An alternative to vehicle type approval regulation: Continuous Vehicle Emissions Monitoring (CVEM)

White paper

Next Green Car and NXP Semiconductors

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1. Executive summary

While the initial vehicle emissions standards (which form part of type approval) were highly successful in reducing real-world vehicle emissions by an order of magnitude, the rate of reduction has recently slowed. There is evidence that some pollutants, in particular NOx, have not in fact measurably improved since 2006.

It is now widely accepted that the current approach is not fit-for-purpose as the test cycle (currently NEDC)[1] does not adequately represent real-world driving conditions. Even its replacement, the WLTP due in 2017,[2] will only marginally reduce, not eliminate, the discrepancy between test and real-world emissions.[3]

A second development, the introduction of Real Driving Emissions (RDE) testing, may also have limited impact as its primary aim is only to reduce the permitted exceedance of emissions over maximum levels as specified in the legislation.

An alternative or complementary approach to future type approval testing is to introduce a system of **Continuous Vehicle Emissions Monitoring (CVEM)**, which utilises existing On-Board Diagnostic (OBD) sensors to monitor emissions, and export this data to a central off-board server for reporting purposes.

This white paper proposes the use of Continuous Vehicle Emissions Monitoring to complement laboratory and RDE vehicle emissions testing.

Modern vehicles are already equipped with sensors that monitor exhaust emissions including: CO_2, NOx and (to an extent) particulates. With the on-going evolution of vehicle connectivity, by 2020 the majority of light-duty vehicles will be capable of transferring this data to a central server from where it could be collated and used for regulatory use. The European eCall Directive already requires that all cars from April 2018 must have a mobile data link.

In addition to laboratory and RDE testing, CVEM will offer three new functions: (i) Enable regulators to monitor national and local fleet emissions in real-time; (ii) Permit more accurate auditing of fleet emissions in place of emissions modelling; and (iii) Provide transparency for consumers, whose levels of confidence have been challenged, most notably in 2015 with the VW emissions scandal.

For vehicle regulators not to adopt monitoring technologies based on the latest data platforms would be a missed opportunity and would undermine future attempts to control emissions and promote cleaner vehicle technologies. Now is the time, therefore, for regulators to develop and implement a system of Continuous Vehicle Emissions Monitoring using on-board sensors and digital communication platforms as an integral part of future vehicle type approval.

[1] New Emissions Drive Cycle: https://www.dieselnet.com/standards/cycles/ece_eudc.php
[2] WLTP: https://www.dieselnet.com/standards/cycles/wltp.php
[3] ICCT: http://theicct.org/sites/default/files/publications/ICCT_WLTP_EffectEU_20141029.pdf.

2. Vehicle emission standards and type approval

Since 1993, European directives have imposed reducing limits on light-duty vehicle emissions for carbon monoxide (CO), nitrogen oxides (NOx), hydrocarbons (HCs) and particulates (PM_{10}).[4] The NOx limit for example was lowered from 500 mg/km in 2001 to 80 mg/km in 2015. EU regulation on car CO_2 emissions was also introduced in 2009 with the limit of 130 g/km (for 2015) averaged over all new vehicles for each manufacturer. A limit of 95 g/km was agreed for 2021.[5]

The key impact of emission (and cleaner fuel) standards has been to accelerate the introduction of emission control technologies including, for petrol cars: the three-way catalytic converter, and fuel injection systems; and for diesels: Lean-NOx catalysts, Selective Catalytic Reduction (SCR) and diesel particulate filters (DPFs).

The emissions standards form an important part of the system of 'type approval', the regulatory mechanism for ensuring that cars and vans sold within the EU meet minimum environmental and safety standards.[6] The process involves the testing of a representative production vehicle and component parts at an accredited facility.

Once approved, a European Community Whole Vehicle Type Approval (ECWVTA) certificate is issued which permits vehicle sales and use in all EU Member States. An ECWVTA certificate also allows manufacturers to issue a Certificate of Conformity to buyers and users of each vehicle.

Type approval emissions tests are conducted in a laboratory on a rolling-road dynamometer. During the test, the vehicle is 'driven' on a simulated route using (currently) the New European Driving Cycle (NEDC), which consists of one extra-urban and four urban cycles. Measurements are averaged to produce 'official combined' figures for CO_2, energy use and regulated pollutants.

In response to evidence of increasing discrepancies between real-world driving emissions and official test results (based on NEDC in the EU and test cycles used in other jurisdictions), a new Worldwide harmonized Light vehicles Test Procedures (WLTP) has been developed within the UNECE World Forum for Harmonization of Vehicle Regulations for introduction in 2017.[7]

A second response to the deficiency of the NEDC is the introduction of a Real Driving Emissions (RDE) test using Portable Emissions Measurement Systems (PEMS) to check that the test cycle sufficiently represents the real-world. The RDE test will have a binding impact on the type approvals from September 2017 for all newly approved types of vehicles (from September 2019 for all new vehicles).[8]

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[4] 'PM_{10}' denotes particulate emissions of up to 10 microns in diameter.
[5] http://ec.europa.eu/clima/policies/transport/vehicles/cars/index_en.htm
[6] http://www.dft.gov.uk/vca//vehicletype/ecwvta-framework-directive.asp
[7] https://en.wikipedia.org/wiki/Worldwide_harmonized_Light_vehicles_Test_Procedures
[8] http://europa.eu/rapid/press-release_IP-15-5945_en.htm

3. Limitations of laboratory and 'real-driving' tests

While the early standards (Euro 1-3) were highly successful in reducing real-world vehicle emissions by an order of magnitude, the rate of reduction slowed during 2006-2015 (Euro 4-6). Moreover, there is now evidence that some pollutants, in particular NOx, have not in fact measurably improved since Euro 4.[9]

It is widely accepted that the failure of tighter standards in reducing actual emissions is in part a consequence of the current type approval testing process. As a result of increasing vehicle power and an out-dated drive cycle, testing a sample vehicle over the NEDC is no longer sufficient to estimate emissions generated during the dynamic driving typical of real-world driving conditions.

Furthermore, there is now a great deal of evidence showing that manufacturers have become highly adept at 'beating the test'; using permitted test procedures that ensure that emissions test results are as favourable as legally possible.[10] (This excludes the use of 'defeat devices' by Volkswagen as revealed in 2015.)

Evidence of the deficiency of the current regime has been presented by the International Council on Clean Transportation (ICCT)[11] which has monitored the widening gap between test and real-world emissions for petrol and diesel cars. Whereas the under-reporting of CO_2 was only around 7% in 2000, this has increased to almost 40% in 2015.[12] For tailpipe NOx, the gap is even greater with measured discrepancies of up to a factor of seven for the latest Euro 6 vehicles.

In addition to the advent of more powerful engines, the NEDC fails to adequately represent real-world driving as it does not include sustained motorway driving, plus ancillary loads such as air-conditioning and heating are switched off. Manufacturers are also able to arbitrarily reduce their emissions results by 4%.[13]

To date, the regulatory and industry response has been to focus on improving the test cycles with the aim of making them more representative of real-world driving. In particular, the WLTP, developed to better represent actual driving cycles, will be adopted in 2017 for emissions testing and structuring the regulatory framework.

In its favour, a key advantage of the WLTP is the inclusion of more frequent and rapid accelerations which makes the cycles more representative of real-world driving. A second improvement is the inclusion of three WLTP test cycles, the appropriate cycle being selected according to the power-to-weight ratio of the vehicle under test.

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[9] http://www.theicct.org/real-world-exhaust-emissions-modern-diesel-cars
[10] T&E 2013. Mind the Gap! Why official car fuel economy figures don't match up to reality. http://www.transportenvironment.org/
[11] International Council on Clean Transportation. URL: http://www.theicct.org/
[12] http://www.theicct.org/real-world-exhaust-emissions-modern-diesel-cars
[13] T&E 2013. Mind the Gap! Why official car fuel economy figures don't match up to reality.

However, although an improvement, the WLTP will reduce, not eliminate, the discrepancy between the test cycle and real-world emissions. Analysis conducted by the ICCT shows that adoption of the WLTP will only improve accuracy by between 5.7% and 7.7% for fuel economy and CO_2.[14] Its use will also reinforce the reliance of regulatory frameworks on fixed test cycles.

The European regulator's latest approach to overcoming the issues related to the use of a test cycle is the adoption of a new Real Driving Emissions (RDE) test which employs Portable Emissions Measurement Systems (PEMS) to check that the cycle sufficiently represents real-world conditions. Working closely with the car industry, the RDE test will have an impact on the type approval process from 2017.

The RDE is a welcome advance which will, when fully up and running, provide robust data showing the difference between the emissions as measured on the forthcoming WLTP cycle and in the real-world. Interestingly, the use of PEMS, itself a relatively recent advance, imitates the original technique used by European and North American agencies to highlight the deficiencies of the NEDC.

However, even the adoption of RDE measurements will only have limited impact as its aim, as agreed, is focused on reducing so-called Conformity Factors (CFs) which are used to quantify the exceedance of each RDE measured emission as compared to its maximum test limit as specified in the relevant legislation.

The CF for NOx, for example, will be introduced in two stages for new European models: (1) CF less than or equal to 2.1 by September 2017; and (2) CF less than or equal to 1.5 by January 2020.

The effect of adopting CFs greater than unity will, therefore, be to relax the forthcoming emissions standards based on the WLTP as developed by the UNECE. Hence, even the introduction of the RDE tests in parallel with the new WLTP, will be unable to fully rectify the well documented deficiencies of the current vehicle type approval regime for emissions.

Figure 1: Vehicle dynamometer facility[15]

Figure 2: Real driving emissions testing[16]

[14] http://theicct.org/sites/default/files/publications/ICCT_WLTP_EffectEU_20141029.pdf
[15] Image: European Commission Joint Research Centre https://ec.europa.eu/jrc.
[16] Image: WhatCar? 2014, sourced from Newspress photo library.

4. Continuous Vehicle Emissions Monitoring (CVEM)

While enhancing vehicle testing with RDE measurements is to be fully supported, the concern is that, given its primary focus on test *validation*, even WLTP+RDE will not provide a long-term solution for emissions regulation. It also fails to audit actual emissions at the fleet level; a requirement that will have increasing regional importance for carbon reporting and air quality monitoring.

As is already the case with the NEDC regime, it is likely that, once the new WLTP and RDE legislative frameworks are in place, vehicle manufacturers will again learn how to optimize test results without significantly impacting emissions generated by real motorists in a wide-range of real driving conditions. The use of Conformity Factors also threatens to undermine future emissions standards.

4.1 CVEM: A new approach

An alternative or complementary approach to future type approval testing is to introduce a system of **Continuous Vehicle Emissions Monitoring (CVEM)**. This approach utilises existing on-board sensors to monitor actual emissions and fuel consumption in real-time, and exports this information to a central off-board server for reporting purposes.

This white paper proposes the use of Continuous Vehicle Emissions Monitoring to complement laboratory and RDE vehicle emissions testing.

With the on-going evolution of vehicle electronic systems, the majority of M1 and N1 light-duty vehicles are (or will soon be) capable of independently monitoring a number of on-board systems. Already the average new car comes equipped with as many as 50 on-board electronic control units (ECUs) designed for a variety of 'advise', 'entertain', 'assist' and 'control' functions.[17] Examples include the monitoring of tyre pressure and brake-wear, emergency braking and adaptive cruise control.

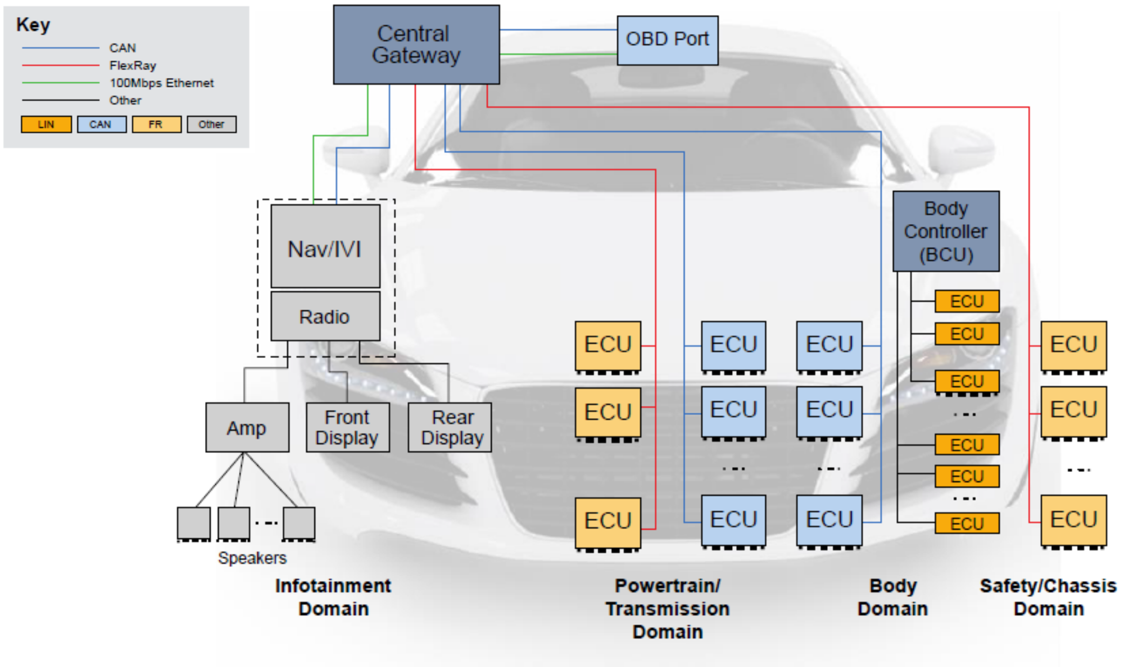
With respect to emissions monitoring, modern vehicles are equipped with in-built sensors to measure a number of regulated pollutants; data which is required to control some types of after-treatment systems (such as SCR for diesels). This is achieved using sensors which monitor after-treatment performance, exhaust emissions and fuel consumption data in real-time. Emissions that can be monitored include CO_2, NOx and (to an extent) particulates.

Existing legislation specifies that OBD data is available for selected third party access for purposes of engine maintenance and fault diagnostic reporting. Some manufacturers are already using on-board communication systems to transfer this

[17] Freescale (now NXP) presentation. we.CONECT AACT! 2015 Conference, Berlin, Sept 2015.

information back to a central server for analysis and to enhance customer service.[18] The central proposal of this white paper is that this OBD data should also be made available for regulatory reporting.

Figure 3: Typical vehicle network architecture[19]



There are currently two options for collecting OBD information. Most modern vehicles include mobile phone data systems to provide features like traffic updates and internet access. This platform can be used to send the emissions data to a central server. If a vehicle does not have a data connection, the second approach is to download stored vehicle data during an MOT test or scheduled service.

The level of vehicle connectivity is rapidly increasing with the commercialisation of connected car services and the development of autonomous vehicles; more than 100 Exabytes of data is already generated by vehicles each day. After the building and utilities sectors, the automotive sector is forecast to be the third largest market for connected products by 2022.[20]

Motivated primarily by the desire to develop new customer services, a number of major car makers are installing 4G as standard in new cars; Vauxhall's OnStar 4G service, for example, launched in 2015.[21,22] A minimum level of car connectivity is,

[18] http://bimmersoftware.com/bmwlogger-2
[19] Freescale (now NXP) presentation. we.CONECT AACT! 2015 Conference, Berlin, Sept 2015.
[20] *Ibid.*
[21] http://www.vauxhall.co.uk/onstar/index.html
[22] http://stakeholders.ofcom.org.uk/binaries/research/cmr/cmr15/CMR_UK_2015.pdf

in any case, now required by EU law; the European eCall directive means that all cars from April 2018 must have a mobile data link.[23]

4.2 OBD emissions monitoring

On-Board Diagnostic (OBD) systems monitor the performance of the engine and the correct operation of after-treatment components, including those responsible for controlling emissions. The first OBD platforms were introduced by General Motors in 1980 to monitor emissions from petrol light-duty vehicles in North America. California was one of the first jurisdictions to mandate OBD systems in 1991 (using the OBD-II standard), with Europe following in 2001.[24]

Now with standards across the US and Europe, OBD systems offer three protocols:

- **Threshold monitoring**: A fault indicator light is activated when sensors detect emission levels above a threshold defined as a multiplier of the emission standard. European/US OBD regulations require thresholds for NOx and PMs; US OBD requirements also include NMHCs[25] and CO.
- **Non-threshold monitoring:** Involves the electrical monitoring of engine and after-treatment components to check for operational stability or system failure.
- **OBD testing/validation:** A series of engine and component-specific tests that confirm correct OBD functionality under the established threshold values. These require manufacturers to have correlated system performance with emissions to determine conditions that cause emissions to exceed thresholds.

Depending on the event measured, OBD monitoring can be continuous or only conducted during certain pre-set conditions. For the latter, in-use performance ratio (IUPR) monitoring values have been agreed that specify minimum measurement frequencies. An IUPR value of 0.1, for example, means that at least one monitoring event is conducted over 10 trips.

Using current OBD technology, the emissions that can be monitored include:

- **NOx**: Most modern diesel systems have a NOx sensor which is used to determine the amount of SCR additive to use to reduce the NOx levels in the exhaust. The level of emissions can be obtained directly from the NOx sensor or indirectly by monitoring the use of the additive.
- **Particulates**: Although no existing sensor can measure particulates directly, the particulate trap can be monitored. The amount of particulates generated can then be estimated by counting how often the trap has to be regenerated.

[23] https://ec.europa.eu/digital-agenda/en/news/ecall-all-new-cars-april-2018
[24] ICCT 2015. Global Overview of On-Board Diagnostic (OBD) Systems for Heavy-Duty Vehicles.
[25] Non-methane hydrocarbons.

- **CO_2**: While not measured directly by an on-board sensor, CO_2 emissions can be inferred by measuring fuel use, the latter being correlated to *mass air flow* as monitored in the standard OBD dataset.

Although current on-board sensors are unable to measure emissions to the same level of accuracy as laboratory and PEMS used for formal emissions testing, OBD measurement resolution is more than sufficient for regulatory purposes.

This is supported by the fact that the existing EU legislated OBD threshold levels differ less from Euro standards than do current Conformity Factors. For example, for Euro 6 the final agreed diesel OBD emissions threshold for NOx is 140 mg/km, which exceeds the emission standard by 1.85 as compared to a CF of 2.1.[26]

The OBD requirements for Euro 6 are being introduced in phases, the most recent affecting new type approvals from December 2015. In 2017/18, more stringent levels of OBD thresholds will be implemented; the latter due to increased penetration of direct injection engines.[27] These lower thresholds will require more accurate monitoring and an increase in OBD sensor sensitivity.

4.3 Implementation issues for CVEM

As with all new technologies and protocols, careful thought will need to be given to CVEM implementation with particular focus on data-related issues.

One major concern with reporting data is the invasion of privacy. All collected OBD vehicle data will need to be anonymised so that it cannot be tracked back to an individual driver or vehicle. The aim should be limited to collating received data by vehicle type and/or model (as is the case for existing type approval).

Legal advice will be required as to how privacy (as well as other) data issues can best be managed. A number of legal firms, including Osborne Clarke in the UK, are already developing their expertise in this area in preparation of the projected growth in the connected car sector.[28]

Program roll-out will also need to be planned. As it may not be practical to initially introduce CVEM at a national level, a staged program or demonstration project could be tested on a well-defined fleet across a bounded geographic area. This would highlight any unforeseen implementation issues, raise industry awareness, validate the system and allow for a gradual roll-out to a wider region.

An initial project might, for example, focus on diesel taxis and/or delivery vehicles in London. Another suggestion would be to target the emerging fleet of plug-in

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[26] http://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:32012R0459&from=EN
[27] Maciej Szymanski, Policy Officer at the European Commission's DG Enterprise & Industry, 03/18/2013. Interview with Automotive IQ. URL: http://www.automotive-iq.com/exhaust/interviews/european-commission-weighs-in-on-upcoming-vehicle/
[28] http://www.osborneclarke.com/connected-insights/publications/connected-vehicles-legal-and-regulatory-update/

hybrid vehicles for which the correlation between type approval and actual emissions is less well established and difficult to corroborate.

While the main target for CVEM would be new vehicles, a real-time monitoring system could also be developed for an existing fleet. This could be accomplished through the use of low-cost OBD-II modules that plug into the standard diagnostic port now required on all light-duty vehicles. Indeed a number of companies already market such low-cost devices to consumers in North America and in Europe. One example from a US company Automatic is shown in Figures 4 and 5.[29]

As already discussed, although the accuracy of on-vehicle measurements is not as high as for formal testing, the resolution is sufficient for monitoring purposes; at the very least OBD measurements are able to detect threshold exceedance events.

Related to accuracy is a potential concern that manufacturers' diagnostics systems could be deliberately calibrated to misreport readings, so undermining a future system based on CVEM. To address this issue, as a counter-measure, the results from each vehicle's diagnostics could be validated against the results obtained during scheduled MOT testing and compared with the results from similar vehicles.

Regarding economic aspects of implementation, the cost of adopting CVEM for new vehicles are likely to be relatively low given that sensor technology is already fitted to new M1 and N1 vehicles as standard. Any additional costs required will be for new on-board software and the server-side data collection systems.

While current sensors are sufficient for current purposes, many companies are already working to improve the accuracy and durability of OBD sensors and measurement systems. Unit costs are also likely to reduce over time with volume production and the development of new solid-state sensors.[30]

Figure 4: Bluetooth device in OBD-II port[31]

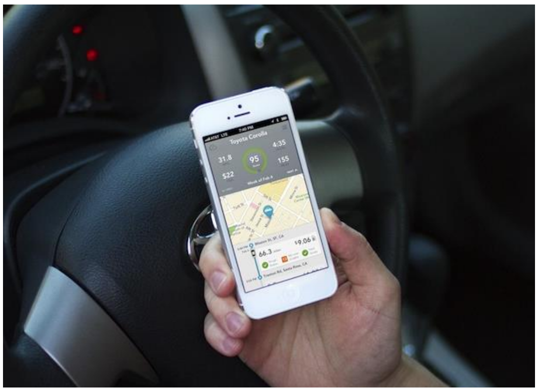

Figure 5: Mobile app showing OBD data

[29] https://www.automatic.com/home/. Drivers could be encouraged to use these monitoring units through the use of vehicle tax discounts or other financial incentives.

[30] Rheaume, Jonathan Michael, 2010. Solid State Electrochemical Sensors for Nitrogen Oxide (NOx) Detection in Lean Exhaust Gases. Ph.D., Mechanical Engineering. UC Berkeley.

[31] Figures 4 & 5: Automatic Labs Inc. (US). https://www.automatic.com.

5. Vision: CVEM as part of the regulatory process

With the continuing evolution of on-board emission sensors, together with the advent of connected car technologies, there is now an excellent opportunity to introduce a system of Continuous Vehicle Emissions Monitoring to complement more traditional approaches to emission testing and regulation.

In particular, CVEM provides regulators with a new tool with which to monitor real-world emissions performance and enforce vehicle emission standards.

In a future system of vehicle type approval as proposed, vehicles would continue to be tested over agreed cycles (such as the WLTP) and the testing regime validated by measurements of vehicles in real-world conditions (using RDE tests). However, in addition, CVEM would provide a new mass-monitoring platform based on anonymised real-time data derived from the whole vehicle fleet.

As well as confirming the validity of test cycles and the robustness of RDE checks, the CVEM data will perform three additional functions:

- First, it will enable regulators to monitor national and local fleet emissions in real-time; a capability which will become more important over time for policy testing and emissions management;
- Second, it will permit more accurate auditing of fleet emissions in place of emissions modelling, the results of which often have low confidence levels;
- Third, it will provide transparency for consumers, whose levels of confidence have been challenged, most notably in 2015 with the VW emissions scandal.[32]

Across the automotive industry, two revolutions are well underway with both attracting major support from national governments around the world. One is the electrification of the power-train and the other the development of connected car services. In combination, these developments potentially offer a major advance in reducing carbon emissions and improving local air quality from road transport.

For vehicle regulators not to adopt monitoring technologies based on the latest data platforms being deployed on new vehicles would, therefore, be a missed opportunity and would undermine future attempts to control emissions and promote cleaner vehicle technologies.

For this reason, now is the time for regulators to develop and implement a system of Continuous Vehicle Emissions Monitoring using on-board sensors and digital communication platforms as an integral part of future vehicle type approval.

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[32] http://www.nextgreencar.com/emissions-scandal/

6. About the authors

Dr Ben Lane, Director of Next Green Car, is an expert in the assessment of the environmental impact of vehicle technologies, whose career has included academic research and industry consultancy. In addition to life cycle emissions assessments, he has extensive knowledge of environmentally-focused transport policy and end-user attitudes including car buyer behaviour.

Jeffrey Loeliger is a Systems Engineer with NXP Semiconductors. He has over 27 years' experience in the automotive electronics industry and currently designs computer chips for controlling car engines and associated systems. NXP Semiconductors is the leading supplier of semiconductors to the automotive industry globally.

6.1 Next Green Car

Next Green Car is an online publisher and data provider with significant experience of building web-sites and web-based applications. Its main site nextgreencar.com is the UK's leading green car website.

In addition to providing independent information, the NGC website is highly data driven, its database including over 50,000 commercially available models in the UK. CO_2 and cost data is imported from several sources and merged with server-side algorithms to produce an information service for private and fleet car buyers.

Next Green Car has also developed Zap-Map (zap-map.com), one of the most comprehensive charge point maps in the UK. The Zap-Map charging point data is derived from various sources including the National Charge Point Registry, dealership groups, branded networks and independent locations.

6.2 NXP Semiconductors

NXP Semiconductors N.V. (NASDAQ: NXPI) enables secure connections and infrastructure for a smarter world, advancing solutions that make lives easier, better and safer. Built on more than 60 years of combined experience and expertise, the company has 45,000 employees in more than 35 countries.

As the world leader in secure connectivity solutions for embedded applications, NXP is driving innovation in the secure connected vehicle, end-to-end security & privacy and smart connected solutions markets.

Company website: http://www.nxp.com