POLICY UPDATE

JANUARY 2017

REAL-DRIVING EMISSIONS TEST PROCEDURE FOR EXHAUST GAS POLLUTANT EMISSIONS OF CARS AND LIGHT COMMERCIAL VEHICLES IN EUROPE

ICCT **POLICY UPDATES** SUMMARIZE REGULATORY AND OTHER DEVELOPMENTS RELATED TO CLEAN TRANSPORTATION WORLDWIDE.

In 2015, the European Union (EU) adopted the first two pieces of legislation[1] designed to implement the new real-driving emissions (RDE) test procedure for measuring vehicle emissions. Two more legislative packages[2] are currently under development to complete the project. The goal is to establish a more representative pollution test for cars and light commercial vehicles (vans). The RDE test will gradually take effect in 2017. It will apply to all new cars by the beginning of 2021 and all new vans by the beginning of 2022. The new procedure will complement the current laboratory certification of vehicles with on-road testing under more realistic real-world conditions.

POLICY BACKGROUND

EU regulators have been using the New European Driving Cycle (NEDC) since the early 1990s[3] to certify exhaust emissions of cars and light commercial vehicles in an easy, repeatable, and reproducible manner. The test uses a chassis dynamometer in a vehicle-emissions laboratory under well-defined ambient conditions for temperature and humidity. Vehicles can be specially prepared for the test. All vehicle types must pass this and similar tests before market introduction. The system is referred to as the *emissions type approval* or *emissions certification process*. The NEDC has an average speed of 33 km/h and a maximum acceleration of 1.2 m/s^2. The vehicle is stopped for approximately 25% of the cycle duration. Modern vehicles complete the NEDC using a modest share of available engine power and covering a limited portion of possible real-world operating conditions.

In 2011, the research body of the European Commission, the Joint Research Centre (JRC), published a report highlighting the large and growing discrepancies between laboratory and on-road emissions, especially for nitrogen oxide (NO_x) emissions

1 Both packages were published in the *Official Journal of the European Union* in 2016, as regulations EU 2016/427 and EU 2016/646.

2 The details of the four packages of the RDE legislation can be found in Annex I.

3 Regulation 91/441/EEC amending Directive 70/220/EEC on the approximation of the laws of the member states relating to measures to be taken against air pollution by emissions from motor vehicles.

from diesel cars[4]. Those findings triggered the creation of a working group on real-driving emissions under the supervision of the European Commission. The Commission is the authority in charge of supervising and proposing all legislation related to type approval for road and non-road vehicles. EU member states then amend, adopt, or reject the legislation.

The legal framework existing in the early 2010s stipulated that "The manufacturer shall equip vehicles so that the components likely to affect emissions are designed, constructed, and assembled so as to enable the vehicle, in normal use, to comply with this Regulation and its implementing measures."[5] There is no specific definition of "normal use" in the regulation, and the implementing legislation specified only that the NEDC laboratory test be performed to certify light-duty vehicles.[6] The 2011 JRC study showed that the NEDC did not accurately capture the NO_x emissions from normal use of diesel cars.

The real-driving emissions working group was assigned to develop a new, complementary test procedure that would be more representative of normal use covering a representative range of driving conditions.[7] The new legislative text was split into four "packages"[8]; the first two packages were published in March and April 2016 as regulations (EC) 2016/427 and (EC) 2016/646. This policy update summarizes the legislative content of those two packages.

An on-road test procedure based on the application of portable emissions measurement systems (PEMS) has been in place since 2014 for determining heavy-duty vehicles' in-use compliance; this was part of the Euro VI emissions regulation for heavy vehicles.[9] The test, along with other elements of the regulation, appears to have been effective so far, with observed real-world emissions decreasing significantly from Euro V levels.[10]

SUMMARY OF KEY ELEMENTS OF THE RDE LEGISLATION

- Data collected every second by the PEMS unit must be analyzed using two separate evaluation tools to validate the trip's validity. For example, trips that are driven too smoothly or too aggressively are rejected, requiring that the test be repeated.
- The RDE test is performed as part of emissions type approval on public roads in real traffic, using PEMS. Initially, only NO_x and particulate number emissions are included in binding limits.
- With publication of the regulatory text early in 2016, a monitoring period went into effect. Automakers must perform valid RDE tests, but without binding limits. Emission results must be made publicly available. The aim is to allow manufacturers, technical services, and type-approval authorities to become familiar with the new procedure.

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4 http://ec.europa.eu/clima/policies/transport/vehicles/docs/2011_pems_jrc_62639_en.pdf

5 Regulation (EC) 715/2007, Article 5 (1)

6 Regulation (EC) 692/2008

7 Emission limits have been raised through the use of a Conformity Factor, as defined later in the document.

8 The details of the four packages of the RDE legislation can be found in Annex I.

9 Regulation (EC) 595/2009

10 More details in ICCT (2015). Comparison of real-world off-cycle NOx emissions control in Euro IV, V, and VI, http://www.theicct.org/comparing-real-world-nox-euro-iv-v-vi-mar2015 and ICCT (2017). NOx emissions from heavy-duty and light-duty diesel vehicles in the EU: Comparison of real-world performance and current type-approval requirements, http://www.theicct.org/nox-europe-hdv-ldv-comparison-jan2017

- The RDE testing conditions are designed to be representative of driving conditions normally encountered on European roads. A range of boundary conditions were adopted to exclude certain types of conditions. There is no quantified evidence to estimate the share of real-life driving events that would be included in RDE tests.
- RDE vehicle families reduce the number of tests to be performed for each manufacturer. Key criteria for the family definition relate to configuration of the after-treatment system.
- A connection between the PEMS and the vehicle's electronic control units is authorized, but not compulsory. The legislation recommends performing a validation test using the chassis dynamometer to make sure the PEMS functions correctly.
- The implementing legislation (EC) 692/2008 was amended to include a requirement for vehicle manufacturers to declare emission-control strategies to technical services and type-approval authorities. This improves transparency and makes it possible for authorities to identify potentially inappropriate emission-control strategies before market introduction.
- Several additions to the regulatory text were expected in late 2016 and early 2017 as part of the third and fourth RDE packages. Key elements of the third package are to include evaluation of cold-start emissions and, for the first time, particle number measurements are required. The third package also adapts RDE test provisions for hybrid vehicles and considers regeneration events for the evaluation of vehicle emissions. The fourth package will cover market surveillance testing including by third parties—a key element to enforcement.[11]

DETAILED OVERVIEW OF THE LEGISLATION

NOT-TO-EXCEED LIMITS FOR RDE TESTS

The Euro 6 NO_x emission limit of 80 mg/km for diesel engines applies to all new cars beginning on September 1, 2015. To allow for lead time, not-to-exceed (NTE) limits were introduced in two phases in Regulation 2016/646. These NTE limits are expressed in the equation below as the adopted Euro 6 emission limits multiplied by a so-called conformity factor (CF).

$$NTE_{pollutant} = CF_{pollutant} \times TF(p_1,\ldots,p_n) \times \text{EURO-6}$$

There are two conformity factor phases for NO_x emissions: (a) a temporary phase, Euro 6d-TEMP, with a value of 2.1, meaning that vehicles approved under Euro 6d-TEMP can emit 2.1 times the Euro 6 limit; and (b) a final phase, Euro 6d, for which the conformity factor is the margin of uncertainty of the PEMS measurement. After intense political debate, the EU member states voted to set this margin at 50%, leading to a final CF of 1.5. The legislation also includes the possibility for the European Commission to revise the conformity factor annually, taking into account the technical progress of PEMS devices. For comparison, the JRC's technical assessment concluded that PEMS measurement uncertainty compared with laboratory equipment was 30% for NO_x.[12]

Consequently, the initial diesel RDE limit will be 168 mg/km—multiplying the Euro 6 NO_x emission limit of 80 mg/km by the CF of 2.1 (Figure 1)—beginning on September 1, 2017, for new types and September 1, 2019, for all types. Then, the

11 The details of the four packages of the RDE legislation can be found in Annex I.

12 JRC (2015), RDE—Preliminary uncertainty assessment, https://circabc.europa.eu/sd/a/48498955-3eef-486c-9d11-1cfbc57b3cdf/2015_09_14_error_calc_final.ppt

RDE NO_x emission limit for diesel cars will decrease to 120 mg/km—the Euro 6 NO_x emission limit of 80 mg/km times the final CF of 1.5—beginning on January 1, 2020, for new types and January 1, 2021, for all types. The RDE limits are tighter for gasoline vehicles, with a Euro 6 NO_x emission limit of 60 mg/km (not shown in Figure 1).

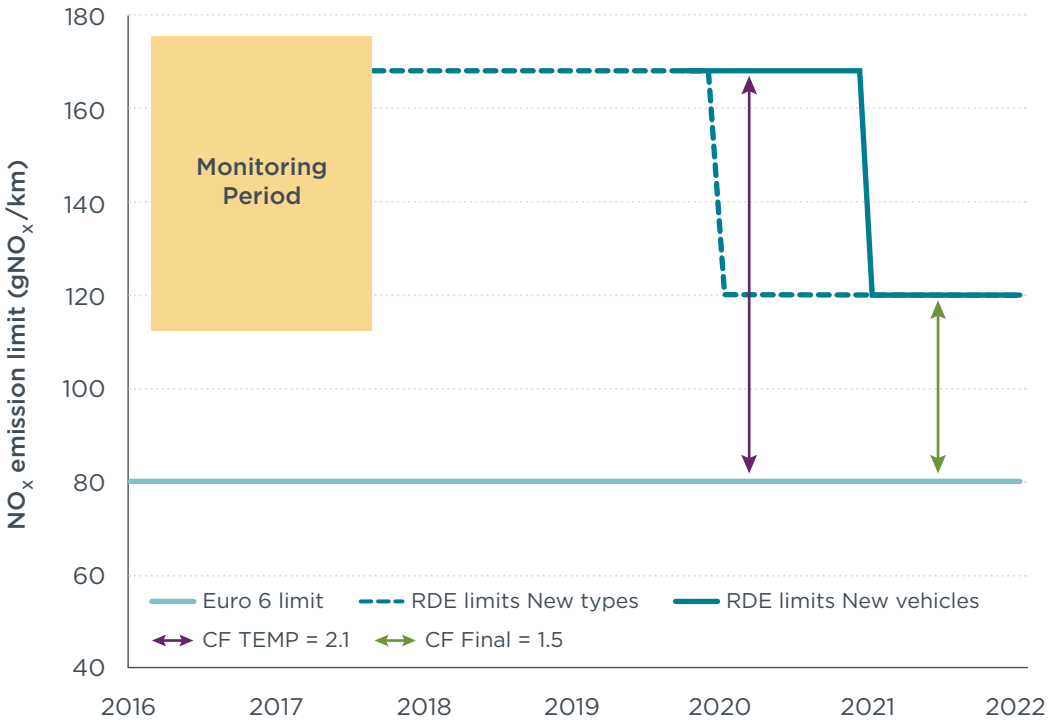

Figure 1. RDE NO_x emission limits time table for diesel passenger cars and car-derived light commercial vehicles (for other types of light commercial vehicles, a separate timeline and separate emission limits apply).

To ensure that vehicles perform well in urban driving conditions, CFs have to be met for the whole RDE trip as well as for the urban part separately.

In addition, a transfer function (TF) was introduced to normalize the driving conditions and make them more uniform and comparable. The regulatory text of the second RDE package sets the TF to 1.

Starting in 2016, there is a monitoring period for new vehicle types during which the RDE test has to be performed and a valid trip approved, but no binding limit is being enforced. The aim is to allow manufacturers, technical services, and type-approval authorities to become more familiar with the new RDE procedure.

RDE TEST PROCEDURE

Even though the RDE test is conducted on public roads open to traffic, there are provisions to ensure that test trips cover a broad range of driving conditions typically encountered by European drivers. Boundaries have been set to define what constitutes a valid RDE trip. The laboratory NEDC test represents a fixed set of testing conditions, such as a predetermined speed profile and a narrow ambient temperature range of 20°C to 30°C, so that the test is repeatable and reproducible. By contrast, the RDE test has a broader range of parameters, each with ample margins allowed to cover a broad spectrum of driving possibilities.

TRIP SPECIFICATIONS

RDE trips cover three types of operation: urban, rural, and motorway. These classifications are based purely on speed: A car traveling up to 60 km/h will be considered to be operating in urban conditions; at 60 to 90 km/h, in rural conditions; and above 90 km/h, in motorway conditions.

The urban/rural/motorway mix, based on the speed definition, should be evenly distributed for each category (Table 1), within a 10% tolerance.

Table 1: Distance and speed specifications for each urban, rural, and motorway part of the RDE test.

Trip specifics		Provision set in the legal text
Total trip duration		**Between 90 and 120 min**
Distance	Urban	>16 km
	Rural	>16 km
	Motorway	>16 km
Trip composition	Urban	29%[13] to 44% of distance
	Rural	23% to 43% of distance
	Motorway	23% to 43% of distance
Average speeds	Urban	15 to 40 km/h
	Rural	Between 60 km/h and 90 km/h
	Motorway	>90 km/h (>100 km/h for at least 5 min)

BOUNDARY CONDITIONS AND DATA EVALUATION

In addition to specifying the trip characterization, other defined boundary conditions include ambient conditions, stop times, maximum speed, and altitude. A set of additional dynamic boundary conditions has been added for the second RDE legislative package to (a) limit the cumulative positive elevation gain over a trip to 1200 m/100 km and (b) exclude driving that could be regarded as too smooth or too aggressive, based on indicators such as speed and acceleration.

To be valid, each urban, rural, and motorway section of an RDE trip must be below the line in Figure 2 showing speed multiplied by acceleration and above the line showing relative positive acceleration. To illustrate how dynamic boundary conditions work, three hypothetical trips were added to the limit curves. Only Trip 1 is valid, because Trip 2 would be too aggressive in urban driving and Trip 3 too passive on both rural and motorway sections.

13 There is only a 5% tolerance for the lowest urban share to make sure there is at least 29% of valid RDE trips distance performed under urban conditions.

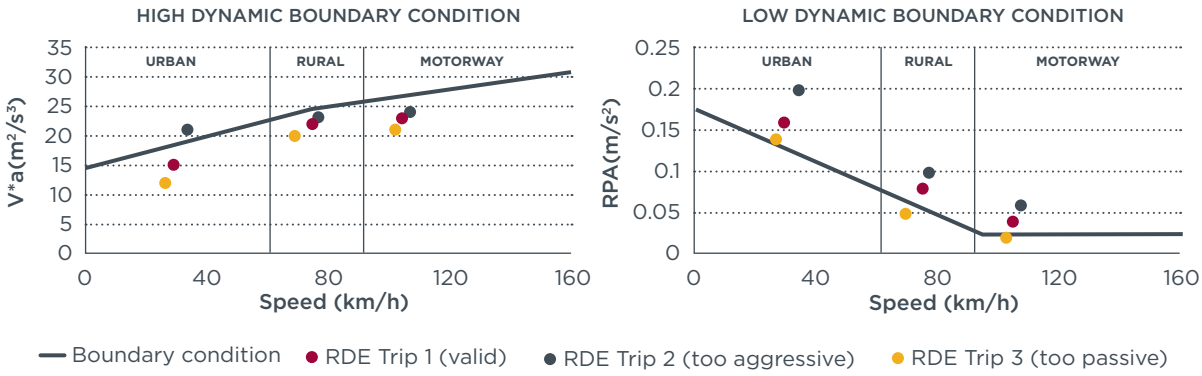

Figure 2. Dynamic boundary conditions with three illustrative RDE trips.

For ambient conditions of temperature and altitude, two sets of boundary conditions exist: "moderate" and "extended" (Table 2). If a data point falls within the extended conditions, the emissions measured have to be divided by a factor of 1.6. Any data point falling outside of the boundary conditions makes the whole trip invalid.

Table 2. Boundary conditions for RDE tests.

Parameter		Provision set in the legal text
Payload		≤90% of maximum vehicle weight
Altitude	Moderate	0 to 700 m
	Extended	Between 700 and 1300 m
Altitude difference		No more than a 100-m-altitude difference between start and finish
Cumulative altitude gain		1200 m/100 km
Ambient temperature[14]	Moderate	0°C to 30°C
	Extended	From –7°C to 0°C and 30°C to 35°C
Stop percentage		Between 6% and 30% of urban time
Maximum speed[15]		145 km/h (160 km/h for 3% of motorway driving time)
Dynamic boundary conditions	Maximum metric	95th percentile of *v*a* (speed * positive acceleration)
	Minimum metric	RPA (relative positive acceleration)
	Curves shapes shown in Figure 2.	
Use of auxiliary systems		Free to use as in real life (operation not recorded)

** Corrected from the original table.*

It is important to note that the legislation allows automakers to carry out as much as 50% of the RDE type-approval tests themselves, witnessed by a technical services company. The rest of the tests are to be performed by approval authorities or their legal representatives.

14 Ambient cold temperature threshold differs until September 2019 for new type and September 2020 for all new cars. Moderate temperature starts at 3°C and extended temperatures range from –2°C to 3°C.

15 Local speed limits remain in force, but going over the speed limit does not invalidate the test.

For processing data collected during an RDE trip, two evaluation tools were independently developed and included as part of RDE Regulation 2016/427. The first one, explained in Appendix 5 of Annex IIIA of the regulatory text, is the moving-average window method developed by the European Commission JRC. One associated software is called EMROAD. The second tool, explained in Appendix 6 of Annex IIIA, is the power-binning method developed by the Technical University of Graz. One associated software offered is called CLEAR.

Both tools use trip data on engine power or CO_2 emissions or both to decide whether a particular driving situation was relatively demanding. The tools then mathematically correct or weigh the measured exhaust emission levels upward or downward based on that driving situation.

The objective of the data evaluation is to control at least partially for the variability of operating conditions encountered on an RDE trip. To be accepted by a type-approval authority, a trip has to be validated and processed with at least one of the two data evaluation tools.

VEHICLE SELECTION, THE "PEMS TEST FAMILY"

The RDE legislation reduces the number of required tests by defining a "PEMS test family" as including all vehicles with the same powertrain and engine-block type, or number and disposition of cylinders. Engine size within a PEMS test family can differ by as much as 22% for engines larger than 1500cc and by 32% for engines smaller than 1500cc, although at least one type of each engine size has to be PEMS tested. The emissions-control system must be the same within a PEMS test family. Technical features requiring separate PEMS tests include engine size, gearbox type, number of driven wheels, and high and low power-to-mass ratio variants.

REPORTING OF RESULTS

The legislation requires automakers to prepare technical reports on RDE tests and make some of the information available publicly online via dedicated websites[16] under Article 3.1.3.2 of Annex IIIA. Manufacturers must provide more detailed technical reporting free of charge upon request to those with a "justified interest." Type-approval authorities must do so at "reasonable costs," according to Articles 3.1.3.3 and 3.1.3.4 of Annex IIIA.

STRENGTHS OF THE RDE REGULATION

- The RDE test for light-duty vehicles covers a wide spectrum of driving conditions typically encountered in Europe. This is a significant shift from the NEDC test and will require automakers to design emission-control systems that are robust over a broad range of testing conditions.
- The realistic test conditions of RDE are expected to result in significant emission reductions, especially in metropolitan areas where transportation-related NO_x air-quality problems are most pressing; RDE emission limits apply for the urban part of an RDE trip as for the whole trip.
- Because of the RDE tests, PEMS measurement technologies are expected to improve rapidly as several manufacturers compete for a growing market. Miniaturization is already well underway, shrinking the newest PEMS tools to

16 ACEA (2016), Access to Euro 6 RDE monitoring data, http://www.acea.be/publications/article/access-to-euro-6-rde-monitoring-data

approximately 70 kg from 200 kg for earlier generations. Further refinements are expected to focus on user friendliness, reliability, and accuracy.

- The second RDE package was finalized after Volkswagen's violations of U.S. emissions law became public. Provisions were added to minimize the risk of such issues in Europe and to improve transparency. Emission-control strategies now have to be declared to the technical services and type-approval authorities. The implementing legislation, EC 692/2008, was amended to require that manufacturers provide "extended documentation" to the type-approval authorities that will remain confidential. Some less-detailed results of RDE tests will be available publicly and upon request, increasing public awareness and access to approval information.
- A clause inserted as part of political negotiations with the European Parliament offers the possibility to annually review the RDE conformity factor to account for improvements in the accuracy and reliability of PEMS equipment.

AREAS FOR IMPROVEMENT OF THE RDE REGULATION

- Although the RDE system aims to better reflect real-world driving conditions, a single RDE test of any given vehicle can result in a range of results, even with all of the boundary conditions being fully met. Differences between the most and least favorable test conditions provide a limit on the repeatability of RDE tests. To achieve significant real-world emission reductions, it is important to ensure that new vehicles are tested not only under the most favorable conditions but also under a range of possible boundary conditions, as defined in the legislative text. This is even more important given that vehicle makers can carry out as much as 50% of RDE tests themselves. Independent re-testing by authorities and third parties can help to ensure broader coverage of RDE tests. The fourth RDE package is expected to address this.
- The current RDE regulation applies only to pre-production vehicles provided by manufacturers. In the future, the scope of testing should include surveillance of in-use vehicles, independently sourced and tested, to reliably achieve fleet-wide emission reductions. This issue will also be addressed in the fourth RDE package.
- The current version of the RDE test still excludes a significant portion of real-world driving conditions, including a range of ambient temperatures and dynamic driving and altitude boundary conditions. Such conditions can potentially contribute disproportionately large amounts of NO_X emissions. Similarly, the current conformity factors allow on-road NO_X emissions significantly higher than the Euro 6 limits.
- Although the present focus of the RDE regulation is on air pollutant emissions, RDE testing will also measure and record CO_2. The RDE procedure does not foresee systematically analyzing the CO_2 information, even though doing so would allow for a better understanding of the real-world performance of new vehicles in terms of CO_2 emissions and fuel consumption.

EXPECTED FUTURE UPDATES

The third RDE legislative package was adopted by EU member states in December 2016 and includes the measurement and limitation of particulate number (PN), adaptation of the RDE test for hybrids, and provisions to include cold-start emissions and emission after-treatment system regeneration events. The introduction of a PN not-to-exceed limit, with a conformity factor of 1.5, combined

with a cold-engine start test is expected to require the use of improved emissions-control technology, especially for vehicles equipped with gasoline direct injection engines. Because the urban driving emissions limit has to be met separately and includes the cold start, these new provisions are expected to substantially reduce emissions in cities where public exposure is greatest.

The fourth RDE package, scheduled for discussion and adoption in 2017, will introduce the possibility for third parties to carry out RDE tests that would trigger action by the authorities if significant deviations from type-approval measurements were found. The fourth RDE package will also introduce in-use surveillance tests.

ANNEX I: THE FOUR PACKAGES OF THE RDE LEGISLATION

The RDE legislation has been divided into four legislative packages for enactment over several years. The European Commission chose this approach because of the broad and technical nature of the text, covering various areas such as specifications for measurement equipment, trip definitions, and boundary conditions.

The four packages are divided as follows and are subject to progress of the RDE working group on the final two pieces.

1. The first package, voted on in May 2015 and published in the *Official Journal of the European Union* in March 2016, includes the basic features of the RDE test, such as characterization of the RDE trip, the vehicle family concept, description of the data evaluation tools, technical requirement of the PEMS equipment, and reporting obligations.
2. The second package, voted on in October 2015 and published in the *Official Journal of the European Union* in April 2016, includes more political outcomes, such as the determination of the conformity factors and the timetable for RDE implementation. Technical features include the introduction of dynamic boundary conditions and a limit for altitude gain together with a detailed approach to calculating it.
3. The third package, voted on in December 2016, includes the introduction of the particulate number measurement along with a conformity factor of 1.5. The package also features specific legislative provisions for hybrids and a procedure to include cold starts and regeneration events in the RDE test.
4. The fourth package, still in the preliminary stages, is expected to cover in-service compliance and surveillance tests along with specific provisions for light commercial vehicles (vans).