

# Certification Procedures for Advanced Technology Heavy-Duty Vehicles: Evaluating Test Methods and Opportunities for Global Alignment

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## ABSTRACT

Advanced technology heavy-duty vehicles such as hybrids present unique regulatory challenges. Hybrids employ an additional energy source in conjunction with an internal combustion engine for motive power, and the interactions between the engine and the hybrid components affect criteria pollutant emissions and fuel consumption. Often, an engine installed in a hybrid vehicle will operate very differently from the same engine installed in a conventional vehicle driven over the same route. One of the difficulties in integrating vehicles such as hybrids into regulatory programs is developing the proper certification test procedures for criteria pollutant and greenhouse gas (GHG) emissions so that these advanced technologies and vehicles are evaluated fairly and consistently as compared to their conventional counterparts. This paper seeks to inform policy makers of the alternatives for moving toward more holistic approaches to testing and certifying powertrain systems and complete vehicles. The first part of the paper describes and compares the options for testing the emissions and fuel efficiency performance of heavy-duty vehicles from a technical perspective. The paper then goes on to discuss some of the specific regulatory challenges posed by the fact there are a myriad of test method and test cycle options and combinations that could potentially be used in a certification program. Finally, the paper concludes with an examination of the opportunities and challenges of developing a "world harmonized" certification procedure for heavy-duty hybrid and advanced technology vehicles.

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## INTRODUCTION

Worldwide, commercial vehicles are the largest growing contributor to air pollution, fuel consumption, and global warming emissions in the on-road transportation sector [1]. As with passenger vehicles, there are a variety of fuel, engine, and powertrain technology options for trucks and buses that can reduce criteria pollutant and greenhouse gas (GHG) emissions compared with conventionally powered diesel and gasoline vehicles. Examples of these advanced technologies include hybrid-electric, plug-in hybrid-electric, and hybrid hydraulic-powered drivetrains.

One of the challenges facing regulators is to develop or modify certification procedures so that these advanced technologies and vehicles are evaluated fairly and consistently as compared to their conventional counterparts.

Regulatory efforts to control criteria pollutant emissions from heavy-duty vehicles date back to the late 1980s and early 1990s in the mature vehicle emission control programs of the United States, Japan, and the European Union. In all of these programs, criteria pollutant standards are applied at the engine level only and expressed as an allowable mass of emissions per unit of engine work (g/kWh or g/hp-hr), and certification is based on engine dynamometer testing. One of the drawbacks of these engine-based standards and test methods is that they are unsuitable for properly assessing vehicles such as hybrids, whose engines operate in different speed-load regimes during in-use driving compared to engines in conventional powertrains.

Existing engine certification test cycles are designed to offer a reasonable approximation of how an engine installed in a conventional vehicle would operate during in-use



driving. In hybrids, which employ an additional energy source in conjunction with an internal combustion engine for motive power, the interactions between the engine and the hybrid components affect criteria pollutant emissions and fuel consumption. Often, an engine installed in a hybrid vehicle will operate very differently from the same engine installed in a conventional vehicle driven over the same route. If the typical in-use hybrid engine duty cycle is significantly different from the certification cycle, testing the hybrid engine as if it were a conventional engine may misrepresent its g/kWh emissions and fuel use profile under real-world conditions. In addition, the amount of net engine power required to drive a certain distance is typically lower for hybrid vehicles than for conventional vehicles; despite having the same g/kWh emissions and fuel use as a conventional vehicle, a hybrid might have lower gram-per-mile emissions and fuel use. To avoid these circumstances, certification should ideally be based on testing the engine and hybrid components as a complete system.

In an effort to move towards a systems certification approach and a better integration of hybrid vehicles into emissions testing programs, the Working Party on Pollution and Energy (GRPE), which is an entity of the United Nations Economic Commission for Europe (UNECE), has an Informal Group on Heavy-Duty Hybrids (hereto referred to as the GRPE HDH Group) that is in the process of developing an amendment to Global Technical Regulation No. 4, which established a harmonized type-approval procedure for heavy-duty engine exhaust emissions. The amendment will provide a test procedure and harmonized technical requirements for certifying pollutant emissions and carbon dioxide (CO<sub>2</sub>) from heavy-duty hybrid vehicles. The GRPE aims to have the test procedure finalized and adopted by June 2014.

## METHODS OF CERTIFYING ADVANCED TECHNOLOGY HEAVY- DUTY VEHICLES

Advanced technology heavy-duty vehicles present unique regulatory challenges. One of the difficulties in integrating vehicles such as hybrids into regulatory programs is developing the proper certification test procedures for criteria pollutant and fuel efficiency/GHG emissions. Unlike the light-duty vehicle space, where per-mile vehicle-based standards and chassis dynamometer testing are the accepted certification convention for all vehicle types and architectures, the choice of a test method for heavy-duty vehicles is more complicated.

Medium- and heavy-duty vehicles are produced in a much greater range of sizes and configurations than light-duty vehicles, and have a more diverse range of in-use duty cycles. Also, chassis dynamometers and the associated facilities that can accommodate the significant loads and test apparatus of heavy-duty vehicles are often expensive and much less common than light-duty chassis dynamometers. As such, governments and industry have historically opted for work-

specific engine-based standards and engine dynamometer testing for criteria pollutant emissions certification. However, because traditional engine dynamometer testing may not be adequate for properly evaluating hybrid systems and vehicles, governments and industry have been formulating different strategies for certifying emissions and fuel consumption performance. [Table A1](#) summarizes the current options for testing hybrids and other advanced technology heavy-duty vehicles. These options include chassis dynamometer-based testing, engine dynamometer-based testing, powertrain test cell-based testing, simulation model-based testing, and test track or in-use testing. All of these options are described further below.

## Full Vehicle Chassis Dynamometer Testing

In this test method, the full vehicle is mounted on a dynamometer with the drive wheels resting on one or more large cylindrical rolls. The vehicle is stationary during testing, but the drive wheels spin the rolls to simulate driving at different speeds. The dynamometer imparts varying loads to the drive wheels to represent varying vehicle inertial load, rolling resistance, and aerodynamic drag throughout the drive cycle. The vehicle driver follows a specific profile of speed versus time, and is usually given a computerized driver's aid, which shows actual speed versus target speed in real time. The Society of Automotive Engineers (SAE) has developed a recommended practice for conducting emissions and fuel economy tests of heavy-duty vehicles on chassis dynamometers (SAE J2711) [2], and the Environmental Protection Agency (EPA) has detailed procedures for conducting emissions testing (40 CFR Part 86 [3], 40 CFR Part 1065 [4]).

The most significant benefit of this test method is that it effectively brings the entire drivetrain into the test. As such, it can be used to provide a realistic assessment of distance-specific emissions and fuel use for a wide range of advanced vehicle and drivetrain technologies, including all hybrid configurations.

Chassis dynamometer testing is time consuming and expensive. A further limitation is its method of simulating vehicle aerodynamic loads. Because the vehicle is stationary during the test, the aerodynamic load is not imposed on the vehicle surface as it is during driving. Instead, a simulated aerodynamic load is imposed on the vehicle through the tires by adjusting the load on the dynamometer rolls. In effect, the dynamometer uses inertial and electrically generated loads applied through the vehicle's tires to simulate aerodynamic load.

The required load is determined by conducting an on-road coastdown test prior to the dynamometer testing. In a coastdown test the vehicle is accelerated to some speed and then allowed to coast to a stop without applying the brakes, while vehicle speed versus time is recorded. By calculating the varying deceleration rate of the vehicle over time, one can impute the forces (rolling resistance and aerodynamic drag) that were operating on it at each speed. This information is

programmed into the dynamometer so that it will impose the appropriate load on the vehicle at each point in the test cycle. The vehicle is then mounted on the dynamometer, and a dynamometer coastdown test is conducted to ensure that the coastdown profile is the same on the dynamometer as it was on the road.

While this method of evaluating and simulating rolling resistance and aerodynamic drag on a dynamometer is theoretically sound, it is critical that the coastdown test be conducted correctly. The “accuracy” of chassis dynamometer testing is limited by the accuracy of the coastdown data used to calibrate the dynamometer for a specific vehicle. The largest constraint on coastdown testing is finding an appropriate location to conduct the test (a straight and level road of sufficient length where the air is relatively still). The accuracy and repeatability of coastdown tests are significantly affected by test track configuration and ambient conditions.

## Engine Dynamometer-based Testing

In this testing approach, the engine and the hybrid system components are exercised together using a standard engine dynamometer, in which power and torque are measured from the crankshaft of the engine. The engine and hybrid system act in harmony, as they would under real-world driving conditions.

This testing configuration is applicable only to pre-transmission parallel hybrid systems in which an electric motor/generator is installed on the engine output shaft between the engine and a conventional manual, automatic, or automated-manual transmission. In such systems, both the engine and hybrid components (i.e. motor/generator, energy storage system, power electronics, and hybrid controls) are capable of delivering power to the engine output shaft to drive, through the transmission, the wheels or auxiliary components. The engine and hybrid components are controlled by a Hybrid Control Module (HCM), which determines the instantaneous proportion of power to be delivered from the engine and the hybrid drive motor to meet the instantaneous power requirement of the vehicle. A schematic of a pre-transmission parallel hybrid system is shown in [Figure 1](#), with the dotted line denoting the system boundary for this testing approach. To drive a specific route, a pre-transmission parallel hybrid system would typically provide the transmission the same torque requirements that the engine alone would in a conventional vehicle. Such a system could therefore be tested using a conventional engine dynamometer and current engine certification test cycles.

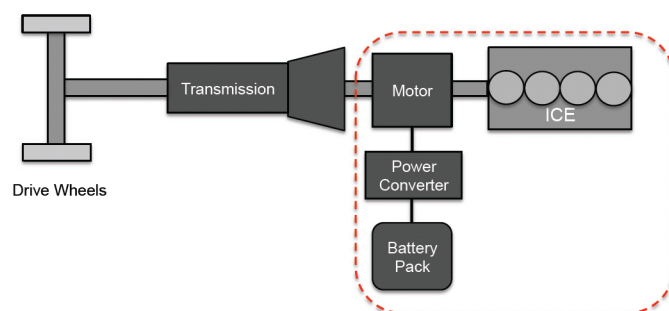


**Figure 1. A pre-transmission parallel hybrid and the system boundary for engine dynamometer-based testing.**

In a post-transmission parallel hybrid configuration, one or more electric motors and gearing are combined into a device that takes the place of a conventional automatic transmission and is used to deliver power from the engine output shaft to the wheels. In this configuration the hybrid “transmission” might provide a pure mechanical path, a pure electric path, or a combination thereof to deliver the power produced by the engine and hybrid system battery to the vehicle's wheels. A schematic of a post-transmission parallel hybrid system is shown in [Figure 2](#).

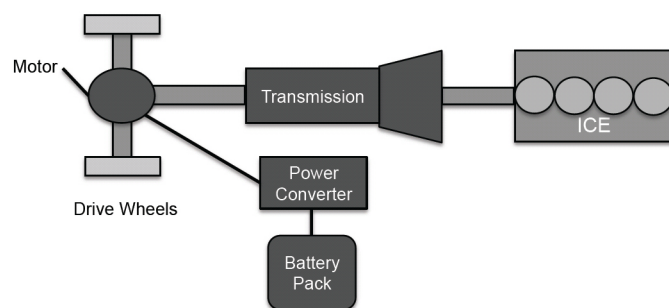


**Figure 2. A post-transmission parallel hybrid configuration.**

In a series hybrid there is no mechanical path between the engine and the vehicle wheels. A generator is attached to the engine output shaft, and a separate electric motor is attached to the drive wheels; the engine supplies power to the generator, which produces electricity to power the drive motor to drive the wheels. Series systems typically do not include a conventional transmission, but may include a gear set attached to the drive motor. A schematic of a series hybrid system is shown in [Figure 3](#).

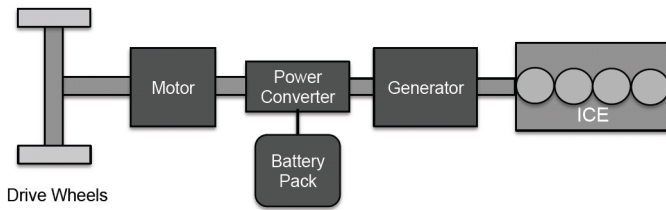


**Figure 3. A series hybrid configuration.**

Engine certification test cycles are designed to simulate torque and speed at the engine output shaft; to test a post-transmission or series hybrid, the test cycle must simulate the torque and speed at the transmission output shaft. Typical engine dynamometers are unsuitable for testing post-transmission parallel and series hybrids because they typically cannot accommodate the additional rotational inertia and speeds associated with the inclusion of the transmission.

One of the most attractive aspects of the engine dynamometer test method is that it is consistent with existing criteria pollutant regulatory programs, which currently use engine dynamometers for all emissions certification testing. Governments and industry are accustomed to using engine test cycles such as the U.S. Federal Test Procedure (FTP) Transient Cycle and the European Transient Cycle (ETC) for certification purposes. It should be noted that as part of the upcoming Euro VI regulation, the ETC will be replaced by the World Harmonized Transient Cycle (WHTC).

The United States will be allowing this option for charge-sustaining hybrid certification in the first phase of its fuel efficiency/GHG program. Its approach to certifying hybrid vehicles in this program is discussed in detail in section 2.4.

## Powertrain-based Testing

To test a post-transmission or series hybrid system in isolation from a vehicle, one would need a powertrain test cell. A powertrain test cell would differ from a traditional engine test cell in that it would require a dynamometer that can accommodate the additional rotational inertia and speeds associated with the inclusion of the “transmission” in the test setup. In practical terms, a powertrain test cell would need to have the power absorption capabilities of a traditional heavy-duty chassis dynamometer, but with the power absorbers connected directly to the transmission output shaft, rather than to rollers that support the drive wheels of the test vehicle.

A powertrain test cell could be used to test any type of hybrid system (pre- or post-transmission parallel hybrid, or series hybrid) as well as alternative/advanced transmissions. Engine test cycles are not suitable for post-transmission powerpack testing because they simulate torque-speed characteristics at the engine output shaft. For this type of testing configuration one would need a test cycle that simulates torque-speed characteristics at the transmission output shaft. Such a cycle could be derived from a speed versus time vehicle cycle such as the World Transient

Vehicle Cycle (WTVC), based on an assumed rear-end gearing ratio and typical vehicle power requirements (vehicle mass, rolling resistance, and aerodynamic drag coefficient) for a given hybrid system.

For reference, the vehicle speed (km/hr) versus time pattern of the WTVC cycle is depicted in Figure 4, and the engine speed and load characteristics of the WHTC cycle are shown in Figures 5 and 6 respectively.

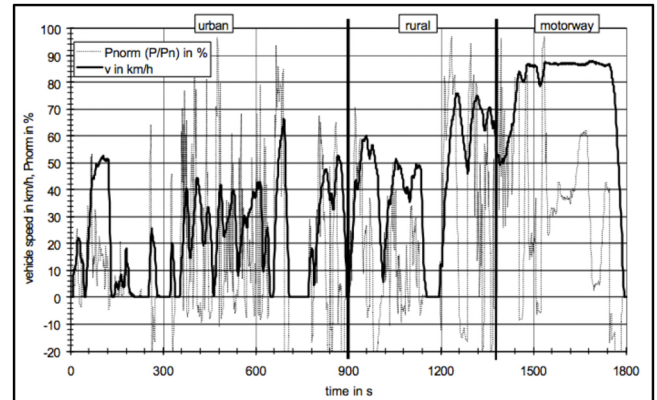
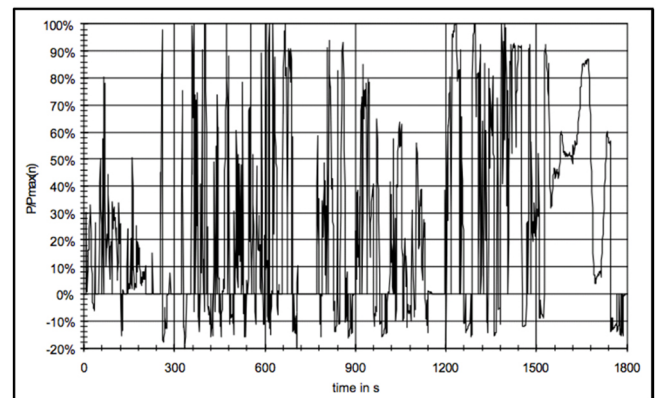
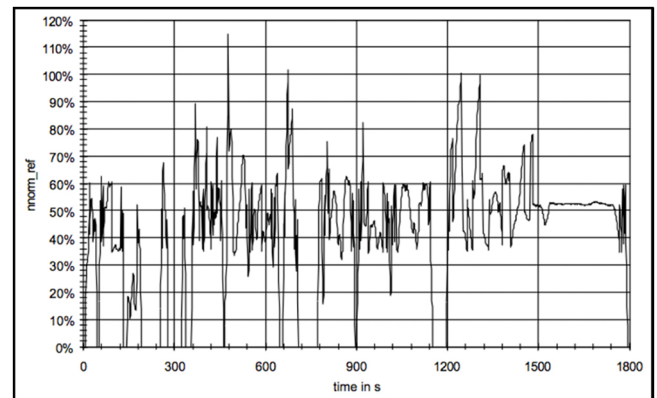


**Figure 4. The vehicle speed versus time pattern of the WTVC [5].**



**Figures 5 (top) and 6. The engine speed and load patterns of the WHTC [5].**