Plug-in truck grant

CHASSIS DYNAMOMETER & TRACK-BASED TEST PROCEDURES FOR APPROVAL OF ZERO EMISSION AND ZERO-EMISSION CAPABLE HEAVY-DUTY VEHICLES

Test procedures for verification of zero-emission range eligibility and for measuring energy consumption, range, pollutant and greenhouse gas emissions.

1 Scope

This document provides an accurate and reproducible suite of procedures for simulating the operation of plug-in electric, fuel-cell electric, hybrid and range-extended heavy-duty/commercial vehicles (over 3.5t gross vehicle weight) on dynamometers or test tracks for the purpose of measuring their emissions and to evaluate their energy consumption and electric-only range, as part of the assessment of their eligibility for the Plug-In Truck Grant (PITrG).

For the test results to be used as evidence of PITrG eligibility for a range of different vehicle configurations (but with identical drivetrains), a "worst-case" approach should be followed. This should ensure as far as reasonably possible that the zero-emission capability and (where applicable) tailpipe emissions performance of all vehicles covered are very unlikely to be any worse than the vehicle presented for test.

The intention is to test the vehicle in its normal road-going condition (i.e. complete vehicle) and operating strategy as far as reasonably practical, within the constraints of the equipment and test cycle(s). Where this is not feasible (e.g. ex-factory chassis-cab vehicles), simulations are permissible, e.g. headboards to simulate body aerodynamic effects, load strapped directly to the chassis rails or use of VECTO-approved standard bodies. Any aspect of vehicle operation which needs to be modified for the test shall be discussed with the test centre and recorded in the test report. Simulation of RCV operation is not permitted, such vehicles must be tested with a representative (for domestic waste collection services) and fully functional RCV body, bin-lift and compaction capability.

For vehicles equipped with a combustion engine, as well as measuring pollutant emissions performance to determine if the vehicle meets or exceeds Euro VI equivalence, specifically for NOx and particulates, the procedure requires the calculation of Tank-to-Wheel (TTW) Greenhouse Gas (GHG) emissions to determine if the vehicle achieves at least a 50% GHG reduction compared to a conventional Euro VI vehicle of the same load carrying capacity.

These procedures currently cover trucks suitable for general haulage and (separately) Refuse Collection Vehicles. Testing of other heavy-duty vehicle types may require alternative test cycles or approaches, as determined by OZEV in conjunction with Zemo Partnership (hereafter referred to as Zemo).

Vehicles that could be configured for general haulage or as RCVs must be tested and approved in each condition separately for both options to be PITrG eligible.

The minimum requirements for PITrG eligibility are currently to evidence at least 60 miles zero emission operating range and the maximum speed. Where an internal combustion engine (ICE) is fitted the pollutant emissions adherence to Euro VI and evidence of tailpipe greenhouse gas (GHG) emission are required. Testing for full zero emission range capability and electrical energy consumption are required for ICE-equipped vehicles but for pure battery electric or fuel-cell electric vehicles are at the discretion of the manufacturer but will be verified by Zemo and published within the Zemo certificate for public information and any future criteria.

2 Test preparations

2.1 Test site – dynamometer testing

The ambient temperature levels encountered by the test vehicle in the dynamometer laboratory shall be maintained at 18°C+/- 2°C throughout the test.

Ambient temperatures must be recorded at the beginning and end of the test period.

Adequate test site capabilities for safe venting and cooling of batteries, containment of flywheels, protection from exposure to high voltage, or any other necessary safety precaution shall be provided during testing.

One or more speed tracking fans shall direct cooling air to the vehicle in an attempt to maintain the engine operating temperature as specified by the manufacturer during testing. These fans shall only be operating when the vehicle is in operation and shall be switched off for all key-off dwell periods. Fans for brake cooling can be utilized at all times. Additional fixed speed fans should be used if required and must be documented in the test report.

2.2 Test site – track testing

The ambient temperature levels encountered by the test vehicle on the test track should be 18°C+/-15°C throughout the test – Test temperature for the test vehicle should be within 8°C of the comparator test temperature if a comparator vehicle is tested. Track testing below 3°C is not recommended but is permitted as long as the test house can be sure there was no snow or ice on the track during testing.

Ambient temperatures must be recorded at the beginning and end of the test period.

2.3 Pre-test data collection

Prior to testing, detailed characteristics of the vehicle should be recorded, including details of the battery/fuel-cell, the internal combustion engine (if fitted) and the vehicle's gross weight and maximum payload.

For all tests involving the use of an internal combustion engine, a fuel sample shall be taken for potential analysis at a later date. The vehicle will be tested using the fuel with which it arrives at the test facility. Fuels should meet the requirements of EN590 (Diesel) or appropriate alternative standards for other fuels. Any exceptions to this should be advised by the vehicle supplier for reporting purposes.

All vehicles (test and comparator) will have a photographic record made of the overall aerodynamic package fitted and of the Vehicle VIN plate to allow full specification records to be kept.

2.4 Operation of the vehicle

If the vehicle is unable to be driven on the chassis dynamometer in its conventional operating mode, then the reasons for this should be provided by the vehicle supplier in advance of the tests for reporting purposes (e.g. regen braking system not able to work fully under dyno conditions). Any deviations from standard operation must be approved by Zemo prior to testing. In such cases, track-based testing (with the vehicle fully in its conventional operating mode) may be considered a more suitable alternative.

2.5 Condition of the Vehicle

Vehicle Stabilization -- Prior to testing, any vehicle with a combustion engine shall be stabilized (de-greened) to a preferred minimum distance of 3,000km. This will be documented in the test report. Tests at lower mileage will be considered in discussion with the test facility and Zemo. Pure Battery

Electric Vehicles and Fuel-Cell Electric Vehicles may be tested with less than 3,000km on the odometer.

Body – Where feasible, the vehicle shall be provided for test in a condition representative of normal general haulage freight operations, with a load box or bed (flat or curtain-sided). Additional ancillary devices may be fitted if they do not interfere with the loading or unloading of the vehicle (usually with a fork-lift and concrete blocks) and as long as they can be de-activated during the tests so as not to consume additional energy. Other than for RCVs, where a representative body is not feasible, appropriate simulations shall be permitted (e.g. headboard with representative maximum frontal area) and must be used if PITrG eligibility is needed for a range of vehicle configurations over and above that tested. Plans for testing based on such simulations should be discussed and agreed with Zemo beforehand.

Tyres -- Manufacturer's recommended tyres shall be used and shall be the same size as would be used in service. Tread depths will be recorded and documented in the test report.

Tyre Pressure -- Tyre pressures should be set at the beginning of the test to manufacturer's recommended pressure. This will be documented in the test report.

Lubricants -- The vehicle lubricants normally specified by the manufacturer shall be used. This specification shall be supplied by the vehicle supplier in advance of the tests and recorded in the test report.

Gear Shifting – The vehicle shall be driven with appropriate accelerator pedal movement to achieve, as far as reasonably practicable, the time versus speed relationship prescribed by the drive cycle(s). Both smoothing of speed variations and excessive acceleration pedal perturbations are to be avoided and may cause invalidation of the test run. In the case of test vehicles equipped with manual transmissions, the transmission shall be shifted in accordance with procedures that are representative of shift patterns that may reasonably be expected to be followed by vehicles in use.

It is not a requirement that test houses should follow precisely the exact gear change points and strategies specified by Type Approval legislation that use the same cycles (e.g. WHVC), though they may do so if they feel such an approach meets the requirements of the preceding paragraph.

Where a test vehicle is unable to achieve the maximum acceleration rates and/or top speeds of the drive cycle(s), it shall be driven in such a way as to replicate the journey distance defined in the overall drive cycle, for example by extending the time at cruising speed, while following as closely as possible the specified drive cycle at each point on the route.

2.6 Dynamometer Specifications

The evaluation of the emissions should be performed using a laboratory that incorporates a chassis dynamometer, a full-scale dilution tunnel, and laboratory-grade exhaust gas analysers as described in ECE R49 (Heavy-duty engines). The chassis dynamometer should be capable of simulating the transient inertial load, aerodynamic drag and rolling resistance associated with normal operations of the vehicle. The transient inertial load should be simulated using appropriately sized flywheels and/or electronically controlled power absorbers. The aerodynamic drag and rolling resistance may be implemented by power absorbers with an appropriate computer control system. The drag and rolling resistance should be established as a function of vehicle speed. The actual vehicle weight for the on-road coast down should be as close as possible to the anticipated vehicle testing weight as simulated on the dynamometer. The vehicle should be mounted on the chassis dynamometer so that it can be driven through a test cycle. The driver should be provided with a visual display of the desired and actual vehicle speed to allow the driver to operate the vehicle on (or as close as possible to) the prescribed cycle.

2.7 Dynamometer Calibrations

The dynamometer laboratory should provide evidence of compliance with calibration procedures as recommended by the manufacturer.

2.8 Inertial Load

Inertial load must be simulated correctly from a complete stop (e.g., total energy used to accelerate the vehicle plus road and aerodynamic losses should equal theoretical calculations and actual coast-downs).

2.9 Road Load

Road load and wind losses should be simulated by an energy device such as a power absorber. Road load should be verified by comparison to previously tested vehicles having similar characteristics or by coast-down analysis on the track.

2.10 Dynamometer Load Coefficient Determination

The dynamometer coefficients that simulate road-load forces shall normally be determined as specified in Directive ECE R83. The vehicles shall be weighted to the correct dynamometer test weight when the on-track coast-downs are performed. Where conventional coast-down testing is not feasible (e.g. a vehicle cannot be placed in neutral without regenerative braking being activated), the vehicle's power requirements at fixed steady-state speed increments shall be measured, covering the full range of test cycle speeds, and the dyno load coefficients adjusted to match the tested average values.

2.11 Dynamometer Settings

The dynamometer's power absorption and inertia simulation shall be set as specified in ECE R83. It is preferable to ensure that the dynamometer system provides the appropriate retarding force at all speeds, rather than simply satisfying a coast-down time between two specified speeds. The remaining operating conditions of the vehicle should be set to the same operating mode during coast-downs on track and on the dynamometer (e.g., air conditioning, etc).

2.12 Dynamometer Test Instrumentation

Equipment referenced in ECE R83 or R49 (including exhaust emissions sampling and analytical systems) is required for emissions measurements, where appropriate. All instrumentation shall be traceable to national standards.

Regulated emissions (HC, NH_3, CO, NO, NO_2, and PM) and GHG emissions (CO_2, N_2O and CH_4) shall be sampled over the entire cycle(s) and the results presented as g/km, along with Particle Number (PN).

The chassis test laboratory will be used to measure actual cycle distance during a test.

2.13 Track Test Instrumentation

Tailpipe emissions to be measured with PEMS equipment approved to ECE R49 standards, measuring CO, HC, CO_2, PN, NO and NO_2 as a minimum requirement. CH_4 and, if available, N_2O should also be measured if possible.

Fuel consumption for both test and comparator vehicles should be measured using calibrated appropriate fuel flow meters. All independently fitted instrumentation shall be traceable to national standards.

2.14 Deviations from Standard Procedure

It is permissible to deviate from the prescribed procedure in cases where it can clearly be shown that this would result in a more realistic simulation of real-world vehicle operation.

Any deviations from the standard test procedure must be recorded in the test report and approved by Zemo prior to testing.

2.15 Vehicle operating modes

For hybrid or range-extended vehicles, the vehicle will be tested in each operating mode (e.g. Charge depleting - from full battery, Charge sustaining – with depleted battery and (if fitted) Charging - charging battery from combustion engine). Emission and energy consumption will be measured. The vehicle must meet the equivalent of Euro VI level emission when operating in any mode. Manufacturers must declare if there are any alternative operating modes and ensure that the one with the highest emissions expected is included in testing.

Recharging requirements must be stipulated by the vehicle manufacturer, the default option will be to recommend standard rapid charging at 50kW nominal. The charging method and rate used should be noted but must not be less than 22kW.

2.16 Test validation

At the end of each cycle run, the total distance travelled by the vehicle over that test run will be noted from the GPS (track) or dynamometer distance measurements. Adherence of the driver to the test cycle target speeds will be noted, and a regression will be performed to compare actual speeds with target speeds on a second-by-second basis. Target speed (x) and actual speed (y) should be charted in 1Hz increments and a trend line inserted with a zero intercept. If the resulting trend line has a slope that varies from unity by more than 10% or an R^2 of less than 0.8 the test run should be considered an invalid representation of that test cycle. The actual distance travelled by the vehicle or dynamometer roller(s) should be used for the test cycle distance value.

If at any point during the test, vehicle propulsion is not possible, or the driver is warned by the vehicle to discontinue driving, then the test is terminated.

2.17 Pass/fail criteria

The detailed assessments of the minimum range and GHG emissions performance of each vehicle are described in the relevant following chapters. When testing any vehicle equipped with an internal combustion engine against the requirement that its pollutant emissions shall meet or be lower than those of an equivalent Euro VI diesel vehicle, the emissions limits detailed in Annex 1 shall be used.

The baseline GHG emissions performance figures to be used to assess if such a vehicle meets or exceeds the 50% GHG reduction requirement are detailed in Annex 2.

3 Zero-Emissions range testing

For PITrG eligibility, all vehicles must meet a minimum zero-emission range requirement, currently set at 60 miles (96 km). Adherence to this requirement shall be determined in accordance with one or other of the procedures defined in this section. Testing is used to measure average energy consumption over defined duty cycles, to verify that they meet the minimum range requirement and to calculate their anticipated range on a single charge (or full load of hydrogen).

Vehicle manufacturers should provide information to the test house on how to access cables to install current clamps or suitable energy measurement equipment. Manufacturers of hydrogen vehicles should discuss with the test house and Zemo in advance the best way to measure hydrogen consumption and refuelling requirements.

During the tests, the test facility shall measure (at 1Hz) all energy data from the moment the vehicle is energized, excluding the actual start event. This can be via independently fitted current clamps (with an assumed nominal system voltage as provided by the vehicle manufacturer) or using CANBUS reported current and voltage. The energy measurement system used shall be recorded in the test report.

3.1 Vehicle Loading

N2 and N3 HGVs intended for general haulage shall be tested at a simulated kerb weight plus driver weight (Mass in Running Order) and 60% +/-5% of the specified maximum payload capacity. In the case of testing of chassis-cab vehicles, additional weight shall be applied to simulate a representative body.

Refuse collection vehicles (RCVs) shall be tested at Mass in Running Order (including body) and 50% +/-5% of the specified maximum payload capacity. The vehicle must be physically loaded with sufficient quantity of rubber chippings to perform the required number of compaction cycles in a realistic and representative way – the manufacturer and test house should discuss and agree with Zemo in advance of testing how best to achieve this. Bin-lifting shall also be performed during the tests, with a total mass acting on the bin lift mechanisms of 50 kg for each lift (representing two domestic refuse bins weighing 25kg each). There is no requirement for any load to be transferred from bin to vehicle during the tests.

The unladen weight of the vehicle shall be determined prior to test by the technical service carrying out the test and the measured value will be used if different from the declared Mass in Running Order, unless previously agreed with Zemo.

3.2 Chassis Dynamometer Test Procedures

3.2.1 Vehicle setup

The following vehicle ancillaries will be used: Non-standard ancillaries such as refrigeration units shall be switched off.

- All standard ancillaries on, including:
  a. All exterior sidelights and dipped beams on.
  b. Interior heating set to 21°C if automatically controlled or, if manually controlled, set to achieve a steady-state in-cab temperature of no less than 21°C (as verified by the test house).

3.2.2 Dynamometer Driving Procedure

The test sequence starts with a "fully charged" vehicle, to simulate a vehicle leaving a depot having been left stationary while charging for a prolonged period beforehand. The vehicle may be moved under its own power to the test facility if charging is not carried out directly in the dyno facility but in any event the start SOC must be no less than 95%.

3.2.3 Verification of minimum zero-emission driving capability requirement

For the simplest possible verification of the PITrG's minimum zero-emission driving capability (60 miles/96 km) of pure battery electric or fuel cell electric vehicles, it is not necessary to measure energy consumption. The vehicle, at or close to fully charged and otherwise meeting all other test conditions, can simply be driven over a specified drive cycle of at least that distance and, providing it achieves that without fully depleting its battery or hydrogen stores, it shall be deemed to have met the minimum requirements. The exact drive cycle to be driven varies by vehicle type, as specified in Table 1.

For general haulage HGVs, the sequencing of the individual phases to complete the overall drive cycle (inner-city, town and rural, see Figure 1 below) shall be at the discretion of the test house.

For RCVs, the test house may also vary the sequencing provided that each repeat of the RCV CVRAS cycle is completed in full and with the required minimum number of bin-lifts and compactions. During the Dense Urban Collection and Rural/Suburban Collection phases (see Figure 2 below), the minimum required numbers of bin-lifts and compaction cycles are:

- Dense Urban: 100 bin-lifts (25 kg each) or 50 bin-lifts (50 kg each), 25 compaction cycles.
- Rural/Suburban: 40/20 bin-lifts (25/50 kg each), 10 compaction cycles.

Table 1. Drive cycles for minimum ZE capability assessment

Vehicle Type	Repeats of each phase (total distance)			
	Inner-City	Town	Rural	Total
N2	9x (43 km)	4x (32 km)	2x (24km)	99 km
N3 <= 27t gross weight	6x (29 km)	4x (32 km)	3x (36 km)	97 km
N3 > 27t gross weight	4x (19 km)	4x (32 km)	4x (48 km)	99 km
Refuse Collection Vehicles	8x RCV CVRAS cycle with bin-lifts and compactions (41 km) and 21 repeats of the Transfer phase (56 km) without bin-lifts or compactions			

Zemo recommends, however, that applicants instead follow the appropriate alternative procedure below. These procedures ensure not only that the vehicle is capable of driving no less than 60 miles on a single charge (or hydrogen store) but also its rate of energy consumption and its likely overall zero-emission range. These figures will be of great interest to potential users of these vehicles and the test procedures provide a standardized, independent assessment method to enable proper like-for-like comparisons across different vehicles.

Any vehicle equipped with an internal combustion engine capable of recharging the on-board energy store or providing direct propulsion (i.e. that are ICE range-extenders or plug-in hybrid vehicles) must be tested in accordance with the appropriate alternative procedure below, as their full zero-emission range capability is needed to assess their compliance against the minimum 50% tailpipe GHG reduction requirement of PITrG (see section 4). All tests on such vehicles prescribed here (Section 3) are to be carried out in zero-emission (charge depleting) mode only.

3.2.4 (Alternative) Energy Consumption & Range Tests – N2 and N3 HGVs for General Haulage

Battery current should be measured at a frequency of at least 1Hz using suitable current flow meters. Ideally, this should be via current clamps fitted independently by the test house but where this is not feasible, CAN Bus current data can be used. Battery State of Charge (%) shall be recorded from the in-vehicle display at the start and end of each test cycle/phase and, if available, from the CAN Bus.

If the CAN Bus option is used for current flow, battery system voltage shall also be recorded. If current clamps are used, power and energy shall be calculated based on the nominal system voltage provided by the manufacturer.

If using CAN Bus data, the test house should consult with Zemo prior to testing to ensure the correct (SAE J1939) parameters are to be logged.

Starting with the battery fully charged (or with full hydrogen tanks in the case of an FCEV), the vehicle shall be driven over 4 complete runs of the Zemo HGV CVRAS test cycle, as illustrated in Figure 1 (a total distance of just over 60 miles). Pausing between drive cycles (to facilitate driver breaks) is allowed with vehicle switch off. These should be noted.

Any vehicle that fails to achieve this distance with zero tailpipe emissions (except water vapour in the case of hydrogen fuel cell vehicles) before completion of the fourth cycle, shall be deemed to have failed the PITrG minimum range requirement, unless the following conditions are satisfied:

- Any vehicle very close to completing fully the fourth cycle, but not quite doing so, will have its range checked through calculation (in accordance with the procedures defined below). If the calculated zero emission range exceeds 60 miles, it shall be deemed to have passed the minimum range requirement.

On completion of the fourth cycle:

- If the reported SOC is 15% or lower, or the reported available range is 16 km (10 miles) or less, the vehicle shall be plugged in and brought back to a full State of Charge (or be re-filled with hydrogen). The charging electricity (in kWh) or hydrogen (in kg) required to achieve this shall be recorded, as shall the on-board energy/hydrogen consumption getting from the end of the fourth test cycle to the recharge/re-fill point, and combined with the measured on-board energy consumption for the same overall SOC change to calculate a charging efficiency percentage.
- If these SOC/available range requirements are not met, the vehicle shall be driven additional distance until such time as one or other of them is met, with energy/hydrogen consumption continuously recorded (at 1Hz). This can be at any speed or combination of speeds.

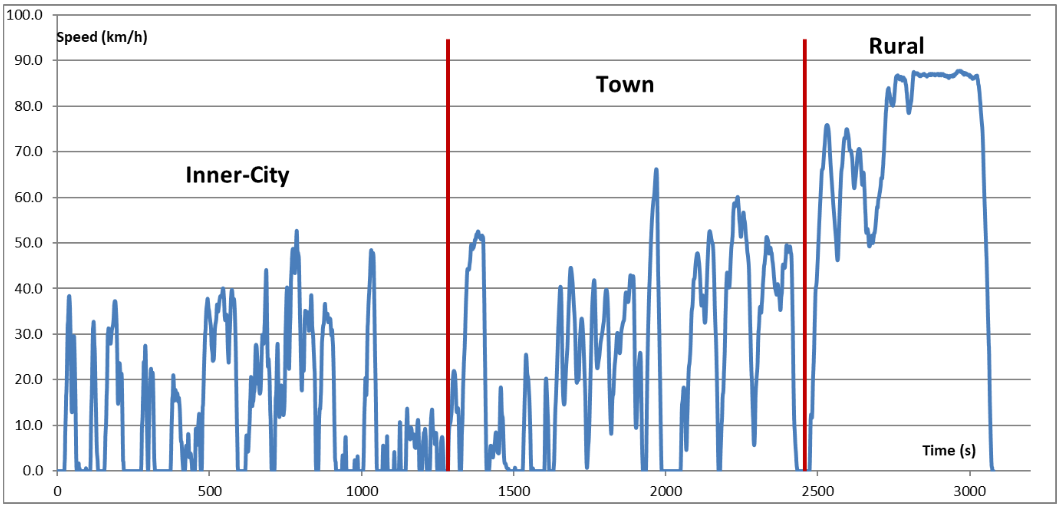


Figure 1. Zemo HGV CVRAS Test Cycle (total distance 24.9km/15.5 miles)

3.2.4.1 Calculation of Maximum Range – N2 and N3 HGVs for General Haulage

The test results shall be used to determine the average charge kWh/km (or kg/km) energy consumptions over each of the three cycle phases (duty cycles). All successfully completed phases during the four test runs shall be used to calculate these averages. A fourth cycle average, corresponding to a Regional Delivery duty cycle, shall be calculated by summing the average energy consumed over the Town and Rural phases and dividing the combined distances from those same two phases.

From these per-phase averages, a single overall weighted average shall be calculated according to the weightings given in Table 2.

Table 2. Duty Cycle Weightings for General Haulage HGVs

Vehicle Type	Weighting Factors			
	Inner-City	Town	Regional Delivery	Rural
N2	40%	30%	20%	10%
N3 <= 27t gross weight	30%	30%	20%	20%
N3 > 27t gross weight	20%	20%	30%	30%

The test house shall measure the total maximum usable energy available from the battery (in kWh) or on-board hydrogen storage (in kg). This can be done by first fully depleting the battery or hydrogen tanks and measuring the amount of electrical energy/hydrogen needed to fully replenish it/them, or by calculation from the overall test results:

Maximum useable energy available = On-board energy consumed during full test programme / Start-End change in SOC (which shall be no less than 80%).

"Start", "End" and "full test programme" here means all on-board energy consumption from the point at which the vehicle was first un-plugged from its charger (or hydrogen filler) to the point at which it returned (having completed all the above testing).

The weighted average on-board kWh/km or kg/km figure shall then be divided into the measured useable capacity to calculate the maximum vehicle range. This calculated maximum zero-emission range (MZR) must exceed the 60 mile (96 km) minimum applicable range defined for PITrG eligibility.

3.2.5 (Alternative) Energy Consumption & Range Tests – Refuse Collection Vehicles

Battery current should be measured at a frequency of at least 1Hz using suitable current flow meters. Ideally, this should be via current clamps fitted independently by the test house but where this is not feasible, CAN Bus current data can be used. Battery State of Charge (%) shall be recorded from the in-vehicle display at the start and end of each test cycle/phase and, if available, from the CAN Bus.

If the CAN Bus option is used for current flow, battery system voltage shall also be recorded. If current clamps are used, power and energy shall be calculated based on the nominal system voltage provided by the manufacturer.

If using CAN Bus data, the test house should consult with Zemo prior to testing to ensure the correct (SAE J1939) parameters are to be logged.

Starting with the battery fully (at least 95%) charged (or with full hydrogen tanks in the case of an FCEV), the vehicle shall be driven over 4 complete runs of the RCV CVRAS test cycle, as illustrated in Figure 2 (a total distance of just over 20 km). Pausing between drive cycles (to facilitate driver breaks) is allowed with vehicle switch off. These should be noted.

During the Dense Urban Collection and Rural/Suburban Collection phases, the minimum required numbers of bin-lifts and compaction cycles are:

- Dense Urban: 100 bin-lifts (25 kg each) or 50 bin-lifts (50 kg each), 25 compaction cycles.
- Rural/Suburban: 40/20 bin-lifts (25/50 kg each), 10 compaction cycles.

Any vehicle that fails to achieve this distance with zero tailpipe emissions (except water vapour in the case of hydrogen fuel cell vehicles) before completion of the fourth cycle, shall be deemed to have failed the PITrG minimum range requirement.

On completion of the fourth cycle:

- Any RCV equipped with a combustion engine capable of recharging the on-board energy store or providing direct propulsion (i.e. that is a range-extender or plug-in hybrid vehicle) shall immediately after completion of the fourth test cycle be required to complete an additional distance of 76 km. This shall be achieved by completing a further four repeats of the CVRAS RCV test cycle, with bin-lifting and compactions, and then 21 repeats of the Transfer phase (without bin-lifting or compactions). On-board energy consumption shall also be measured during this additional driving, but it must be achieved with zero tailpipe emissions (except water vapour in the case of hydrogen fuel cell vehicles).
- The vehicle shall be driven additional distance until such time as either the reported SOC falls to 15% or less, or the reported available range falls to 16 km (10 miles) or less, with on-board energy/hydrogen consumption continuously recorded (at 1Hz). This can be at any speed or combination of speeds but should be done in such a way as to achieve an average speed during this additional distance of at least 38 km/h. Bin-lifting and compaction is not required during this driving.
- If the reported SOC is 15% or lower, or the reported available range is 16 km (10 miles) or less, the vehicle shall be plugged in and brought back to a full State of Charge (or be re-filled with hydrogen). The charging electricity (in kWh) or hydrogen (in kg) required to achieve this shall be recorded, as shall the on-board energy/hydrogen consumption getting from the end of the fourth test cycle to the recharge/re-fill point, and combined with the measured on-board energy consumption for the same overall SOC change to calculate a charging efficiency percentage.

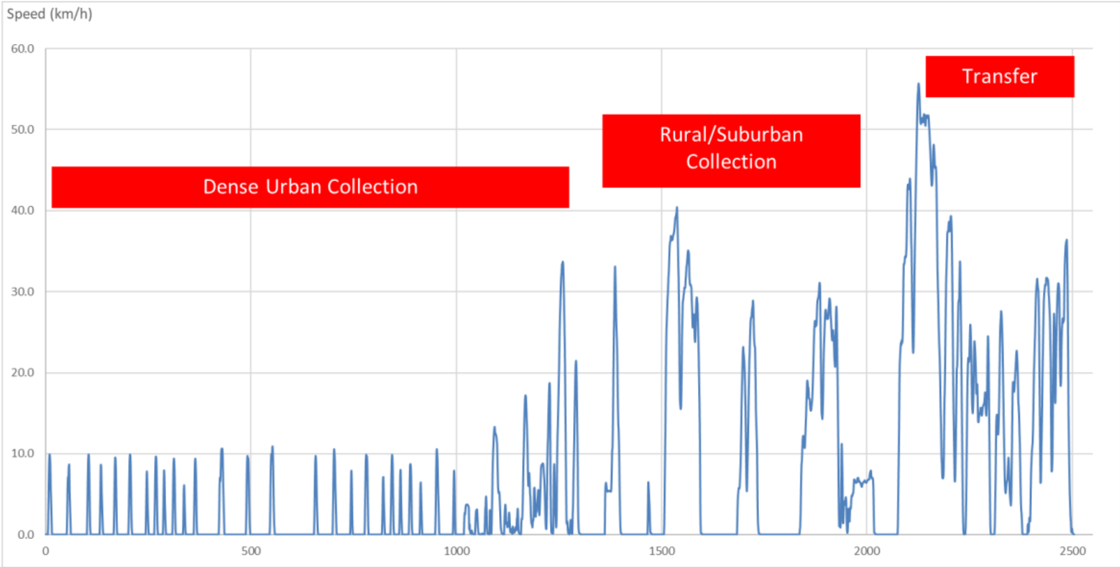


Figure 2. RCV CVRAS Test Cycle (total distance 5.2km/3.2 miles)

3.2.5.1 Calculation of Maximum Range – RCVs

The test results shall be used to determine the average kWh/km (or kg/km) on-board energy consumptions over each of the three cycle phases (duty cycles). All successfully completed phases during the four test runs shall be used to calculate these averages.

The test house shall measure the total maximum usable energy available from the battery (in kWh) or on-board hydrogen storage (in kg). This can be done by first fully depleting the battery or hydrogen tanks and measuring the amount of charge electrical energy/hydrogen needed to fully replenish it/them, or by calculation from the overall test results:

Maximum useable energy available = On-board energy consumed during full test programme / Start-End change in SOC (which shall be no less than 80%).

"Start", "End" and "full test programme" here means all on-board energy consumption from the point at which the vehicle was first un-plugged from its charger (or hydrogen filler) to the point at which it returned (having completed all the above testing).

The overall average on-board energy consumption (in kWh/km) shall be calculated as the (8 x the total average energy consumed across all three phases) + (21 x the average energy consumed over the Transfer phase) divided by (8 x average cycle distance + 21 x average Transfer phase distance). This overall cycle average consumption shall then be divided into the measured useable capacity to calculate the maximum vehicle range. This calculated maximum zero-emission range (MZR) must exceed the 60 mile (96 km) minimum applicable range defined for PITrG eligibility.

3.3 Track-Based Test Procedures

The default option for all track-based testing is to use basically the same procedures and duty cycles as for the above chassis-dynamometer based testing but on an essentially flat test track (defined as being one whereby each test cycle can be completed with a maximum elevation change of ± 10 metres and maximum gradient at any point of ± 1%).

3.3.1 Vehicle setup

The following vehicle ancillaries will be used: Non-standard ancillaries such as refrigeration units shall be switched off.

- All standard ancillaries on, including:
    a. All exterior sidelights and dipped beams on.
    b. Interior heating set to 21°C (if automatically controlled) or otherwise set to achieve that condition (as verified by the test house), unless the ambient temperature during the tests is below 11°C in which case the cabin heater shall be set to achieve a cab temperature no lower than 10°C above the ambient.

3.3.2 Track Driving Procedure

The test sequence starts with a fully charged (95% minimum SOC) vehicle, to simulate a vehicle leaving a depot having been left stationary while charging for a prolonged period beforehand, accepting there may be some distance between where the vehicle is charged and the start point on the test track.

3.3.3 Practice and Warm Up Runs

The test vehicle will be operated through a preliminary run of the desired test cycle(s). During this preliminary run, the driver will become familiar with the vehicle operation. Additional preliminary runs will be made, if necessary, to assure that the vehicle, driver, and laboratory instrumentation are performing satisfactorily (prior to a full recharge and formal start of testing).

3.3.4 Use of other track cycles

Other test cycles, e.g. those developed by Zemo specifically for track-based testing of HGVs may be used. Use of such other cycles for PITrG approval testing must be agreed in advance with Zemo and the applicant or test house may need to go through a process of additional testing to ensure their suitability and equivalence to the default test cycles. To be suitable, the routes driven on the track should have no more than 10m overall (start to finish) elevation change, but there are no restrictions on gradient over the course of the test cycle. Each test cycle must meet specific requirements (e.g. regarding minimum distance, kinetic intensity and average speed) to demonstrate equivalence.

4 Internal combustion engine emissions testing

Vehicles without a combustion engine capable of recharging the on-board energy store or providing direct propulsion (i.e. that are pure BEV and/or FCEV, not ICE range-extenders or plug-in hybrid vehicles) automatically qualify under the 50% GHG reduction and pollutant emissions requirements of PITrG, so need only be tested for their ZE capability and (optionally) energy consumption and range, as above.

Vehicles equipped with a combustion engine capable of recharging the on-board energy store or providing direct propulsion (i.e. that are range-extenders or plug-in hybrid vehicles) must, in addition, be tested in their "engine-on" mode to provide the data needed to assess compliance with the 50% GHG reduction and pollutant emissions requirements of PITrG.

Applicants may be asked to provide for testing a suitable Euro VI diesel-only comparator vehicle (to be agreed with Zemo but essentially with similar maximum payload characteristics as the PITrG vehicle being assessed). The results will be used to provide baseline GHG emissions figures if suitable baseline data does not already exist. The ownership of any baseline vehicle test data will be shared with Zemo to incorporate into broad robust baseline information to be developed across the market.

Vehicle loading and set up requirements shall be the same as for the zero-emission energy and range tests except that the onboard store(s) of electrical or hydrogen fuel cell energy shall first be depleted to their minimum permitted level such that the combustion engine is operating.

4.1 Dynamometer test procedure

The objective of the testing programme is to measure at least 3 repeat tests of the vehicle in charge sustaining mode (CS). The per-kilometre emissions results are then used to assess the vehicle's Euro VI equivalence for pollutant emissions and combined with the results from the zero-emission energy and range testing to assess the vehicle's overall tailpipe GHG emissions over a defined journey length.

4.1.1 GHG emissions

Emissions and fuel consumption for the CS mode will be determined from the three CS test cycles. Net energy change during CS operation must be incorporated if greater than 5%, using the AZF Method described below.

4.1.2 AZF Method for vehicles with >5% Net Energy Change

If the engine has partially or fully re-charged the battery during the three repeated CS tests (by >5% SOC), this residual battery capacity figure (in kWh) shall be used to calculate the additional zero tailpipe emissions range (AZR) of the vehicle in km, by dividing it into the weighted average energy consumption calculated from the zero-emissions energy and range test results, in kWh/km. The "Additional ZTE Range Factor" (AZF) shall then be calculated:

For tests using the CVRAS HGV cycle, AZF = (75 + AZR)/75

For tests using the CVRAS RCV cycle, AZF = (15 + AZR)/15

The average emissions from the CS tests shall be calculated in g/km (or Number/km for PN) by dividing the total measured emissions of each species in g by the total distance covered during the tests in km. The GHG emissions shall be calculated using official 100-year GWP conversion factors for N_2O and CH_4 to arrive at a g/km tailpipe CO_2e figure.

To calculate the overall GHG impacts and to verify the 50% GHG reduction requirement, default journey distances (DJD) shall be used, varying by HGV type in accordance with Table 2, and it shall be further assumed that the vehicle starts this journey with a fully charged battery and ends it with its battery fully discharged (unless MZR ≥ DJD km, in which case the 50% GHG requirement is automatically met).

For vehicles with MZR < DJD km, the average g/km GHG emissions (CO_2, N_2O and CH_4) for this journey (GHG_{DJ}), shall be calculated as follows:

$GHG_{DJ} = ((DJD – MZR) \times GHG_{Test} / AZF) / DJD$

Where GHG_{Test} is the average tailpipe GHG emissions measured from the CS tests, weighted by phase in accordance with the same requirements as for calculating MZR (Table 1 above).

If the Net Energy Change during the CS tests is <= 5%, AZF is deemed to be 1.00

Not part of the 50% assessment but required for reporting, GHG g/km calculations shall be made assuming journeys of 150, 200, 250, 300, 400 and 500 km.

Table 2. Default Journey Distances

Vehicle Type	N2	N3 up to 27t	N3 >27t	RCV
Default Journey Distance (km)	250	300	400	200

4.1.3 Pollutant emissions

The measured CS-mode cycle average pollutant emissions shall be used to assess the PITrG requirements for equivalence to Euro VI, defined in Annex 1. These shall be calculated by dividing the total emissions in each CS test by the distance covered during that test with the engine running (i.e. any parts of the test cycle completed in zero-emission/charge depleting mode shall be disregarded).

4.2 Track-based test procedure

The default option for all track-based testing is to use basically the same procedures, duty cycles and calculation methods as for the above chassis-dynamometer based testing but on an essentially flat test track and otherwise in accordance with the track-based testing requirements defined for zero-emission energy and range testing above.

Use of other cycles for PITrG approval testing must be agreed in advance with Zemo.

5 Reporting

The final test report shall include all measured parameters including vehicle configuration, vehicle statistics, test cycle and calculated test results.

The following information will be included in the report:

- Vehicle/technology name, vehicle to which fitted and supplier's name and address.
- Name of Technical Service carrying out the test, the test method and cycles used and date(s) tested.
- Essential vehicle and technology characteristics, including the maximum frontal area of the vehicle tested.
- Name and organization of test witness(es).
- Exhaust Emissions and Fuel Economy - The exhaust emissions, fuel economy and electrical energy consumption of the vehicle, if measured during each test. The measurements shall be reported in grams per kilometre, litres (or kg) per 100 kilometres and charging kilowatt-hours per kilometre respectively. Charging kWh here means the metered grid energy needed, i.e. the measured on-board energy consumption divided by the measured charging efficiency. NOx shall be calculated with the NO mass factored up to NO_2 equivalence.
- Actual Distance Travelled - The actual distance that the dynamometer roll surface travelled shall be measured during each test phase (or derived from GPS data for track-based testing). The total emissions and distance covered across the whole test cycle (all phases) shall be used to calculate the averages.
- Tank-to Wheel emissions - Values for TTW GHG emissions will be presented for CO_2, N_2O and CH_4 in the form of CO_2e. GWP values of 25 for methane and 298 for nitrous oxide shall be used.
- Other consumables – if for correct operation, the vehicle consumes any other reagents (e.g. AdBlue), the amounts consumed shall, where possible, also be measured and recorded in the test report.
- Applicants must allow all data collected by the test house and specified by these procedures to be made freely available to the Office for Zero Emission Vehicles as part of any application for PITrG approval. This data may be used by OZEV and/or Zemo Partnership, including to generate summary test result reports/certificates for publication (with, where measured, the tested vehicle efficiency, range and charging information).

Annex 1. Pollutant emission limits permitted to assess Euro VI equivalence.

Exhaust emission parameter	N2 HGVs	N3 HGVs	RCVs
Mixed oxides of Nitrogen (NOx)	500 mg/km	800 mg/km	1500 mg/km
Nitrogen Dioxide (NO_2)	100 mg/km	160 mg/km	250 mg/km
Particulate matter (PM) – dyno tests only	10 mg/km	15 mg/km	10 mg/km
Number of particles (PN)	6×10^{11}/km	6×10^{11}/km	6×10^{11}/km

Annex 2. GHG emissions limits to achieve 50% reduction over equivalent diesel vehicles (for use if direct comparator vehicle not tested).

Based on previous testing by Zemo of various Euro VI HGVs, the following graphs shows how overall tailpipe GHG emissions vary with tested payload (with weightings as defined for each vehicle category). A line of best fit is used to derive a general mathematical model and 50% of that model's predicted GHG figure for a given tested payload is used as the limit value for that payload, with a 3% assumed up-lift of the diesel GHG figures to allow for the effects of N_2O emissions (which were not routinely measured during the previous test programme).

The weighted average GHG limit values are calculated by the following equations (which are subject to updating and revision, applicants should check with Zemo for the latest figures):

i. For N2 vehicles:

   GHG limit value in gCO_2e/km = (0.05 x Tested Payload in kg) + 126

ii. For N3 vehicles up to 27 tonnes gross weight:

   GHG limit value in gCO_2e/km = (0.026 x Tested Payload in kg) + 272.4

iii. For N3 vehicles over 27t gross weight:

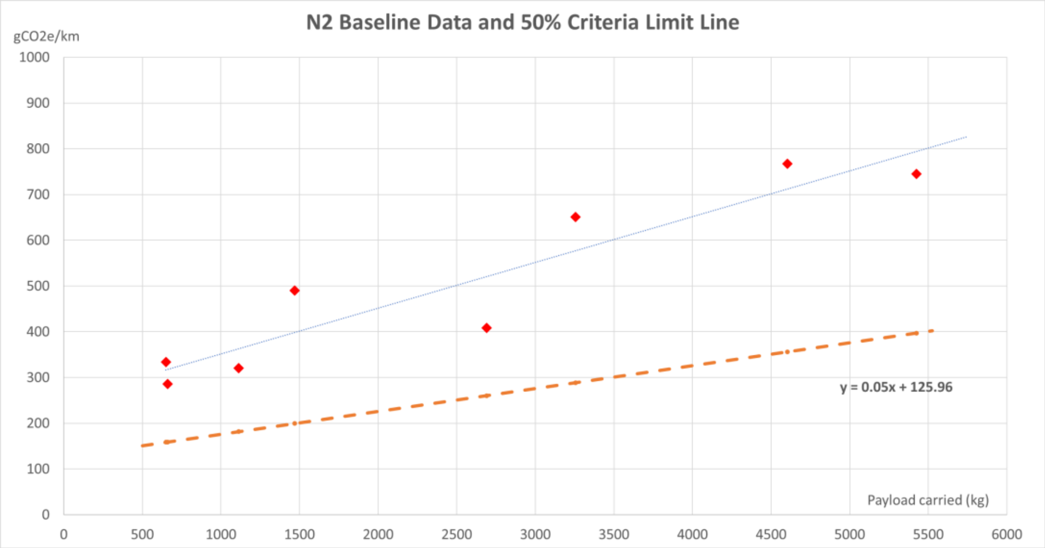
   GHG limit value in gCO_2e/km = (0.011 x Tested Payload in kg) + 372

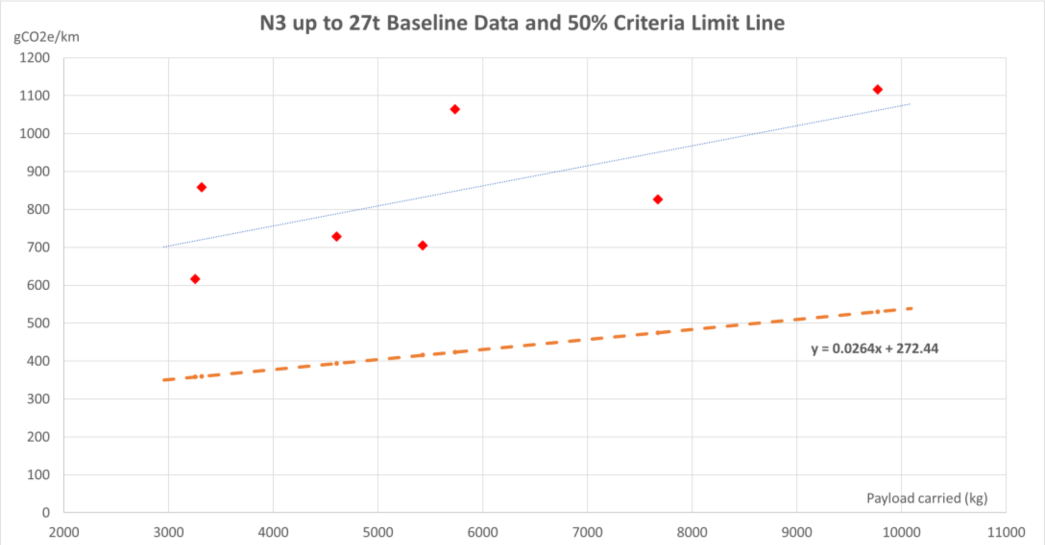
iv. For Refuse Collection Vehicles, 25-27t gross weight:

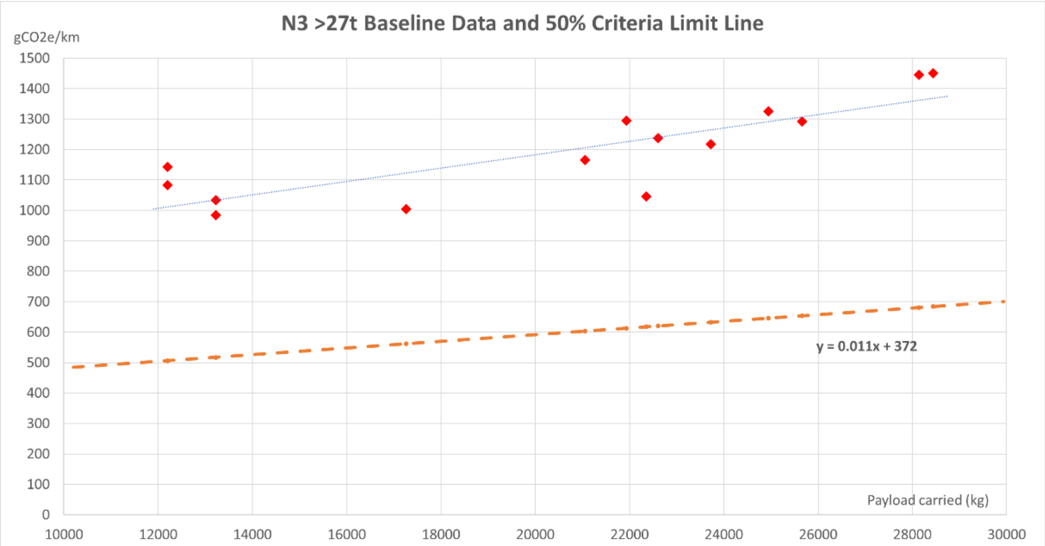
   GHG limit value in gCO_2e/km = 1,200

"Tested Payload" means the overall weight of the tested vehicle (including a trailer if articulated) minus the unladen weight of the vehicle (tractor unit if articulated).

For RCVs below 25t gross weight, or above 27t, baseline data is not currently available – applicants will need to supply a Euro VI diesel equivalent vehicle for baseline testing.


N2 Baseline Data and 50% Criteria Limit Line
gCO2e/km
y = 0.05x + 125.96
Payload carried (kg)


N3 up to 27t Baseline Data and 50% Criteria Limit Line
gCO2e/km
y = 0.0264x + 272.44
Payload carried (kg)


N3 >27t Baseline Data and 50% Criteria Limit Line
gCO2e/km
y = 0.011x + 372
Payload carried (kg)