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THE FUTURE OF VEHICLE EMISSIONS TESTING AND COMPLIANCE

HOW TO ALIGN REGULATORY REQUIREMENTS, CUSTOMER EXPECTATIONS, AND ENVIRONMENTAL PERFORMANCE IN THE EUROPEAN UNION

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EXECUTIVE SUMMARY

Recent studies demonstrate a growing discrepancy between official and real-world fuel consumption and emission values of new passenger cars. In the European Union, average fuel consumption and carbon dioxide (CO_2) emissions for new vehicles are about 40 percent higher than official type-approval figures indicate. Average real-world emissions of nitrogen oxide (NO_X) from new diesel cars have been found to be about seven times higher than suggested by the manufacturers' data.

In the meantime, a growing base of evidence indicates that one of the underlying reasons for the observed discrepancies, and also for the dramatic increase over time, is shortcomings in the testing schemes that determine how new-vehicle emission levels are measured. Furthermore, it has become clear that there are also shortcomings in the compliance protocols that determine how emission levels are verified and how penalties are imposed. These shortcomings have allowed vehicle manufacturers increasingly to exploit tolerances and flexibilities, leading to downward-trending type-approval emission levels that are not matched by a similar decrease in real-world emission levels—indeed, the real-world values contradict the type-approval results. The recently uncovered use of an illegal defeat device by Volkswagen crosses a line between illegality and the simple exploitation of legal loopholes that allow manufacturers to observe the letter of a regulation while disregarding its spirit and intent. But it nevertheless serves to dramatically highlight a broader underlying problem with today's vehicle emissions testing and compliance systems.

A key objective of this report is to compare and contrast the current vehicle testing and compliance schemes in the EU and the United States. By putting the two systems side by side (Figure 1.), it can be seen that the fundamental difference is not so much the actual vehicle testing itself but the strong focus on independent conformity testing coupled with enforcement authority in the U.S. In the EU, by contrast, this element of independent re-testing is largely absent from the regulations, and the involved regulatory bodies are more restricted with respect to their enforcement authority.

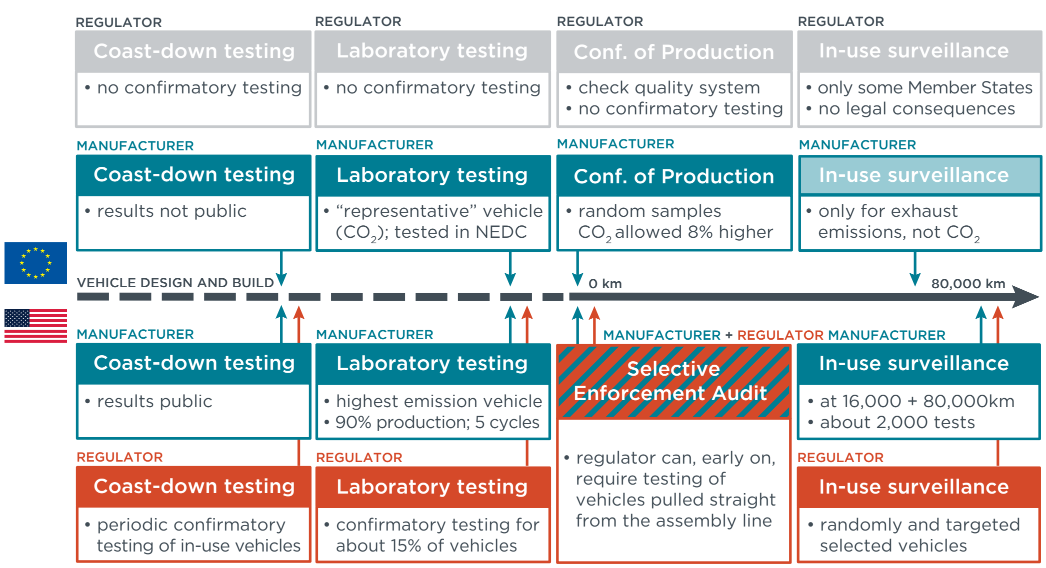

Figure 1. Overview of the EU and U.S. vehicle emissions testing and enforcement schemes.

For example, the road load coefficients[1] of vehicles type-approved in the EU are not publicly available, and no authority or independent organization in the EU carries out independent re-testing of vehicle road loads. This is despite the fact that a vehicle's road load coefficients are a crucial input parameter for the chassis dynamometer tests carried out later in the laboratory and heavily influence the resulting official fuel consumption and CO_2 emissions of a vehicle. In the U.S., on the other hand, the Environmental Protection Agency (EPA) regularly carries out its own independent road load conformity testing. In the past, the EPA has forced several manufacturers to take action when a deviation between the road load declared by the manufacturer and the road load determined by the EPA was found.

As a secondary objective, this report describes a number of measures that could be introduced in the EU to improve the current vehicle emissions testing and compliance scheme. Specific recommendations include:

- Introducing the **Worldwide Harmonized Light Vehicles Test Procedure (WLTP)** as well as **regional specifications** that go beyond the WLTP itself (such as an ambient test temperature of 14°C in the EU instead of the 23°C foreseen in the WLTP)
- Introducing a **testing and target scheme regarding the efficiency of vehicle air conditioning systems**
- **Strengthening the road load determination procedure** by ensuring that measurement results become publicly accessible and by introducing independent conformity testing for road load coefficients
- Establishing a **European type-approval authority**, acting as a neutral party between vehicle manufacturers and technical service companies and with the authority to demand the recall of a vehicle model or issue penalties if significant deviations were found as part of conformity testing, thereby ensuring a maximum level of independence and credibility
- Introducing a **real-world adjustment factor** for vehicle fuel consumption and CO_2 emission figures
- Putting a **stronger focus on in-use conformity testing of series vehicles**, complemented by **on-road PEMS testing not only for air-pollutant emissions but also for fuel consumption and CO_2**
- **Further developing consumer websites**, by providing an EU-wide platform for vehicle owners to report everyday experience regarding fuel consumption

It is understood that some of the changes outlined in this report are substantial and would entail significant preparations before they could be implemented in the regulations. Nevertheless, this report aims at thinking beyond measures that are already in the planning stages today, and to sketch a more fundamental revision of the vehicle testing and enforcement scheme that will better align emissions test results, customer experiences, and environmental performance in the future.

1 The road load coefficients characterize the forces that a car has to overcome to travel (mostly aerodynamic and rolling resistance) as a function of vehicle speed. They are determined through a coast down test.

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ABBREVIATIONS

CAA	Clean Air Act
CF	Conformity Factor
CO_2	Carbon dioxide
CoC	Certificate of Conformity
CoP	Conformity of Production
ECU	Engine Control Unit
EEA	European Environment Agency
EPA	Environmental Protection Agency
EU	European Union
FTP	Federal Test Procedure
IFEU	Institute for Energy and Environment Research
IUCP	In-Use Confirmatory Program
IUVP	In-Use Verification Program
km/h	Kilometers per hour
LNT	lean-burn NO_x adsorbers
NEDC	New European Driving Cycle
NO_x	Nitrogen oxide
OBD	On-Board Diagnostics
PEMS	Portable Emissions Measurement System
RDE	Real Driving Emissions
SCR	Selective Catalytic Reduction
SEA	Selective Enforcement Audit
TNO	Netherlands Institute for Applied Scientific Research
UBA	Federal Environmental Agency
U.N.	United Nations
UNECE	United Nations Economic Commission for Europe
UK	United Kingdom
U.S.	United States
WLTP	Worldwide harmonized Light vehicles Test Procedure
WVTA	Whole-Vehicle Type-Approval

1. INTRODUCTION

A number of recent studies demonstrate that there is a discrepancy between vehicle emission test results used for new vehicle type-approval and “real-world”, on-road, emission levels:

» For **CO_2** emissions of passenger cars in the EU, this “gap” has grown from less than 10 percent in 2001 to about 40 percent in 2014 (Tietge, et al., 2015). For light-duty vehicles in the U.S., a similar discrepancy level has been found, but with a significantly smaller *increase* of the gap over time (from about 20 percent in 2004 to about 35 percent in 2012) (Mock, et al., 2013).

» **NO_x** emissions of modern Euro 6 diesel passenger cars in the EU were found to be — on average — about seven times higher than indicated by their official laboratory test results, with some individual vehicles performing significantly worse (Franco, et al., 2014). In the U.S., limited testing recently led to discovery of an extreme case of discrepancy in real-world NO_x performance, the revelation that Volkswagen had employed an illegal defeat device on certain models (Thompson, et al., 2014).

The discrepancy between official type-approval test data and real-world behavior of vehicles, and in particular the rapid increase in that discrepancy over time, are of concern for several stakeholders:

» For **consumers**, the increasing gap between CO_2 emission figures results in higher than expected fuel costs.[2] An average EU car driver will pay an estimated €450 more per year on fuel than manufacturers’ sales brochure claims suggest (Tietge, et al., 2015). Diesel cars were incentivized in many European countries in recent years, but now could be banned from inner-urban areas because of their high on-road exhaust pollutant emissions (Neumaier, 2010; The Telegraph, 2014).

» For **society**, the increasing CO_2 emissions gap is problematic because it means that only about half of the CO_2 reductions achieved by light-duty vehicles over the last 10 years is “real,” making it more challenging to meet agreed-upon climate mitigation objectives and to reduce dependency on oil imports (Tietge, et al., 2015). Similarly, urban areas in the EU are still struggling with high ambient NO_x concentrations and the associated health problems (EEA, 2014).

» For **governments**, the CO_2 gap can mean a significant loss of tax revenues, as most EU member states base their vehicle taxation schemes at least partially on type-approval CO_2 emissions. It can therefore happen that fiscal incentives are granted for vehicles and technologies that are not as beneficial in terms of CO_2 as the official test results suggest (Tietge, et al., 2015). Similarly, some EU member states provided fiscal incentives for the early introduction of Euro 6 diesel cars, while recent test results indicate that these vehicles tend to have significantly higher on-road NO_x emission levels than originally anticipated (Franco, et al., 2014).

» For **vehicle manufacturers**, the increasing gap, for both CO_2 and NO_x, has the potential to undermine the credibility of individual companies, and even the entire auto industry — with an effect also on vehicle sales numbers. It is still too early to determine what the recent Volkswagen defeat device scandal will mean for the

2 This is due to the fact that CO_2 emissions and fuel consumption are directly proportional. Any discrepancy between type-approval and real-world CO_2 emissions therefore translates into an equivalent gap for fuel consumption figures.

company and for diesel technology in general, but it seems likely that the long-term impacts will be substantial. That developing story vividly illustrates why it is also important to keep in mind that inadequate and inconsistent testing and compliance schemes place those companies that comply with the standards during real-world conditions at a competitive disadvantage.

A number of studies analyze the underlying reasons for the discrepancy between official test results and real-world figures (Kadijk, et al., 2012; Schmidt & Johannsen, 2010; ElementEnergy and ICCT, 2015)[3]:

» The increasing exploitation of tolerances and flexibilities in the test procedure is seen as a key reason for the growing gap in **CO_2** emissions. For example, a 2012 study by the Netherlands Institute for Applied Scientific Research (TNO) compared road load values for eight passenger cars, and concluded that CO_2 emissions of the more recent vehicles were about 11 percent lower than those of comparable older vehicle models. This reduction in CO_2 emissions in newer vehicles was due to an increased exploitation of flexibilities in the road load testing procedure (Kadijk & Ligterink, 2012).

» Another of the main drivers identified is the increasing deployment of technologies that show a higher CO_2 reduction benefit in the test procedure than under real-world driving conditions. This is linked to the fact that the New European Drive Cycle (NEDC) currently used in type-approval tests includes significantly more phases of idling and low-load areas than is typical of real-world driving. A prominent example is the stop-start technology that is nowadays used in more than one-third of all new passenger cars in the EU, compared to less than 5 percent in 2007 (Mock (ed.), 2014) and only 6 percent of 2014 passenger cars in the U.S., which uses a different test cycle with less idle time (EPA, 2015).

» A third, significantly less relevant, factor in the increasing CO_2 gap is the growing popularity of vehicle air-conditioning systems (Hoffmann & Plehn, 2010). As the use of air-conditioning systems is not part of the official vehicle CO_2 test, this development explains part of the increasing gap between official and real-world CO_2 figures.

» For the gap in official versus real-world **NO_x emissions from diesel cars**, a key driver is the effort of vehicle manufacturers to maintain the ownership experience and avoid the (small) negative tradeoffs that come with improved emissions performance. A properly functioning lean-burn NO_x adsorber (frequently called a lean NO_x trap, or LNT) system comes at the expense of a small fuel consumption penalty of between 1 and 2 percent—which, unlike uncontrolled NO_x emissions, is directly perceived by the owner of the vehicle. For vehicles equipped with Selective Catalytic Reduction (SCR, an alternative technology to LNT) systems, manufacturers may be inclined to reduce the amount of the aqueous urea solution that such systems inject into the exhaust gas stream to react with NO_x, as a way to reduce the frequency with which that solution must be replenished. The less frequent these refill intervals are, the more convenient it is for the driver — a point

3 In this context, it is important to understand that, especially for CO_2, there are notable differences among individual drivers and individual trips. Hence, emission levels from one trip cannot be directly compared to the emission levels from another trip. To overcome this comparability issue, we need to look at the aggregate results for a large number of trips and drivers. Using this approach, clear trends can be identified and it is therefore these aggregated average results that we generally focus on when analyzing emission trends (Tietge, et al., 2015).

manufacturers often make when confronted with high in-use NO_x emissions for diesel cars (DIE WELT, 2013).

In the EU, there are two measures foreseen for the short term that are expected to reduce the existing level of discrepancy for CO_2 and NO_x emissions:

» For CO_2 and exhaust pollutant emissions, introduction of the new **WLTP** is scheduled for 2017. The WLTP was developed at the United Nations (UN) level and, compared to the current NEDC (New European Drive Cycle), better reflects the reality of everyday driving (Mock, et al., 2014).

» For exhaust pollutant emissions, and in particular NO_x from diesel cars, the introduction of a Real Driving Emissions from light-duty vehicles (**RDE**) procedure has recently been approved. This RDE procedure will add mandatory on-road testing using Portable Emissions Measurement Systems (PEMS) on top of the current entirely laboratory-based test procedure (Mock, 2014).

It is expected that the WLTP and RDE procedures will bring some improvements and reduce the level of observed discrepancy between official and real-world emissions. However, it is also expected that a substantial gap will still remain and that the gap may grow again in the future (ElementEnergy and ICCT, 2015). This is because neither WLTP nor RDE will address all the shortcomings of the current test procedure, as will be explained in more detail in Section 3.

The objective of this report is to think ahead, beyond the introduction of the WLTP and RDE in the EU, and to sketch a more fundamental revision of the vehicle testing and enforcement scheme that would better align test results with customer experiences in the future. It is *not* the objective of this report to describe these suggested revisions in great detail; some of the changes outlined here are substantial and would have to be implemented carefully and over time. Rather, the purpose of this report is to start outlining some possible future solutions for further discussion and refinement.

For this report, test procedures for determining CO_2 emissions and fuel consumption as well as exhaust pollutant emissions such as NO_x or particulate matter are taken into account. The focus of the report is on light-duty vehicles in the EU (and to some extent the U.S.), but the elements discussed apply equally to other markets that have adopted elements of the EU emissions certification procedure into their own legislation (*e.g.*, China, India, South Korea, or Russia).

In Section 2, the current vehicle testing procedures in the EU and U.S. are described and compared. Section 3 then outlines a number of measures that can be introduced to improve the EU testing procedure. Section 4 summarizes the findings, taking into account the viewpoints of policymakers, vehicle manufacturers, and consumers.

2. VEHICLE EMISSIONS TESTING IN THE EU AND U.S.

In this chapter, we describe vehicle emissions testing as it is currently carried out in the EU and the U.S. We focus on testing for regulatory purposes[4] (including enforcement), but we also include vehicle emissions testing in a broader sense: as it is, for example, carried out by car clubs for consumer information. Before going into the details of the EU and U.S. testing, Section 2.1 defines different types of testing as a background for the following sections. Sections 2.2 and 2.3 then focus on vehicle emissions testing and enforcement for the EU and U.S., with Section 2.4 providing a summary comparison between both systems.

2.1. VEHICLE EMISSIONS TESTING METHODS

For this report, we distinguish between four basic types of vehicle emissions testing, summarized in Figure 2 and explained in more detail below.

repeatability, reproducibility

representativeness

Laboratory testing for regulatory purposes
- On a chassis dynamometer with driving resistances from a separate road load test
- Following a regulatory test protocol (e.g. NEDC)
- Fixed speed trace (no traffic), no uphill / downhill driving, fixed temperature, air conditioning off, ...

Enhanced laboratory testing
- On a chassis dynamometer with driving resistances from a separate coast-down test
- Following a modified test protocol (e.g. ADAC EcoTest)
- Fixed speed trace (no traffic), usually no uphill / downhill driving, fixed temperature, air conditioning on, ...

On-road testing
- On a normal road, using PEMS or OBD data-logger equipment to collect data
- Defined set of test vehicles, tested for a limited time, possibly using professional drivers
- Random speed trace (normal traffic), including uphill / downhill driving, air conditioning on, ...

On-road data recording
- On a normal road, using OBD data-logger equipment or manual recording to collect data
- Normal drivers, monitoring the performance of their vehicles over a long period of time
- Random speed trace (normal traffic), including uphill / downhill driving, air conditioning on, ...

Figure 2. Overview of types of vehicle testing discussed in this report.

» **Laboratory testing for regulatory purposes** is carried out on a chassis dynamometer in a specially designed testing facility. At least two of the wheels of the vehicle are spinning during the test, but the vehicle itself remains stationary. The driving resistances (vehicle inertia, rolling resistance, aerodynamic resistance) are previously determined in a separate test (the *road load* test) and are then simulated in the laboratory by adjusting the resistance of the chassis dynamometer. The exhaust of the vehicle is collected and analyzed to calculate emission levels and fuel consumption for the test cycle. Details of the test cycle (speeds, accelerations, etc.) and test procedure (ambient temperature, etc.) are defined in a test protocol (for example, NEDC in the EU). Results of vehicle laboratory testing are generally reproducible, i.e., if two different laboratories test the same vehicle and apply the same testing conditions, they then should obtain very similar test results. On the other hand, vehicle laboratory testing is somewhat artificial and not fully representative of real-world driving, which often results in unrealistically low

4 It should be noted that evaporative emissions and testing are not included in the scope of this paper.

emission levels. In an attempt to overcome this shortcoming, a series of laboratory tests under different conditions can be carried out for one vehicle in order to better represent the full range of real-world driving situations.

- **Enhanced laboratory testing** is closely related to laboratory testing for regulatory purposes. The vehicle is still tested on a chassis dynamometer, with its resistances being simulated based on road load testing results. What is different is the testing protocol: It is often based on a regulatory testing protocol but then modified to better reflect real-world driving. For example, Europe's largest car club, the Allgemeiner Deutscher Automobil-Club (ADAC), has defined its own test procedure, the ADAC EcoTest.[5] The EcoTest largely follows the NEDC and WLTP but with some modifications: In addition to testing the vehicle in NEDC and WLTP, it is also tested in a special highway cycle (the ADAC Autobahn-Cycle). Furthermore, for parts of the EcoTest the air-conditioning system of the vehicle is turned on. The EcoTest also relies partly on input data obtained directly from vehicle manufacturers (for example, the road load data for simulating aerodynamic and rolling resistance of the vehicles tested). Test results of the EcoTest are used by ADAC for consumer information purposes. Vehicle manufacturers themselves carry out similar tests for benchmarking purposes, where they test their own vehicles and those of competitors using the official test procedures (NEDC, WLTP, etc.), as well as internally developed test procedures that better reflect driving behavior of their customer groups. The results of these vehicle manufacturers' tests are generally not public.
- **On-road testing** is carried out on a vehicle while driving on a normal road, being part of the normal traffic flow. The most widely used technique for on-road emissions testing is PEMS, which involves equipping the vehicle with portable, on-board analyzers. The main PEMS unit is temporarily attached to the back of the vehicle, and the vehicle exhaust is collected, analyzed, and recorded as it is driven. On-road testing results are highly representative of real world driving when carried out under everyday driving conditions. However, the results are only representative of the driving conditions of the individual test, and they lack the reproducibility of laboratory tests, making it challenging to incorporate these techniques in regulations. In addition, the results are influenced by uncontrolled sources of variability (e.g., traffic or weather conditions), and they are thus not easily reproducible, i.e., testing the same vehicle at two different locations will produce two different results. Even testing the same vehicle at the same location twice will likely give two different results (for example, because during one trip a traffic light was green while during the other trip the same traffic light was red). In return, on-road tests provide the most complete information about the real-world emissions behavior of vehicles, and are excellent tools for linking specific driving conditions to emission rates and identifying shortcomings in the control of certain pollutants.
- **On-road data recording** is similar to on-road testing, with one major difference: While for on-road testing a specific set of vehicles is selected and equipped with testing devices for a limited time, possibly also using professional drivers, on-road data recording is carried out for extended periods of time as the customer drives his/her own vehicle. On-road data recording is mainly used to gather fuel consumption (and thereby indirectly also CO_2) data, and it requires the customer either to use a logging device that is connected to the vehicle's On-Board Diagnostics (OBD) or to keep a manual log of the amount of fuel consumed and

5 http://www.adac.de/infotestrat/tests/eco-test/

distance driven between two stops (for example, between re-fuelling events). Many vehicle drivers do record their on-road fuel consumption and even make the results public. For example, the German website Spritmonitor.de[6] has more than 300,000 registered users reporting real-world fuel consumption figures for their vehicles. Similarly, drivers of company cars are usually required to record the amount of fuel purchased and the distance driven between fuelling events. Fuel consumption data from on-road data recording is generally highly representative of real-world driving. Results for an individual vehicle and an individual trip are not reproducible, but because the data is collected over a long period and aggregated over a large number of drivers conclusions can be drawn about the average real-world fuel consumption of vehicle models.

2.2. EUROPEAN UNION

Overview of the EU type-approval process

Before a new vehicle model goes into production, usually several months in advance, the vehicle manufacturer kicks off the type-approval (also known as "homologation") process to demonstrate that the vehicle meets all the technical and administrative requirements to be sold in the EU. Details of the type-approval process are defined in a number of EU and United Nations Economic Commission for Europe (UNECE) regulations, a key one being Framework Directive 2007/46/EC. The type-approval process consists of several steps, including approval for individual components (such as headlamps, mirrors, tires), system approvals (for example, brake system, exhaust pollutant emissions, etc.), and then finally Whole Vehicle Type-approval (WVTA).

Each EU member state has its own designated type-approval authority; examples include the Kraftfahrt-Bundesamt (KBA) in Germany, the Centre National de Réception des Véhicules (DRIEE) in France, and the Vehicle Certification Agency (VCA) in the United Kingdom.[7] Vehicle manufacturers are not bound to a specific type-approval authority, as approvals obtained in any member state for a component, system, or whole vehicle are recognized by other member states. It is not unusual for a manufacturer, for example, to obtain type-approval for the fuel consumption and exhaust pollutant emissions of a vehicle in Luxembourg but the final WVTA in Germany.

Within each member state there are technical services appointed by the type-approval authority to carry out type-approval tests. The number and nature of these technical services varies among member states. In Germany, there are currently 82 technical services listed.[8] Most of these are privately owned companies based in Germany.[9] Others are technical service companies from other EU member states that are accredited for type-approval testing in Germany.[10] In France, on the other hand, there is only a single technical service company, UTAC, and all type-approvals in France have to go through it.[11] A unique aspect particularly of the UK system is that VCA (the UK type-approval

6 http://www.spritmonitor.de
7 A list of all EU approval authorities can be found here: http://ec.europa.eu/DocsRoom/documents/10942
8 A list of all technical services by member state can be found here: http://ec.europa.eu/DocsRoom/documents?tags=technical-service-auto&pageSize=30&sortCol=title&sortOrder=asc
9 At least in one case a technical service is partially owned by a vehicle manufacturer: MBTech EMC GmbH is part of the MBTech Group, of which Daimler holds 35 percent of shares.
10 For example, IDIADA Automotive Technology, also being the owner of a popular vehicle proving ground in Spain: http://www.applusidiada.com/en/activity/Proving_ground-1328274726564
11 http://www.utac.com/en/homologation/offre/Pages/default.aspx

authority) also offers its services as one of the technical service companies. The VCA highlights this fact in their marketing materials: "VCA is a combined Approval Authority and Technical Service, which will help you to get your products to market quickly."[12]

Once the vehicle manufacturer has selected a type-approval authority and technical service company, it can then choose to carry out the necessary testing at its own facilities, with a representative of the technical service witnessing the test, or it can commission the technical service to carry out the testing on behalf of the manufacturer. The most common procedure for larger manufacturers is to test a vehicle model in its own facilities and to have the technical service to witness the final test that is then used to obtain the type-approval certificate.

Vehicle selection and pre-production laboratory testing

Not every new vehicle model of a manufacturer needs to go through the type-approval process; only new vehicle *types* do. Vehicles are categorized as being of the same *type* if they have the same inertia mass and the same engine and vehicle characteristics.[13] All further details of a vehicle define different vehicle *variants* and *versions*.

For exhaust emission testing, the manufacturer selects a vehicle for testing that is "representative of the type to be approved."[14] Alternatively, in agreement with the type-approval authority, the manufacturer may also select a vehicle that is not representative of its type but "combines a number of the most unfavorable features with regard to the required level of performance." As a result, for exhaust pollutant emissions often only one vehicle of a type is tested — the one with the (expected) highest exhaust pollutant emissions, as the exhaust emission limits are simply pass or fail, and the manufacturer can be sure that all other vehicles of the same type will have lower exhaust pollutant emissions and would therefore also meet the limit.

For CO_2, on the other hand, every gram counts for the manufacturer's fleet average value. As a result, for CO_2 the manufacturer will usually not test only one vehicle of a type (the regulation permits testing only the one with the highest CO_2 emissions) but instead will test each vehicle variant separately to reduce the CO_2 emission average of its fleet as much as possible. In this context, it should be noted that the exhaust and CO_2 emission tests are not necessarily carried out together, i.e., it is possible for the manufacturer to choose different pre-production vehicles for each of the tests.

The vehicle to be tested is then put on a chassis dynamometer and run according to the guidelines of the NEDC test procedure.[15] Usually, during the design process for a new vehicle model, manufacturers will internally define target values for fuel consumption and emissions based on experience from previous model cycles and on extensive computer simulations. The type-approval engineer for that vehicle within the company

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12 http://www.dft.gov.uk/vca/additional/files/vehicle-type-approval/related-information/type-approval-brochure.pdf

13 UNECE R83 defines a vehicle type as: "Vehicle type means a group of vehicles that do not differ in the following respects: The equivalent inertia determined in relation to the reference mass as prescribed in Table A4a/3 of Annex 4a to this Regulation; and the engine and vehicle characteristics as defined in Annex 1 to this Regulation." EU-directive 2007/46/EC, Annex II B, defines a vehicle type as being from the same manufacturer, having the same "manufacturers' type designation" and being the same in terms of "essential aspects of construction and design".

14 See EU-directive 2007/46/EC, article 11

15 A description of the NEDC test procedure and the various flexibilities and tolerances provided there for vehicle testing (for example, tire selection, vehicle running in, etc.) is outside the scope of this paper. See instead Mock, et al., 2014.

is then responsible for reaching the targets during type-approval testing. Once the manufacturer's type-approval engineer is satisfied with the results of the internal vehicle laboratory tests, an emission value for the vehicle is declared. Then a final test is carried out, either by the technical service or with the technical service witnessing the manufacturer's test. For CO_2, if the value measured during this final test does not exceed the declared value by more than 4 percent, the declared value then becomes the official type-approval figure for that vehicle type.[16] In practice, this procedure has led to a situation in which the manufacturer generally deducts 4 percent of a vehicle's CO_2 test result (for example, if the measured CO_2 emission level for a vehicle is 100 g/km, then the declared value by the manufacturer is 96 g/km), as the precision of testing with modern emissions measurement equipment is good enough to reproduce test results with a very high confidence (Kadijk & Ligterink, 2012).

Road load determination

During vehicle testing on a chassis dynamometer in a laboratory, the vehicle itself is not moving; only its wheels are spinning. The dynamometer simulates the inertia of the vehicle and its effect on acceleration and deceleration as well as the rolling and aerodynamic resistances. The driving resistance input data for the chassis dynamometer is determined outside the laboratory, during a *road load* test (also called *coast down* test) on a specially designed test track (Figure 3). This means that during laboratory testing the vehicle on the dynamometer experiences at any speed the same resistance as if it were running on that test track.

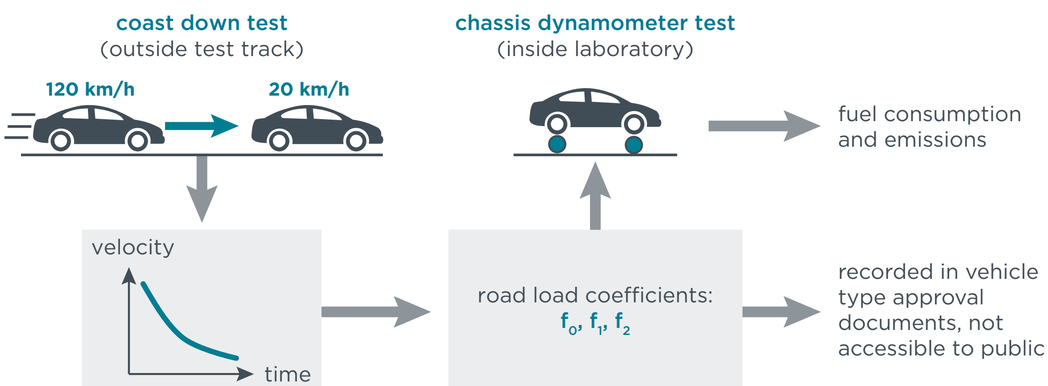

Figure 3. Schematic illustration of the road load determination procedure in the EU.

During coast down tests, the vehicle is brought to a certain speed on the test track (for example, 130 km/h), and the gearbox is then placed in the "neutral" position.[17] While the vehicle is rolling on the test track, it slowly loses speed due to aerodynamic and rolling resistances. For a number of reference speeds between 20 and 120 km/h, differing by 20 km/h from one another, the coast down time is measured over an interval from +5 to -5 km/h of the reference speed. Using the coast down time and the mass of the

16 For more details, see EU-directive 93/116/EC: "If the measured value of CO_2 exceeds the manufacturer's declared CO_2 value by more than 4 percent, then another test is run on the same vehicle. When the average of the two test results does not exceed the manufacturer's declared value by more than 4 percent, then the value declared by the manufacturer is taken as the type-approval value. If the average still exceeds the declared value by more than 4 percent, a final test is run on the same vehicle. The average of the three test results is taken as the type-approval value."

17 Details on the measurement procedure of vehicle road load can be found in Annex 4a — Appendix 7 of UNECE regulation No. 83.

vehicle, the sum of the resistance forces can be calculated for each reference speed. The coast down test is repeated several times (in both directions, with wind speeds kept to a minimum) until a certain statistical accuracy is reached. A second order polynomial regression line is drawn through the forces determined at the reference speeds, and its coefficients are referred to as the *road load coefficients* of the vehicle. These coefficients are represented as f_0, f_1, and f_2 values.

Road load testing is usually carried out for every vehicle variant. However, to reduce the number of coast down tests required, the manufacturer — in agreement with the technical service company — can also carry out a single road load test per vehicle type and then simulate the road load factors for all other variants on the computer. Other ways to reduce the number of coast down test runs include choosing to only test a worst case variant or, alternatively, choosing not to conduct a road load test at all, and instead to use a set of so-called default road load coefficients defined in the regulation. For passenger cars, the latter option is hardly ever taken. For light-commercial vehicles, it is not unusual for manufacturers to prefer the default values since these vehicles are offered in a wide variety of versions, which it would be difficult to test separately (Kadijk & Ligterink, 2012). As for type-approval testing in general, also for road load determination, a manufacturer can choose to carry out it own testing and have a technical service company witness it, or commission a technical service company to carry out the required coast down tests on its behalf.

There is common agreement that the road load coefficients determined from coast down testing are of special importance, as (a) they have a large influence on the fuel consumption and CO_2 emissions of a vehicle as determined by chassis dynamometer tests, and (b) coast down testing is rarely ever repeated during the production cycle of a vehicle model (Kadijk & Ligterink, 2012; Schmidt & Johannsen, 2010). For example, when re-testing selected vehicles on a chassis dynamometer in a laboratory, the ADAC EcoTest still relies on the official road load settings as determined during the original coast down testing of the manufacturer (and provided to ADAC by the respective manufacturer). This is because coast down testing is relatively time-consuming and costly. Only a few studies exist where coast down testing for selected vehicles was carried out by an independent third party (Kadijk & Ligterink, 2012).

In contrast to the U.S., in the EU coast down test results are not public information. The coast down time intervals are recorded in the type-approval documents of the vehicle[18] but are treated as competitive information and are therefore not made available to the general public.

In-production and in-use testing

In the EU, once the type-approval road load determination and laboratory tests are carried out by the technical service, or the manufacturer’s tests are witnessed by the technical service, the certificate of Conformity of Production (CoP) is the last step of the type-approval process. For a manufacturer to obtain and maintain the CoP certificate throughout the production phase of a vehicle, it must demonstrate that each vehicle is manufactured in accordance with the approved specifications. In practice, it is often sufficient for the manufacturer to demonstrate that it has a quality-management system (such as is defined by ISO 9001) in place.

18 EC/692/2008, Annex I, Appendix 3, Art. 4 “Dynamometer load setting information”.

The EU regulations[19] also require the manufacturer to test emissions from vehicles randomly chosen from the assembly line.[20] For CO_2, the emission value found by the manufacturer during this in-production test is allowed to be at most 8 percent higher than the type-approval CO_2 figure. The manufacturer is required to present the test results to the corresponding type-approval authority. Independent tests performed by a third party other than the type-approval authority are not foreseen by EU regulations.

In-use testing of vehicles registered in the EU is carried out only for exhaust pollutant emissions, not for CO_2. For exhaust pollutant emissions, every two years the manufacturer has to test a certain number of vehicles, depending on the sales volume of the vehicle model in question. Between 3 and 20 vehicles have to be tested in the laboratory, each from 0.5 to 5 years old, with 15,000 to 100,000 km accumulated mileage (Daimler, 2013). As for CoP testing, the manufacturer reports the test results to the corresponding authorities; independent tests by the authorities themselves are generally not foreseen.

Only a few EU member states carry out additional in-use vehicle tests. For example, in Germany until recently, about 15 vehicles were tested each year as part of the *Feldüberwachung* program of the Federal Environmental Agency (UBA).[21] Similarly, in Sweden also about 15 vehicles per year are tested by the Swedish Transport Agency[22]. Generally, these tests mirror the type-approval process, i.e., focusing on the NEDC, but also include additional driving cycles (for example, the ARTEMIS driving cycle).[23] If a significant divergence between the type-approval and test results is found during these member state test programs, it can be brought to the attention of the manufacturer, but it does not have any legal consequences.

2.3. UNITED STATES

Overview of the U.S. vehicle testing and enforcement program

Before the Clean Air Act (CAA)[24] was passed in 1970, the vehicle compliance program in the U.S. was very similar to the current EU program and only covered prototypes for new vehicle certification. The CAA changed that, giving the Environmental Protection Agency (EPA) the authority to ensure that all vehicles coming off the assembly lines meet the applicable standards. It also authorized the EPA to hold manufacturers responsible for vehicles meeting standards throughout their useful lives, provided that customers properly maintain them. Lastly, the CAA required manufacturers to warrant individual emissions control components on vehicles to protect consumers. Over the years, the EPA compliance program has evolved from one that focused mainly on verifying that prototype and new production vehicles comply with standards to one that places strong emphasis on in-use testing and durability requirements to ensure that emission standards are met throughout the useful life of a vehicle.

19 See in particular EC/2007/715.

20 In fact, the manufacturer can ask the respective type-approval authority for permission to test vehicles that have been run-in for max. 3,000 km for gasoline vehicles and max. 15,000 km for diesel vehicles, in order to eliminate the so-called "green vehicle effect" and achieve lower emission levels.

21 http://www.umweltbundesamt.de/themen/verkehr-laerm

22 http://www.transportstyrelsen.se/sv/vagtrafik/Miljo/Luftkvaliet-i-tatorter/Avgaser/Hallbarhetsprovning-av-avgasrening/

23 The ERMES group brings together some results from these in-use vehicle testing programs: http://www.ermes-group.eu/web/who_we_are

24 http://www.epa.gov/air/caa/amendments.html

The various elements of the U.S. light-duty vehicles' compliance program are outlined in Figure 4, and are explained in more detail in the sections below.

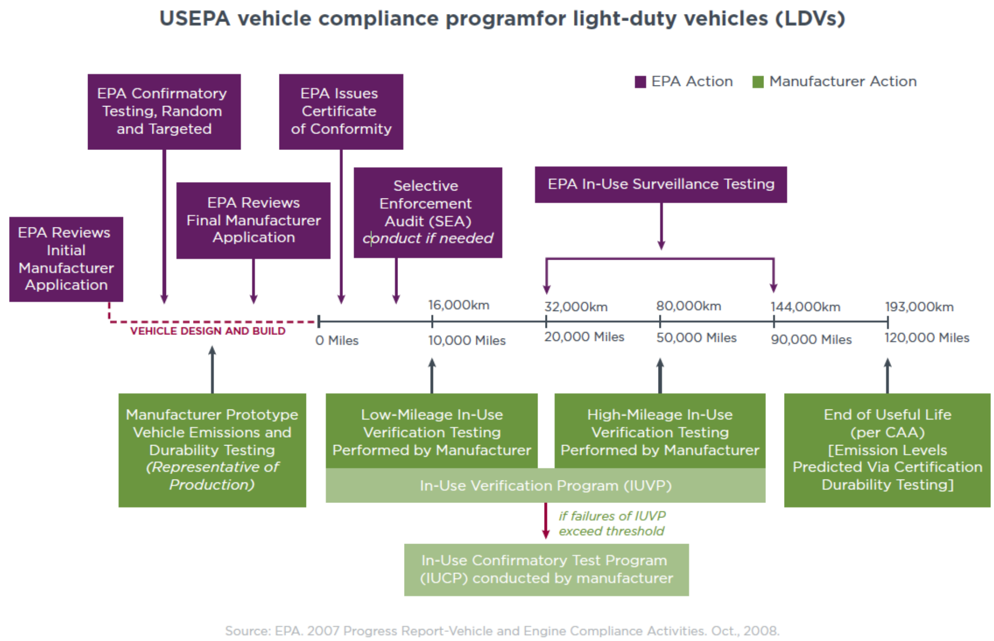

Figure 4. EPA vehicle compliance program for light-duty vehicles (EPA, 2008).

Vehicle selection and pre-production laboratory testing

Under the CAA Section 206, all engines and vehicles sold in the U.S. must be covered by a Certificate of Conformity before they can enter the market. Manufacturers must perform certification testing for all *test groups* that they choose to certify.[25] A test group, or engine family, is a group of vehicles or engines having similar design and emission characteristics, including engine displacement, cylinder number, arrangement of cylinders and combustion chambers (e.g., in-line or in "V" configuration), and subject to the same type of emission standards. The manufacturer is required to select and test the vehicle within every test group that is expected to generate the highest level of emissions and experience the most rapid deterioration in emissions performance over time.[26] These vehicles are tested by the manufacturer on the Federal Test Procedure (FTP), Highway, US06, SC03, and 20°F (-7°C) FTP tests. For CO_2 emissions and fuel economy, there are separate requirements for selecting and testing the highest sales volume vehicle within each engine family, as well as selecting the vehicle that is equipped with the highest sales volume tire. Furthermore, it is required that the testing include enough vehicle configurations to cover at least 90 percent of the vehicles produced in each model year. This last requirement is designed to ensure that the average CO_2 value for the manufacturer is based on an unbiased sample of actual vehicle production. It also means that manufacturers routinely test additional configurations after the model year is done to ensure that over 90 percent of production is tested. The tests for CO_2 are carried out in the laboratory on the FTP and highway tests. All vehicles tested must pass the emission standards, with deterioration factors

25 For a summary of the data collection and verification process in the U.S., see also (Fung & He, 2010).

26 CFR (Code of Federal Regulations) (2011), Title 40, sec. 86, National Archives and Records Administration, 2011.

applied. Test results and deterioration factors must be recorded in the certification applications to demonstrate compliance.

In the U.S., the authorities carry out their own confirmatory vehicle tests to validate the emission and fuel economy test results reported for certification by the manufacturers. In recent years, the EPA has selected about 15 percent of all test groups for confirmatory testing; two-thirds of the selected test groups (10 percent) are randomly selected, and the remaining third (5 percent) are targeted test groups (EPA, 2008). All light-duty vehicle confirmatory tests are conducted at the EPA's testing laboratories.

The majority of vehicles targeted for confirmatory testing are those models that use new technology or new designs. Others are targeted because of potential emission concerns, in particular models with emission levels close to the maximum permitted (those with only a small emission margin). If the vehicle fails the first test, a retest is allowed and the manufacturer may choose to inspect the test vehicle to determine what went wrong. If a vehicle fails two valid tests, no certificate will be issued unless the manufacturer makes changes and submits a new application. If the vehicle passes on the first or second test, the EPA value is used instead of the manufacturer's value.

Road load determination

Vehicle manufacturers carry out coast down tests on a designated test track to determine the road load factors needed for simulating the driving resistance (rolling and aerodynamic resistance) of the vehicle on the chassis dynamometer in the laboratory. For these coast down tests, the EPA has established requirements how to conduct the coast down testing outside the laboratory and for how the road load coefficients are applied inside the laboratory for chassis dynamometer testing.

All official road load values determined by manufacturers in the U.S. are accessible online to the general public. The EPA also periodically conducts confirmatory coast down testing on in-use vehicles. The effectiveness of the EPA's coast down enforcement is demonstrated by the recent settlement with Hyundai and Kia over improper road load values.[27] Hyundai and Kia were forced to correct the road load coefficients for many of their vehicles, retest the affected vehicles with the correct road load values, correct their fuel economy/CO_2 results, revise their fuel economy label values and CAFE/CO_2 standard compliance, and pay a $100 million civil penalty. Ford, Daimler, and BMW also recently corrected some erroneous road load values. In Ford's case, Ford found the error during routine internal testing and self-reported the correction to the EPA, along with correcting fuel economy label values[28]. This illustrates how in-use enforcement by the EPA has caused manufacturers to properly conduct coast down testing and monitor their own procedures.

In-production and in-use testing

There is a series of in-production and in-use confirmatory tests foreseen in the U.S. regulations. The main aspects of these confirmatory tests are explained below.

The **Selective Enforcement Audit (SEA)** program started in the mid-1970s and aims to identify cases where prototype vehicles supplied by manufacturers are not representative of production. The CAA allows the EPA to require testing of vehicles

27 http://www2.epa.gov/enforcement/hyundai-and-kia-clean-air-act-settlement

28 https://media.ford.com/content/fordmedia/fna/us/en/news/2014/06/12/ford-motor-company-lowers-fuel-economy-ratings--for-six-vehicles.html

pulled straight off the assembly line, at the manufacturer's expense, without prior notice. The SEA gives the EPA an opportunity to assess, early on, whether certified vehicles are actually being built adhering to the specifications of the prototype, and thereby serves as a means to check the conformity of production for a manufacturer. It also serves as a check to see if manufacturers are allowing sufficient compliance margins to account for natural variation in emission control components.

EPA uses information from many different sources to target testing under the SEA, including a manufacturer's compliance history, compliance margin, certification data, inspection and maintenance data, technology reviews, and defect reports. If a model fails SEA testing, the EPA has the power to revoke or suspend certification until the manufacturer can demonstrate conformity with the standards. Because penalties for failing the SEA tests are disruptive to manufacturers, manufacturers soon began to test 100 times as many vehicles as the number audited by the EPA. By the mid-1980s, failed light-duty vehicle audits were a rare occurrence. This led the EPA to shift light-duty vehicle SEA staff and resources to in-use vehicle testing programs and heavy-duty vehicle SEA efforts (Bansal & Bandivadekar, 2013). The EPA has not conducted any SEA for light-duty vehicles in many years, but the agency reserves the right to conduct SEA tests if problems such as reporting fraud or improper testing are suspected.

Under the **In-Use Verification Program (IUVP)**, the EPA requires manufacturers to conduct chassis dynamometer testing of in-use vehicles at both low mileage (10,000 miles, or 16,000 km) and high mileage (50,000 miles, or 80,000 km). Manufacturers must test one to five vehicles per test group. About 2,000 industry-wide tests were performed in 2007. If 50 percent of vehicles in a test group fail and the average emission levels are greater than 1.3 times the standard limits, the manufacturer must automatically conduct an **In-Use Confirmatory Program (IUCP)** test. In the IUCP, test vehicles are selected and tested following the requirements of Confirmatory Testing (described in the next section). Failure of IUCP tests can lead to recalls. Manufacturers are required to report all IUVP data to the EPA. This large database allows the EPA to concentrate on future vehicle design issues, particularly on the deterioration of emissions control devices under real-life driving conditions. IUVP data is also used to assess and update the deterioration factors used for future pre-production testing and the procedures used to determine them.

In addition to manufacturer-conducted IUVP and IUCP tests, the EPA itself conducts **in-use surveillance tests** either at its testing facility or at authorized testing centers. Vehicles can be selected at random or they can be targeted based on data suggesting that particular vehicles require additional EPA testing. Manufacturers are contacted if their vehicles are picked for in-use testing and may observe the testing and maintenance being performed. For surveillance, the EPA typically recruits three to five vehicles from vehicle owners that are two or three years old from the south eastern Michigan area (in proximity to the EPA Ann Arbor laboratories in Michigan). The EPA ensures that the cars have been properly maintained and used or, if needed, performs required maintenance before testing. The agency carries out in-use surveillance tests for 100–150 vehicles per year (EPA, 2013).

While most in-use surveillance testing used to be conducted by the EPA, it is now generally conducted by manufacturers under the IUVP, as described above. Testing enters the confirmatory phase if the surveillance results (or IUVP results) indicate a substantial number of vehicles in a class may exceed emission standards during their useful life and if the manufacturer declines to resolve the problem. The manufacturer can voluntarily recall the vehicles at any time or may come up with another method to fix the problem to avoid mandatory recalls. The EPA works with manufacturers to agree on appropriate remedies to obviate a recall. However, it has the authority under Section 207(c) of the CAA to order a recall if voluntary measures are not agreed upon (CAA, 1970).

The EPA also requires manufacturers to monitor known defects in emission control systems of properly maintained engines. They must submit defect reports to the EPA whenever 25 or more vehicles of the same model year are found to have the same emissions-related defect. The defect reports must estimate the proportion of vehicles that contain a defective part and must assess the impact of the defect on emissions. A recall can be initiated if as little as 1 percent of an engine family has the same defective part, assuming that defect has a significant impact on emissions. The EPA has also fined manufacturers for failure to establish a robust defect tracking and reporting system.

2.4. COMPARING THE EU AND U.S. TESTING AND ENFORCEMENT SCHEMES

Figure 5 summarizes the key aspects of the EU and U.S. schemes for testing light-duty vehicle emissions, including measures for enforcing the applicable emission limits/targets in practice.

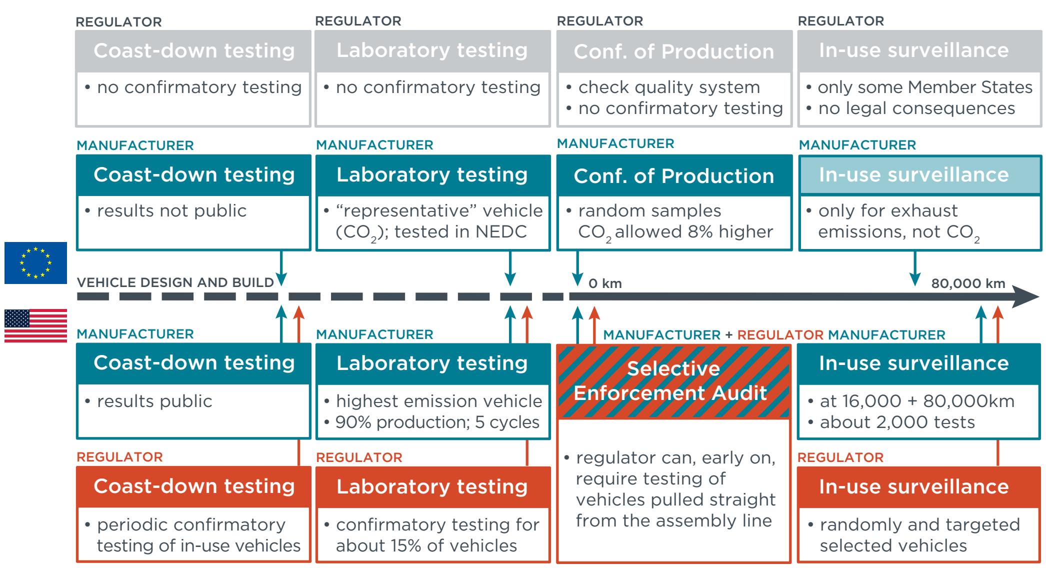

Figure 5. Overview of the EU and U.S. vehicle emissions testing and enforcement schemes.

In the EU, generally the manufacturer carries out its own vehicle tests, witnessed by a technical service company; in some cases, the technical service company carries out the testing on behalf of the manufacturer. Independent confirmatory tests by the regulator (i.e., the European Commission and/or EU member states) are not foreseen in the current EU system. By contrast, while most of the testing burden in the U.S. is also on the vehicle manufacturer, the regulator (EPA) carries out — or at least has the legal authority and technical capacity to carry out — confirmatory tests for all the various steps. The U.S. regulator also has the power — and has made use of that power in the past — to issue penalties and even demand a recall of a vehicle type if any violations of the testing regulations are discovered:

- Before the actual vehicle emissions test in the laboratory, the manufacturer carries out **coast down tests** on a specially designed test track to determine the road load coefficients that will then be used to simulate aerodynamic drag and rolling resistance of the vehicle on the chassis dynamometer in the laboratory. In both the EU and the U.S., vehicle manufacturers have to follow technical guidelines when carrying out these tests. For the U.S., the EPA recently refined and clarified the procedures to be used when determining road load coefficients.[29] For the EU, the current road load determination procedure allows for a number of flexibilities that can be exploited to arrive at road load coefficients that are not representative of normal vehicles on the road anymore (Kadijk & Ligterink, 2012; Kadijk, et al., 2012). In the EU, it is impossible to carry out systematic comparisons between road load coefficients determined by vehicle manufacturers and those determined for the same vehicles by independent laboratories, as the type-approval road load coefficients are not publically accessible. This stands in contrast to the U.S., where the road load coefficients for every vehicle model on sale can be accessed by anyone online.[30] Furthermore, in the U.S., the EPA periodically carries out confirmatory coast down testing on in-use vehicles, and in the past the agency has forced vehicle manufacturers to correct misleading road load coefficients.[31] In comparison, in the EU, once a vehicle manufacturer has carried out a coast down test that has been witnessed by a technical service company, the results are neither published nor are they subject to confirmatory testing by any of the EU or Member State agencies.
- For vehicle **testing in the laboratory**, using a chassis dynamometer, in the EU a “representative” vehicle configuration (or — for exhaust pollutant emissions — the configuration with the highest emission level) is chosen. In the U.S., for exhaust pollutant emissions, the configuration with the highest emission level is selected, while for CO_2 emission testing the highest selling vehicle configuration, including the highest selling tires, is selected. An additional important difference is that in the U.S., for CO_2, it is required that the testing carried out cover at least 90 percent of the vehicles produced in each model year. In the EU, laboratory testing is carried out by the vehicle manufacturer with a representative from a technical service company witnessing the type-approval laboratory test. In the EU the vehicle is tested using the NEDC test protocol; in the U.S., the vehicle is tested on the FTP and Highway cycles for CO_2 and also on the US06, SC03, and 20°F (-7°C) FTP tests for exhaust pollutant emissions, thereby covering a large spectrum of driving and ambient conditions (this is referred to as the five-cycle approach). The NEDC laboratory testing procedure offers a number of flexibilities that can be exploited to lower type-approval CO_2 emissions (Kadijk, et al., 2012). Another significant difference between the laboratory testing procedures in the EU and the U.S. concerns confirmatory testing. While independent re-tests by the authorities are not foreseen in the EU, in the U.S. the EPA selects about 15 percent of vehicles for carrying out confirmatory tests at its testing laboratories.

29 http://www.epa.gov/otaq/datafiles/cd1504.pdf

30 http://iaspub.epa.gov/otaqpub/pubadvsearch.jsp

31 See for example the 2014 Hyundai and Kia settlement: http://www2.epa.gov/enforcement/hyundai-and-kia-clean-air-act-settlement

- To ensure **conformity of production** in the EU, vehicle manufacturers are required to carry out emission tests on vehicles chosen at random from the assembly line. For CO_2, the emission level tested is allowed to be up to 8 percent higher than the type-approval level. The type-approval agency in charge checks whether there is an internal quality audit program in place within the manufacturer's production facilities. Independent confirmatory tests are not foreseen in the EU. In the U.S., the SEA program allows the EPA to require testing of vehicles pulled straight off the assembly line, at the manufacturer's expense, without prior notice.
- **In-use surveillance** exists in the EU only for exhaust pollutant emissions, with the manufacturer being obliged to test in the laboratory a sample of 3–20 vehicles per model family every two years. None of the EU type-approval agencies carries out in-use surveillance testing. Some EU Member States have their own testing programs, but without any legal consequences for manufacturers if deviations between test results and type-approval data are found. In the U.S., the regulator requires the manufacturer to carry out laboratory testing for 1–5 low- and high-mileage vehicles per model family every year. If significant deviations are found, more testing is required and, in the worst case, a recall of vehicles on the market can be initiated by authorities. In addition to the manufacturer's testing, the EPA also carries out its own in-use surveillance testing, with a randomly and targeted selected vehicle sample.

3. THE WAY FORWARD

The following sections focus on the EU and explore various options to eliminate shortcomings in the current vehicle-testing scheme. These shortcomings are ultimately the underlying reasons for the observed discrepancy in CO_2 and NO_x emission levels when comparing official test results and real-world, on-road driving experience. Some of the suggested options below could be introduced relatively quickly, and they could help reduce the gap in the short term. Other options would require a more fundamental revision of the testing scheme, but promise a more profound impact. It should be noted that it is not the objective of this report to describe any of the options in great detail. Instead, the intention is to provide some high-level suggestions that will then be subject to more detailed analysis and discussion later on. The discussion of the current situation and possible ways forward focuses on CO_2 emissions from all passenger cars, and NO_x emissions from diesel-powered passenger cars.

3.1. INTRODUCING THE WLTP

Between 2007 and 2014 the Worldwide Harmonized Light Vehicles Test Procedure (WLTP) was developed at the United Nations Economic Commission for Europe (UNECE). The regulatory draft text, called the Global Technical Regulation (GTR), was approved by the U.N. member organizations in March 2014, and is ready to be implemented in regional and national law[32] (ICCT, 2014). In the EU, implementation of the WLTP is planned for 2017. From then on, every new vehicle type must be tested using the WLTP instead of NEDC (Mock, et al., 2014).

Key changes of the WLTP when compared to the NEDC are[33]:

- A longer (1,800 seconds instead of 1,180 seconds), higher-speed (mean velocity 47 km/h instead of 34 km/h), and more transient **driving cycle**, with a maximum speed of 130 km/h instead of 120 km/h in the NEDC
- A higher vehicle **test mass**, taking into account optional equipment and payload of a vehicle; in the NEDC, only the lightest version, without any optional equipment, was tested
- A slightly lower ambient **test temperature**, defined at a set point of 23°C ±5°C, instead of 20°C –30°C in the NEDC
- A number of changes in the **test procedure**, intended to make the WLTP more realistic than the NEDC and offer fewer flexibilities

Given these improvements of the WLTP over the NEDC, it is generally expected that WLTP testing will result in more realistic exhaust and CO_2 emission values than testing a vehicle under the NEDC. However, there is also some skepticism that the WLTP will indeed result in significantly more realistic test results. A key reason is the lack of enforcement—i.e., confirmatory tests—in the EU, a situation that will remain unchanged even after the introduction of the WLTP. Furthermore, there are also a number of issues with the WLTP itself, described in more detail below:

- Some aspects of the WLTP in fact **result in lower emission values than would testing a vehicle on the NEDC**. For example, while for manual transmissions the use of

32 This refers to Phase 1A of the GTR. There are still some open issues around the technical details of the WLTP, mostly with respect to testing electrified vehicles, and it was decided to deal with these aspects in future phases of the WLTP. Phase 1B of the GTR is expected to be adopted in January 2016.

33 For a full list, refer to: (Mock, et al., 2014)

fixed gear positions for testing was mandatory in the NEDC, in the WLTP the gear shift points for manual transmissions will be calculated based on engine and vehicle parameters. As a result, the engine is operated in higher efficiency areas of the engine map, thereby resulting in lower CO_2 emissions on the WLTP than the NEDC. Another example refers to the duration of the WLTP test cycle. As the new cycle is significantly longer than the NEDC, the relative impact of emissions at cold start will be considerably smaller. This is particularly relevant for exhaust pollutant emissions, such as NO_x, where high emission levels are observed during the first few minutes after engine start before the catalyst converter warms up and starts operating. These cold start emissions will now be averaged over a longer test period in the WLTP, thereby resulting in generally lower emission levels than on the NEDC.

- A key question concerns *how* the WLTP will be introduced, i.e., **how existing emission targets will be transferred from NEDC to WLTP**. For exhaust pollutant emissions, the European Commission expects a 1:1 conversion, so that the existing emission limits of the Euro standards[34] remain as they are, without any adaption to the new test procedure. For CO_2, the European Commission has decided to carry out a correlation exercise that will come up with individual factors for each manufacturer. This should allow translating existing CO_2 targets for 2020/21 from the NEDC to the WLTP. For this correlation exercise, it would be fundamentally wrong to take into account the *full* set of differences between NEDC and WLTP, as this would be equivalent of translating all existing shortcomings of the NEDC into the new test procedure. Instead, those aspects that are new in the WLTP but only aim at fixing existing shortcomings and bringing the test procedure closer to its original intention have to be excluded from the conversion factor. A detailed assessment came to the conclusion that a correction supplement of 5–7 percent seems to be justified, i.e., existing CO_2 targets should on average be adjusted upwards by 5–7 percent to reflect the new testing conditions under the WLTP (Mock, et al., 2014). If the NEDC-WLTP correlation factor suggested by the Working Group at the EU level turns out to be higher than that, then the new WLTP CO_2 target values will effectively become less stringent than the original ones based on NEDC.
- Every new test procedure **implicitly includes "loopholes"** that may potentially be exploited over time. This is due to the fact that testing procedures are very complex and mostly developed by industry representatives. The regulatory text for the WLTP consists of more than 200 pages of detailed technical descriptions of how the testing has to be carried out, and about 75 percent of the participants of the WLTP Working Group at U.N. level were representatives from industry and technical institutes (Mock, et al., 2014). In this context, it is likely that some technical details of the regulation might be overlooked or that it only becomes obvious later on that some flexibilities might be interpreted in a different way than originally expected.

3.2. INTRODUCING REGIONAL SPECIFICATIONS BEYOND THE WLTP

There are some details that the U.N. member organizations could not agree on when developing the WLTP and decided to delegate to the regional level instead. For example, during the development of the WLTP, the European Commission suggested setting an ambient test temperature of 14°C, which would better represent European driving

34 http://transportpolicy.net/index.php?title=EU:_Light-duty:_Emissions

conditions than the 23°C foreseen in the final version of the WLTP. However, no agreement could be achieved at U.N. level, which is why the EU decided to implement a slightly modified version of the WLTP with a lower ambient test temperature of 14°C. It is estimated that this will increase measured CO_2 emissions by about 2 g/km (Mock, et al., 2014) and it likely will have a larger impact on pollutant emissions, as it will increase aftertreatment light-off times. In principle, the EU could decide to implement further measures that go beyond the standard, U.N., version of the WLTP, similar to the lower test temperature.

3.3. INCLUDING AIR-CONDITIONING SYSTEMS

Nearly all new vehicles in the EU today are equipped with air-conditioning systems. The average annual extra CO_2 emissions of a car caused by the use of air conditioning units is estimated to be about 3 percent (Weilenmann, Alvarez, & Keller, 2010). Yet, air conditioning is not considered in the NEDC test procedure and will not be part of the WLTP either. The European Commission is therefore developing a separate test procedure for mobile air-conditioning systems, although it is not yet clear when exactly this test procedure will be implemented. Furthermore, for the time being it is not foreseen to introduce any efficiency targets for vehicle air-conditioning systems, i.e., there will only be monitoring of the air-conditioning systems that manufacturers bring to market. For comparison, in the U.S., the SC03 air-conditioning test is used to control exhaust pollutant emissions and is a factor in determining the adjustment for fuel economy label values, but it is not directly incorporated into U.S. CO_2 emission standards, which are based only on the FTP and highway tests. The U.S. CAFE and CO_2 standards do include credit provisions for more efficient air conditioning designs.

3.4. STRENGTHENING THE ROAD LOAD DETERMINATION PROCEDURE

As explained in Section 2.2, the determination of the road load coefficients for a new vehicle type is of utmost importance, as the results will be used as input for all emission measurements of the entire vehicle family. It is therefore not surprising that vehicle manufacturers invest a lot of effort to carefully select an appropriate testing facility and to prepare the test vehicle for optimal results. For example, for coast down tests manufacturers regularly use “specially prepared” tires (that could be shaved into the most favorable form and baked in an oven to reduce rolling resistance) that have very poor handling characteristics and could not be driven safely on public roads (Kadijk, et al., 2012). This optimization of tires for testing alone can reduce type-approval CO_2 emission levels by an estimated 2 percent, a reduction that would not be realized in real-world driving (Kadijk, et al., 2012). In total, it is estimated that the exploitation of flexibilities in the NEDC road load determination procedure on average results in CO_2 emissions that are about 10 percent higher than claimed by the official type-approval figures. Thus, manufacturers’ optimizations during the coast-down procedure explain about one quarter of the overall gap observed between type-approval and real-world CO_2 emission levels (ElementEnergy and ICCT, 2015).

A report prepared as input for the WLTP development lists a number of flexibilities in the NEDC procedure for determining road load coefficients, and provides recommendations for how to strengthen the procedure (Smeds & Riemersma, 2011). Many of these recommendations have been taken into account during the development of the WLTP. For example, the WLTP will no longer permit heating or aging of the test tires (Mock, et al., 2014). However, even under the WLTP some flexibilities are expected to remain. For example, there will still be a lack of defined standards for the smoothness of the test track road surface. Furthermore, the WLTP defines entirely new options for determining road load coefficients, such as testing the vehicles on a moving belt in a wind tunnel laboratory instead of on a road test track. It is impossible to predict the exact amount of flexibilities that will come along with these new testing options, but it is expected that even under the WLTP there will still remain a difference between the road load coefficients determined for type-approval and the actual vehicle performance on the road (ElementEnergy and ICCT, 2015).

A fundamental problem with the road load determination procedure in the EU is that an independent verification of coast down testing results is virtually impossible because the type-approval road load coefficients are treated as proprietary information and are not accessible to the public. Similarly, the entire Certificate of Conformity (CoC) document that includes all type-approval test results for a vehicle is not accessible to the public. This is very different from the situation in the U.S., where the corresponding documents for all vehicles can be accessed online[35] and where even a separate overview table for coast down test results for all vehicles exists. A similar publication of the European type-approval road load coefficients would be a first step towards more realistic coast down testing results, as then it would be possible for independent parties to retest vehicles and compare the results to the official type-approval road load coefficients.

Furthermore, it is expected that the introduction of a road load verification program in the EU could help to ensure alignment of type-approval and real-world road load of new vehicles. In the U.S., the EPA selects vehicle types for retesting of the road load figures as needed. For example, after not conducting confirmatory coast-down tests for many years, the EPA has tested numerous vehicles from each manufacturer over the last three years. This led to Hyundai, Kia, and other manufacturers to correct the road load coefficients for some vehicles. For the EU, a similar confirmatory program has been suggested (Riemersma, 2012). Called a *feedback approach*, the principle idea is to focus on the vehicles in production and to carry out checks to ensure that they comply with the road load determined during type-approval, instead of setting many detailed requirements and tightening the tolerances allowed during testing. During the development of the WLTP at the UNECE level, this feedback approach was discussed but considered to be a certification issue rather than a test procedure requirement. It was therefore decided to not implement it as part of the WLTP and to continue the discussions about its implementation at the EU level, with little progress since 2012.

3.5. ESTABLISHING A EUROPEAN TYPE-APPROVAL AUTHORITY

In most Member States of the EU, vehicle testing for type-approval typically happens at the manufacturer's laboratory, with an accredited technical service witnessing the testing. Alternatively, the testing takes place in the laboratory of the technical service company. In both cases, the support of the technical service is commissioned and paid for by the manufacturer. Technical services generally are privately owned companies that compete with each other. It is therefore not unusual for a vehicle manufacturer to have its vehicles type-approved in a Member State in which it operates no production facility or development center, but where type-approval testing can be carried out more easily or at lower cost than in another Member State. For example, the 2011 Volvo V70 1.6D DRIVe was type-approved in Spain, even though the vehicle is produced in

35 http://iaspub.epa.gov/otaqpub/pubadvsearch.jsp and http://www.epa.gov/otaq/tcldata.htm

Sweden. In the case of the 2011 BMW 116i, the whole vehicle type-approval was issued in Germany, but the emissions' type-approval part was issued in Luxembourg[36].

This situation does not have inherent negative implications, but it creates a potential conflict of interest: The technical service competes with other technical services and is paid for its services directly by the manufacturer — the same manufacturer that it is supposed to objectively supervise. The financial contribution of type-approval testing to the income of a technical service company can be very high. For example, for the UK VCA (which is not only a technical service but also a type approval authority) 70 percent of its income is derived from vehicle manufacturers through type-approval work (The Telegraph, 2015). To eliminate this potential conflict of interest, the direct connection between vehicle manufacturer and technical service should be broken.

A first step in this direction would be to ensure that the technical service company is paid by the type-approval authority instead of the vehicle manufacturer. If a manufacturer wished to type-approve a new vehicle type, it would contact a Member State type-approval authority and pay a fee to this authority that covered all required testing. The type-approval authority would then assign a technical service company to carry out and/or witness the testing and would pay the company for its services. This system would eliminate any possibility of a conflict of interest between the vehicle manufacturer and the technical service company. It would, however, not resolve the current situation in which national type-approval authorities compete with one another for manufacturers type-approval applications — another potential conflict of interest.

A second step therefore would be to set up an independent European type-approval authority. If a manufacturer wished to type-approve a new vehicle type, it would contact the European type-approval authority, which then would either assign the application to a national type-approval agency or directly select and commission a technical service to carry-out or witness the required vehicle tests. In either case, the technical service would be directly paid by the European or Member State type-approval authority. In such a system, national type-approval authorities would no longer compete with each other, which would help to retain full independence and objectivity of the type-approval bodies.

A European type-approval authority would also allow for the creation of a fund for independent in-use verification testing by EU or Member State authorities, using fees collected from vehicle manufacturers. As explained in Section 2.2, independent confirmatory testing of new vehicles is currently not foreseen in the EU. In the U.S., on the other hand, the EPA already has legal authority to charge manufacturers a fee for each certificate of conformity issued, which revenue it uses to cover the direct costs of testing and enforcement activities.

3.6. INTRODUCING A REAL-WORLD ADJUSTMENT FACTOR

All of the measures described above target the way a vehicle is tested and aim at reducing the difference between test results and real-world driving. But there is another, complementary, pathway forward for CO_2 emissions. Whatever the test results are, it is possible to introduce an adjustment factor to translate measured CO_2 test results into more realistic figures for consumer information. While this approach cannot replace

36 Private communication with Kraftfahrtbundesamt (KBA), Sept. 19, 2014.

improvements in the test procedure itself, it provides a relatively simple, short-term solution to better inform customers about the average real-world performance of the vehicles on offer.

Since 1984, fuel economy label adjustments have been made in the U.S. Two different sets of fuel economy data exist for each vehicle: the laboratory test results and the label values. Initially, the adjustment factors used were quite simple: the city (FTP) test result (in miles per gallon) was adjusted downward by 10 percent and the highway test by 22 percent.[37] However, over the years concern developed that the shortfall between the test results and real-world fuel economy was increasing. In 2006 the fuel economy label adjustments were revised to better reflect current real-world fuel economy. The new adjustment factors came into effect in 2008. The formulas behind the new U.S. adjustment factors are quite complex, but overall the fuel economy test results are adjusted downwards by about 20 percent (Mock, et al., 2013). The higher the baseline fuel economy (the lower the baseline fuel consumption), the larger the percentage adjustment. This is because some in-use factors, such as air-conditioning load, are relatively constant over a wide range of vehicle and engine sizes, and so these relatively constant loads have a greater impact on vehicles with lower baseline fuel consumption. The adjusted fuel economy label figures in the U.S. very accurately reflect the current average real-world performance of the vehicle fleet (Mock, et al., 2013)[38].

For the EU, simple empirical models were constructed to predict in-use fuel consumption of passenger cars based upon input parameters such as vehicle mass, engine capacity and power, and the vehicle's type-approval fuel consumption (Ntziachriston, et al., 2011). The corresponding adjustment formula was applied for the first time in the European Environmental Agency's 2013 CO_2 Monitoring Report (EEA, 2014). While the underlying empirical models are still relatively simple and have important limitations, the introduction of a real-world adjustment factor is an important step for EU CO_2 reporting and could be further refined in the future. In a next step, real-world adjustment factors could also be applied for reporting CO_2 emissions and fuel consumption on vehicle labels for consumer information, and potentially also as the basis for vehicle taxation schemes in EU Member States.

In principle, it would also be possible to go one step further, applying a relatively high overall adjustment factor for the vehicle fleet, while allowing a manufacturer to obtain a lower adjustment factor for a given vehicle model if it can provide credible data demonstrating that the vehicle model performs substantially better under real-world driving than predicted by the general adjustment factor. For example, a manufacturer could voluntarily commission on-road testing of a reasonable vehicle sample under real-world conditions and make the results transparent to the public in order to warrant a lower adjustment factor for the vehicle model tested under real-world conditions. Or, instead, manufacturer/model specific adjustment factors could be derived using on-road PEMS testing (see Section 3.8).

37 See EPA website for details: http://www.epa.gov/fueleconomy/documents/420f14015.pdf

38 See also presentation from Jeff Alson (EPA), titled "U.S. Fuel Economy and Environment Label Compliance Program", May 2015, http://beuc.eu/great-fuel-consumption-scam#ourconference http://www.spritmonitor.de https://www.fueleconomy.gov/mpg/MPG.do?action=garage

3.7. INTRODUCING THE REAL DRIVING EMISSIONS TEST PROCEDURE

For vehicle air pollutant emissions, the introduction of the Real Driving Emissions (RDE) procedure is expected to yield emission test results that are more in line with real-world driving experience (Franco, et al., 2014). With the RDE, instead of testing the vehicle only in a laboratory, additional testing will be conducted on the road during normal driving. The vehicle's emissions will be analyzed and recorded using PEMS equipment (see Section 2.1).

Because air pollutant emission levels will vary somewhat across PEMS trips, the raw measurement data will be normalized. To accomplish this, during RDE the CO_2 emissions of a vehicle will be also measured using PEMS equipment. If CO_2 emissions in a particular section of a trip are especially high, that will be taken as an indication that the trip is relatively demanding, and the raw pollutant emissions will be adjusted down. Conversely, for a trip section with relatively low CO_2 emissions, the measured air pollutant level will be adjusted upwards.

A conformity factor (CF) is then applied: The air pollutant level determined during on-road RDE testing may not be higher than the laboratory limit value times the CF. For example, for NO_X emissions of Euro 6 diesel passenger cars, the laboratory type-approval limit is set at 80 mg/km. If the CF was set at 1.1, a vehicle would only pass type-approval if its emissions are below 80 mg/km in the laboratory and below 88 mg/km during on-road RDE testing.

The general framework of the RDE procedure was adopted by EU Member States in May 2015. Details of the procedure, including applicable CFs, are expected to be decided upon before the end of 2015. It is anticipated that RDE testing will begin in 2016.

While RDE is expected to result in lower real-world air pollution levels of new vehicles, some important limitations will remain. For example, there are exclusion criteria that limit the range of testing conditions that are accepted as normal driving for the RDE procedure. This is a concern because pollutant emissions can increase by orders of magnitude under some in-use conditions; the exclusion of a small percentage of driving conditions could omit a sizeable share of total emissions. Furthermore, as RDE will be part of the type-approval process, it will still only be prototype vehicles that get tested — in-use PEMS testing of randomly selected vehicles from customers is not foreseen for the initial stage of RDE.

3.8. INTRODUCING COMPREHENSIVE CONFORMITY TESTING AND EXTENDING ON-ROAD TESTING TO CO_2

For CO_2 emissions, on-road vehicle testing comparable to the RDE is not yet foreseen in the EU. Similarly, no independent in-use conformity testing exists at this point, for CO_2 or air pollutant emissions. Even with the introduction of the WLTP (for CO_2 and air pollutant emissions) and the introduction of RDE (for air pollutant emissions), new cars would still be tested in the laboratory only, making use of a specially prepared pre-series vehicle version. In order to better align official and real-world emissions data, for the future it is important to introduce a comprehensive in-use conformity-testing scheme in the EU. Under such a scheme, EU or Member State authorities would be given the right to systematically retest a subset of production vehicles in order to determine whether their emission levels are in line with the manufacturers' declared type-approval measurement data. If a significant deviation is found, penalties would be imposed on the manufacturer. Such a market surveillance approach resembles what is already standard practice in the U.S. The number of vehicles to be tested would not have to be high; focusing on a sample of vehicles would already ensure that there is an incentive for in-use compliance while keeping the cost of testing low.

Furthermore, it is possible to complement such a conformity-testing scheme by on-road CO_2 testing of vehicles, similar to the RDE scheme that is already being introduced for air pollutant emissions in the EU. One possible approach would be to make use of PEMS test results not only to check air pollutant emissions under real-world driving conditions but also carry out a similar crosscheck for CO_2 emissions. The manufacturer would still have its vehicles tested under WLTP laboratory conditions, but these laboratory test results would be checked against PEMS results via CO_2 conformity factors. If the deviation found between laboratory test results and PEMS on-road results exceeded some threshold, a penalty would be imposed on the manufacturer.

Going one step further, it would be conceivable to turn the current type-approval testing process upside down and from the regulatory side to fully focus on testing in-use series vehicles under real-world driving conditions, rather than pre-series vehicles under laboratory conditions. Under this approach it would be the manufacturers' responsibility to declare the CO_2 and air pollutant emission levels for a new vehicle model under real-world driving conditions. It would be up to the manufacturer to decide how these emission levels are measured or simulated, without any oversight and re-testing by authorities. Then, once a vehicle model is available for sale, the regulatory authorities would carry out on-road PEMS tests on a selected number of vehicles to verify the manufacturer's emission level declarations. Depending on the conformity factor derived, i.e., on how much the measured emission levels fell above or below the emission limits, penalties or even a recall of the vehicle model could apply. This kind of approach would help to shift the focus of vehicle optimization more towards on-road performance, as there would be a strong incentive to design new vehicles for best performance under a wide range of real-world conditions. Furthermore, there would be entirely new possibilities for reducing emissions, using technical measures that today do not show any effect in the test procedure and are only provisionally handled by introducing off-cycle and eco-innovation credits.

3.9. FURTHER DEVELOPING CONSUMER WEBSITES

A number of websites allow car owners to report the real-world fuel consumption performance of their vehicles. Generally, users have to register and select a vehicle from a database and can then report regular fuel consumption figures based on the on-board computer of the vehicle or the mileage driven and the fuel purchased in between fueling stops. An example is the German website Spritmonitor[39] where about 300,000 users regularly report their own fuel consumption figures.

This kind of website can be highly relevant for anyone planning to purchase a new vehicle, as it allows for a good overall comparison of the real-world fuel consumption behavior of a particular vehicle model to other vehicles. Though results with the specific individual driver, in the aggregate they follow a normal distribution pattern and allow for a good understanding of average fuel consumption and CO_2 figures for real customers during everyday driving, even on an individual vehicle model level (Tietge, et al., 2015).

39 http://www.spritmonitor.de

A practical disadvantage of the information provided on consumer websites is the time lag between a new vehicle model being introduced on the market and having enough customers reporting about its real-world fuel consumption. For this reason, it is usually not possible to draw useful conclusions about a particular vehicle model until about six months after market introduction.

For the future, it could be possible to further develop the existing consumer websites or to offer new possibilities for consumers to report their real-world experiences. At present, the websites in the EU are run by private companies and organized in a decentralized way; for example, websites for Germany and the UK are entirely separate. In the U.S., on the other hand, there exists a government-run website[40] with about 140,000 users regularly reporting fuel economy performance. Developing a similar website for the EU, perhaps operated by the EEA and available in all EU languages, could potentially reach more users than the current, fragmented approach.

Going one step further, more customer-specific fuel consumption and CO_2 emission estimates could be provided. Any of the current regulatory test cycles is only an artificial abstraction of on-road driving and potentially not in line with the daily driving behavior of some customers. This was not so much a problem in the past, when driving a conventional petrol or diesel car in an inner-urban environment or on a highway was relatively similar in terms of fuel consumption. But with increasing electrification, it becomes more important how those vehicles are actually driven on the road: The fuel consumption of a modern plug-in hybrid car can range from close to zero when driven mostly within the city using the electricity stored in the vehicle's battery to more than 10 l/100 km when driven on a highway using the vehicle's engine.

There are research and demonstration projects trying to overcome this fundamental problem. For example, in the "My eDrive" project by the German car club ADAC and the Institute for Energy and Environment Research (IFEU), a car buyer uses his Smartphone or other device that can track GPS information to record his individual driving profile over a certain time period.[41] When going to a manufacturers' website on the Internet the customer can then upload his recorded GPS driving profile and in return receive fuel consumption and CO_2 emission figures for each of the manufacturers' vehicles specifically calculated for his own personal driving profile. As a result, for example, the customer could learn whether, based on his daily driving profile, a hybrid or electric vehicle would be a suitable option or whether he should stay with a conventional combustion engine vehicle.

40 https://www.fueleconomy.gov/mpg/MPG.do?action=garage

41 See http://www.erneuerbar-mobil.de/de/projekte/vorhaben-im-bereich-der-elektromobilitaet-von-2013/begleitforschung/dateien-pressematerial-etc/flyer-my-e-drive.pdf

4. CONCLUSIONS

One objective of this report was to compare and contrast the current vehicle testing schemes in the EU and U.S. A key finding was that, while U.S. regulators put a strong emphasis on independent conformity testing, this element is still largely absent from the EU regulations. Furthermore, U.S. agencies have far-reaching authority, which they have regularly made use of, to demand the recall of a vehicle model or even issue penalties if any significant deviations are found as part of conformity testing. The most recent example of this authority is the revelation of Volkswagen's defeat device by the U.S. authorities. By contrast, in the EU regulatory enforcement power is more limited and scattered across Member State type-approval authorities.

Another objective of this report was to briefly describe several measures that could help to improve the vehicle-testing scheme and bring type-approval results more in line with the actual vehicle performance experienced by customers. The focus of this part of the report was on the EU, even though it is acknowledged that there is still room to improve the vehicle-testing scheme in the U.S. and other markets worldwide.

Table 1. provides an overview of the various measures discussed in this report and indicates how each of the measures would contribute to improving the vehicle-testing scheme.

Table 1. Overview of selected measures to improve the vehicle-testing scheme in the EU.

	More precise & representative definition of testing	Shift focus to on-road emissions of series vehicles	Strengthen independent verification testing	Improve customer information
Introducing WLTP	X			
Regional specifications beyond WLTP	X			
Air conditioning systems	X			
Revised coast-down procedure	X		X	
European type-approval authority			X	
Real-world adjustment factor		X		X
RDE procedure		X		
RDE for CO_2 + conformity testing		X	X	X
Improve consumer websites				X

A current focus of attention in the EU is to **further refine the existing testing schemes** by introducing more detailed and updated definitions of the procedures to follow and to define testing conditions that are more representative of real-world driving. A key measure in this respect will be the **introduction of WLTP**, with its more realistic driving cycle and its improved definition of the testing procedure itself. **Introducing regional specifications beyond WLTP** would allow EU regulators to go a step further—for example, by defining an ambient test temperature that is closer to the average temperature in the

EU than for WLTP. Similarly, **introducing a test procedure and target system regarding the efficiency of vehicle air conditioning systems** will also help to better define the test procedures and align them more closely to real-world customer experience.

However, as discussed in this report, the gains possible by refining the existing testing scheme are ultimately limited. Vehicle technologies become more and more complex, and modern electronics allow for calibrating and optimizing vehicles to an extent that could not have been anticipated years ago. This trend will continue, making it necessary to further adapt and refine the testing procedures in the future. A complementary approach to improve the vehicle-testing scheme is to **focus more on on-road testing of series vehicles**. The introduction of a **real-world adjustment factor** would be a first step in this direction, acknowledging that emissions on the road tend to be significantly higher than the official type-approval results. This measure would also serve as a means to better inform customers before their vehicle purchase decision. Introducing the **RDE procedure** for air pollutant emissions is another important step towards on-road emission determination. While this measure was recently adopted in the EU, so far it is restricted to a limited number air pollutants and vehicle types, and it is still based on prototype vehicles, with the testing process largely under the control of the manufacturers themselves. An important element for the future would be to **extend the RDE test procedure to CO_2**.

In terms of **strengthening independent verification testing**, a **comprehensive in-use conformity testing program** would give the EU authorities the right to systematically retest mass production vehicles in order to determine whether their emission levels are in line with the manufacturers' declared type-approval measurement data and to issue penalties and demand recalls, if needed. In this context, the introduction of a **European type-approval authority** is expected to further strengthen independent verification testing in the EU, by ensuring that technical service companies carrying out or witnessing type-approval tests do not find themselves with a potential conflict of interest, being commissioned directly by the vehicle manufacturers. This EU-wide authority could also take on responsibility for carrying out regular on-road PEMS tests as described above. Similarly, an **improved coast down procedure** that would allow for road load coefficients being publicly available and for EU authorities to independently retest vehicle road loads, would help to strengthen independent verification testing.

Finally, **improving existing consumer websites and creating a common EU-wide platform** for consumers to report the real-world fuel consumption of their vehicles would help to better inform customers about on-road vehicle performance characteristics and thereby allow them to make better purchase decisions. In particular, for electric vehicles, it will become more and more important to communicate customer-specific energy consumption figures, for example by taking into account the individual driving profile of each customer.

It should be emphasized that a key objective of this report was to think ahead, beyond the introduction of WLTP and RDE in the EU, and to sketch a more fundamental revision of the vehicle testing and enforcement scheme that will then allow better aligning test results and customer experiences in the future. It is understood that some of the changes outlined are substantial and would be complex to implement. We should remind ourselves that our current vehicle testing schemes date back to the 1960s or 1970s, and that it took us about 10 years to develop the WLTP. It is exactly for this reason that it is important to start revising the future of vehicle testing already today.

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