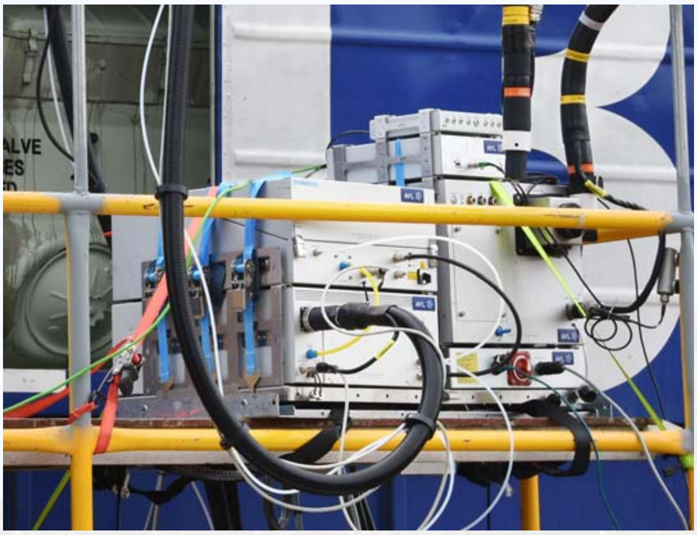
This design improves thermal fatigue life, reduces stresses and deflection, increasing valve and valve seat life. This design also includes a hardened stem tip that extends below the contact area of the keepers resulting in a reduction of dropped valves.

Valve Rotators

Valve rotators induce a controlled spin on the valves to reduce uneven wear on the valve and the valve seat. This improves valve sealing and reduces the occurrence of hard starting.

UL power assemblies are available as new or Utex for all 645 and 710 engine models.

ELECTRO MOTIVE



Diesel Locomotive Emissions Upgrade Kit Demonstration Project

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