



Euro Stage V – NRMM In-Service Monitoring of Emissions Services

EU2016/1628 amendment EU2022/2387

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HORIBA MIRA: Key Facts



- Established 1946 by UK Government and Industry.
- Leading vehicle, test and systems engineering consultancy
- 600+ Staff; 75% Engineers and Technicians
- 842 acre (336 ha) site
- 62 mile (100km) proving ground facility
- 38 major laboratory facilities
- Has established Technology Park attracting global businesses
- UK national centre of excellence in transport sector R&D
- Acquired by HORIBA in 2015 and integrated with their Automotive business



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Overview of MIRA Capabilities within Emissions testing



Overview of MIRA Capabilities within Emissions testing

Real World Emissions

- ❑ Dedicated Real world propulsion centre team and workshop facilities
- ❑ Equipment: HORIBA OBS-ONE PEMS for Gaseous & Particle number emissions, HORIBA Rugged enclosure for heavy-duty and Non-road mobile machinery (NRMM) testing
- ❑ Experience delivering legislative PEMS testing for Light-duty, Heavy-duty and NRMM markets
- ❑ Offer Development, Certification and In-service PEMS testing
- ❑ Offer test solutions both at MIRA (UK) and at customer sites or proving grounds worldwide



Laboratory Based

Vehicle Propulsion Centre (VPC)

- ❑ WLTP compliant 4WD chassis dynamometer
- ❑ Laboratory temperature replication of -20°C - 35°C
- ❑ Gradient simulation capability
- ❑ Altitude simulation capability (MEDAS)
- ❑ RDE cycle replication (including with robot driver)



Powertrain Propulsion Centre (PPC)

- ❑ Steady-state and transient Powertrain dynamometer test cells
- ❑ High speed, high torque dynos (470kW, 1000Nm, 10000rpm)
- ❑ Low speed, high torque dynos (220kW, 3200Nm, 3200rpm)
- ❑ Environmental emulation testing (temperature, altitude and humidity)



Hardware requirements

For NRMM In-service monitoring, test measurements will comply with the requirements of Appendix 1, EU 2017/655. HORIBA OBS-ONE GS12 PEMS comprises of the following measurements;

Analyzers

- Gaseous exhaust emissions: CO, CO₂, NO, NO_x [ppm, %vol, g/s, total g] (& calculated NO₂)
- Total Hydrocarbons: THC [ppmC, g/s, total g]
- 4 or 6 metre sampling line

Exhaust

- Exhaust volume flow and mass flow [m³/min, g/s]
- Exhaust temperature (tailpipe) [°C]
- Exhaust pressure (tailpipe) [kPa]
- EFM range A to G type (32-127mm OD [0 – 45m³/min])

Fuel

- Fuel consumption from carbon balance [g/s, total g]

Ambient

- Ambient temperature [°C]
- Ambient relative humidity [%RH]
- Barometric pressure [kPa]

Location

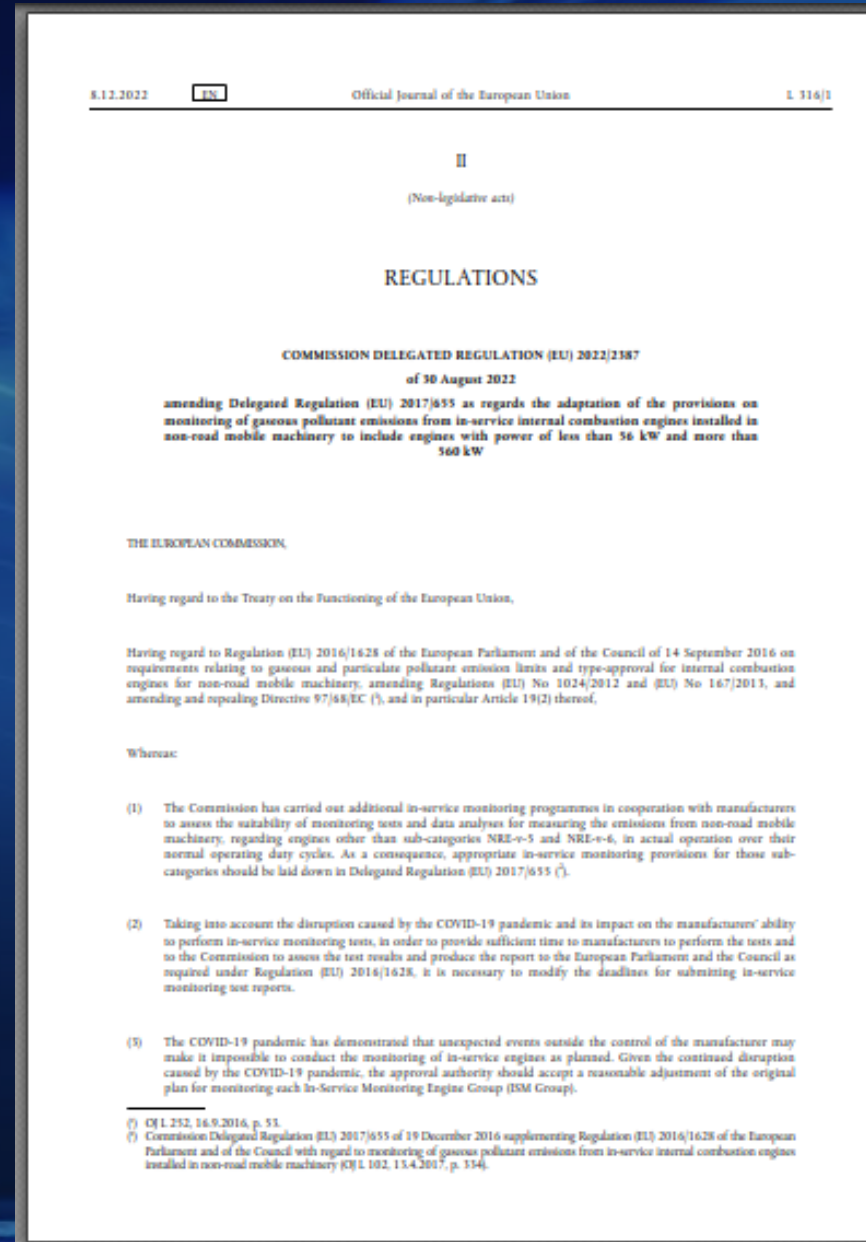
- GPS [Vehicle speed (km/h), Position; Latitude and Longitude (degrees), Altitude (m)]

Vehicle

- Vehicle CAN data via standard protocols (ISO27145, ISO15765-4 or J1939); up to 64 channel capability. (ECU data must comply with minimum requirements in Appendix 7 of EU 2017/655.)



Overview of NRMM EU Stage V In-Service Monitoring Regulation



EU Stage V NRMM ISM Emissions Regulation



EU 2016/1628. Supplementing this is EU 2017/655 (Amended by 2022/2387).

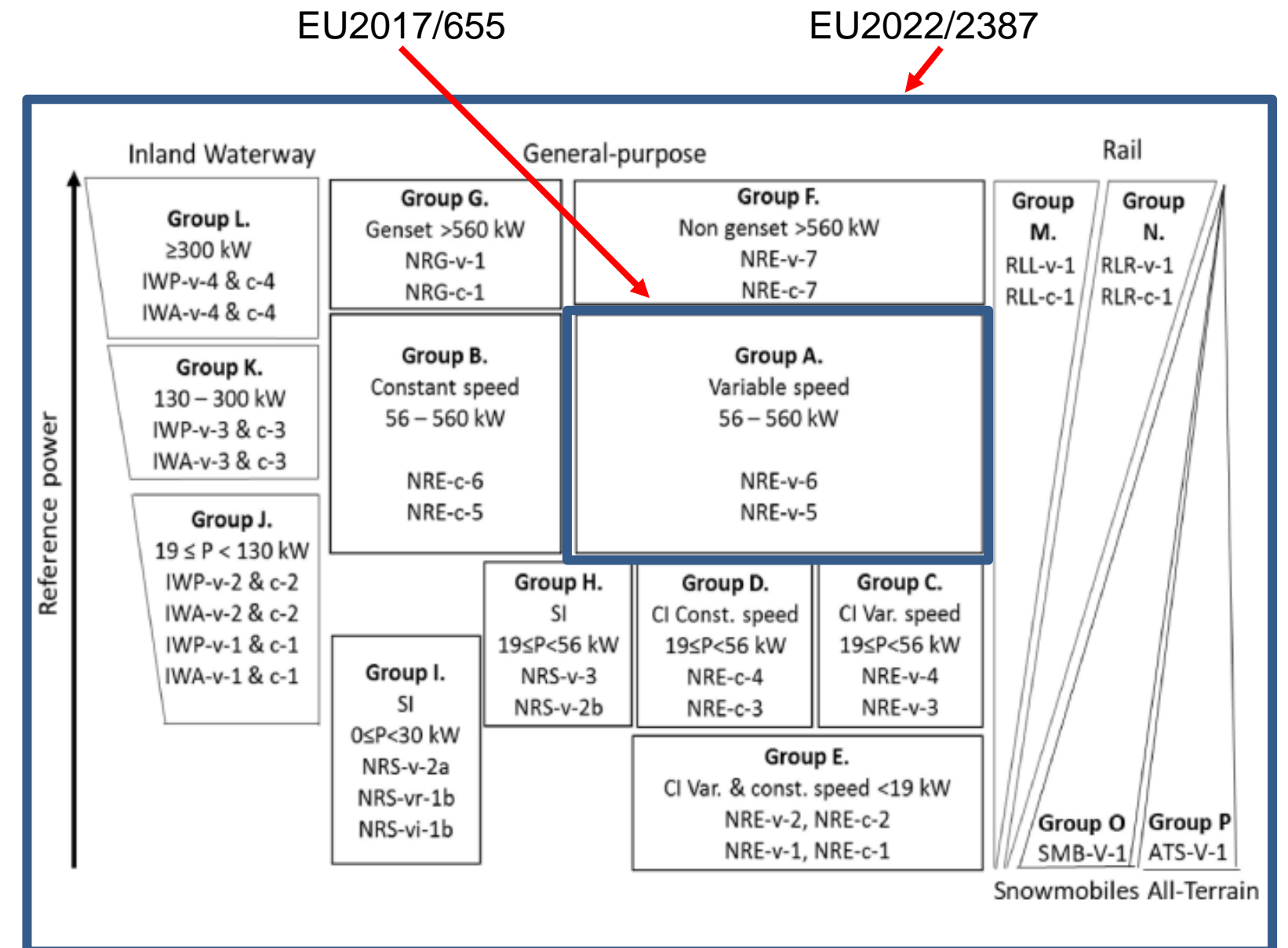
EU Stage V regulation mandates the requirement for the **Engine manufacturer** to perform In-service monitoring (ISM) of emissions – Not the machine manufacturer!

Requirement for In-Service monitoring (ISM) of Emissions for NRMM first implemented in EU2017/655 (December 2016) applicable to Group A (NRE-v-5 & NRE-v-6) subcategory machines (Non-road equipment with an engine power rating between 56-130kW and 130kW-560kW respectively).

EU2017/655 Regulation for ISM recently amended by EU2022/2387 (December 2022) extending the deadline for ISM due to the impacts of Covid-19 and increasing the scope of machine types and engine power ratings required to do ISM (<56kW and >560kW)

Testing is completed during the machines usual operation, else the Engine manufacturer can perform a 'representative duty cycle' which is agreed with their type approval authority prior to test commencement

Emissions to be monitored are gaseous emissions CO, CO₂, NO_x and THC



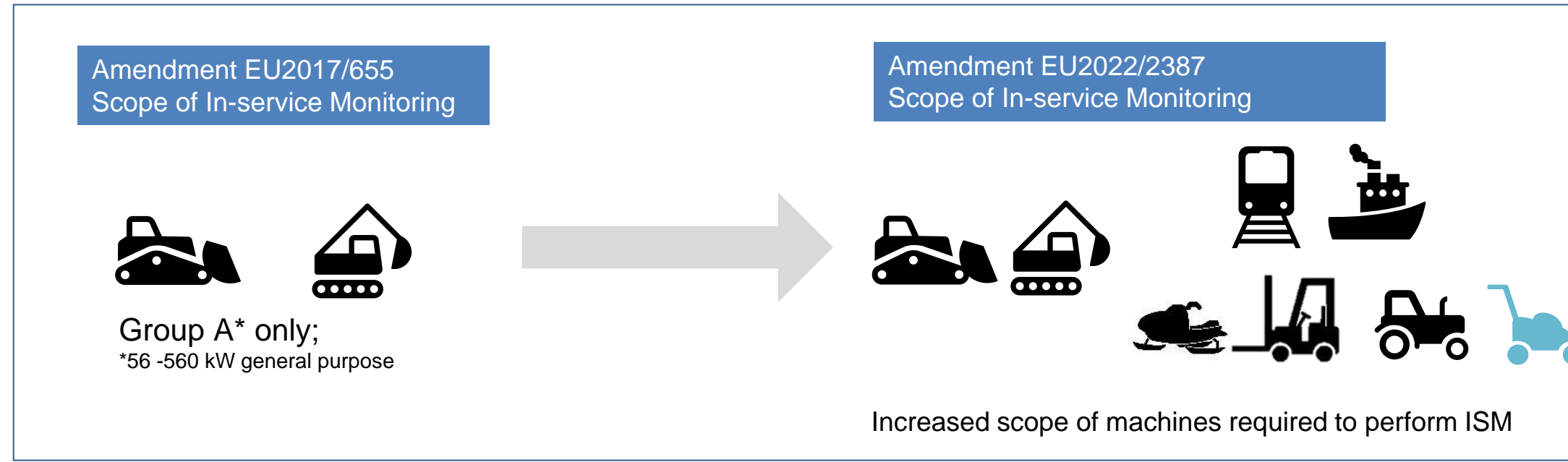
Machines required for ISM testing

EU 2016/1628. Supplementing this is EU 2017/655 (Amended by 2022/2387).



ISM Group	Engine (sub) categories	Engine Power rating	Description	Testing option
A	NRE-v-5, NRE-v-6	56kW-130kW, 130kW-560kW	Non-road equipment variable speed engine	Engine in machine only ISM test
B	NRE-c-5, NRE-c-6	56kW-130kW, 130kW-560kW	Non-road equipment constant speed engine	Engine in machine only ISM test
C	NRE-v-3, NRE-v-4	19kW-37kW, 37kW – 56kW	Non-road equipment variable speed engine	Engine in machine only ISM test
D	NRE-c-3, NRE-c-4	19kW-37kW, 37kW – 56kW	Non-road equipment constant speed engine	Engine in machine only ISM test
E	NRE-v-1, NRE-c-1 NRE-v-2, NRE-c-2	0kW-8kW 8kW-19kW	Non-road equipment variable speed engine, constant speed engine Non-road equipment variable speed engine, constant speed engine	Engine in machine or engine dyno ISM test
F	NRE-v-7, NRE-c-7	>560kW	Non-road equipment variable speed engine, constant speed engine	Engine in machine only ISM test
G	NRG-v-1, NRG-c-1	>560kW	Non-road equipment variable speed engine for generating set, constant speed engine for generating set	Engine in machine only ISM test
H	NRS-v-2b, NRS-v-3	19kW-30kW, 30-56kW	SI engines with a swept volume greater than 1L that are not included in category NRSh, SI engines that are not included in category NRSh	Engine in machine only ISM test
I	NRS-vr-1b, NRS-vi-1b NRS-v-2a	0kW-19kW 19kW-30kW	SI engines below 19 kW exclusively for use in hand-held machinery with an engine volume greater than 0.225L SI engines with a swept volume less than 1L that are not included in category NRSh;	Engine in machine or engine dyno ISM test
J	IWP-v-1, IWP-c-1 IWA-v-1, IWA-c-1 IWP-v-2, IWP-c-2 IWA-v-2, IWA-c-2	19kW-75kW 19kW-75kW 75kW-130kW 75kW-130kW	IWP -Engines used for direct or indirect propulsion of inland waterway vessels IWA - Auxiliary engines for use in inland waterway vessels	Engine in machine only ISM test
K	IWP-v-3, IWP-c-3 IWA-v-3, IWA-c-3	130kW-300kW 130kW-300kW	IWP -Engines used for direct or indirect propulsion of inland waterway vessels IWA - Auxiliary engines for use in inland waterway vessels	Engine in machine only ISM test
L	IWP-v-4, IWP-c-4 IWA-v-4, IWA-c-4	>300kW >300kW	IWP -Engines used for direct or indirect propulsion of inland waterway vessels IWA - Auxiliary engines for use in inland waterway vessels	Engine in machine only ISM test
M	RLL-v-1, RLL-c-1	>0kW	Engines for the propulsion of railway locomotives	Engine in machine only ISM test
N	RLR-v-1, RLR-c-1	>0kW	Engines for the propulsion of railcars	Engine in machine only ISM test
O	SMB-v-1	>0kW	SI engines used in snowmobiles	Engine in machine or engine dyno ISM test
P	ATS-v-1	>0kW	SI engines used in all terrain and side-by-side vehicles	Engine in machine or engine dyno ISM test

Machines required for ISM testing



EU Stage V NRMM ISM Emissions Regulation



Testing Scheme options and deadlines

ISM Group	Engines per year method	EDP method	Deadline for testing	A	B	EDP
A	9 for 4 years	9 engines <a% EDP 9 engines >b% EDP	26 th December 2024 26 th December 2026	20% (56-130kW) 30% (130-560kW)	55% (56-130kW) 70% (130-560kW)	8000hrs
B, F, G, J, K, L, M, N	Number of engines for testing dependant upon total EU engine families produced within the ISM group and combined annual production – next slide	Number of engines for testing dependant upon total EU engine families produced within the ISM group and combined annual production – next slide	Low EDP - 26 th December 2024 High EDP - 26 th December 2026 Or first test must be completed within: - 12 months after first engine was installed within the NRMM - 18 months after starting the production of an approved engine type or family within the ISM group	10% (<56kW) 20% (56-130kW) 30% (>130kW)	10% (<56kW) 20% (56-130kW) 30% (>130kW)	Dependant on engine category – defined within (EU2016/1628 Annex V) Emission Durability periods
C, D, E, H, I	Number of engines for testing dependant upon total EU engine families produced within the ISM group and combined annual production – next slide	Number of engines for testing dependant upon total EU engine families produced within the ISM group and combined annual production – next slide	26 th December 2024 26 th December 2026	Testing based on age (Figure 2) – next slide	Testing based on age (Figure 2) – next slide	Dependant on engine category – defined within (EU2016/1628 Annex V) Emission Durability periods
O, P	Number of engines for testing dependant upon total EU engine families produced within the ISM group and combined annual production – next slide	Number of engines for testing dependant upon total EU engine families produced within the ISM group and combined annual production – next slide	Low EDP - 26 th December 2024 High EDP - 26 th December 2026	O – 1600km or 20% P – 1350km <0.1L 2700km >0.1L or 10%	O – 4400km or 55% P – 5400km <0.1L 10800km >0.1L Or 40%	O – 400hrs P – 500hrs <0.1L 1000hrs >0.1L

Alternative requirements for small volume manufacturers

EU Stage V NRMM ISM – Test Methodologies

In-machine ISM Engine test

- ❑ Preferred option and is applicable option for all ISM engine categories.

Test preparation

PEMS quality checks, machine inspection and suitability check, engine diagnostic check, fluid sampling, fuelling, pre arrival information request to engine manufacturer

PEMS Installation

Fabrication of exhaust to flowtube adaptor, PEMS mounting (on or off machine)

Test setup

PEMS test setup, regulation setup, machine information setup, flowtube setup, ECU data logging

ISM test

Test to be completed during machines typical operation or using a 'representative duty cycle'. PEMS measurement of gaseous emissions, ambient conditions, location data and ECU data (where applicable)

Data processing and reporting

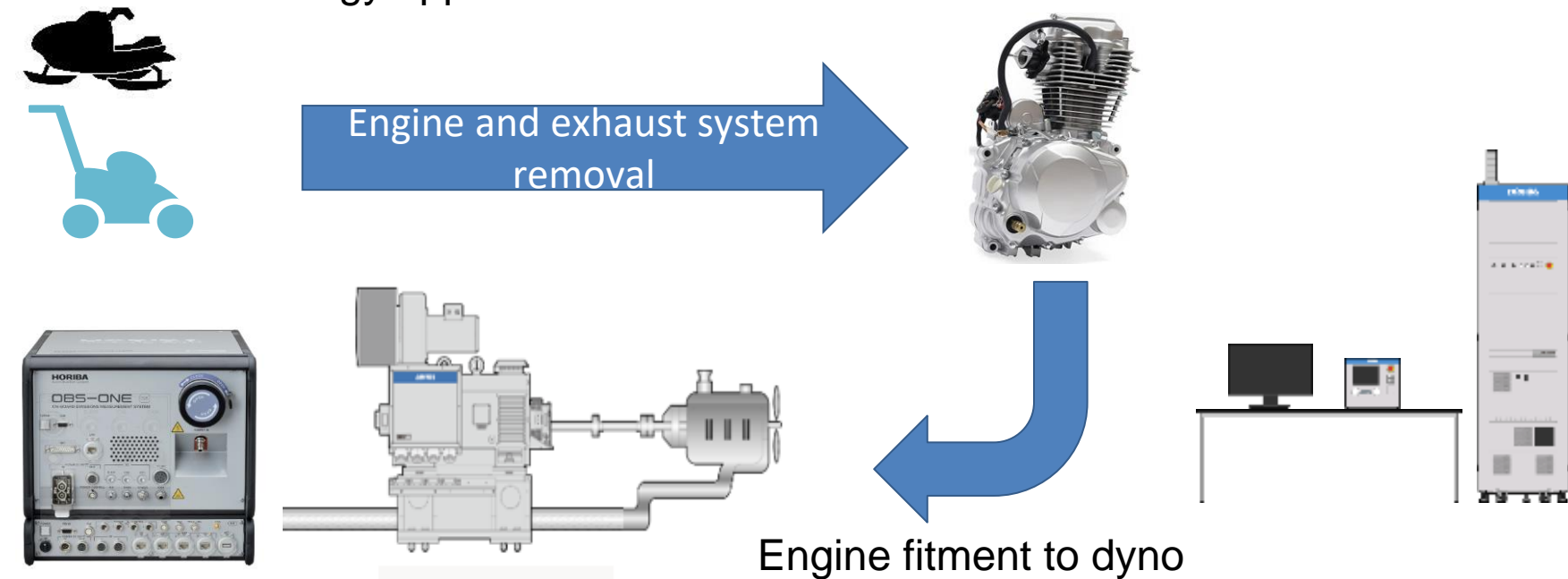
Data processing and calculations, test validation, report generation to Appendix 8 and engine manufacturer to submit test report to approval authorities

Machine Dedit

Removal of test equipment

Engine Dynamometer ISM test

- ❑ Alternate testing option for Group E, I, O & P (Small machine engines) due to the practical challenges performing ISM testing with the engine fitted to the machine
- ❑ Engine, including the emission control system may be removed from the machine, and tested in dynamometer test bench.
- ❑ Test duty cycle shall be used as determined by the manufacturer and agreed with the approval authority
- ❑ Measured by PEMS system, which may be supplemented by concurrent measurements using test bench instrumentation (however not mandatory)
- ❑ Test process (test setup, duration, measurement requirements, post processing, calculations and verification) follows the same conventional ISM test methodology approach



MIRA NRMM In-Service Monitoring On-site Test Facilities



HORIBA MIRA on-site secure workshop facilities

Real-World Propulsion Development Centre workshop



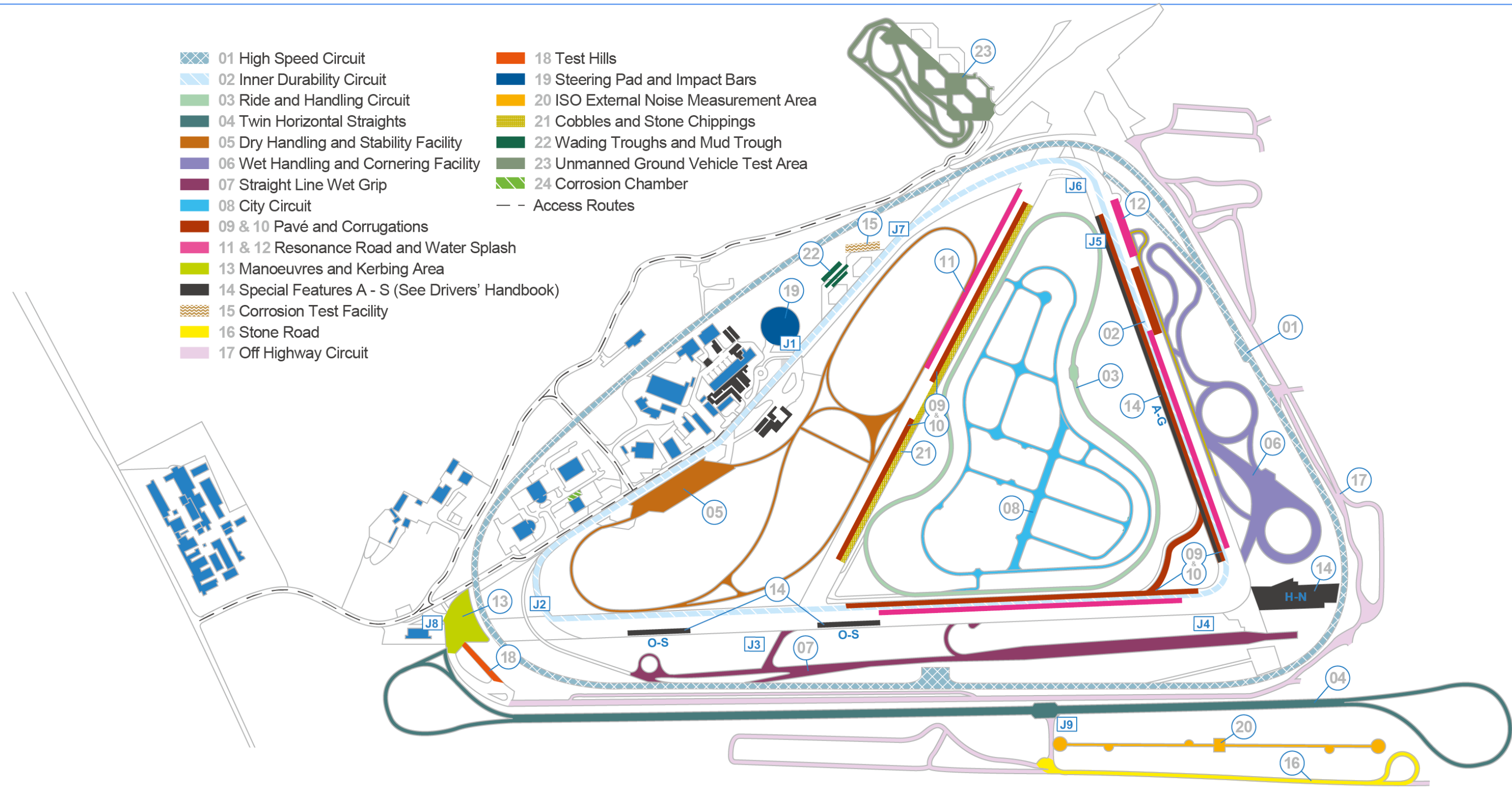
- Purpose build PEMS workshop for machine preparation
- Secure machine storage facilities
- PEMS in-house quality checking facilities
- 3x ramps for machine PEMS installation
- Machining area for fabrication of bracketry and PEMS mounts
- Machine fluid sampling facilities

NRMM Test area preparation areas

- Secure and confidential preparation areas for machine storage close to the test area
- Workshop and hard-standing concrete areas close to test location for machine PEMS installation
- Access to lifting apparatus to mount PEMS system to machine
- Access to close by office space for customers to work nearby to the machine test location if they wish to witness testing



MIRA Proving ground overview



HORIBA MIRA Proving ground test facilities facilities



1. NRMM Proving ground
2. Off-road proving ground circuit
3. Hardstanding NRMM trials area
4. MIRA proving ground lake

1. NRMM Proving Ground



- ❑ Purpose built NRMM proving ground suitable for construction machinery such as Excavators performing digging cycles in an environment representative of typical use.

2. Off-road proving ground circuit



- ❑ Purpose built MIRA off-road proving ground suitable for in-service testing of machines such as (but not limited to) ATV's in an environment representative of typical use.

3. Hardstanding NRMM Trials area



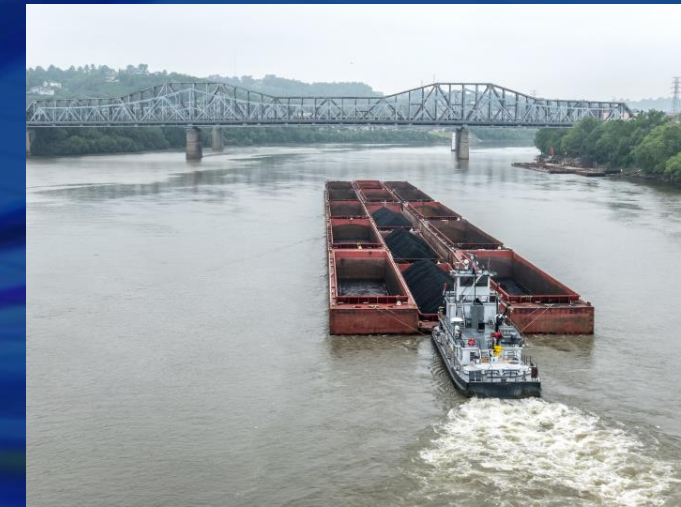
- ❑ Hardstanding concrete area suitable for heavy mobile machine preparation activities including PEMS installation.
- ❑ Area suitable for In-service monitoring testing of smaller mobile machinery such as forklifts or static machinery such as Generators.

4. MIRA proving ground lake



- ❑ MIRA lake area located within the proving ground, suitable for testing machinery with water-based applications such as water pumps

MIRA NRMM In-Service Monitoring testing solutions



Real World NRMM In-Service Monitoring of Emissions test solutions

- ❑ MIRA offer an end-to-end test solution of consultancy, test equipment, test service provider and testing facility provider
- ❑ MIRA can offer test solutions for in-machine engine emissions testing for all machine types it's practically possible to test in-service
- ❑ MIRA offer test solutions at MIRA, and at customer sites or proving grounds globally
- ❑ MIRA have purpose built, secure and confidential test facilities at our headquarters in the UK
- ❑ MIRA have a specialist team of PEMS engineers and technicians with proven experience testing NRMM for a variety of machine types for world renowned OEM's
- ❑ MIRA's technical expertise and experience, means the engine manufacturer is supported throughout the test process and machine downtime is limited due to MIRA's >90% test success rate making testing as efficient as possible
- ❑ MIRA can offer mileage/service hours accumulation services to the Engine manufacturer to meet the regulatory requirements

Engine Dynamometer test solutions

- ❑ Group E, I, O & P (Small machine engines) can have the engine and aftertreatment system removed from the machine and the ISM test take place on the engine dynamometer using a representative duty cycle due to the practical challenges performing ISM testing with the engine in the machine testing during its typical operation
- ❑ MIRA has a number of engine test cells which can be used to perform ISM testing according to the manufacturers agreed duty cycle with emissions measurements using PEMS.
- ❑ MIRA can offer mileage/service hour accumulation services to the engine manufacturer to meet the regulatory requirements
- ❑ MIRA can offer the end to end solution of machine arrival, engine and aftertreatment removal, engine palletisation and fitment to engine dynamometer testbed, ISM test, data analysis and reporting, engine re-fitment to machine and return back to delivery condition.



EU Stage V NRMM Emissions Test Service



- ❑ HORIBA MIRA can support Stage V ISM requirements using HORIBA portable emissions measurement systems (PEMS) and specialist Real world propulsion team at MIRA UK engineering facilities, or locations/facilities globally (both MIRA or customer supplied)
- ❑ HORIBA MIRA understand that the in-service monitoring must follow an agreed test plan, according to the testing scheme option chosen by the engine manufacturer such as; EDP (emissions durability period), engines per year, or engine age model – an example ISM plan table is shown at the bottom
- ❑ HORIBA MIRA can provide an indicative ‘price per test’ option depending on the customer requirements, allowing for test options to be considered prior to the issue of a formal contract, covering a full test programme.

Example NRMM ISM plan for a Group P (ATS-v-1) engine manufacturer with ≥ 7 engine families within the ISM group and a combined annual production for EU market >50 for the remaining engine families produced when discarding the four engine families with the highest annual production for EU market

Group P ISM Plan	Number of engines to be tested			
	To be completed before 26 th December 2024		To be completed before 26 th December 2026	
	2023	2024	2025	2026
<2700km odometer reading	2	2		
>10800km odometer reading			2	2

Emissions Durability Period (EDP) is defined within Annex V of EU Stage V regulation EU 2016/1628

Euro Stage V NRMM ISM – Testing Service Options Available



Capability	HORIBA MIRA	Remarks
Test Cycle & Test Method Creation	✓	HORIBA MIRA can support test method and test cycle (duty cycle) development.
Measurement System & Fixtures	✓	HORIBA OBS-ONE PEMS with anti vibration rugged enclosure, & fabrication of all fixtures as required.
Installation of PEMS, Calibrations, Auxiliary Equipment	✓	Equipment/ facility hire, PEMS Calibrations & quality checks, calibration gases, FID fuel, all provided by MIRA
Project Engineer & Technician Support	✓	HORIBA MIRA Project Engineer (technical lead) and technicians assigned to run the project & all testing
Measurement & Reporting of Results	✓	HORIBA MIRA compile and issue regulatory test report to the customer upon completion and validation of the test. Calibration pack of all required documentation also supplied to customer and Type Approval Authority
Test Site & Preparation	✓	HORIBA MIRA can support testing on the secure MIRA proving ground and operate from dedicated PEMS workshop facilities. Alternatively, MIRA can support testing at suitable customer provided facilities or MIRA can be responsible for providing testing facilities worldwide
Machinery Operator & Preparation	✓	HORIBA MIRA can provide a trained machinery operator to ensure correct duty cycle operation. Otherwise, this can be supplied by the customer
Customer's engineers/ TAA witnessing testing	✓	Secure facilities at HORIBA MIRA can host supporting Engineers and TAA to witness as required

Other options are available upon request and customer specific circumstances, please ask for more detail

5 key challenges of NRMM ISM and MIRA solutions



Regulatory understanding: - EU Stage V In-service monitoring testing requires practical knowledge and understanding of three regulations (EU2016/1628, EU2017/655 & EU2022/2387), which requires significant testing experience and expertise to ensure the testing completed is compliant with the regulations



MIRA has proven expertise delivering EU Stage V NRMM in-service monitoring for several globally renowned NRMM engine manufacturers both in the UK and globally. Finally, as well as a test service provider, MIRA offers engineering consultancy to our customers throughout the ISM process so they understand the requirements and results.

PEMS Installation and Operation: - Due to the wide range of machinery required to perform NRMM In-service monitoring testing, there's significant challenges installing the PEMS system and associated equipment to the machine. This is especially difficult in small mobile machines such as ATV's and Snowmobiles.



MIRA has a designated Real driving emissions (PEMS) team who have developed over 7 years experience installing HORIBA PEMS to a large range of vehicle and machines including; Light duty vehicle, Heavy duty vehicle and Non-road mobile machinery (NRMM). MIRA's position within the HORIBA group enables us access to bespoke and best in class equipment to achieve accurate and robust measurement results even in the harshest environmental conditions. Additionally, MIRA can offer engine dynamometer in-service monitoring testing options for Group E, I, O & P engines where installation of PEMS on the machine isn't feasible

Testing Location: - Test location can be challenging as it is often difficult to source a suitable testing facility. Additionally, there can then be high logistical costs transporting machines to the test site. Transportation of machines is time consuming and costly since the machine is out of service and unable to be used for its typical use, therefore minimisation of downtime and highly efficient testing is crucial.



MIRA is able to offer testing solutions both at our bespoke NRMM proving ground in the UK midlands, or at customer sites both in the UK and globally. Furthermore, MIRA has a test success rate >90% for In-service monitoring testing with PEMS, therefore providing an efficient testing experience and minimising downtime.

Machine Scope: - EU Stage V covers a wide variety of machines including; Non-road equipment, Generators, Inland waterway boats, Railway locomotives, snowmobiles & ATV's. This poses challenges finding a test service provider with expertise and facilities to be able to offer solutions for all machine types.



MIRA has vast experience delivering PEMS testing for a wide range of vehicle applications including light duty vehicles, heavy duty vehicles and NRMM, therefore has expertise to be able to test any type of machine required under the EU Stage V ISM regulations. Additionally, MIRA has a number of proving ground facilities and test options both in the UK and overseas, therefore will be able to offer test facilities for all machine types.

Machine Operator: - EU Stage V covers a wide variety of machines including; Non-road equipment, Generators, Inland waterway boats, Railway locomotives, snowmobiles & ATV's. Arranging hire of a professional and competent operator to the test site can be costly and time consuming



MIRA is a world leading testing organisation with a large number of highly skilled and qualified staff able to operate many different machines. In most circumstances MIRA can provide a machine operator for the test programme which simplifies the engine manufacturers organisational requirements and costs of having to source a machine operator.

Key Points of HORIBA MIRA's Offer

- MIRA is a world class and highly skilled vehicle and machine testing organisation, with many years of experience delivering PEMS testing including EU Stage V in-service monitoring testing for globally renowned engine manufacturers
- MIRA has vast experience with installation and operation of PEMS equipment across a wide range of vehicles including fabricating all the required bracketry
- MIRA is able to offer engine dynamometer based In-service monitoring test solutions for Group E, I, O, P engines
- MIRA is able to offer testing solutions at its site in the UK, at global customer sites and also has a range of test site options in mainland Europe to suit your requirements
- MIRA can offer the end-to-end solution of completing the whole test process including; engineering consultancy to understand the requirements of the regulations, installation of PEMS system, test execution, data processing and reporting, and support with submission to the approval authorities
- MIRA has access to all the required hardware to offer accurate and repeatable testing even in the harshest and most challenging testing environments
- MIRA can offer mileage/service hour accumulation services



MIRA take full responsibility for the testing programme limiting the required input from the engine manufacturer!

Case study – Non-road Mobile machinery - HDI

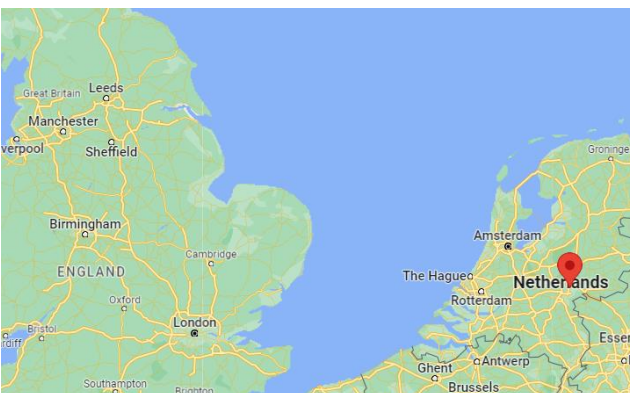
About the project

- Before the amendment to regulation EU2017/655 extending the deadline, Engine manufacturers who supply engines between 56-560kW for use in non-road equipment had to test 9 engines before the end of 2022 (if they had chosen the EDP test method)
- MIRA provided test equipment, staff, proving ground facilities in the Netherlands, and arranged rental of all test machines to perform the testing of 9 machines over 2 separate 3-week test trips from September-November 2022 to meet the deadline
- The testing completed during machines usual operation performing continuous 'digging and dumping'

About the Machines tested:

Testing of 5 different machine types (9 machines in total) including crawler and wheeled excavators

- Euro Stage V emission level
- Engine power rating ~100kW – 200kW



Hyundai Doosan Infracore



Thank you for listening – Any Questions?



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