Application Form

Exemption Request Form

Date of submission: 29 June 2017

1. Name and contact details

1) Name and contact details of applicant:

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Function:	Manager, Technical and Regulatory Affairs	Address:	Rue Joseph Stevens 7 1000 Bruxelles, Belgium

2) Name and contact details of responsible person for this application (if different from above):

Company:	EUROMOT	Tel.:	32-2-893-21-40
Name:	John Mortell	E-Mail:	john.mortell@euromot.eu
Function:	Manager, Technical and Regulatory Affairs	Address:	Rue Joseph Stevens 7 1000 Bruxelles, Belgium

This exemption request is submitted with the support of:

EUROMOT	The European Association of Internal Combustion Engine Manufacturers
NATIONAL ASSOCIATION OF Manufacturers (see separate letter)	National Association of Manufacturers
AEM ASSOCIATION OF EQUIPMENT MANUFACTURERS	AEM – Association of Equipment Manufacturers
OPEI OUTDOOR POWER EQUIPMENT INSTITUTE	OPEI – Outdoor Power Equipment Institute

2. Reason for application:

Please indicate where relevant:

- ■ Request for new exemption in: Annex III
- ☐ Request for amendment of existing exemption in
- ☐ Request for extension of existing exemption in
- ☐ Request for deletion of existing exemption in:
- ☐ Provision of information referring to an existing specific exemption in:

  ☐ Annex III ☐ Annex IV

No. of exemption in Annex III or IV where applicable: ______

Proposed wording: ______

Lead in solders of sensors, actuators and engine control units (ECUs) that are used to monitor and control engine systems including turbochargers and exhaust emission controls of internal combustion engines used in equipment that are not intended to be used solely by consumers.

Duration where applicable: Maximum validity period

☐ Other: ______

3. Summary of the exemption request / revocation request

This exemption covers use of lead in solders of sensors, actuators and engine control units that are required for the operation of internal combustion engine systems that are in scope of the RoHS directive except types intended to be used solely by consumers.

The exemption is needed at this time as any changes to engines that could affect safety, reliability or emissions of substances regulated by the Non-Road Mobile Machinery Emissions Regulation has a very long development and reliability validation cycle which easily spans 8+ years to complete, starting with technology suitable solder alloys and suitable components being available.

Internal combustion engines that are in scope of RoHS are also in scope of the Non-Road Mobile Machinery (NRMM) Emissions Regulation. The conditions experienced in and close to an engine and exhaust can be very severe with elevated temperatures and vibration levels that may cause early failure of solder bonds. As a result, the reliability of engines made with lead-free solders cannot be assured and extensive research needs to be carried out. If an engine is redesigned so that lead-free soldered components can be used, re-validation under the NRMM Emissions Regulation will be required as this has mandatory emissions and durability requirements and also involves extensive engine testing.

Although many engines are used in types of equipment that are covered by specific exclusions of the RoHS Directive, such as in forms of transport, there are certain types of equipment that are not excluded. RoHS includes in scope some types of NRMM that are leased, so may be used by both professionals and consumers. These types of products are used for long periods daily unlike dedicated consumer products and so experience the same stresses and reliability issues as dedicated professional products. Most of these products, however, face the same technical challenges in assuring the safety, reliability and emissions of products under both RoHS and other relevant European Union directives, meaning that an exemption is critical in allowing them to continue serving the European market.

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4. Technical description of the exemption request / revocation request

(A) Description of the concerned application:

1. To which EEE is the exemption request/information relevant?

Name of applications or products: Electrical control components of NRMM engine systems

a. **List of relevant categories**: (mark more than one where applicable)

1	☐	7	☐
2	☐	8	☐
3	☐	9	☐
4	☐	10	☐
5	☐	11	■
6	☐		

b. **Please specify if application is in use in other categories to which the exemption request does not refer:** Engines intended solely for consumer use and engines designed for types of equipment that are excluded from the scope of the RoHS Directive.

c. **Please specify for equipment of category 8 and 9:**

The requested exemption will be applied in

☐ monitoring and control instruments in industry

☐ in-vitro diagnostics

☐ other medical devices or other monitoring and control instruments than those in industry

2. **Which of the six substances is in use in the application/product?** (Indicate more than one where applicable)

Pb ■ Cd ☐ Hg ☐ Cr-VI ☐ PBB ☐ PBDE ☐

3. **Function of the substance**:
Lead is a constituent of solder alloy used to make electrical connections to components.

4. **Content of substance in homogeneous material (%weight)**:
35 – 40% lead in solder

5. **Amount of substance entering the EU market annually through application for which the exemption is requested**:

   Estimated at about 3 tonnes lead on the EU market per year

   Estimated at about 25 tonnes lead on the global market per year

   Please supply information and calculations to support stated figure.

   The actual quantity of lead is uncertain because many different types of sensor, actuator and ECU are used and the lead content of most of these has not been measured[1]. However a few representative sensors, actuators and ECUs have been analysed and the quantity of lead in soft solder measured.

   - Sensors, estimated average amount of lead in solder = **5g per engine**
   - Actuators, estimated average amount of lead in solder = **6g per engine** 1g per actuator (assume six on average per engine)
   - ECUs, estimated average amount of lead in solder = 35g
   - The total amount per engine is therefore: 46g

   This is similar to the amount of lead in solder estimated in two published studies in vehicle engines[2]. These engines are not the same as modern engines used in professional stationary and NRMM as they will not be subject to the same emissions requirements and so modern engines are likely to contain more types of sensors and more complex control electronics.

   The number of engines that are placed on the EU market annually that are in scope of RoHS was estimated by EUROMOT as about 68,000 units[3]. This is estimated to be about 12% of the global total of 570,000 units.

6. **Name of material/component**: Tin/lead alloy, tin/lead/silver alloy for solder used with engine control sensors, actuators and engine control units (ECU).

7. **Environmental Assessment**: Not applicable to this exemption request

LCA: ☐ Yes
☒ No

(B) In which material and/or component is the RoHS-regulated substance used, for which you request the exemption or its revocation? What is the function of this material or component?

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[1] Also, this depends on the complexity and emissions requirements for the engine. The example lead quantities used here are for typical professional engines, whereas smaller engines such as are used in types of equipment that are typically leased will have fewer sensors and simpler ECUs and so will contain less solder. However, EUROMOT believe that the number of these types of simpler products that are a) not intended for consumers and b) also those not excluded by the RoHS definition of professional non-road mobile machinery is relatively few and so the amount of lead in these products is small in comparison with the quoted figures.

[2] A report by Okopol estimated about 50g per vehicle (so not all of this is part of the engine) and in an ELV exemption review in 2008 by Oeko Institut estimated about 30 grams.

[3] This estimate excludes leased products that are in scope and discussed in footnote 1. EUROMOT has not been able to estimate a reliable total but believe that the number in scope is not large.

Solders are used in most types of sensors, actuators and in electrical circuitry of engine control units. Each of these three is discussed separately below:

Types of sensors

This exemption is requested for use of lead in solders used to make electrical connections within sensor modules that are used for the control of professional use engines in scope of the RoHS Directive. Each design and model of engine uses a specific range of sensors that are selected to ensure the correct performance, fuel efficiency and emissions. Some engines will have many more sensors than others. The list below in Table 1 includes the types of sensor that are used with engines in scope of RoHS although some are much less commonly used than others.

Some of the engines that are in scope of RoHS are also in scope of the NRMM legislation is the Regulation 2016/1628 so also have to comply with emissions limits. The upcoming stage V requirements of the Non-Road Mobile Machinery (NRMM) Regulation (2018 – 2020), will require more stringent emission limits. This amends the limits on emissions of carbon monoxide, hydrocarbons, nitrogen oxides and particulates for a wide variety of engines and depend on the type of ignition used, type of fuel, power rating and other engine characteristics. Compliance is based on type of approval of engine types and will be required from 1 Jan 2018 to 1 Jan 2020 and will increase the variety of sensors that are needed in many types of engine systems.

If changes to engines are made due to RoHS are significant, such as using a different sensor or a different ECU design, as this could affect emissions, then re-validation under the NRMM Regulation would be required, which will take as long as the testing needed for type approval of a new engine design.

The list below is intended to be an illustrative list of types of sensor that may be used although a few other types may also be used in a small number of types of engines. Some are commonly used in engines, others are only used in a few types of engines and some will mainly be used in engines that need to comply with NRMM engine stage V, but are not excluded from RoHS. There is also a trend to use sensors that have multiple functions such as measurement of both pressure and temperature or oil level and oil temperature. A temperature sensor may also be combined with a thermostat to control temperature.

Table 1. Types of sensors that are used in engine systems for that will be in scope of the RoHS directive

Description	Function of sensor
Air pressure sensor	Measures air pressure
Air temperature sensors	Air temperature sensors are used to adjust the fuel mixture for changes in air density
Ammonia sensor	Measures ammonia concentration in exhaust gases and sends signal to engine management. Ammonia is produced from NOx by diesel catalytic converters
Blow-by flow sensor	Blow-by is the gas which is blown past the piston rings or which is caused by valve guide or turbocharger leakage. These are less common sensors that measure the flow rate of these gases.
Coolant temperature sensor	Sensor that measures the temperature of the engine coolant. Important as this determines when the engine has reached its operating temperature so that the control module can adjust the fuel/air ratio.

Coolant level sensor	Sensor that monitors the level of coolant in the coolant reservoir of the heat exchanger circuit of the engine
Current sensor	Measures the current in amps in power circuits
DFN pressure sensor	Measures differential pressure by comparing a high pressure with a lower pressure at two locations within an engine. May be needed for stage V.
Engine exhaust temperature sensor	Measures exhaust gas temperature and sends signal to engine control module. Important for controlling engine efficiency and its emissions
Engine speed	A device that detects and transmits the position of rotating members such as flywheel ring gears and camshaft drive gears for the purpose of measuring rotational speed.
Fluid level sensors	Measures the level of fluids (fuel, oil, etc.), may be required for stage V.
Fluid quality sensors	Measures characteristics of lubricating oil or fuel to determine suitability and remaining useful life (indicate a need to change). These are used in stage V engines and an example would include water in fuel sensors
Fuel pressure sensors	Measures pressure of fuel in the fuel lines
Humidity sensors	Measures humidity of the air at air intake. Mostly used in gas fuel engines
Knock sensors	Detects detonation or spark knock inside engine by detecting engine vibrations so the engine control module can momentarily retard timing. Used only in natural gas engine.
Mass flow sensor	Measures the mass of fuel or air flowing to the engine to get the correct mass ratio. This is more accurate that volume flow which depends on temperature and pressure.
Methane sensor	Measures methane concentration, used only in natural gas engine
MLT NAV data sensor	Measures speed, position and orientation of engine components. Used only in some models of engine.
Nitrogen oxide (NOX) sensor (nitrous oxide)	Measures NOX in exhaust gases after passage through exhaust treatment device. Used to adjust the fuel/air ratio to control NOx emissions and required for stage V compliance
Oil level sensors	Measure level of lubricating oil inside engine
Oil pressure sensors	Measures oil pressure engine lubrication system
Oil temperature sensors	Measures oil temperature inside engine
Oxygen sensors	Used for fuel mixture feedback control, but are fairly uncommon.
Particulate sensors	Measures the amount of particulate matter in exhaust gases, either exiting the engine or exiting the exhaust pipe. Uncommon but may be needed more for stage V in the future

Position sensors	Determines a linear or rotary position, typically of a camshaft for engine timing or of the throttle. May be used instead of a distributor. Also used as an exhaust gas recirculation (ECR) position sensor. Some manufacturers use one sensor to measure engine speed and position. Position sensors may also be used as components inside actuators such as to measure relative position change for control of turbo boost, air throttle position and EGR Valve position
Pressure (absolute) sensors	Measures absolute pressure, such as manifold pressure sensors measure engine load so that ignition timing can be advanced and retarded as needed
Transmission speed sensors	Detects and transits the position of rotating parts for the purpose of measuring rotational speed
Turbocharger speed sensor	Measures and transmits position of rotating parts of a turbocharger for measuring rotational speed
Viscosity sensors	Measures viscosity of a fluid such as a lubricant
Water sensors	Measures water in fuel

All of the above sensors measure a characteristic of the engine / exhaust system and transmits the information to the engine's control unit. The signals from sensors control the engine to ensure maximum fuel efficiency and to control the composition of exhaust gas emissions. Because of their function, most of the above sensors have to be located next to or even within an engine, attached to the exhaust system or to a turbocharger. Most of these locations will be at high temperature and subject to vibration, large temperature cycles and be subjected to sudden high g-force shocks.

Sensor design

All engine sensors convert a parameter into an electrical signal which is used to control the running of the engine. The types of engines that are in scope of the RoHS Directive are required to be energy efficient, very reliable and to meet engine emissions legislation and the sensors are used to ensure that each of these requirements are met. Lead is used in solders to make electrical connections internally within the sensor components. Various types of sensing elements are used, depending on the parameter being measured. These include:

- Negative temperature coefficient (NTC) transducers used as temperature sensors up to 200°C. These are metal oxide semiconductors to which electrical connections are made.
- Thermocouples consisting of metal wires used to measure higher temperatures (up to 1500°C.)
- Variable reluctance (magnetic) sensors for position, speed and rotation.
- Hall-effect transducers, e.g. as camshaft position sensors. These are made of silicon or other semiconductors to which electrical connections are made. Hall-effect devices often incorporate amplifier circuits.
- Variable resistance (potentiometers), such as for throttle position and air flow.
- Pressure sensors, these can be silicon or piezoelectric MEMS (microelectromechanical system) devices
- Accelerometers – piezoelectric crystals and MEMS devices, used as anti-knock sensors
- Hot wire air flow (uses a platinum wire)
- Oxygen sensors based on doped zirconia with porous platinum electrodes. These operate at >300°C.

Many of the above sensors are built into modules with control electronics (e.g. a small PCB) that generates a stable output that is sent to the engine control unit.

The applicants of this exemption are engine manufacturers who do not manufacture or have design control over sensors. However the sensors must function reliably and give accurate output signal in order to function correctly. Some engines are used in equipment in scope of RoHS and also the Non-Road Mobile Machinery (NRMM) Emissions" Directive, 97/68/EC and its subsequent amendments with most recently Regulation 2016/1628. This legislation requires types of engines to be type-approved whereby a Member State competent authority certifies that it meets the essential technical requirements of the legislation. Sensors control engine emissions and so any change in design or supplier of sensors may require lengthy emissions testing and recertification. This legislation imposes limits on the emissions of:

- Carbon monoxide (CO)
- Hydrocarbons (HC)
- Nitrogen oxides (NOx)
- Particulates (PT)

The emissions limits are expressed as g/kWh and depend on the net rated power of the engine measured in kW. The limits have been amended several times since the original directive was adopted and as described above and "Stage V" will come into effect from 2018. Note that the definition of Non-Road Mobile Machinery (NRMM) used in the RoHS Directive is different to the definition in Directive 97/68/EC and the more recent amending Regulation 2016/1628 and so although "professional Non-Road Mobile Machinery" is excluded from the scope of RoHS, the RoHS definition does not exclude all types of equipment that are "made available exclusively for professional use",[4] and which are also in scope of Regulation 2016/1628[5].

Although many engines are used in types of equipment that are covered by specific exclusions of the RoHS Directive, such as in forms of transport, there are certain types of equipment that are not excluded. RoHS includes in scope types of NRMM that are leased, because these may be used by both professionals and consumers. These types of products are used for long periods daily unlike dedicated consumer products and so experience the same stresses and reliability issues as dedicated professional products. Most of these products, however, face the same technical challenges in assuring the safety, reliability and emissions of products under both RoHS and other relevant European Union directives, meaning that an exemption is critical in allowing them to continue serving the European market. Engine emissions are affected by many parameters that control an engine including temperature, engine and turbo-charger speed, lubricant viscosity, fuel/air ratio which are in turn affected by air pressure, fuel flow rate, etc. Each engine is designed with specific types of sensors that has been thoroughly tested to ensure that they will be reliable and the engines will meet the emissions limits. Reliability cannot be assured and engines may not meet emissions limits if sensors have to be replaced by different sensors from different suppliers or by sensor types of different designs. Like-for-like exact equivalents, where the only difference is that tin/lead solder is replaced by lead-free solders very often do not exist. RoHS compliant sensors that are made with lead-free solders are increasingly available for passenger cars to comply with the ending of the lead in solder exemption of the EU ELV Directive. However, where a sensor is available and appears to be useable, its reliability in engine applications cannot be assured as the use conditions are different to passenger cars, as discussed below in section 6.

[4] This is the wording used in the RoHS Directive exclusion of NRMM in Article 2(28)

[5] This was reviewed in 2015 by the Oeko Institut for the European Commission and the report is available from http://bookshop.europa.eu/en/study-for-the-analysis-of-impacts-from-rohs2-on-non-road-mobile-machinery-without-an-on-board-power-source-on-windows-and-doors-with-electric-functions-and-on-the-refurbishment-of-medical-devices-pbKH0415180/

Types of actuators

Actuators are electromechanical devices that control the operation of engines, such as by controlling the opening of valves that control air flow rate, pumps for fuel and other devices that are parts of engines. Illustrative examples of the types of actuators that might be used in engine systems in scope of RoHS are listed below. A few other types may also be used in some engines systems. Note however, that each engine type will use only some of these types of actuator.

Table 2. Examples of types of actuators that may be used in engine systems

Actuator	Function
Solenoid (some types are also called cold start relay)	An electromagnetic device which is used to close low voltage - high current contacts to engage starter motor or other high current connections such as cold weather starting aids.)
HCI Dosing Pump	Hydrocarbon injection pump that sprays fuel into exhaust to heat the catalytic converter which must be hot to function correctly
Fan Clutch(FWD) – PWM	Engages and disengages fans that cool engines or coolants. Important for maintaining high energy efficiency and controlling emissions. These can also reverse direction of air flow to aid in keeping cooling package clean of debris in some applications
Fan Clutch(Rev) – On/Off	
DEF Rev Valve	Diesel exhaust fluid valve
DEF Tank Coolant Valve	Motorised valve
DEF Dosing Valve Motor	Motor for valve
EGR valve	Exhaust gas recirculation valve
Exhaust Throttle(H)	Regulates the flow of exhaust gases
Fuel Transfer Pump	Fuel pump
DEF Pump	Diesel exhaust fluid pump
Alternator Enable	Actuate alternator (alternators generate electricity to charge batteries and operate equipment)
Smart Alternator (LIN)	Type of alternator
Turbo actuator (waste gate and variable geometry types are both used)	These actuators are used to control the function of engine turbo chargers and to control atmospheric boost pressure
Fuel Injectors	Control fuel injection into cylinder
Fuel Inlet Control Valve	Control fuel flow into fuel rail

Most actuators contain electrical devices that move when a voltage is applied. Many types use electric motors which require motor control circuits to ensure that the movement distance is correct. Electrical connections, using solder bonds will always be required to these electromechanical devices that convert an applied voltage into a precise movement.

Engine control units

All sensors and actuators are connected to engine control units (ECU) that monitor and control the operation of the engine. These are essential to ensure that emissions are limited to acceptable levels and that fuel efficiency is maximized. ECUs are fairly complex electronic assemblies and are essentially the “brain” of the engine that uses the input data from many sensors to control the engine using the actuators, fuel injectors, etc. These contain one or more printed circuit boards. Some are made by engine manufacturers and others are designed and produced by third parties. Some are manufactured using lead-free solders but their long term reliability in most types of equipment that are in scope of RoHS is not yet assured. More time is needed to determine whether these ECUs will be sufficiently reliable (i.e. whether unexpected failures will occur) and also that they will not be detrimental to engine emissions or engine "durability" (i.e. its expected lifetime).

Manufacturers of equipment that contain engines determine where ECUs are located, but frequently the most appropriate location is attached to the engine and so the solder bonds of these units are exposed to the same temperatures, vibration and shock as the sensors that are installed in engines.

There are technical reasons why the ECUs are mounted directly on engine blocks. These include:

- To regulate temperature, some designs are cooled by fuel flow.
- Good electrical earth connections are essential for the electronics of engines so that signals are sent to sensors and actuators which are also earthed via the engine or chassis. Mounting on the engine block guarantees good earth connection. Another benefit is that this also helps to avoid electromagnetic interference that would be detrimental to the operation of sensitive control circuits and so could affect emissions
- Vibration will occur in NRMM and this has to be well understood for the reliability of the engine. Attaching engine control units to engines means that these will experience the same well understood levels of vibration and range of frequencies and so can be designed and tested to be reliable under these conditions.
- To limit the need for additional wiring to connect ECUs mounted away from engines. This additional wiring can potentially cause EMC issues and adds unnecessary weight which may increase fuel consumption if the engine is also used to move the equipment.

Types of equipment with engines that require sensors, actuators and ECUs
Sensors, actuators and ECUs for which an exemption is requested are used, for example in engines that are used in:

- Generator sets
- Diesel engine powered compressors
- Pumps, such as irrigation pumps, water and sewage pumps, etc.
- Drilling machines
- Rock crushers
- Welding sets that are mounted onto trailers.
- Products that are typically leased to both professionals and consumers and so are not excluded by the RoHS definition of professional NRMM, for example, some types of chain saws, leaf blowers, some types of mowers, small-size diggers, etc.[6]

The above are illustrative examples of types of equipment that are in scope of the RoHS Directive and are not covered by the exclusions from the RoHS Directive

Stationary equipment that is too small to be excluded from RoHS as a part of a large-scale fixed installation or be a large-scale stationary industrial tool will be in scope and so may need this exemption.

Generator sets that are in scope of the RoHS directive are types that are transported on trailers and in containers which are transported to fixed locations where they are used for a few days, weeks, months or years before being moved to another location or are permanently located. These generators incorporate engines and are in scope of RoHS and require this exemption.

The largest size generator generates more than 375kW so are intended to be used in large-scale fixed installations and so may be excluded from RoHS, but only if they are designed to be permanently installed. These very large generators are used at temporary locations such as for disaster relief and so will not be excluded from RoHS. The EC's RoHS FAQ guidance[7] states that installations with rating >375kW would be regarded as large-size, but they are not excluded if they do not meet the RoHS definitions of "stationary industrial tools or fixed installations".

[6] For examples, see https://www.hss.com/hire
[7] http://ec.europa.eu/environment/waste/rohs_eee/pdf/faq.pdf

These “Gen-sets” contain an internal combustion engine and an electricity generator along with the necessary ancillary equipment. These may be used as a permanent or temporary power source or be used only intermittently as a standby or emergency generator. High reliability is essential, especially when these are used as emergency back-up generators for hospitals in case of a power cut.

Another example of applications for engines is shown in the figure below:

Figure 1. Diesel engine powered compressor

The compressor shown in Figure 1 is professional transportable industrial equipment but is not excluded from RoHS as it is used stationary for fairly long periods when in use. Other professional applications that may be considered to be in scope of RoHS is for engines that are used for pumps used in professional installations that are too small to be large-scale fixed installations, for example irrigation pumps used in farms. Some irrigation pumps are moved from one location to another, but can be used at a fixed location for quite long periods. Other applications include drilling machines, rock crushers and welding sets that are mounted onto trailers, but are used at one location for fairly long periods. Another example is shown in the image below:

Figure 2. Temporary power source with 6.7 litre diesel engine used in a construction site. Dirt and dust are an issue at these locations.

Comparison of engines covered by this exemption request with engines in passenger road vehicles

The engines used in these applications are different to engines that now use “lead-free” sensors, actuators and engine control units which are in scope of the EU End of Life Vehicle

(ELV) Directive whose scope is passenger cars, small vans and small buses. The ELV Directive also bans lead (along with RoHS) but has had an exemption for lead in solders until 2016 when this ended, although only for new type approved models. This exemption ended because suitable lead-free solder alloys were developed (as discussed in section 6) and could be used in new type approved road vehicles. The lead in solders exemption is still applicable to models that were type approved before 2016. The table below compares the conditions that sensors, actuators and ECUs will experience in these two types of applications.

Table 3. Comparison of use conditions of sensors in passenger cars and in engine applications covered by this exemption request[8]

Parameters	Passenger road vehicles in scope of the ELV Directive	Engine applications as required by this exemption request
Temperature	Up to 150°C	Up to 150°C, exhaust sensors can be up to 600°C
Vibration	Up to 11.5 g RMS, but generally less severe than NRMM	Up to 12 g RMS. ECUs may be exposed to 95 – 105°C and at up to 12g RMS.
Fuel	Petrol or diesel	Diesel, natural gas and petrol. Some diesel engine exhausts are also dosed with diesel exhaust fluid (DEF) to reduce NOx emissions[9]
Duty cycle	Private cars (UK) are used on average for only 4% of the time[10].	30 – 70% are typically used for testing NRMM engines and is believed to be representative
Proportion of time at full load	Relatively small, no data but probably less than 5% of time when in use[11].	Up to 100% (commonly required for generators)
ATEX compliance[12]	Not required	May be required (this will limit the sensors and other components that can be used as they may need to be approved for ATEX compliance by a Notified Body)
Environment	Passenger cars are exposed to water and salt water spray, some dust, although engines, their sensors and control units tend to be shielded from these so only suffer from condensation and temperature fluctuations.	Many types of corrosive chemicals when used in factories, oil refineries, etc. Salt spray, high humidity, dust and dirt (e.g. in building sites, quarries, etc. so in much larger quantities than passenger cars) and frequent large temperature cycles

Notes on above table

- The duty cycle of passenger cars will be fairly varied. An average of 4% is equivalent to about 1 hour per day, but some cars are used for much longer periods (such as taxis

[8] Data provided by engine manufacturers except where other sources are quoted
[9] Most diesel engines made today which meet the most current NOx emissions limits utilize DEF fluid.
[10] See Q5 from http://www.racfoundation.org/motoring-faqs/mobility#a5 . Note that average UK passenger car miles per year in 2015 was 7,900 miles (source RAC), whereas the UK HGVs average was 33,000 miles per year (calculated from UK government statistics).
[11] One study show fuel use in grams per second. Assume that peak load is when this is the highest values, such as in figure 15 of the paper, the peaks account for <10% of the total time with 5% appearing to be typical. https://www.repository.cam.ac.uk/bitstream/handle/1810/261082/Bishop_et_al-2016-Applied_Energy-VoR.pdf?sequence=1
[12] Equipment and protective systems intended for use in potentially explosive atmospheres Directive (ATEX) 94/9/EC

and delivery vehicles), although only rarely more than 8 hours per day (33%)
- The proportion of time at full load has a very large impact on the operating temperature and level of vibration that the sensors and other electronics experience. These are both considerably more severe at full load than when idling.
- ATEX certified equipment must be constructed using ATEX approved electronic modules and sensors. The sensors and modules used in passenger vehicles do not need to be ATEX approved and so these cannot be used in types of engine equipment that require ATEX certification.

Although the maximum temperature and vibration experienced by passenger car engines and NRMM engines are similar, the proportion of time that NRMM engines experience high temperature and severe vibration will be considerably more than passenger car engines.

(C) What are the particular characteristics and functions of the RoHS-regulated substance that require its use in this material or component?

Electrical connections in sensors, actuators and in ECUs are made using solder alloys which should have a combination of the following essential requirements:

- Low melting point – ideally high enough not to melt or deform at the operating temperature, but not so high that bonding causes damage to materials of the sensor, in particular the polymer insulation that is used.
- Sharp melting point – solder should be molten for as short a time as possible to minimize the thickness of intermetallic phases (as thick layers are brittle and so can be unreliable). Ideally a eutectic alloy is used such as Sn37%Pb.
- Very low and stable electrical conductivity – metals are ideal
- High thermal conductivity – when used with power components to conduct heat away, again metals are ideal
- Resistance to chemicals and to corrosion – lead and tin are relatively inert to the range of substances which the equipment is likely to be exposed. Silver and copper corrode when exposed to hydrogen sulphide gas which can occur in industrial environments
- Resistance to premature failure due to high temperatures, thermal cycles, vibration, sudden shock and combinations of these effects
- Solder grain structure and the intermetallic compounds formed during the soldering (bonding) process must be robust to the unique thermal and vibration environment of these engines

Electrical connections need to be made within sensors, actuators and ECUs to connect electronic components to conductors (wires or printed circuit boards) and to connect electrical components and ECUs to wiring looms to ensure that measurements are accurate and the often small signals are accurately transmitted to engine control units. There are several ways of making electrical connections; crimp, weld, solder, etc. but of these options, soldering has been used for many decades to obtain the most reliable electrical bonds with very low electrical resistance within sensors, actuators and engine control units for making connections to sensing elements and to electronic components.

Each sensor unit has internal electrical connections and external terminals and the number of these connections and the design of circuits are different for each type of sensor. There are a variety of different designs of level, pressure and other types of sensors (each having different performance accuracy and durability), so that electrical connectors within sensors need to be made to a variety of materials including metals and electro-ceramic materials. Within many sensor units, the electrical connection must be made to a flat surface of a component's pads and so crimps connections are unsuitable. Welding and brazing are too hot and will damage the sensing materials as well as insulating polymers and so usually only solders are suitable. Solder alloy selection and other bonding methods are discussed below in more detail in section 6.

Transmission of an electrical signal between sensors, actuators and engine control units is made by insulated copper wire which has a very low electrical resistance and has been found over many decades to be reliable in the types of equipment relevant to this exemption request.

Solders are alloys that heated to about 200°C (most lead-free solders need to be somewhat hotter) and when molten, form a strong "chemical" bond to the substrate material by reacting at the surface to form a very thin layer of an intermetallic phase. When the solder cools and freezes, the alloy should bond strongly to the intermetallic layer which should be strongly adherent to the substrate material. Weak bonds can however be formed if unsuitable solder alloy compositions are used or if the soldering process is not carried out correctly, for example so that the intermetallic layer becomes too thick. These reliability issues are also discussed in section 6.

Once solder bonds in sensors, actuators and ECUs have been formed, they should ideally maintain a low electrical resistance for the lifetime of the engine and they must survive the hostile environmental conditions that will be experienced:

- Solder bonds of engine sensors, actuators and engine control modules that are attached to engines will experience very large temperature fluctuations, which can cause thermal fatigue failure. For example, engines used in cold climates in the winter, such as in northern Sweden and Finland can reach -20°C and below (-40°C is not uncommon at some locations). In use, sensors inside and adjacent to the engine can reach over 150°C. This wide temperature range can impose large stresses on solder bonds depending on the sensor design.
- Engines will vibrate for very long periods and this can cause high frequency fatigue to solder bonds due to the repeated strain imposed.
- Equipment with engines in scope of RoHS is used at fixed locations but is moved between locations. This can be over very rough terrain such as in quarries and building sites and this can cause sudden shocks which impose very high g-forces on solder bonds (similar to dropping equipment onto a hard surface)
- Equipment with engines are used in a wide variety of installations including chemical factories, oil refineries and marine environments where they are exposed to corrosive chemicals, high humidity and high temperature, etc. These hostile conditions can accelerate corrosion of components and circuitry. Another potential failure mode is with exposed solderable coatings. This can occur because the wetting of component pads on PCBs by lead-free solders is inferior to that of leaded solders so that areas of pads remain uncoated[13]. When these are electroplated with tin and exposed to corrosive or high humidity environments, they can be susceptible to the formation of tin whiskers that can cause short circuits. Tin whiskers are mainly an issue when low voltages are generated by a sensor because a short circuit caused by a whisker will alter the output voltage so that the sensor transmits the wrong signal and does not control the engine. Mitigation measures against whiskers are known and are used, but until these are implemented in engine sensors and these are thoroughly tested in realistic environmental conditions, the reliability will not be known. These areas that are not wetted by solder can also suffer from corrosion in corrosive atmospheres that can occur in factories and this causes an open circuit failure.

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[13] There are many publications on this issue, for example, http://www.umel.feec.vutbr.cz/~szend/novinky/wettability.pdf

Because of typical use conditions of these types of equipment, the solder bonds need to be resistant to thermal fatigue, fatigue due to vibration, sudden shocks, resistance to corrosive environments and the solderable coatings must not form long whiskers that could cause short circuits.

The long term reliability of equipment with engines relies on the reliability of all of the individual components that are used, including all of the sensors, actuators and ECUs. Engine systems can contain many of the types of sensor and actuator as well as the ECU listed above and only one of the solder bonds needs to fail to cause the NRMM to stop functioning correctly.

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5. Information on Possible preparation for reuse or recycling of waste from EEE and on provisions for appropriate treatment of waste

1) Please indicate if a closed loop system exist for EEE waste of application exists and provide information of its characteristics (method of collection to ensure closed loop, method of treatment, etc.)

Not applicable

2) Please indicate where relevant:

☒ Article is collected and sent without dismantling for recycling

☒ Article is collected and completely refurbished – Some equipment is refurbished

☒ Article is collected and dismantled refurbished (most refurbished parts are used as spare parts or to rebuild used engines. Very few types are sold as "new" components):

☐ The following parts are refurbished for use as spare parts: ECUs, sensors and actuators

☐ The following parts are subsequently recycled: ECUs, sensors and actuators that are defective and cannot be repaired

☐ Article cannot be recycled and is therefore:

☐ Sent for energy return

☐ Landfilled

3) Please provide information concerning the amount (weight) of RoHS substance present in EEE waste accumulates per annum:

☒ In articles which are refurbished	See below
☒ In articles which are recycled	See below
☐ In articles which are sent for energy return	______
☐ In articles which are landfilled	______

Parts of end of life engine systems are either recycled or refurbished for reuse. The percentages of used parts that are refurbished depend on the type of engine and equipment in which it is used and the type of part, but typical values are as follows:

Table 4. Proportions of ECUs, sensors and actuators that are refurbished at end of life of equipment and the corresponding quantities of lead[14]

Part	Proportion refurbished	Amount of lead present per year[15]
ECUs	90% are refurbished, the rest recycled	2.14 tonnes in reused ECUs 0.24 tonnes recycled ECUs
Sensors	About 60% are refurbished, mainly for use as spare parts	204 kg in reused sensors, 136 kg in recycled sensors
Actuators	About 80% are refurbished, mainly for use as spare parts	325 kg in reused actuators 82 kg in recycled actuators
Totals		2.67 tonnes in reused equipment 0.46 tonnes in recycled components

6. Analysis of possible alternative substances

(A) Please provide information if possible alternative applications or alternatives for use of RoHS substances in application exist. Please elaborate analysis on a life-cycle basis, including where available information about independent research, peer-review studies development activities undertaken

Alternatives to lead-based solders are discussed below.

Lead-free solder alloys

These would be the most promising substitute materials which can be evaluated without the need for sensors actuators and ECUs to be redesigned if lead-free components are available. However, they are often not available and so redesign is frequently needed. Solder alloys are widely used by the electronics industry and have recently also been used in passenger cars and small vans in scope of the EU ELV directive. However lead-free solders are not required by legislation in large commercial road vehicles or in types of Non-Road Mobile Machinery such as excavators and bulldozers that are outside of scope of the RoHS Directive. Types of engines that will be in scope of the RoHS Directive from 23 July 2019 currently use lead-based solders as the sensors used are identical to those used in other types of NRMM and also in large commercial vehicles which are out of scope of both the RoHS and ELV Directives. The types of engines and associated equipment (such as turbochargers and exhaust systems) that use

[14] Proportions estimated by engine manufacturers
[15] Assumes number of engines in scope of RoHS excluding consumer only products, reaching end of life in the EU is 68,000, the same number as new sales.

sensors that require this exemption can experience the following environmental and use conditions:

- They often suffer much more severe vibration than most other types of electrical equipment and also is more severe than road vehicles
- Unusually large temperature cycles
- They may need to operate at higher temperatures as heat is generated by the engine, but when the equipment is used at a fixed location, there is only limited cooling air flow, unlike in road vehicles. Sensors and actuators are attached directly to parts of engines, some are inside engines and some attach to exhausts systems and so will be at a higher operating temperature than circuit boards which can be mounted further away from the engine and exhaust. Control modules are usually attached to engines, as discussed above.
- Due to the locations where this equipment is used, components may be exposed to corrosive substances, high humidity and dirt that contains ionically conducting materials that accelerate corrosion.
- These types of equipment can operate for much longer periods and under higher load than passenger vehicles that are in scope of the EU End of Life Vehicle (ELV) Directive 2000/53/EC, which could exacerbate the effect of the above parameters

Vehicles in scope of the ELV Directive and type approved since 1 Jan 2016 now use lead-free sensors, actuators and control units, but the performance and reliability of these in the hostile environments that are experienced by the types of engine equipment that are in scope of RoHS is not yet known. Due to the more severe conditions, substitute bonding technology may be inferior and less reliable to current methods and materials.

The ELV Directive entered force in 2002 but included an exemption for lead in solders that covered all applications. Eventually, research identified one suitable substitute lead-free solder, but it has only been since 1st January 2016 that it has been possible for the ELV exemption for lead in solders to attach electrical components to PCBs and in terminal finishes to expire and this is only for models of vehicles that were type approved after 1 January 2016. The exemption is still valid for vehicles that were type approved before this date. The automotive industry has therefore spent so far 14 years developing lead-free soldering technology for passenger cars. The first issue found was that the lead-free solders that were developed initially and that were used in consumer electronics after RoHS took effect in July 2006, were unsuitable for engine-compartment applications. The tin, silver, copper (SAC) alloys that were first developed for consumer electronics were found to have inferior thermal fatigue performance compared to tin/lead in automotive engine compartment conditions[16]. Research showed that adding one more element to SAC either gave an alloy with too high a melting temperature (so damaged components) or too low a maximum operating temperature for engine compartment applications[17]. Automotive and solder alloy manufacturers collaborated to develop a novel six-component alloy (called InnoLot) that was superior to the standard SAC alloys and this will be used as the lead-free soldering alloy where higher operating temperatures are experienced in vehicles that are in scope of the ELV Directive.

One of the main reason that SAC alloys that are used for consumer electronics are unsuitable with engine systems is the high use temperature which can be up to 150°C[18] with vibration as

[16] See figure 3 of “Lead-free for High-reliability, High-temperature Applications”, H. Steen and B. Toleno, http://www.henkel-adhesives.com/com/table_images/181928_LF_High_Reliability_High_Temp_App.pdf

[17] The alloy is called InnoLot and contains tin, silver, copper, nickel, bismuth and antimony http://www.onboard-technology.com/pdf_giugno2008/060806.pdf

[18] The automotive industry specified 150°C as the maximum operating temperature for a lead-free solder.

an additional issue. Large thermal cycles with vibration is shown in tests to be worse than either effect alone. Engines in scope of RoHS are used at fixed locations and so do not experience the air flow that moving vehicles experience. Also, they are under load most or all of the time in use and so the operating temperature of sensors in these engine applications can be significantly hotter than in passenger cars and hot for much longer periods. Vibration also tends to be more severe (see Table 3). It is therefore not known if the automotive SAC alloy will be reliable in these types of equipment (as discussed below) and lengthy research will be required.

Research into long term reliability of lead-free solders subjected to the types of hostile environmental conditions experienced by equipment with engines in scope of RoHS, covered by this request, has been carried out and is discussed below:

Vibration:

Vibration can cause solder bonds to fail by cracking and this phenomenon is also known as high cycle fatigue. Engines need to be designed to withstand vibration forces of up to 12 g. The susceptibility to high cycle fatigue is dependent on; the g-force, whether the vibration is random or directional, vibration frequencies, design, the composition of the solder alloy and other variables such as the terminal coating composition and type of PCB laminate material.

Research published by the National Physical Laboratory (NPL) with solder bonded to copper plates in order to eliminate the effect of design showed that tin/lead solder was superior to the lead-free alloys tested (SAC0305 and SAC387), especially at higher frequencies[19]. NPL's tests showed that at all frequencies, SnPb had a lower probability of failure than any of the four SAC alloys they tested and this was especially the case at the higher frequencies of 400 and 800Hz that were assessed. The numbers of vibration cycles to 20% probability of failure from Wiebull plots were:

Table 5. NPL vibration results – cycles to failure

Solder alloy	20% probability at 400Hz	20% probability at 800Hz
SnPb	200,000	20,000
SAC305	100,000	2,000
SAC387	60,000	8,000
SAC 0305	40,000	4,000
Annealed SAC305	9,000	-

A comparison of SnPb and SAC solder bonds to SnPb and SAC alloy ball grid array package on FR4 laminate at vibration g-forces of 10g and higher by Calce showed that Sn37Pb solder is more reliable than SAC solder[20]. Another publication[21] also shows that at high vibration load (30g) with chip resistors on a laminate circuit board, the lifetime of SnPb solder bonds is considerably longer than SAC305 and SN100C (Sn-0.7Ni-0.05Cu+Ge) solders.

Often research has given contradictory results but the reason was demonstrated by research carried out by JGPP[22] which showed that susceptibility depends on:

- The solder alloy composition

One solder manufacturer indicates that InnoLot can be used at up to 165°C,

19 High-Frequency Vibration Tests of Sn-Pb and Lead-Free Solder Joints, D Di Maio and C Hunt, NPL report MAT 2, August 2007

20 Vibration Durability Investigation for SAC and SnPb Solder: Based on JCAA/JG-PP Lead-Free Solder, Project Test Results, CALCE Electronic Products and Systems Center, 2006.

21 http://www.dfrsolutions.com/wp-content/uploads/2012/06/2008_03_ni_modified_sncu_vibration.pdf

22 T. Woodrow, JCAA/JG-PP Lead-free solder project: Vibration and Thermal Shock Tests", April 2006. http://www.jgpp.com/projects/lead_free_soldering/April_4_Exec_Sum_Presentations/040406WoodrowVibThShock.pdf

- Type of component
- Position on circuit board (as this affects the g-force)
- g-force

The JGPP research used test boards having several types of components each attached at several positions. Three lead-free solders and SnPb solder were compared. At lower g-forces, no failures occurred during the 7 hour period of the test but at moderate to high g-forces, there were many failures. The most susceptible type of component to fail was the ball grid array (BGA). The test board had several of these and most of BGAs had bond failures before other types of component although the time to failure was strongly dependent on the location on the PCB. Results with BGAs showed that during the tests, failures were significant at g-forces above 9g and that the lead-free solders tested failed before SnPb. In these tests, g-forces were increased once every hour. Results for two of the BGAs are shown below (BGAs U4 and U6 were of the same type).

Table 6. Proportion (%) of BGAs with failed bonds during vibration testing comparing SnPb with SAC and SACB solders

	BGA U4			BGA U6		
g-force	**SnPb**	**SAC**	**SACB**	**SnPb**	**SAC**	**SACB**
9.9	40	80	100	0	20	0
12	80	100	100	20	60	40
14	100	100	100	40	100	60
16				60	100	100
18				60	100	100
20				80	100	100

SAC = Tin, silver and copper
SACB = Tin, silver, copper and bismuth

As component location affects vibration failure it is difficult to compare different types of component but most of the other types of components at locations adjacent to U4 and U6 and so experiencing similar vibration force and amplitude, failed after longer periods than these BGAs.

Research for a Ph.D. thesis compared SnPb with various SAC alloys including “InnoLot” solder and tin/copper/nickel (SnCuNi) solder[23]. This showed that SAC305 and SnCuNi were very inferior to SnPb in the range of stresses assessed, whereas tests with InnoLot at 30MPa nominal stress gave performance that was similar to SnPb (25°C and 600Hz, although the test conditions were not identical for these two alloys). This study showed that InnoLot was superior to standard SAC alloys, which helped to confirm its use in passenger car applications, but is insufficient to know how it will behave in more severe NRMM applications, especially as in more detailed published results, InnoLot was slightly superior to SnPb at 30MPa but inferior to SnPb at about 34MPa and higher stress levels[24].

Large temperature cycles:

Large cyclic temperature changes will occur with engine systems. For example the sensors will reach very low ambient in Northern Europe at night in the winter when the engine is not in use. Temperatures below -20°C are not unusual in Northern Sweden and Finland and -45 to -50°C is recorded fairly regularly[25]. When the engine is running, some sensors that are attached to the engine or to the exhaust pipe can reach 100 - 150°C and hotter, such as in hot exhaust gases.

[23] Lead-free Solders for High-Reliability Applications: High-Cycle Fatigue Studies, N. Barry Ph.D. thesis 2008, http://etheses.bham.ac.uk/198/1/Barry08EngD.pdf
[24] See slide 38 of http://thor.inemi.org/webdownload/2014/BA_Test_Tech_Aug/05_Lin_Henkel.pdf
[25] http://en.ilmatieteenlaitos.fi/seasons-in-finland

This large temperature range can result in large stresses being imposed on solder joints due to differential thermal expansion and contraction of the component and substrate which have different thermal expansion coefficients. This is especially a problem with larger ceramic components (such as chip resistors and ceramic ICs, but this can also be an issue with many other types of component) on polymer laminate PCBs. Ceramics (and silicon die) have typically much lower thermal coefficient of expansion (TCE) than polymeric PCB laminate materials and stresses bare imposed as illustrated below.

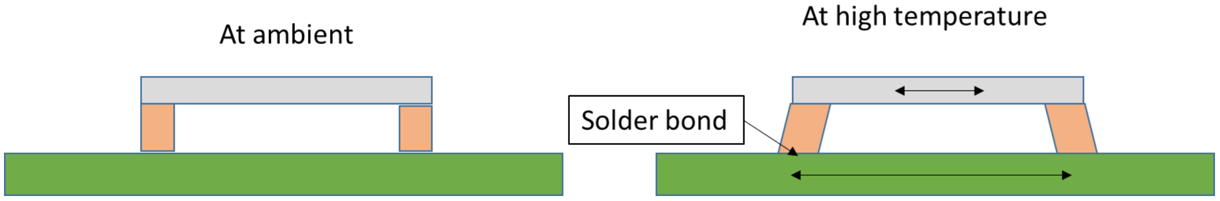

Figure 3. Strain imposed on solder bonds due to heating laminate (green in above) with a larger TCE than the TCE of the component (grey in the above diagram)

There are many publications that compare SnPb with a variety of lead-free solder compositions. These show that thermal fatigue performance of lead-free solders is different to SnPb and it can be superior or inferior depending on:

- Alloy composition, and;
- Stress imposed on solder bonds, which is dependent on component and laminate design, dimensions, materials used and the size and rate of the cyclic temperature range

Due to the many parameters that can affect stress level, it is very difficult to predict service lifetimes. It is also difficult to estimate lifetimes from accelerated testing as acceleration factors for tin/lead and lead-free solders are different. However, research has shown that overall, lead-free alloys tend to be superior to SnPb at low stress levels, whereas SnPb is superior overall at high stress levels.

Drop shock

Early research with lead-free solders showed that these had inferior drop shock performance compared with SnPb solder. This was a concern with portable devices that are often dropped such as mobile phones.

Research published by Heaslip et al[26] in 2005 compared the drop performance of printed circuit boards (PCBs) having ball grid array (BGA) devices made using SnPb with SAC305 solders. Drop performance of PCBs made with SnPb and Sn3.8Ag0.7Cu BGA balls and solder pastes were compared using drop heights of 406 and 610 mm. Two types of failure were noted: “hard” faults where permanent open circuits occurred and “soft” faults where brief periods of high electrical resistance occurred. Brief periods of high electrical resistance are sufficient to cause a sensor to malfunction and transmit an incorrect signal that could detrimentally affect emissions and fuel efficiency. A selection of Heaslip’s results is shown in the table below which shows the when the first soft failures occurred after the following numbers of drops:

[26] Heaslip, Ryan, Rodgers & Punch Stokes Research Institute and University of Limerick, “Board Level Drop Test Failure Analysis of Ball Grid Array Packages” …….

Table 7. Results of drop shock tests with SnPb and SAC solders

Drop height mm.	Number of drops until soft failure	
	SnPb	SAC
406	Best 200, worst 70	Best ~40, worst 10
610	Between 30 – 70 drops + one test after only 10 (possibly due to a solder defect)	All failed after <20 drops

This research clearly shows that SAC305 solders have significantly inferior drop performance than SnPb and so if engine sensors were to be made with SAC305 solder, they could be more likely to fail than SnPb soldered versions. As a result of these results, which has been confirmed by other researchers, alternative types of lead-free alloys have been evaluated for comparison with SnPb solder.

Research published in 2007 compared the drop performance of simulated BGA assemblies soldered using a wide range of solders[27]. This research used 17 lead-free solder alloy compositions including three alloys with ~3% silver, the rest with lower amounts of silver and these were compared with SnPb solder. All of the SAC alloys with ~3%Ag gave significantly inferior performance to SnPb confirming Heaslip's results. However several of the SAC alloys that contained ~1% silver plus certain additives gave slightly superior drop performance to SnPb when tested in the "as reflowed" condition. This condition is however unrepresentative of electrical equipment as all solders "age" in use and this changes their microstructure so that they perform differently. This research also compared drop test performance of more representative aged samples and this showed that only one lead-free solder was superior to SnPb. This alloy contained 1.1% silver (Ag) and 0.13% manganese (Mn) which survived after a minimum of about 15 drops whereas SnPb survived a minimum of 10 drops in these tests. It would appear therefore that if drop performance were the only important criteria Sn1.1Ag0.64Cu0.13Mn could be used, but due to other performance limitations such as its rather high melting temperature for use in solder pastes (this melts in the range 217 - 227°C) and as this alloy is not available commercially, it cannot be considered as a practical substitute.

Some manufacturers are now however using commercially available SAC105 solders in applications where being dropped is likely such as for mobile phones and it is clear that these have superior drop performance to SAC 305 solder[28]. Solders with low silver content have however been found in comparative testing to give inferior thermal fatigue performance[29], so choice of solder has to be a compromise and needs to consider which failure modes are the most significant – due to thermal cycling or being dropped.

Limited drop testing of InnoLot solder has been published[30] and these show that it is overall slightly inferior to SAC alloys (alloys with about 3% silver were used), although results were very dependent on the type of electronic component and SAC alloy composition. Overall results from all components tested were.

InnoLot Average number of drops to first fail = 5 drops

SAC Average number of drops to first fail = 5.9 drops

InnoLot can perform much worse than SAC when used on some types of components, but was

[27] Weiping Liu and Ning-Cheng Lee, "The Effects of Additives to SnAgCu Alloys on Microstructure and Drop Impact Reliability of Solder Joints", Journal of Materials, July 2007
[28] Zhang, Cai, Suhling & Lall, "Aging effects on the mechanical behaviour and reliability of SAC alloys", Proceedings of the ASME 2009, July 19-23, 2009, San Francisco, California, USA
[29] IPC study, abstract from https://www.itri.co.uk/solders/solders/study-compares-themal-fatigue-of-sac105-and-sac305-solders
[30] See Henkel presentation in footnote 11, slide 42.

superior with others. For example, failure occurs after only 10 drops with an InnoLot soldered 196 – PBGA (plastic ball grid array) using Au-Ni board finish compared to 20 drops with SAC solder. InnoLot is a high silver content solder and so based on previous research described above is very likely to be inferior to SnPb for drop-shock resistance. If InnoLot solder were to be used in engine components then reliability will be a significant concern as reliability will be uncertain, as the equipment is likely to experience sudden shocks that impose the very high g-forces that occur when dropped (such as when it is unloaded from vehicles or containers) or when transported over very rough terrain.

Higher operating temperature

Apart from the effect on cyclic thermal fatigue described above, the reliability at operating temperatures that are higher than those experienced by most types of electrical equipment has been much less thoroughly studied. Most published testing assumes an ambient of 25°C, whereas NRMM engine and exhaust gas sensors may operate at >150°, although electrical circuitry is designed to be used at up to a maximum of 150°. The automotive sector, when looking for lead free solders to comply with the ELV directive soon realized that the available standard SAC solders would not be sufficiently reliable and were overall less reliable than SnPb solders, mainly due to the higher operating temperatures and so they needed to develop lead-free solders that would be reliable in passenger vehicles.

Lead-free solder research for “engine compartment” applications (i.e. close to the engine, but also next to exhaust systems and so operating at elevated temperatures) has been carried out. As discussed above, R&D showed that standard SAC alloys were unsuitable and inferior to SnPb and as a result a special six-component “InnoLot” alloy was developed (and patented by Henkel) which appeared to be superior to standard SAC alloys[31]. This is the main lead-free electronics soldering alloy that has been developed for engine compartment automotive applications (for passenger cars).

The operating temperatures experienced by electrical components in engine systems is similar to those that can occur in passenger vehicles but will often be at the highest temperatures for a much larger proportion of their lifetime and the effect of this on reliability is as yet unknown. The automotive lead-free solder called InnoLot solder has not been fully assessed for reliability for engine use conditions.

One publication suggests that at temperatures of up to about 200°C, high melting point solders such as 5% tin, 93.5% lead, and 1.5% which has a melting point of 294°C[32] could be used (lead in these alloys are exempt from RoHS by exemption 7a of Annex III). This type of solder is very different to standard solders such as SAC and SnPb being harder and requiring much more aggressive and corrosive fluxes. Their high melting point means that they cannot be used on standard PCB laminates and many types of plastic packaged electronic components will be damaged at the soldering temperature which is typically 30 – 50°C higher than alloy’s melting temperature (so at up to 350°C for Pb5%Sn1.5%Ag). Thermal fatigue and vibration resistance of these alloys has not been comprehensively studies and no data appears to be published. Therefore, the reliability of these alloys in engine applications is not known.

There are other higher melting point solders available such as those listed below:

Table 8. Examples of high melting point solder alloys

Alloy	Melting temperature	Performance
Sn65%Ag25%Sb10% (J-alloy)	233°C (eutectic)	Alloys with this amount of antimony will be hard and

[31] http://www.henkel-adhesives.com/com/table_images/181928_LF_High_Reliability_High_Temp_App.pdf
[32] http://www.analog.com/en/analog-dialogue/articles/high-temperature-electronic-pose-design-challenges.html

		brittle
Sn95%Sb5%	237 - 240°C	Alloys with this amount of antimony will be hard and brittle
Au80%Sn20%	280°C (Eutectic)	Too hard and brittle for bonding multi-terminal components or larger area bonds. Too high a melting point, so soldering would damage most polymers
93.5%Pb 5%Sn1.5%Ag	294°C (Eutectic)	See comments above

NPL has carried out an extensive study into soldering with high melting point solders[33]. The results of this study with two high melting point solder alloys were:

- SnSb8% solder paste was reflowed at 275°C, but solder wetting was incomplete. Aging at 200°C for 1000 hours resulted in halving of the shear strength of the solder bond, which suggests that reliability could be poor
- The high melting point solder, Pb93.5Sn5Ag1.5; solder paste required a reflow temperature of over 330°C, but solder wetting was not complete. Shear strength decreased from 54 to 41 after aging at 200°C for 1000 hours (units not given in paper, but are probably MPa). 330°C is much too hot for most components and laminates.

These results show that both alloys would be difficult or impossible to use due to the high reflow temperature and that the reliability of the SnSb alloy may be poor as indicated by the large decrease in bond shear strength.

Corrosion:

Failures of electrical circuits due to corrosion can occur, especially when they are exposed to corrosive gases such as hydrogen sulphide and to liquids such as those present at industrial locations where some engines are used.

An issue with most lead-free solders is that they contain silver such as in the SAC alloys. Silver is very susceptible to the formation of dendrites which form when a potential difference exists between conductors. Silver dissolves from the anode and is redeposited as long filamental growths (known as dendrites) on the cathode and eventually cause a short circuit. An example is shown in the microscope image below.

[33] Practical Guide to Soldering PCBs with High Temperature Solder Alloys, Good Practice Guide No 136, Chris Hunt and Bob Willis, National Physical Laboratory, ISSN 1368-6550, 2015.

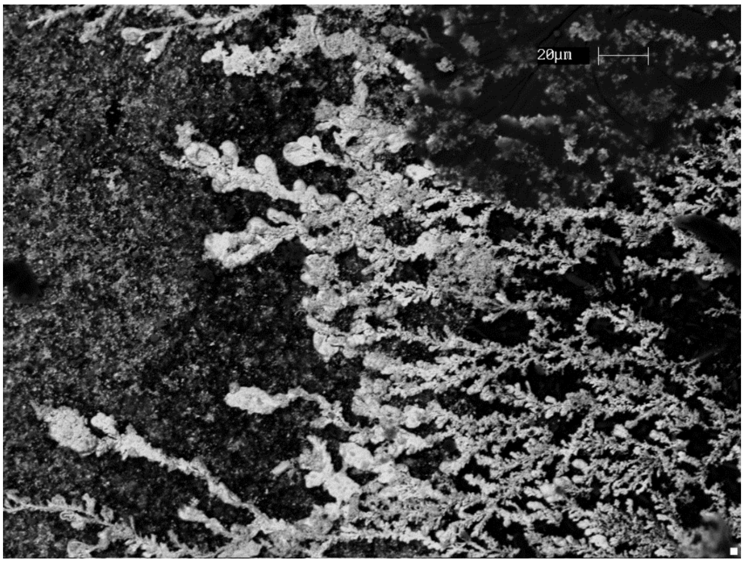

Figure 4. Microscope image of silver dendrites on a printed circuit board

Dendrite formation requires that the surface between the conductors is both wet and contains ionically conducting contamination. Ionic materials that could cause dendrite formation include salts that dissolve in surface moisture (e.g. condensation) from dirt and soil that are commonly present in construction sites and farms, salts from sea spray at marine locations and corrosive gases that may be present in chemical factories and oil refineries, etc.

Hostile environments that contain gases have been found to cause early failure of lead-free soldered PCBs. Molten lead-free solder wets the substrate solder pads less well than tin/lead solder and so can result in an unwetted area around the solder bond. Where there is an unwetted area at the edge of the pad that connects to a conductor track, corrosive gases such as hydrogen sulphide, chlorine and NOx can cause corrosion of the exposed copper pad and eventually loss of metal that can cause an open circuit. This can be prevented by redesign of circuit layouts and good soldering process control, but this requires additional development time to ensure that quality can be maintained. Conformal coatings do not always prevent this type of failure as gases can migrate through these coatings to reach the metal pads and tracks[34].

Welding and brazing

Welding requires a temperature of well over 1000°C, the temperature needed to melt copper. At this temperature, all types of polymer insulation will be destroyed. Brazing is typically carried out at about 450 - 500°C at which all types of polymer would be destroyed

Plug and socket connectors and crimp connections

This form of bonding is suitable only for some types of connection. These cannot, for example be used for surface mount components and are also inappropriate for through-hole components on printed circuit boards. Crimp connections are suitable for wire and round connectors so that the crimp can grip the terminal and wire. These cannot be used on flat surfaces and are often unsuitable inside sensors and actuators where there is too little space available.

Components such as sensors and actuators can easily be replaced if they are connected to other parts or to the wiring harness using plug and socket connectors and these are very common in passenger vehicles and are also used in engine systems, although these can be unreliable when used in hostile environments for long lifetime equipment. Inferior reliability has two main causes.

- Because these are a physical bond, unlike soldering, when there are temperature fluctuations, these cause differential expansion and contraction of the terminals.

[34] Personal communication from Edif ERA failure analysis department

Vibration can also cause small movements. These can cause repeated sideways movement that can cause the terminals to slide against each other very slightly. After each movement, this exposes fresh metal by disrupting the protective air formed oxide at the surface to air which then re-oxidizes. Gradually the amount of oxide builds up until there is sufficient to increase the electrical resistance. Increased resistance affects the signals from sensors, which can negatively affect emissions, it also causes resistive heating which accelerates oxidation so that eventually a runaway situation occurs and the bond becomes insulating. This process is called fretting and can cause failure of tin plated and less commonly gold/nickel terminals[35].

- Contact pressure from the crimp or from a plug and socket connection is maintained by the tensile properties of the crimp metal or by the socket material. However, all metals suffer from a process called creep where the metal relaxes and the contact force decreases. This exacerbates the fretting corrosion described in the above bullet as it allows more movement. Research has shown that the mechanical strength of crimps can be poor when the electrical conductivity is optimized. Also, in conditions of high temperature and vibration such as in engine applications, crimps may be unsuitable and some research has shown that they can be unreliable[36].

Conducting adhesives

These are not widely used as an alternative to solders because their long term reliability can be inferior and there is also a tendency for the contact resistance to increase over time mainly due to surface oxidation of terminal surfaces. This occurs as the copper conductor diffuses to the surface (through electroplated over-layers of tin, silver, etc.) where it rapidly forms electrically insulating copper oxide when exposed to air. The conductor particles in some types of adhesive can also oxidize or corrode. Silver is commonly used as the conductor particles, but forms insulating sulphides when exposed to traces of hydrogen sulphide which is fairly common in industrial sites where engine systems are used. Also, if precious metal particles are used, these can form a galvanic cell with the substrate copper accelerating its oxidation. Vibration is another factor that can negatively affect reliability of conducting adhesives by delaminating the adhesive bonds.

A recent review of substitutes for high melting point solders, published by CALCE[37] considered conducting adhesives, but concluded that these materials are usually unsuitable because of their inferior electrical and thermal conductivity. Also, at elevated temperatures with high humidity, the polymers that are used are unstable and so they would be unsuitable for power semiconductor die attach (the main topic of this study). They would therefore also be unreliable with sensors, actuators and ECUs where consistent low electrical conductivity is required because unstable conductivity would affect the accuracy of output signals from the sensors and within circuits. NPL also considered commercially available conducting epoxy adhesives for high temperature electronic interconnects but all failed giving zero shear strength after aging at 200°C for 1000 hours[33].

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[35] Degradation of Road Tested Automotive Connectors Johnathan Swingler, John W. McBride, and Christian Maul, IEEE TRANSACTIONS ON COMPONENTS AND PACKAGING TECHNOLOGIES, VOL. 23, NO. 1, MARCH 2000 http://eprints.soton.ac.uk/21455/1/21455.pdf Also;
Deterioration Analysis of Automotive Connectors Used in High Mileage Vehicles, Shigeru SAWADA*, Atsushi SHIMIZU and Yasushi SAITOH http://global-sei.com/technology/tr/bn81/pdf/81-02.pdf

[36] See page 392 of "Electrical Contacts: Principals and Applications" 2nd ed. Paul G Slade, CRC download from https://books.google.co.uk/books?id=N7LMBQAAQBAJ&pg=PA410&lpg=PA410&dq=fretting+crimp+terminals&source=bl&ots=v9L0lmpRmD&sig=mMO5SqG263dA8mKJWAszyjG1jIA&hl=en&sa=X&ved=0ahUKEwibnPPaiuTPAhUIaxQKHXxkDLMQ6AEIWjAJ#v=onepage&q=fretting%20crimp%20terminals&f=false

[37] High lead solder (over 85%) solder in the electronics industry: RoHS exemptions and alternatives. S. Menon, E. George, M. Osterman and M. Pecht, J Materials Science, Materials Electronics (2015) 26, 4021 – 4030.

Solderless designs

This is scientifically impractical for many types of sensor that have internal electronic functions and for all actuators and all control modules. Many types of sensors need to be mounted onto printed circuit boards with other electronic components (for example digital temperature sensors are supplied as surface mount 8 terminal packages). A few types of sensor are mechanical in function internally and so solder can be avoided, however these sensors need to be connected to the engine control module using electrical connectors.

(B) Please provide information and data to establish reliability of possible substitutes of application and of RoHS materials in application

Included above in previous section 6A.

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7. Proposed actions to develop possible substitutes

(A) Please provide information if actions have been taken to develop further possible alternatives for the application or alternatives for RoHS substances in the application.

The automotive industry is developing lead-free soldered sensors, actuators and ECUs for use in vehicles that are in scope of the ELV directive that have been type approved since 1 January 2016. However passenger cars and other vehicles in scope of ELV that were type approved before this date can continue to use lead-based solders due to the exemption. However, not all of the new "lead-free" sensors, actuators and automotive engine control units will be suitable for use in engine systems in scope of this exemption request due to having to operate within a different performance range, more hostile environmental conditions or not being ATEX approved. However, some of these components are functionally suitable and so are being evaluated to determine if performance is suitable, whether the engines will meet mandatory emissions requirements of the EU NRMM Regulation and if they will have the required long term reliability and maintain emissions within legal limits over the lifetime of the engine. Design and testing of new engine designs can start only when suitable RoHS compliant sensors and actuators become available (i.e. **all** sensors and actuators as lead-free versions for each type of engine) and this relies on manufacturers of these components providing suitable lead-free soldered versions. Manufacturers of sensors, actuators and ECUs that are designed for commercial road vehicles (these are excluded from the ELV Directive) are not required to comply with RoHS and these road vehicle components are often the same as those used in engine systems in scope of this exemption request. However, engines that are in scope of RoHS account for only a tiny proportion of the commercial engine components markets and as a result, manufacturers have only a small incentive to develop components specifically for this market and this is delaying development of substitutes.

Lead-free components are increasingly available for passenger cars but these may not all be suitable in NRMM which usually use types of sensors, actuators and control units that are designed to be used with large commercial vehicles that are excluded from the ELV and RoHS directives and so are not required to be lead-free. Some engine manufacturers produce their own engine control units and so have design control and some lead-free soldered control units have been designed and are being tested for reliability as well as for compliance with the NRMM Emissions regulation "stage V" requirements. There is however a resource issue here. NRMM engine manufacturers are having to redesign engines to comply with Stage V of the NRMM

Emissions Regulation and redesigned engines will be needed between 2018 and 2021, but RoHS compliance is needed by 2019. As described below, redesign, testing and gaining approval of engines requires a great deal of time and effort. Every time a design change is made, re-approval is needed which is almost as much work as gaining approval for a new design. Also each manufacturer has access to a finite number of specialist trained engineers who can design and test engines and so will not have the capacity to redesign and gain approval for all engines in their portfolios to meet Stage V and RoHS in time for the RoHS deadline in 2019.

The introduction of new engine components requires several steps as follows:

When a new lead-free component becomes available, it is first tested to determine if its functionality is suitable and it meets the reliability specification. These are first assessed in laboratory test rigs (not in engines) including by accelerated testing for vibration and thermal fatigue. If they pass these preliminary tests, they are assessed for reliability in bench mounted engines and finally are field tested in engines installed in working equipment. Typically 50 engines need to be field tested to assess reliability and to ensure compliance with emissions legislation. Laboratory testing of components has been found by engine manufacturers to be insufficient as sensors, actuators and ECUs can behave very differently in engines and in field testing than in lab tests and so engine and field tests must also be carried out to determine whether they will be reliable, give long lifetimes and meet durability and emissions legislation requirements.

Testing in engines cannot begin until all of the sensors, actuators and control units used with a particular engine are available as RoHS compliant types because the NRMM will not otherwise comply with the RoHS Directive. Although some sensors and other components are currently available as RoHS compliant versions, there are still many types that do not comply, for example, because the sensor manufacturer is still using lead-based solder.

Each manufacturer uses their own test program and this will be different to those of other manufacturers. Requirements and test programs are based on the manufacturers' knowledge of the real conditions that their products experience, which will differ between different types of equipment. Examples of the performance and reliability requirements of manufacturers of engine systems includes the following:

Table 9. Performance and reliability requirements of engines in scope of this exemption request

Characteristic	Requirement
Vibration at 10Hz – 2kHz	Maximum 12 g RMS
Mechanical shock	Peak pulse amplitude maximum of $500 m/sec^2$ Number of shocks is 18 with 6 in each axis
Drop shock of components before installation	1m height, 36 drops, 6 on each face as viewed as a cube. Separate tests with packaged components are also carried out.
Thermal cycling	Varies, for example -40 to +150°C, 1000 cycles
Operating lifetime	Typically, 10 calendar years or 20,000 operating hours with a reliability of 99.6%
Sensor output accuracy	This is specified, e.g. at <3% of full scale. Important for compliance with stage V but can be affected if solder bonds deteriorate

Combined vibration and thermal cycling	Simultaneous exposure to vibration and thermal cycles such as with the above examples. This will be with the components powered and under load
Electrical testing	Survive polarity reversal, voltage spikes, etc.
Environmental conditions	Corrosive atmospheres, exposure to chemicals, exposure to dust, washing and salt spray. Should not affect reliability, performance or lifetime.
EMC compliance	This must be determined for the redesigned engine and cannot be assessed by testing individual sensors and other components separately. EMC emissions and susceptibility can only be assessed on completed engines and can significantly lengthen development time.

Although R&D and testing is underway, this will not be complete until after July 2019. Future activities are described below.

(B) Please elaborate what stages are necessary for establishment of possible substitute and respective timeframe needed for completion of such stages.

Reliability assessment of potential substitutes will follow a similar process and timescale to the substitution of engine bearings described in a previous RoHS exemption request.

The stages required before alternatives become available are:

Stage	Requirements
1. Search for alternative components	This is underway and some sensors and actuators (some are designed to comply with the EU ELV directive) and a few ECU designs made with lead-free solders have been identified and are being tested. However many are not yet available as lead-free solder versions and suppliers often cannot give dates when they will be available. As a RoHS compliant NRMM requires all parts to be "lead-free", a completion date cannot be defined
2. Evaluation in components	Function, accuracy and reliability are assessed before testing in engines. This can start only when suitable components and devices are identified
3. Evaluation of lead-free components in engine assemblies	This phase can start if suitable lead-free components are found to be satisfactory and meet all of the manufacturers' requirements. It will be necessary that all sensors, actuators and ECUs that are used with each engine comply with RoHS and have passed testing as components before engine testing can begin.
4. Engine redesign	Alternative sensors, actuators and control units may not be suitable as drop-in replacements, so time will be needed for engine design changes so that available and suitable components can be used (this is described below)
5. Evaluation of lead-free	Can begin this phase only when bench testing of

engines in the field	engines with lead-free designs indicates that these are reliable and performance and emissions are not adversely affected by substitution.

The timescale for re-design and validation of engine sensors, actuators and engine control units is very uncertain as this partly relies on suppliers who have little or no incentive to develop lead-free versions specifically for the industrial equipment sector. The process involves iterative steps in the lab and in field test to develop an effective design in each individual engine platform. Changing to a different sensor, actuator or control unit design may require changing the engine's design, not just replacement of the components only and time will be needed for these changes and to ensure that reliability and emissions are not negatively impacted. Modern engines are controlled by computers which are part of the ECU. When physical redesign is required, rewriting of software is usually also required and this can take many additional months of work.

Engine development, as with any heavy machinery development, is an iterative process that can take several years to be completed before a new engine or engine component is on the market. Condensing current design processes, the primary design phases include Design Validation, Product Validation, Production, and Post-Production monitoring.[38]

Initial Design Validation may begin with bench testing using destructive and non-destructive testing of components. Failure Mode Effects Analysis[39] [FMEA] is normally performed in conjunction with this bench testing. Following bench testing, potential candidate components are further evaluated in controlled testing in whole machinery for Product Validation. Small numbers of prototype machine builds using potential component candidates are constructed and evaluated in controlled operations. Similarly, FMEA may be done on prototypes. After review, production may be begun on approved components. Finally, post-production quality monitoring provides a measure of the components adequacy and robustness.

Engines and engine component development and evaluation can take years to complete. Recent engine development has been required by EU legislation to meet Stage V of the Non Road Mobile Machinery Regulation (and similar United States Tier IV Final[40] emissions) which has been underway for many years and takes many years of work.[41],[42] Sensors will be critical to meeting the new EU Stage V emission requirements, as well as to engine operation, reliability and durability. The iterative engineering validation processes noted above are critical to ensure the engine's durability and reliability.

Moreover, recent changes in engine design to meet these reduced emission requirements have raised issues of engine component robustness. A recent report by the California Air Resource Board cited higher warranty claims when new emissions standards took effect in California in 2004, 2007 and 2010.[43] Similarly, because these same base engine designs and configurations

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[38] Vehicular Engine Design, Kevin L. Hoag M.S., ISBN: 978-3-211-21130-4 (Print) 978-3-211-37762-8 (Online) referencing AVL Engine Design. Also see http://link.springer.com/chapter/10.1007/3-211-37762-X_4#page-1. Note that the engine design validation process starts almost 42 months prior to market introduction and production.

[39] http://asq.org/learn-about-quality/process-analysis-tools/overview/fmea.html

[40] 40 CFR part 1039 (Code of Federal regulations part 1039), "Control of emissions from new and in-use non-road compression-ignition engines"

[41] Non-Conformance Penalties for Heavy-Duty Engines Subject to 2010 NOX Emission Standard: Response to Comments 420r12015, p16 ("new engine development program … 22 months"); p22 ("years of resources").

[42] Draft Technical Support Document: Non-Conformance Penalties for 2004Heavy Duty Highway Diesel Engines 420D02001, p15 ("incorporation of all these technologies is not a simple task … requires several years of research and development").

[43] Evaluation of Particulate Matter Filters in On-Road Heavy Duty Diesel Vehicle Applications, CARB

are utilized in a myriad of applications (including equipment in scope of RoHS), the engineering evaluation process will require testing and validation of any components across all of those applications to ensure performance, robustness and durability. Introduction of mass-produced components such as Pb-free sensors will require extensive testing and evaluation across the myriad applications of Non-Road engines, not just in one type such as with mobile generator sets.

Timescales for the four stages are required when a new substitute component is used in an engine, especially if there is a possibility that it will affect emissions.

1. Identification of suitable sensors, actuators and ECUs that meet the performance requirements. This work has already started and some components that do not contain RoHS restricted substances have been identified, but some types of "RoHS-compliant" sensor and actuator have not yet been identified. This phase is out of the control of engine manufacturers for sensors and actuators as these are designed and manufactured by specialist manufacturers of these products. Therefore it is not possible to determine how long this phase will take for all of the sensors and actuators used in the engines placed on the EU market.

2. Design of new ECUs and validation of performance and reliability by laboratory testing of ECUs, sensors and actuators using accelerated stress testing will take for one engine design up to two years. In practice as the availability of suitably trained engineers is limited, this can take longer and be up to **three years** in elapsed time

3. If the components satisfy the laboratory tests, they are installed into engines and the engines are bench tested to determine how they perform, whether they are reliable, their durability and the long term impact on emissions. Emissions and durability testing are both carried out to obtain data that will be required for NRMM Emissions Regulation type approval if the engine is also used in these applications. This takes for each engine typically **two years** although the elapsed time may be longer.

4. Finally engines with substitute components are tested in non-road mobile machinery in the field. The performance, emissions and reliability are assessed from up to 50 types of machinery with the new engine designs in order to obtain statistically meaningful data. This takes about **two years** although the elapsed time can be longer.

5. Before a new engine design can be manufactured and placed on the EU market and used in NRMM equipment, it must first receive approval from an EU Notified Body for compliance with the NRMM emissions Regulation. When this is obtained, the factory needs to be modified and staff trained in order to produce the new engine and ensure that production quality is high and consistent. This generally takes **an additional year** to complete.

The total elapsed timescale for design, testing, approval and manufacture of a new design of engine that complies with both the RoHS Directive and other applicable legislation such as the NRMM emissions Regulation is estimated to be **about eight years** in elapsed time, but this can start only when all components are available as RoHS compliant versions.

08MAY2015, p12 http://www.arb.ca.gov/msprog/onrdiesel/documents/DPFEval.pdf .

8. Justification according to Article 5(1)(a):

(A) Links to REACH: (substance + substitute)

1) Do any of the following provisions apply to the application described under (A) and (C)?

   ☐ Authorisation

   - ☐ SVHC
   - ☐ Candidate list
   - ☐ Proposal inclusion Annex XIV
   - ☐ Annex XIV

   ☐ Restriction

   - ☐ Annex XVII
   - ☐ Registry of intrusions

   ■ Registration – lead has been registered in the EU[44]

2) Provide REACH-relevant information received through the supply chain.
   Name of document: ______

(B) Elimination/substitution:

1. Can the substance named under 4.(A)1 be eliminated?

   ☐ Yes. Consequences? ______

   ■ No. Justification: Reliability cannot be assured

2. Can the substance named under 4.(A)1 be substituted?

   ☐ Yes.

   - ☐ Design changes:
   - ☐ Other materials:
   - ☐ Other substance:

   ■ No.

   Justification: Reliability cannot be assured

[44] http://www.reach-lead.eu/

3. Give details on the reliability of substitutes (technical data + information): See section 6 above
4. Describe environmental assessment of substance from 0(A)1 and possible substitutes with regard to
   1) Environmental impacts: Not applicable to this exemption request
   2) Health impacts: Not applicable to this exemption request, although poor reliability can negatively impact on health if for example, an emergency generator fails at a hospital when needed due to a power cut.
   3) Consumer safety impacts: Not applicable to this exemption request, although poor reliability can negatively impact on safety

   Do impacts of substitution outweigh benefits thereof? Not applicable to this exemption request

   Please provide third-party verified assessment on this: ______

(C) Availability of substitutes:

a) Describe supply sources for substitutes: Some types of sensors and actuators, many of which that are designed for passenger cars, are made with lead-free solders and are becoming available. However, their reliability in professional stationary and NRMM applications that are in scope of RoHS is not yet assured. A few new types of engine control units are being developed with lead-free solders and are being tested, but reliability of equipment that use these is not assured.

b) Have you encountered problems with the availability? Describe: Yes. Sensors and actuators that are designed for commercial transport and professional stationary and NRMM engine systems are usually made using tin/lead solder or contain components that do not comply with RoHS. This is because most of these sold are used in commercial transport applications which are not in scope of the RoHS Directive. We estimate that less than 1% of these applications will be included in the scope of RoHS in July 2019 and so the manufacturers of sensor and actuator for professional stationary and NRMM engines have very little incentive to develop lead-free versions. Although some sensors and actuators that comply with RoHS have recently been identified and are being assessed, there are many types that are not yet available as RoHS compliant versions.

c) Do you consider the price of the substitute to be a problem for the availability?

☐ Yes ■ No

d) What conditions need to be fulfilled to ensure the availability? This is dependent on the activities of suppliers of sensors and actuators. Professional stationary and NRMM engine manufacturers have very little influence over these suppliers.

Socio-economic impact of substitution: NOT APPLICABLE TO THIS REQUEST

- What kind of economic effects do you consider related to substitution?
  - ☐ Increase in direct production costs
  - ☐ Increase in fixed costs
  - ☐ Increase in overhead
  - ☐ Possible social impacts within the EU
  - ☐ Possible social impacts external to the EU
  - ☐ Other: ______
- Provide sufficient evidence (third-party verified) to support your statement: _______

9. Other relevant information

Please provide additional relevant information to further establish the necessity of your request:

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10. Information that should be regarded as proprietary

Please state clearly whether any of the above information should be regarded to as proprietary information. If so, please provide verifiable justification:

_____
