The U.S. Motor Vehicle Emission Control Programme

BUILDING ON PAST SUCCESSES TO MEET FUTURE CHALLENGES

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The United States motor vehicle emission control programme is noted for its pioneering role and success in limiting exhaust pollution, utilising the three-way catalyst, cleaner fuels, improved engine design and calibration strategies. The progressive lowering of the emission limits by technology-forcing legislation via the agencies of the U.S. Environmental Protection Agency and the California state legislature has resulted in cleaner air. Here, progress to date and future intentions for emissions from gasoline and diesel vehicles are discussed.

The United States motor vehicle emission control programme has rightly earned the reputation as one of the world's great environmental success stories. Today, emissions of harmful pollutants from new cars are a small fraction of those emitted from cars made in the 1960s, and lead, one of the most insidious pollutants, has been completely eliminated from gasoline. As a result, the ambient air in the U.S. is much cleaner than it was 30 years ago even though the U.S. resident population has increased by 33 per cent, vehicle miles travelled have increased by 140 per cent and the gross domestic product has increased by 147 per cent during the same period (1). Of equal importance, the strategies and technologies achieving these significant pollution reductions have contributed to a dramatic increase in fuel economy and have allowed automakers to continue to provide high-performance vehicles to the driving public.

However, despite the enormous progress that has been made in reducing motor vehicle emissions, highway vehicles continue to be one of the primary contributors to air pollution in the U.S. Further, non-road vehicles and equipment account for an increasing contribution to both diesel particulate matter (PM) and oxides of nitrogen (NOx) (2). According to the U.S. Environmental Protection Agency (EPA), over 60 million people in the U.S. still live in areas with unhealthy air (1).

To meet these air quality challenges, the U.S. EPA, over the past several years, has undertaken an unprecedented regulatory initiative to:

- further reduce emissions from on-road light- and heavy-duty vehicles;
- establish new control programmes for a growing variety of off-road vehicles and equipment; and
- limit the allowable levels of sulfur in fuel.

Catalyst-based control technology, which has played a critical role in the past successes of the U.S. programme, will play a major role in meeting these future challenges.

Background

In 1955, smog in Los Angeles was worse than it is in Mexico City today. By the late 1950s, it had become clear that motor vehicles were the primary culprits. In response, Congress passed the Clean Air Act Amendments of 1970 that created the U.S. motor vehicle emission control programme. This Act imposed tough, technology-forcing emission standards and a supporting programme to ensure compliance (3).

Congress required over 90 per cent reduction in hydrocarbons (HC) and carbon monoxide (CO) emissions over uncontrolled levels by the 1975 model year, and an approximately 90 per cent reduction of NOx by the 1976 model year. At that time the technology needed to meet those standards did not exist, but Congress knew that without the 'incentive' of statutory requirements, the automobile industry would not develop the technology needed to clean up vehicle emissions.

Table I

Automobile Emission Standards (grams per mile, g/mi)

Model year	Hydrocarbons	Carbon monoxide	Nitrogen oxides
1960	10.6[1]	84.0[1]	4.1[1]
1970	4.1	34.0	5.0[2]
1975	1.5	15.0	3.1
1980	0.41	7.0	2.0
1981	0.41	3.4[3]	1.0
1983	0.41	3.4	1.0
1994	0.25[4]	3.4	0.4
2001	0.125[5]	3.4	0.2
2004	0.09[6]	1.7[6]	0.07[6]

1. *EPA-estimated pre-control figure*
2. *At first control of hydrocarbons and carbon monoxide caused an increase in nitrogen oxides.*
3. *Waived for certain models that could not economically meet this standard. They met the 7.0 standard instead.*
4. *Non-methane hydrocarbons*
5. *Corporate average*
6. *Phase-in 2004–2007; corporate average*

Thus, Congress adopted performance-based, technology-forcing standards and recognised that lead in gasoline impeded the effectiveness of promising technologies, such as the catalytic converter. Thus, Congress paved the way for the introduction of unleaded gasoline.

In the early 1970s, the original deadlines for the emission standards were postponed several times, less stringent interim standards were set, and the original goal for NOx control was modified. Nevertheless, emission control technologies evolved at a much faster pace than would have occurred without the 'technology-forcing' provisions of the 1970 law.

In 1977, Congress fine tuned the law and mandated that all gasoline-powered cars must meet stringent standards by the 1983 model year (4). In 1990, Congress further tightened the standards beginning with the 1994 model year (the 'Tier 1 standards') and gave the EPA the authority to tighten the light-duty vehicle standards beginning in 2004 (5). In 1999, the EPA adopted the 'Tier 2 standards' that require more substantial reductions in emissions from automobiles, pick-up trucks, vans and sport-utility vehicles (SUVs) to be phased-in between 2004 and 2009 (6). Table I shows the progress in establishing increasingly stringent emission standards for automobiles.

The 1977 and 1990 Clean Air Act Amendments also targeted light-duty trucks, large trucks and buses for emission control. Furthermore, the 1990 Amendments called for the first time upon the EPA to address emissions from off-road vehicles and equipment. In response to the Clean Air Act mandate, the EPA is implementing a comprehensive programme to address emissions from on-road trucks and buses and a wide variety of off-road vehicles and equipment.

Over the past 25 years, the EPA has effectively designed, implemented and enforced the motor vehicle emission control programme to achieve the clean air objectives mandated by Congress. The State of California has also played a vital role in helping to shape the evolution of the U.S. motor vehicle emission control programme. Indeed, California's motor vehicle emission control programme pre-dates the national programme and standards initially adopted by California have often become the U.S. requirements.

Future U.S. Emission Standards and Fuel Quality Requirements

(a) Passenger Cars, Light-Duty Trucks and Medium-Duty Passenger Vehicles

On 10th February 2000, the EPA published new, more stringent standards ('the Tier 2 standards') for light-duty vehicles (passenger cars), light-duty trucks up to 8500 lbs gross vehicle

Table II

Tier 2 and Interim Non-Tier 2 Phase-In and Exhaust Averaging Sets

(The shaded areas indicate averaging sets)

	2001	2002	2003	2004 %	2005 %	2006 %	2007 %	2008 %	2009+ later %	NOx STD, g/mi
LDV/LLDT (Interim)	NLEV	NLEV	NLEV	75 max	50 max	25 max				0.30 avg
LDV/LLDT (Tier 2 + evap)	early banking b	b	b	25	50	75	100	100	100	0.07 avg
HLDT (Tier 2 + evap)	early banking b	b	b	b	b	b	b	50	100	0.07^{d} avg
HLDT (Interim)	Tier 1 b	Tier 1 b	Tier 1 b	25 c, e	50 e	75 e	100 e	50 max		$0.20^{a,d}$ avg
MDPVs (Interim)	HDE	HDE	HDE							
MDPVs (Tier 2 + evap)	early banking b	b	b	b	b	b	b	50	100	0.07^{d} avg

a. 0.60 NOx cap applies to balance of LDT3s/LDT4s, respectively, during the 2004–2006 phase-in years.

b. Alternative phase-in provisions allow manufacturers to deviate from the 25/50/75% 2004–2006 and 50% 2008 phase-in requirements and provide credit for phasing in some vehicles during one or more of these model years.

c. Required only for manufacturers electing to use optional NMOG values for LDT2s or LDT4s and MDPV flexibilities during the applicable interim programme and for vehicles whose model year commences on or after the fourth anniversary date of the signature of this rule. See discussion in text.

d. MDPVs, HLDTs, and MDPVs must be averaged together.

e. Diesels may be engine-certified through the 2007 model year

weight rating (GVWR), and medium-duty passenger vehicles (8501–10,000 lbs GVWR) to be phased in between 2004 and 2009 (6). The phase-in schedule for the Tier 2 standards is shown in Table I and the Tier 2 standards are shown in Table II.

The Agency also established a requirement for all gasoline fuel sold in the U.S. to have a 30 ppm average (avg) sulfur level on an annual basis beginning in 2005 and a 80 ppm sulfur cap beginning in 2006 (6).

The Tier 2 standards require all gasoline and diesel passenger cars, light-duty trucks and medium-duty passenger vehicles to meet the same stringent standards by 2009. The cornerstone of the Tier 2 programme is that manufacturers may choose to comply by certifying the mix of vehicles to different sets of standards or bins, as long as the corporate average meets the applicable interim or final NOx standard. Vehicle manufacturers are required to meet a corporate average 120,000 mile 0.07 NOx standard. Heavier light-duty trucks (called LDT3s and LDT4s) are given more time to meet the corporate average (avg) 0.07 grams per mile (g/mi) NOx standard (100 per cent by 2009) compared to passenger cars and light-duty trucks (LDT1s and LDT2s) (100 per cent by 2007). EPA has also included medium-duty passenger vehicles (< 10,000 lbs GVWR) in the programme. Under the Tier 2 programme, there are eight emission standard bins (Bins 1–8) for the Tier 2 standards, see Table III. Two additional bins (Bins 9–10) are available only during the interim period and will be eliminated before the final phase-in of the Tier 2 programme. An eleventh bin, shown in Table IV, is available only for MDPVs and expires in 2008.

Table III

Tier 2 Light-Duty Full Useful Life Exhaust Emission Standards (grams per mile, g/mi)

Bin #	NOx	NMOG	CO	HCHO	PM	Comments
10	0.6	0.156/0.230	4.2/6.4	0.018/0.027	0.08	a, b, c, d
9	0.3	0.090/0.180	4.2	0.018	0.06	a, b, e
The above temporary bins expire in 2006 (for LDVs and LLDTs) and 2008 (for HLDTs)						
8	0.20	0.125/0.156	4.2	0.018	0.02	b, f
7	0.15	0.090	4.2	0.018	0.02	
6	0.10	0.090	4.2	0.018	0.01	
5	0.07	0.090	4.2	0.018	0.01	
4	0.04	0.070	2.1	0.011	0.01	
3	0.03	0.055	2.1	0.011	0.01	
2	0.02	0.010	2.1	0.004	0.01	
1	0.00	0.000	0.0	0.000	0.00	

a. Bin deleted at end of 2006 model year (2008 for HLDTs).
b. The higher temporary NMOG, CO and HCHO values apply only to HLDTs and expire after 2008.
c. An additional temporary higher bin restricted to MDPVs is discussed below.
d. Optional temporary NMOG standard of 0.280 g/mi applies for qualifying LDT4s and MDPVs only.
e. Optional temporary NMOG standard of 0.130 g/mi applies for qualifying LDT2s only, see text.
f. Higher temporary NMOG standard is deleted at end of 2008 model year

(b) On-Highway Heavy-Duty Engines

The EPA has two separate rulemakings affecting highway HDEs: Phase 1 directed at 2004 to 2006 HDEs and Phase 2 directed at 2007 and later model year HDEs.

Phase 1

On 6th October 2000, EPA published its final rule covering the technological feasibility finding for the previously adopted diesel HDE 2004 standards and new standards for gasoline-powered HDVs (7). The final rule:

- Reaffirms that the 2004 model year NMHC+NOx and PM standards (2.5 g/bhp-hr NOx+NMHC and 0.1 g/bhp-hr PM), originally adopted in 1997, are technologically feasible and can be met with currently available diesel fuel;
- Sets new, more stringent standards for all heavy-duty Otto-cycle (for example gasoline-fuelled) engines and vehicles which will result in an approximate 75 per cent reduction in HC and NOx emissions from this category of vehicles;
- Requires OBD systems for all heavy-duty vehicles and engines at or below 14,000 lbs GVWR and revises the OBD requirements for diesel light-duty vehicles and trucks; and
- Implements additional certification test procedures and associated standards for heavy-duty engines and vehicles to address the issue of off-cycle emissions beginning in 2007.

The standards which will apply to gasoline-powered heavy-duty engines and vehicles are

Table IV

Temporary Interim Exhaust Emission Standards Bin (Bin 11) for MDPVs[a]

	NOx	NMOG	CO	HCHO	PM
Full useful life (120,000 mile)	0.9	0.28	7.3	0.032	0.12

a. Bin expires after model year 2008

Table V Phase 1: NOx and HC Standards for Gasoline Vehicles		
Gross Vehicle Weight (GVW)	NOx (g/mi)	HC (g/mi)
8,500–10,000 pounds 10,001–14,000 pounds	0.9 1.0	0.28 0.33
14,001 pounds and above	1.0 g/bhp-hr (combined NOx and HC)	

shown in Table V. The current NOx standard for both diesel and gasoline vehicles is 4.0 g/bhp-hr. The current HC standard for diesel is 1.3 g/bhp-hr and for gasoline is 1.1g/bhp-hr.

Phase 2

On 21st December 2000, the EPA adopted emission standards for 2007 and later model year highway heavy-duty engines and vehicles and established limits on the allowable levels of sulfur in diesel fuel (8). The regulations call for a 90 per cent reduction in PM and a 95 per cent reduction in NOx emissions from heavy-duty diesel engines compared to the standards currently applicable; tighter standards for gasoline-powered vehicles and a 97 per cent reduction in the allowable levels of sulfur in diesel fuel.

The EPA noted that these regulations are equivalent to removing 13 million of today's trucks off the road. The emission standards for HDEs are shown in Table VI below. The rule will result in NOx and PM exhaust control technology being installed on every on-road HDE.

The final rule has several key elements:

- A sulfur cap of 15 ppm beginning 1st June 2006 for diesel fuel sold for use in highway vehicles (2006–2009: 80 per cent and beginning in 2010: 100 per cent);
- A PM standard of 0.01 g/bhp-hr which would take effect with the 2007 model year;
- A NOx standard of 0.2 g/bhp-hr and a NMHC standard of 0.14 g/bhp-hr, to be phased in beginning with the 2007 model year with 100 per cent compliance by 2010;
- Formaldehyde emission standards and new requirements for crankcase emissions on turbocharged diesel engines;
- Tighter standards for heavy-duty vehicles certified as complete vehicles;
- Standards requiring reductions in evaporative emissions.

The emission standards for complete heavy-

Table VI
Phase 2: Full Useful Life Heavy-Duty Engine Emission Standards and Phase-Ins

		Standard (g/bhp-hr)	Phase-In by model year			
			2007	2008	2009	2010
Diesel	NOx NMHC HCHO	0.20 0.14 0.016	50%	50%	50%	100%
Gasoline	NOx NMHC HCHO	0.20 0.14 0.016	0%	50%	100%	100%
Diesel	PM	0.01	100%			
Gasoline	PM	0.01	0%	50%	100%	100%

Table VII Phase 2: Emission Standards for HDVs			
GVWR	PM	NOx	NMHC
8,500–10,000 10,000–14,000	0.02 g/mi 0.02 g/mi	0.2 g/mi 0.4 g/mi	0.195 g/mi 0.230 g/mi

duty vehicles (HDVs) would be implemented on the same schedule as for engine standards and are shown in Table VII.

(c) Off-Road Vehicles and Equipment

Off-road vehicles and equipment cover a wide range of spark-ignition (SI) and compression-ignition (CI) applications including construction equipment, locomotives, industrial handling equipment, marine vessels and lawn, and garden equipment. Until the mid-1990s, these applications went largely unregulated. But in the late 1990s, the EPA adopted regulations to control emissions from recreation marine engines, locomotives, construction and similar off-road heavy-duty engines, and lawn and garden equipment. For the most part, these standards can be met without the use of exhaust emission control technology, such as the catalytic converter. However as the relative contribution to ambient pollution from these off-road mobile sources continues to grow, EPA plans to require further reductions. Two examples are discussed below.

(i) *Heavy-Duty Off-Road Diesel Engines*

In 2001, EPA is expected to propose new PM standards (referred to as the Tier 3 PM standards) for off-road diesel engines to take effect in the 2006–2008 timeframe which would be comparable to the 2004 on-road HDE PM standard (0.1 g/bhp-hr). EPA is also expected to propose eventually that off-road engines meet emission standards comparable to the on-highway HDEs Phase 2 standards. These later standards (referred to as the Tier 4 standards) would require the use of both NOx and PM exhaust emission control technology. An important component of the EPA's planned clean-up of off-road HDEs is to reduce the sulfur content in diesel fuel used in off-road applications (currently averaging ~ 3000 ppm). EPA may employ a two-phase requirement, first calling for a 500 ppm sulfur limit in 2006 and then a further reduction to a 15 ppm cap to be timed with implementation of the Tier 4 standards, which is anticipated in the 2010 timeframe.

(ii) *Off-Road Spark-Ignition Engines > 25 hp*

In 2001 EPA is planning to propose emission standards for SI engines > 25 hp, used in industrial handling and similar applications. The standards would take effect around 2005 and will be met by the use of three-way catalyst technology.

California's Continuing Lead in U.S. Motor Vehicle Emission Control

As part of the 1970 Clean Air Act Amendments, Congress gave the State of California the unique authority to implement its own motor vehicle emission control programme. Other states may adopt elements of the California programme, but they may not adopt their own programme. The California programme, originally established in the 1960s, has, over the past 30 years, served as the nation's 'laboratory' for proving out new regulatoty programmes and concepts as well as new technologies. For example, the tighter standards for NOx set in California in the 1970s resulted in the first introduction of the three-way catalyst and sophisticated engine controls, which allowed simultaneous control of the three gaseous pollutants emitted in automotive exhaust. More recently, California's light-duty emission control programme, 'Low Emission Vehicle programme (LEV and LEV 2), served as the model for the EPA's Tier 2 standards. California also adopted regulations for a variety of

Table VIII

ARB Planned Control Measures

Control measure	Rule developed
On-Road Mobile Sources	
Lower New Engine Standards	2001
Retrofit Existing Engines	2002
HDV In-Use Compliance Programme	2003
Supplemental HDV Certification Procedures	2000
Off-Road Mobile Sources	
Lower New Engine Standards	2002
Retrofit Existing Engines	2002
Diesel Pleasure Craft Standards	2002
HDE In-Use Compliance Programme	2003
Stationary and Portable Engines	
Address New and Existing Engines (emergency/standby, prime, agriculture, and portable engines)	2002
Federal Action Required	
Locomotives	No date set
Commercial Marine Vessels	No date set
New Farm and Construction Equipment < 175 hp	No date set
New Vehicle Standards and Fuel Specifications	2000

off-road SI engines which have served as a model for standards later adopted by the EPA.

Looking to the future, California is expected to continue its leadership role. For example, in September 2000, California approved a comprehensive plan to reduce the total PM emissions from diesel-fuelled engines by 75 per cent in 2010 and by 85 per cent in 2020 (9). The California Air Resources Board (ARB) plan identifies diesel particulate filters as the principal technology expected to be used to reduce PM emissions from both existing and new diesel engines. Other strategies identified by ARB include fuel cells, electrification, alternative fuels, alternative diesel fuel formulations and additives, and engine modifications.

The ARB plan calls for cutting emissions by at least 85 per cent from up to 90 per cent of the existing on-road, off-road, and stationary engines, and by at least 90 per cent from new engines. The ARB plan recognises that control retrofit might not be technically possible and cost-effective in every engine application and has committed to work with interested parties to insure a fair, cost-effective, and technically sound programme.

Over the next two to three years, the ARB staff will be developing 14 new control measures including four measures that will require the cooperation and action of the U.S. EPA. The 14 control measures are summarised in Table VIII. The control requirements will be phased in between 2006 and 2010.

Future Emission Standards in the U.S.

Meeting Tier 2 by Passenger Cars, Light-Duty Trucks, and Medium-Duty Passenger Vehicles

As noted above, the technological solution to meeting the Tier 2 standards adopted by the EPA will be a systems approach, employing advances in engine technology, advanced catalyst technology and low sulfur fuel. EPA, in its final rule, stated that the type of control strategies likely to be employed included ongoing improvements in computer software, engine air/fuel controls, advances in catalyst designs and catalyst/system integration, increases in noble metal loading and other exhaust system/catalyst system improvements. Table IX lists the types of engine/exhaust/catalyst technology improvements and advancements that will likely be employed to meet the Tier 2 standards. For diesel-fuelled vehicles, EPA stated that exhaust control technology would probably be needed. For NOx emissions, EPA listed lean NOx catalysts, NOx adsorbers and selective catalytic reduction (SCR) as potential technologies. For PM control, EPA identified oxidation catalysts and PM filter technology. EPA stressed the importance of low sulfur fuel in enabling catalyst-based emission control technology to be optimised for maximised emission reductions.

Meeting Phase 1 and Phase 2 Standards by On-Road Heavy-Duty Diesel Engine

Engine manufacturers are expected to use a combination of engine modifications and EGR to meet the Phase 1 2004 standards. In some instances, an oxidation catalyst may be employed to control any increases in PM emissions resulting

Table IX

Advanced Engine/Exhaust/Emission Control Strategies for Gasoline-Powered Vehicles

Technology	Advancements to be employed
Catalyst technology	• Layered washcoat and support materials with high thermal stability • High cell density catalyst supports (substrates) • Thin-walled (lower mass) catalyst supports • Mounting materials with improved durability • New catalyst support designs (e.g., hexagonal cell structure, contoured end cones) • Thermally-insulated components
Electronic engine controls	• Higher idle speeds with engine spark retard • Higher speed computer processors • Model-based control algorithms • Injectors with improved fuel atomisation • Variable cam/valve timing • Electronic EGR • Electronic throttle control • CVT (continuously variable transmission)
Emission system sensors (control and diagnostics)	• Linear oxygen sensors • Planar oxygen sensors • Fast response temperature sensors • Combination NOx/O_2 sensor
Thermal management	• Air-gap manifolds, exhaust pipes, and converter shells offer low heat capacity and high heat insulation to improve converter warm-up and minimise outer surface temperatures

from the use of EGR to ensure that the engine meets the 0.1 g/bhp-hr standard. To meet the expected Phase 2 heavy-duty engine standards, a systems approach will be required, which combines advanced engine technology and both NOx and PM exhaust control technologies. To enable the use and complete optimisation of the existing and emerging NOx and PM exhaust emission control technologies, very low sulfur diesel fuel will be needed. Diesel particulate filters or 'traps' will likely be used to meet the very stringent Phase 2 PM standards. NOx adsorber and SCR appear to be the leading strategies to help meet the tough Phase 2 NOx standards.

Conclusion

The U.S. Environmental Protection Agency is in the process of establishing very stringent emission standards for virtually every category of motor vehicle. These standards, which will take effect in the 2004–2010 timeframe, will require substantial emission reductions over the levels currently required. Meeting these stringent standards present significant engineering challenges. The solution will be an engineered systems approach combining advanced engine designs, advanced catalyst-based control technologies, and low sulfur fuel. Engine, vehicle, and emission control manufacturers are working together to develop and optimise the needed technological solutions. The prospects for meeting these very stringent emissions levels, as reviewed here, appear to be excellent.

References

1 U.S. EPA, Latest Findings on National Air Quality: 1999 Status and Trends, August 2000

2 U.S. EPA, National Air Pollutant Emission Trends, 900–1998, March 2000

3 "Clean Air Act Amendments of 1970" (PL 91-604, 1970)

4 "Clean Air Act Amendments of 1977" (PL 95-95, 1977)

5 "Clean Air Act Amendments of 1990" (PL 101-549, 1990)

6 U.S. EPA, "Control of Air Pollution from New Motor Vehicles: Tier 2 Motor Vehicle Emission Standards and Gasoline Sulfur Control Requirements", 40 CFR Parts 80, 85, and 86, 65 FR 6698 (Feb. 10, 2000)

7 U.S. EPA, "Control of Emissions of Air Pollution from 2004 and Later Model Year Heavy-Duty Highway Engines and Vehicles; Revision of Light-Duty On-Board Diagnostics Requirements", 40 CFR Parts 85 and 86, 65 FR 59896 (Oct. 6, 2000)

8 U.S. EPA, "Control of Air Pollution from New Motor Vehicles: Heavy-Duty Engine and Vehicle Standards and Highway Diesel Sulfur Control Requirements", 40 CFR Parts 69, 80, and 86 (Dec. 21, 2000)

9 California Air Resources Board, Risk Reduction Plan to Reduce Particulate Matter Emissions from Diesel-Fueled Engines and Vehicles, Sacramento, CA, Oct. 2000

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Definitions and Terms Used

Adjusted loaded vehicle weight – the numerical average of vehicle curb weight and GVWR

Gross vehicle weight rating (GVWR) – the value specified by the manufacturer as the maximum design loaded weight of a single vehicle

Heavy-duty vehicle (HDV) – any motor vehicle rated at more than 8500 lbs GVWR or that has a vehicle curb weight of more than 6000 pounds or that has a basic vehicle frontal area in excess of 45 square feet

Heavy light-duty truck (HLDT) – any light-duty truck rated greater than 6000 lbs GVWR

Light-duty truck (LDT) – any motor vehicle rated at 8500 lbs GVWR or less which has a vehicle curb weight of 6,000 lbs or less and which has a basic vehicle frontal area of 45 square feet or less, which is: (a) designed primarily for purposes of transportation of property or is a derivation of such a vehicle; or (b) designed primarily for transportation of persons and has a capacity of more than 12 persons; or (c) available with special features enabling off-street or off-highway operation and use

Light-duty truck 1 (LDT1) – any light light-duty truck up through 3750 lbs loaded vehicle weight

Light-duty truck 2 (LDT2) – any light light-duty truck greater than 3750 lbs loaded vehicle weight

Light-duty truck 3 (LDT3) – any heavy light-duty truck up through 5750 lbs adjusted loaded vehicle weight

Light-duty truck 4 (LDT4) – any heavy light-duty truck greater than 5750 lbs adjusted loaded vehicle weight

Light-duty vehicle (LDV) – a passenger car or passenger car derivative capable of seating 12 passengers or less

Light light-duty truck (LLDT) – light light-duty truck means any light-duty truck rated up through 6000 lbs GVWR

Loaded vehicle weight (LVW) – the vehicle curb weight plus 300 lbs

Medium-duty passenger vehicle (MDPV) – any heavy-duty vehicle with a GVWR of less than 10,000 lbs that is designed primarily for the transportation of persons. The MDPV definition does not include any vehicle which: (a) has a seating capacity of more than 12 persons; or (b) is designed for more than 9 persons in seating rearward of the driver's seat; or (c) equipped with an open cargo area of 72.0 inches in interior length or more

Vehicle curb weight (VCW) – the actual or the manufacturer's estimated weight of the vehicle in operational status with all standard equipment, and weight of fuel at nominal tank capacity, and the weight of optional equipment computer in accordance with 40 CFR 86.082-24

Acronyms and Abbreviations

ARB	California Air Resources Board	**HCHO**	formaldehyde
CI	compression ignition	**HDE**	heavy-duty engine
CVT	continuously variable transmission	**HDV**	heavy-duty vehicle
EGR	exhaust gas recirculation	**HLDT**	heavy light-duty truck
g/bhp-hr	grams per brake horsepower-hour	**lb**	pound
GVWR	gross vehicle weight rating	**LDT1**	light-duty truck 1

Acronyms and Abbreviations, contd.

LDT2	light-duty truck 2	**NMHC**	non-methane hydrocarbon
LDT3	light-duty truck 3	**NMOG**	non-methane organic gas
LDT4	light-duty truck 4	**NOx**	nitrogen oxides
LDV	light-duty vehicle	**O_2**	oxygen
LEV	low emission vehicle	**OBD**	on-board diagnostic
LLDT	light light-duty truck	**ppm**	parts per million
MDE	medium-duty engine	**SCR**	selective catalytic reduction
MDPV	medium-duty passenger vehicle	**SI**	spark ignition
NLEV	National Low Emission Vehicle	**SUV**	sport-utility vehicle

Rhodium Bicentenary Competition

In an exciting two-year period in the early nineteenth century, the discovery of four of the platinum group metals was announced in London. Among these was rhodium, which was described by William Hyde Wollaston to the Royal Society on 24th June 1804 (1).

To mark the approaching 200th anniversary of the discovery of rhodium, Johnson Matthey has decided to hold a Rhodium Bicentenary Competition for a new research project involving any aspect of rhodium science, preferably aimed at the development of a new application. The prize will be the sponsorship of a Ph.D. studentship and a loan of metal with which to conduct the investigation. The competition is open worldwide to scientists in universities and institutes of advanced research who train future scientists.

All proposals for research will be treated with confidentiality and ideas will not be disclosed outside Johnson Matthey. The proposers will be advised of any duplication of ideas or projects. The successful project will have contact with Johnson Matthey scientists over its duration. With due regard to the policies of the institution to which the scientists taking part belong, it is assumed that any intellectual property rights arising during the research will become owned by Johnson Matthey, should the project be developed into a commercial product.

Scientists wishing to participate in the Rhodium Bicentenary Competition should submit a 1-page research proposal directly by E-mail to: rhodium@matthey.com by 1st October 2001. Proposals will be evaluated by a committee chaired by the Director of the Johnson Matthey Technology Centre. More detailed proposals may be requested after the initial assessment. An announcement of the winner will be made in the January 2002 issue of *Platinum Metals Review*.

Reference

(1) Donald McDonald and Leslie B. Hunt, "A History of Platinum and its Allied Metals", Johnson Matthey, London, 1982, p. 147

Biomimetic Chiral Rhodium Catalysis

Recent attempts to mimic the high activity of metalloenzymes involve the molecular imprinting of organometallic systems. This involves a polymerisation reaction in which a pseudosubstrate is attached to a catalyst centre. On removal a shape-selective cavity is left.

Researchers at the Institut für Anorganische Chemie der Ludwig-Maximilians-Universität, Germany, now report a highly active and selective (ee > 99%) chiral Rh(III) catalyst which can asymmetrically reduce acetophenone (K. Polborn and K. Severin, *Eur. J. Inorg. Chem.*, 2000, (8), 1687–1692). The organometallic Cp*Rh complex had a chiral *N*, *N′*-chelate ligand with a styrene side chain; the remaining coordination site was occupied by a methylphenylphosphinato ligand – the pseudosubstrate which mimics acetophenone. During molecular imprinting, the Rh complex was co-polymerised with ethylene glycol dimethacrylate; the phoshinato ligand in the resulting polymer was then replaced by a chloro ligand to generate a shape-selective cavity near the active rhodium centre.