Autogas

Clearing the Air
A Technical Guide on Autogas

Emissions, Test Methods, Standards and Technology

WORLD LP GAS ASSOCIATION

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BACKGROUND

The purpose of this document, "**Clearing the Air, A Technical Guide on Autogas - *Emissions, Test Methods, Standards and Technology***" is to provide technical support information for the WLPGA publication "**Developing a Sustainable Autogas Market, A Guide for Policy Makers**". This latter document focuses mainly on policy to realise a sustainable autogas market throughout the world.

This document addresses the environmental advantages of autogas and progress made with regard to the harmonisation of autogas components, related standards and regulations.

This technical guide consists of three chapters:

- **Chapter 1 Environmental Advantages of LP Gas vehicles** describes the potential advantages of LP Gas vehicles in terms of regulated and non-regulated pollutant emissions, and total fuel cycle analysis (well-to-wheel emissions) on the basis of current LP Gas vehicle emission data.

- **Chapter 2 Autogas Vehicle & Components, Safety Standards & Regulations** mainly addresses the safety aspects of LP Gas vehicles as well as their autogas components. Also discussed are rules in terms of standards and/or regulations used around the world for component design, manufacture and installation on vehicles.

- **Chapter 3 Autogas Fuel Composition Standards and Test Methods** focuses on various autogas fuel standards and specifications of some major countries of the world where autogas is prominently used.

Note: The terms "LP Gas", "LPG", "propane" and "autogas" are frequently used interchangeably. "Autogas" is a marketing term specifically denoted to mean LP Gas used in the motor transport market. Throughout this document "LP Gas" generally refers to a vehicle powered by autogas and equipment used to power a vehicle, whereas "autogas" refers to the fuel. Exceptions occur particularly when specific sources or data are quoted.

Executive Summary

Autogas is widely recognised as a viable alternative motor fuel with more than 7 million vehicles operating throughout the world. Using the same test criteria as for gasoline and diesel vehicles, its environmental benefits over other fuels is proven. Technology regarding the design, manufacturing and installation requirements of automotive LP Gas components is sophisticated and stays current with evolving technologies of conventional vehicles. Further, while meeting the most stringent emission standards, LP Gas powered vehicles deliver performance and economy equal to customer expectations.

Autogas environmental performance

LP Gas vehicles have proven environmental advantages on the same regulatory basis as conventional gasoline and diesel vehicles. These advantages include both regulated and non-regulated pollutants. Regarding regulated pollutants autogas advantages include:

- generally lower hydrocarbon (HC) and carbon monoxide (CO) emissions than conventional gasoline and diesel,
- particulate and nitrogen oxides (NO_x) emissions much lower compared to diesel, and
- no evaporative emissions

LP Gas vehicles also show very positive benefits when considering non-regulated pollutants including:

- very low emissions of air toxics such as polycyclic aromatic hydrocarbons (PAH), nitrogen dioxide (NO_2) and sulphur dioxide (SO_2) especially compared to diesel;
- far lower NO_2 emission and the number of nano particles emitted 30 times lower than a diesel engine even with diesel particulate filters (DPF);
- lowest ozone formation potential, winter smog potential and acidification effect, and
- lower global warming potential (GWP) of about 14 % compared with gasoline vehicles.

In addition, recent durability studies, using the same criteria as for conventional vehicles, demonstrate that LP Gas vehicles show very little emission performance deterioration over the useful life of the vehicle. These tests were performed in the US (up to 120,000 miles) and on the European emission test cycle (80,000 km).

Autogas engine technologies

There is a wide choice of autogas components using a variety of technologies that can be fitted on a wide range of vehicle types. Whether carbureted systems for retrofitted vehicles to comply with minimum emission control standards, or gaseous and liquid sequential or direct injection systems for original equipment manufacture (OEM) vehicles, LP Gas fuel systems match the given engine technology. This includes on-board diagnostics (OBD) and the use of sophisticated after-treatment technologies to ensure compliance with strict emission standards and performance requirements.

Autogas component developments

Autogas components must meet very stringent standards ensuring LP Gas vehicles are at least as safe as other motor vehicles. These standards are constantly updated to adapt to the evolution of technologies whether driven by new LP Gas component design (for example, Euro filling unit or composite automotive containers) or improved test methods.

A world-wide harmonisation of these minimum safety rules related to the design, manufacturing and installation of autogas components is in progress with governmental authorities through the United Nations / Economic Commission for Europe's (UN/ECE) Regulation 67. A parallel effort is being lead by the LP Gas industry with the creation of the ISO/TC22/WG11 dealing with LP Gas containers used in automotive applications.

Autogas fuel composition

A review of current international and national autogas fuel composition standards shows only Europe's EN 589 and Australian specifications are specifically developed to address the critical requirements for autogas, such as Motor Octane Number (MON), residue and sulphur content. In Japan, for instance class 2 of the industrial LP Gas specification is designated for autogas use.

This report defines the range of environmental standards that are rapidly being established for new vehicles. The report also examines emissions data, and clearly highlights where autogas outscores other transportation fuels in terms of reduced pollutant and greenhouse gas emissions. The environmental, economical and technical benefits of autogas clearly demonstrate why autogas is the leading alternative transportation fuel worldwide.

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Acknowledgements

This publication is the first edition of **Clearing the Air, A Technical Guide on Autogas** - ***Emissions, Test Methods, Standards and Technology*** from the World LP Gas Association's Global Autogas Industry Network (GAIN).

This first edition was reviewed by a committee composed of:

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THE ENVIRONMENTAL ADVANTAGES OF AUTOGAS VEHICLES

The purpose of this chapter is to provide an overview of data available regarding the emission performance of autogas vehicles. Most of the data are certification data achieved according to local regulatory emission standards. A review of present and future emission test procedures, and standards applied in Europe, the US, Japan and Australia is provided in Appendix C.

It should be noted that emission performance of autogas vehicles is measured on the same criteria (emission test cycle, durability requirements, etc.) as for the conventional gasoline and diesel vehicles. Most of the data collected concerned OEM's vehicles. Nevertheless, it should be emphasised that most countries having a mature autogas market have, or are implementing, stringent rules relating to retrofit operations. The aim of these rules is to ensure the environmental performance as well as safe performance of all autogas vehicles, whether OEM or retrofit installations.

The advantage of autogas as an environmentally friendly fuel is particularly significant regarding the decrease of emissions compared to conventional vehicles (NO_x, smoke, particulates, benzene, and noise), yet remaining cost effective to the operator.

Autogas vehicles will maintain their environmental advantages compared to other conventional automotive fuels, especially regarding the current unregulated pollutants. With implementation of more stringent emissions standards, new automotive technologies that optimise fuel combustion, such as direct injected gasoline and diesel vehicles, will also benefit autogas.

The Environmental Advantages of Autogas Vehicles

1.1 Regulated Pollutant Emission Data for Autogas Light Duty Vehicles

This section discusses the available data regarding the emissions performance of light duty vehicles. The definition of "light duty vehicle" varies among regulatory authorities. For this discussion and throughout this document "light duty vehicle" is defined as passenger cars and other vehicles having a maximum gross weight of 3,500 kg.

1.1.1. Performance of Autogas Light Duty Vehicles Regarding Regulated Pollutants

Regulated emissions usually addressed in the mandatory emissions standards are:

- Hydrocarbons: HC: distinction may be made between THC (total hydrocarbons), NMHC (non-methane hydrocarbons) or NMOG (non methane organic gases);
- Carbon monoxide: CO
- Nitrogen oxides: (NO and NO_2)
- Particulate matter: PM

1.1.1.1 Autogas Vehicles versus Conventional Vehicles

Most striking are the far lower NO_x and PM emissions compared with diesel vehicles, even diesel vehicles equipped with the most advanced technologies such as particulate traps or special diesel particulate filters (DPF). This is significant because of the generally rapid growth of diesel vehicles in urban areas and the related problems of increased PM emissions. Autogas can make a substantial contribution to lowering PM in these congested areas.

Table 1.1 Regulated autogas, gasoline and diesel vehicle emissions according to the European emission test cycle (EURO 2).

g/km	THC	NMHC	CO	NO_x	PM
Autogas	0.05	0.04	0.30	0.03 to 0.06	< 0.001
Gasoline	0.08	0.07	0.60	0.03 to 0.08	0.001
Diesel	0.06	0.06	0.50	0.30 to 0.50	0.040
Diesel + DPF	0.01	0.01	0.01	0.30 to 0.50	0.002

Source: PM, Ricardo; other emissions, Kfrafthardt-Bundesamt "Fuel Composition and Emissions, Type Approval Data of MY 2001 Light Duty Vehicles, Publication No. 11

Recent tests at Millbrook Proving Ground (UK) show that even for the latest EURO 3 diesels, PM numbers in the 20-100 nanometre range are often two orders of magnitude higher than those recorded for gasoline or autogas fuelled vehicles.

1.1.1.2 Autogas Light Duty Vehicles Compared to Selected other Alternative Fuelled Light Duty Vehicles (compressed natural gas [CNG], methanol, ethanol)

Table 1.2 Alternative fuelled vehicle regulated emissions according to the European emission test cycle (EURO 2).

g/km	THC	CO	NO_x	PM
Autogas	0.05	0.3	0.03 to 0.06	< 0.001
CNG	0.15	0.3	0.03 to 0.06	< 0.001
M85	0.05	0.6	0.05 to 0.08	< 0.001
E85	0.08	0.6	0.05 to 0.08	< 0.001

Source: Kfrafthardt-Bundesamt "Fuel Composition and Emissions, Type Approval Data of MY 2001 Light Duty Vehicles, Publication No. 11

In the context of the European Auto Oil II Programme, the European Commission Consultant estimated future potential of different foreseen alternative motor fuels (based of EURO 4 emission targets and new engine technologies under development).

Table 1.3 Evaluation of alternative fuels for passenger cars/light duty vehicles (EURO 4).

FUEL	CO	HC	NO_x	PM	VEHICLE CO_2	LCA CO_2
CNG	✸	●	✸	✸	✸	●
LPG	✸	✸	●	✸	✸	●
BIOFUEL (E85G)	●	●	●	✸	●	✸
ETBE 15G	●	●	●	-	●	●
DME	✸	●	✸	✸	●	●/✸
FAME 30D	●	●	✕	✸	●	●

✕ PROBLEMATIC ● PROMISING ✸ VERY PROMISING

Source: Prof. C. Arcoumanis, Report Auto Oil II/WG3.
Note: LCA= Life-cycle Analysis

1.1.1.3 Autogas Vehicle Emissions Performance at Cold Start

Another positive characteristic of an autogas engine is the reduced emissions at cold engine start. This phenomenon is particularly important for urban fleet vehicles operating on short trips. Due to this duty cycle, catalysts can have difficulty achieving their light-off temperature thus reducing their optimal performance.

Further, due to its thermo-physical characteristics, the air/fuel ratio of an autogas engine is only slightly influenced by the low ambient temperature. Thus no enrichment is necessary compared to gasoline engines that need strong enrichment when starting at low ambient temperature.

Table 1.4 Example of emission performance of two autogas Renault Euro 2 models compared to the same gasoline engines at cold start (-7°C) according to the European test cycle.

	Renault Clio	Renault 19
CO emissions improvement	98%	95%
HC emissions improvement	80%	70%

Source: Renault

1.1.1.4 Examples of Emission Certification Data for OEM Autogas Light Vehicles

Table 1.5 shows type approval results of warranted conversions of OEM autogas vehicles available in the United Kingdom. These data are issued from the "PowerShift Register" established by the UK Government to create conditions for clean-fuelled vehicles to be practically and economically viable. All applicants seeking grant funding for clean-fuelled vehicles (CFVs) must choose vehicles that appear on the PowerShift Register. For further details on the UK PowerShift programme, see the WLPGA document, "**Developing a Sustainable Autogas Market— A Guide for Policy Makers**".

Table 1.5 Emission results on the European driving test cycle of warranted conversions on OEM autogas vehicles and comparable gasoline vehicles available in the UK.

Vehicle type	CO_2 (g/km)		CO (g/km)		$HC+NO_x$ (g/km)		Fuel consumption (MJ/100km)	
	Autogas vehicle	comparable gasoline vehicle	Autogas vehicle	comparable gasoline vehicle	Autogas vehicle	comparable gasoline vehicle	Autogas vehicle	comparable gasoline vehicle
EURO 2 vehicles models :								
Citroen Xantia 1.8l 16v	172	198	0.49	1.25	0.091	0.209	256	278
Daewoo Lanos 1.4	164	180	1.00	1.17	0.2	0.24	232	254
Daewoo Lanos 1.6	191	206	1.27	1.46	0.20	0.36	270	262
Daewoo Leganza 2.0 Automatic	239	263	1.18	1.66	0.17	0.40	337	366
Daewoo Leganza 2.0	204	234	0.73	1.59	0.15	0.31	287	294
Daewoo Nubira 2.0	191	232	1.17	1.22	0.16	0.30	269	304
Ford Focus 1.8	178	190	0.31	0.53	0.08	0.08	254	N/A
Ford Mondeo 1.8	184	204	0.63	0.81	0.17	0.21	263	274
Nissan Primera 2.0[1]	180	197	0.48	0.49	0.10	0.15	272	252
Nissan Primera Auto 2.0[1]	203	214	0.45	0.47	0.16	0.18	N/A	N/A
Vauxhall Astra 1.4i 16v	150	166	0.11	0.30	0.07	0.16	226	N/A
Vauxhall Astra 1.6i 8v	147	165	0.17	0.29	0.09	0.15	222	N/A
Vauxhall Astra 1.6i 16v	150	177	0.04	0.17	0.09	0.34	226	242
Vauxhall Omega 2.0i 16v	208	226	0.10	0.40	0.07	0.18	313	307
Vauxhall Vectra 2.0i 16v	184	206	0.28	0.42	0.15	0.21	279	282
EURO 3 vehicles models								
Vauxhall Astra 1.6i 16v	151	165	0.41	0.70	0.05	0.08	215	242
Vauxhall Vectra 1.8i 16v	162	183	0.65	0.65	0.05	0.06	231	242
Volvo S40/V40 1.8 Bi-Fuel	167	192	0.56	1.06	0.12	0.22	240	N/A

Source: UK Powershift Programme
[1] OEM approved conversion
N/A = not available

Table 1.6 Comparison of selected OEM dedicated (bi-fuel) model year 1997 and 1998 autogas passenger cars using autogas and gasoline according to the European EURO2 emissions test cycle.

	CO_2 (g/km)		CO (g/km)		HC (g/km)		NO_x (g/km)	
Vehicle type	Autogas vehicle	comparable gasoline vehicle	Autogas vehicle	comparable gasoline vehicle	Autogas vehicle	comparable gasoline vehicle	Autogas vehicle	comparable gasoline vehicle
EURO 2 vehicle models :								
Renault Twingo 1.2 l	135	150	0.30	0.8	0.065	0.120	0.030	0.030
Vauxhall Combo	158	178	0.21	0.93	0.063	0.103	0.154	0.158
Opel Vectra	170	199	0.12	0.13	0.024	0.052	0.033	0.038
Renault Megane 1.6 l	155	175	0.30	0.70	0.050	0.075	0.010	0.020
Renault Laguna 1.8 l	175	200	0.35	1.15	0.060	0.100	0.050	0.070
Ford Scorpio 2.3 l	250	288	0.92	0.97	0.070	0.090	0.030	0.390
Chrysler Voyager 2.5 l	222	260	0.68	1.46	0.060	0.100	0.040	0.14

Source: TNO Report 1998

Some tests of these European vehicles were also performed according to the US Federal Test Procedure (FTP 75) and demonstrated that autogas technology was also able to comply with the very stringent Californian Ultra Low Emission Vehicle (ULEV) standards.

Table 1.7: Performance of an optimised autogas Renault Clio using the FTP 75 emission test cycle.

	CO	NO_x	HC
Reduction of pollutant emissions compared to a gasoline vehicle	- 90% (0.13 g/km)	- 95% (0.010 g/km)	- 80% (0.024 g/km)

Source: Renault

1.1.1.5 Comparison of Autogas and Gasoline Light Duty Vehicle Emissions Durability Performance Based on Useful Life

US data reported to the Environmental Protection Agency (EPA, US) by The Propane Vehicle Council demonstrated that OEM autogas vehicles show very little deterioration of emission performance during useful life (up to 120,000 miles).

Examples of the emissions performance achieved on two Ford models, the F-150 45NP and 46NP versions, are given in the tables below.

Table 1.8 Emissions of Ford F-150 45 NP during useful life compared with gasoline based on US FTP.

g/mile	Low mileage		50,000 mile		120,000 mile	
	Autogas (ULEV)	Gasoline (LEV)	Autogas (ULEV)	Gasoline (LEV)	Autogas (ULEV)	Gasoline (LEV)
NMHC	0.04	0.06	0.04	0.08	0.04	0.12
CO	0.26	0.47	0.50	0.82	0.60	1.71
NO_x	0.03	0.07	0.05	0.17	0.06	0.42

Source: EPA OTAQ (US), LPGV Emission Factors Report

Table 1.9 Emissions of Ford F-150 46 NP during useful life compared with gasoline based on US FTP.

g/mile	Low mileage		50,000 mile		120,000 mile	
Fuel	Autogas (ULEV)	Gasoline (LEV)*	Autogas (ULEV)	Gasoline (LEV)*	Autogas (ULEV)	Gasoline (LEV)*
NMHC	0.04	0.08	0.04	0.10	0.05	0.14
CO	0.87	0.75	1.60	1.10	1.90	1.99
NO_x	0.12	0.04	0.21	0.14	0.24	0.40

Source: EPA OTAQ, LPGV Emission Factors Report
** LEV: Low Emission Vehicle*

In addition to studies that show reduced emissions of autogas engines at cold start, the above data show this advantage extends to the durability emissions tests as well.

Examples of autogas fuelled vehicle emission performance recorded at low temperature are given in the tables below. They demonstrate that emissions from autogas vehicles during the useful life are much lower than that of gasoline vehicles.

Table 1.10 Emissions of Ford F-150 45 NP during useful life compared with gasoline measured at cold start for CO, and at highway conditions for NO_x according to the US FTP.

g/mile	Low mileage		50,000 mile		120,000 mile	
	Autogas (ULEV)	Gasoline (LEV)	Autogas (ULEV)	Gasoline (LEV)	Autogas (ULEV)	Gasoline (LEV)
Cold start CO	N/A	N/A	0.57	4.92	0.57	5.27
Highway NO_x	0.09	0.002	0.01	0.10	0.02	0.35

Source: EPA OTAQ, LPGV Emission Factors Report
N/A= Not Available

1.1.1.6 Autogas Light Duty Versus Conventional Vehicles using Different Real Life Emission Test Cycles

Most emission test cycles for certification ignore the effects of road traffic congestion on exhaust gas emissions and fuel consumption. Two studies recently undertaken in Europe demonstrate significant environmental advantages of autogas vehicles, especially compared to diesel when operating in urban areas.

- A UK study considered the emission performance of commercial delivery vehicles mainly involved in short journeys but stopping many times for delivery, and
- A Dutch study considered the emission performance of vehicles operating in Dutch highway traffic.

1.1.1.6.1 The Millbrook (UK) Study: "Warm Start Emission Test Cycle"

The current European test cycle (MVEG) is not really representative of typical journeys of commercial vehicles operating in urban areas such as courier or similar delivery type vehicles. Such vehicles run high mileage and typically drive 60 to 160 km or more per day, stopping many times for deliveries. Millbrook's (January 2001) "warm start test cycle" compared the emission performance of passenger vehicles (M1 category) operating on gasoline, diesel with ultra low sulphur fuel, and autogas.

This UK study concludes that the use of autogas leads to:

- a 99.5% reduction in urban NO_x compared to diesel. This means that a fleet of 50 diesel delivery vehicles covering about 24,000 km per annum would emit about 788kg of NO_x per annum, 15 kg per annum running on gasoline but only 4 kg per annum running on autogas.
- several orders of magnitude reduction in urban fine particulates compared to diesel,
- a 13% savings of CO_2 compared to ultra low sulphur gasoline.

1.1.1.6.2 The TNO Study

TNO Automotive has undertaken a research programme to determine the effects of road traffic congestion on exhaust gas emissions and fuel consumption of road vehicles on motorways. The Transport Research Centre of the Dutch Ministry of Transport and the Dutch Ministry of Housing, Spatial Planning and the Environment sponsored this programme.

For the purpose of this research, ten real world-driving cycles were developed representing several situations on Dutch motorways. A large group of test vehicles (Euro 2 vehicles at the time of the study were the most modern vehicles) were subjected to these driving cycles on a chassis dynamometer for the measurement of exhaust gas emissions and fuel consumption. The test vehicles were selected randomly from the Dutch car fleet and were actually in use at the time of testing.

Table 1.11 Description of standard test cycles and a selection of real world motorway driving cycles.

Cycle no.	Definition
UDC	European Urban Driving Cycle (for further details, see Appendix C), start between 20 and 25 C
EUDC	European Extra Urban Driving Cycle (for further details, see Appendix C)
EDC	European Driving Cycle (UDC + EUDC - for further details, see Appendix C)
1	Highly congested; speed <10 km/h; "stop and go"
2	Congested; speed between 40 and 75 km/h
3	Not congested; speed between 75-120 km/h, traffic volume over 1000 vehicles per lane per hour, speed limit = 100 km/h
4	Not congested; speed over 120 km/h, independent of traffic volume
5	Shortcut/back road on typical Dutch rural and city roads

Passenger car emissions varied largely based on vehicle type. The absolute levels showed large variations, and the relative difference between the emissions of a car measured in each of the cycles varied considerably as well.

Nevertheless, this study demonstrated that congestion-causing high driving dynamics (cycles 1 and 2), and high speed driving (cycle 4) cause significant emission increases of CO, HC, PM and fuel consumption. This increase is mainly caused by many engine load changes or high engine loads, which lead to temporary (load change) or constant (high load) fuel enrichment for gasoline and autogas cars. During these periods of enrichment the 3-way catalysts of modern gasoline and autogas cars do not oxidise CO and HC, leading to a significant increase of emissions. However, this increase is far lower for autogas vehicles than for the gasoline. Diesel cars show a severe increase of PM at high loads.

The tables below compare the emission performance of the vehicles tested according to the motor fuel being used and their engine size. The performance of the autogas vehicles is generally superior to conventional vehicles in traffic congestion.

Table 1.12 CO emission in g/km for different real world cycles. Numbered columns in tables below refer to driving cycles described in Table 1.11 above.

Vehicle	Type	Fuel	Engine capacity in litres	CO [g/km]							
Make				UDC cold	EUD C	EDC	1	2	3	4	5
Honda	Accord 1.8	Autogas	1.8	2.09	0.97	1.10	9.38	0.10	0.15	0.03	0.21
Renault	Espace	Autogas	2.0	3.35	0.40	1.49	0.63	0.22	1.24	3.49	0.19
Volvo	V70 Bi-Fuel	Autogas	2.5	2.02	0.11	0.77	0.30	0.66	0.24	0.09	0.33
VW	Lupo 1.0	Gasoline	1	3.46	0.25	1.44	2.20	0.98	0.57	3.06	1.23
Renault	Scenic 1.6	Gasolie	1.6	2.30	0.32	1.05	0.65	0.08	0.49	2.06	0.01
Honda	Accord 1.8	Gasoline	1.8	2.52	0.15	1.03	1.12	0.19	0.54	1.69	0.26
Volvo	V40 1.8	Gasoline	1.8	5.94	0.13	2.27	2.09	0.09	0.36	2.35	0.04
Renault	Scenic 1.9D	Diesel	1.9	1.41	0.08	0.57	1.69	0.05	0.02	0.03	0.04
VW	Golf 1.9 TDi	Diesel	1.9	0.76	0.01	0.29	0.77	0.03	0.01	0.03	0.02

Source: TNO

Table 1.13 HC emission in g/km for different real world cycles.

Vehicle	Type	Fuel	Engine capacity in litres	HC [g/km]							
Make				UDC cold	EUDC	EDC	1	2	3	4	5
Honda	Accord 1.8	Autogas	1.8	0.22	0.01	0.08	0.59	0.01	0.01	0.00	0.00
Renault	Espace	Autogas	2.0	0.21	0.01	0.08	0.02	0.00	0.02	0.04	0.00
Volvo	V70 Bi-Fuel	Autogas	2.5	0.14	0.01	0.05	0.03	0.00	0.00	0.01	0.01
VW	Lupo 1.0	Gasoline	1	0.44	0.01	0.17	0.12	0.02	0.02	0.02	0.00
Renault	Scenic 1.6	Gasoline	1.6	0.24	0.02	0.10	0.04	0.01	0.03	0.04	0.00
Honda	Accord 1.8	Gasoline	1.8	0.36	0.03	0.16	0.15	0.03	0.04	0.11	0.02
Volvo	V40 1.8	Gasoline	1.8	0.39	0.01	0.15	0.10	0.00	0.01	0.05	0.00
Renault	Scenic 1.9D	Diesel	1.9	0.18	0.03	0.08	0.24	0.05	0.01	0.01	0.02
VW	Golf 1.9TDi	Diesel	1.9	0.14	0.02	0.06	0.17	0.03	0.01	0.00	0.01

Source: TNO

Table 1.14 NO_x emission in g/km for different real world cycles.

Vehicle	Type	Fuel	Engine capacity In litres	NO_x [g/km]							
Make				UDC cold	EUDC	EDC	1	2	3	4	5
Honda	Accord 1.8	Autogas	1.8	0.30	0.12	0.15	0.16	0.53	0.61	1.49	0.52
Renault	Espace	Autogas	2.0	0.03	0.01	0.01	0.04	0.02	0.02	0.01	0.03
Volvo	V70 Bi-Fuel	Autogas	2.5	0.21	0.57	0.28	0.28	0.20	0.13	0.43	0.24
VW	Lupo 1.0	Gasoline	1	0.25	0.01	0.10	0.01	0.01	0.02	0.01	0.02
Renault	Scenic 1.6	Gasoline	1.6	0.03	0.03	0.03	0.01	0.07	0.04	0.01	0.11
Honda	Accord 1.8	Gasoline	1.8	0.25	0.02	0.11	0.02	0.04	0.04	0.05	0.01
Volvo	V40 1.8	Gasoline	1.8	0.11	0.00	0.04	0.09	0.02	0.04	0.04	0.03
Renault	Scenic 1.9D	Diesel	1.9	0.46	0.46	0.46	1.06	0.83	0.64	2.08	0.79
VW	Golf 1.9TDi	Diesel	1.9	0.43	0.32	0.36	0.95	0.44	0.37	1.03	0.52

Source: TNO

Table 1.15 CO_2 emission in g/km for different real world cycles.

Vehicle	Type	Fuel	Engine capacity In litres	CO_2 [g/km]							
Make				UDC cold	EUDC	EDC	1	2	3	4	5
Honda	Accord 1.8	Autogas	1.8	271	155	194	402	161	150	196	183
Renault	Espace	Autogas	2.0	232	161	187	425	162	172	228	191
Volvo	V70 Bi-Fuel	Autogas	2.5	296	160	205	448	163	141	191	199
VW	Lupo 1.0	Gasoline	1	186	122	146	297	125	118	170	142
Renault	Scenic 1.6	Gasoline	1.6	216	140	168	345	146	143	201	162
Honda	Accord 1.8	Gasoline	1.8	263	159	198	410	171	159	212	200
Volvo	V40 1.8	Gasoline	1.8	254	130	176	499	141	125	152	173
Renault	Scenic 1.9D	Diesel	1.9	199	129	155	282	159	140	206	166
VW	Golf 1.9TDi	Diesel	1.9	182	112	138	255	133	111	166	144

Source: TNO

1.1.2. Performance of Autogas Light Duty Vehicles: Non-Regulated Pollutant Emissions

In addition to the low emissions benefits of regulated pollutants, another benefit of LP Gas is its ultra-low emissions of currently non-regulated pollutants.

1.1.2.1 Classification of the Non-Regulated Pollutants

Non-regulated emissions are classified as:

- Direct toxic: CO, NO_2 , SO_2, aldehydes, and ammonia (NH_3)
- Mobile source air toxics (MSAT) which are presumed or known carcinogens: formaldehyde, acetaldehyde, 1,3 butadiene, benzene, polycyclic organic matter (POM or PAH), number of nano-particulates (nm= 10^{-9} m diameter);
- Causing summer smog (ozone O_3): reaction of several C_1 to C_{12} hydrocarbons and aldehydes together with regulated NO_x and CO emissions;
- Causing winter smog: particulate matter with a diameter smaller than 10 micro-meter together with SO_2 (emitted mainly from other than vehicle sources);
- Causing acidification: NH_3, NO_x and SO_2 (emitted mainly from other than vehicle sources);
- Contributing to global warming potential (GWP): CO_2, CH_4 (methane) and N_2O (nitrous oxide).

Further information on the effects of these non-regulated pollutants is available in Appendix B.

1.1.2.2. Air Toxics and Direct Toxic Pollutant Emissions

1.1.2.2.1 Autogas Versus Conventional Light Vehicles

Autogas air toxic emissions are very low mainly due to low butadiene and benzene emissions. The analysis of combined air toxics of autogas compared to conventional fuelled vehicles shows autogas having the lowest impact on potential cancer risk.

Table 1.16 MSAT vehicle tailpipe emissions measured on the US-FTP cycle [mg/km].

mg/km	VOC [1] exhaust	Formaldehyde	Acetaldehyde	1,3 Butadiene	Benzene incl. evap.	Combined CURE[2]	
						EPA	CARB
Autogas	40	0.47	0.14	0.03	0.16	2.0	0.5
Gasoline	50	0.62	0.24	0.31	3.70	15.1	5.6
CAL-RFG*	45	0.76	0.40	0.25	2.01	11.9	3.7
Diesel	50	0.64	0.26	0.34	2.53	14.8	4.6

Source : US Argonne National Laboratory Report ANL/ESD-44

**CAL-RFG = California Reformulated Gasoline*

Note 1 :VOC = volatile organic compound includes THC, aldehydes, methane, ethane.

Note 2 : CURE = (Cancer Unit Risk Estimate) is calculated from the sum of weighted contributions of each component relative to the CURE of benzene as normalising parameter. Two different methods are used for the estimation of the CUREs: the EPA method (US Federal Environmental Protection Agency) and the CARB method (California Air Resources Board).

Some characteristic data of other toxic emissions such as heavy polycyclic aromatic hydrocarbons (PAH), nano particles (particles of a size below 10µm-PM_{10}), nitrogen dioxide (NO_2), NH_3 and sulphur dioxide (SO_2) highlight the significant advantage of autogas fuelled vehicles, especially compared to diesel. See table below.

Autogas has the lowest PAH emissions compared to gasoline and diesel. Also, the number of particulates is also very low. The number of particulates even after the diesel particulate filter (DPF) is still more than 30 times higher than with autogas.

Table 1.17 Comparison of vehicle emissions measured on the European EDC cycle.

	Heavy PAH [µg/km]	Number of Particles [P_{no}/km]	NO_2 [mg/km]	NH_3 [mg/km]	SO_2 [mg/km]
Autogas	0.2	$3 * 10^{11}$	7	0	3
Gasoline	0.4	$1 * 10^{12}$	7	0	15
Diesel	4.0	$1.2 * 10^{14}$	60	0	30
Diesel +DPF	0.4	$1.1 * 10^{13}$	180	0	4

Sources: TNO, Ricardo (Particulates).

1.1.2.2.2 Autogas versus Selected Alternative Fuelled Light Duty Vehicles (CNG, methanol and ethanol)

Air toxics emitted by the alternative fuels described are roughly comparable except the much higher aldehydes from ethanol (E85). Based on combined air toxics analysis (EPA CURE), autogas has the lowest cancer risk of all alternative motor fuels, especially compared to the alcohol motor fuels (M85 & E85).

Table 1.18 MSAT alternative vehicle emissions measured on the US - FTP test [mg/km].

mg/km	VOC[1] exhaust	Formaldehyde	Acetaldehyde	1,3 Butadiene	Benzene	Combined CURE[2]	
						EPA	CARB
Autogas	40	0.47	0.14	0.03	0.16	2.0	0.5
CNG	20	1.24	0.09	0.006	0.04	2.2	0.3
M85	42	3.80	0.09	0.04	0.48	7.9	1.5
E85	42	2.20	5.37	0.06	0.48	7.5	1.8

Source: TNO
* *Note 1 : VOC = THC, aldehydes, methane, and ethane.*
Note 2 : CURE = Cancer Unit Risk Estimate.

The analysis of other toxic emissions does not show significant differences among the alternative motor fuels considered. The number of particulates with all alternative fuels is very low.

Table 1.19 Alternative vehicle emissions measured on the European EDC cycle.

	Heavy PAH [µg/km]	Number of Particles [P_{no}/km]	NO_2 [mg/km]	NH_3 [mg/km]	SO_2 [mg/km]
Autogas	0.2	$3 * 10^{11}$	7	0	3
CNG	0.1	$3 * 10^{11}$	7	0	1
M85	(0.1)	$3 * 10^{11}$	(7)	(0)	(1)
E85	(0.1)	$3 * 10^{11}$	(7)	(0)	(1)

Sources: TNO, Ricardo (Particulates).
( )= estimates

1.1.2.3. Summer Smog, Winter Smog and Acidification

Autogas motor fuel offers the lowest ozone formation potential, winter smog potential and acidification effect.

1.1.2.3.1 Autogas versus Conventional Light Duty Vehicles

Due to the almost zero HC emissions of the diesel engine with DPF, the summer smog potential of this engine is very low. But winter smog and acidification are higher with the conventional diesel engines (those without the DPF). Nevertheless, it should be noted that autogas vehicles have half the summer smog potential of gasoline vehicles.

Table 1.20 Summer smog, winter smog and acidification (European EDC cycle).

	Summer smog ethene equivalent [mg/km]	Winter smog PM [mg/km]	Acidification NO_x + SO_2 + NH_3 [mmol H^+/km]
Autogas	20	< 1	1.0
Gasoline	40	1	1.5
Diesel	20	40	9.5
Diesel +DPF	4	2	8.5

Source: TNO

1.1.2.3.2 Autogas versus Selected Alternative Fuelled Light Duty Vehicles (CNG, methanol and ethanol)

Except for summer smog potential (for which CNG shows low potential due to its low NMOG emissions), there is no significant difference between the other alternative fuels regarding winter smog and acidification potential.

Table 1.21 Summer smog, winter smog and acidification measured on the European EDC cycle.

	Summer smog ethene equivalent [mg/km]	Winter smog PM [mg/km]	Acidification NO_x + SO_2 + NH_3 [mmol H^+/km]
Autogas	20	< 1	1
CNG	8	< 1	1
M85	25	< 1	1
E85	30	< 1	1

Source: TNO

1.1.2.4. Global Warming Potential (GWP)

Global warming potential (GWP) data provided below are estimates based on tailpipe emissions.

1.1.2.4.1 Autogas versus Conventional Light Duty Vehicles

The GWP of autogas vehicles is comparable to that of indirect injected diesel vehicles, and is still close to the performance achieved by diesel engines with direct injection.

Table 1.22 Greenhouse gases estimated on vehicle tailpipe emissions according to the European EDC cycle.

Average Emissions	CO_2 [g/km]	CH_4 [g/km]	N_2O [g/km]	Global Warming Potential [CO_2 equiv]*	Relative to Gasoline GWP
Autogas	170	0.005	0.010	173	90
Gasoline	190	0.008	0.010	193	100
Diesel IDI	170	0.006	0.005	172	90
Diesel DI	150	0.006	0.005	152	80

Source: TNO
Note : GWP estimated according to IPCC 1996 method with the following factors :CO_2 = 1; CH_4 = 21; N_2O = 310

1.1.2.4.2 Autogas Versus Some Alternative Fuelled Light Duty Vehicles (CNG, methanol, ethanol)

The GWP of gaseous-fuelled vehicles (CNG, autogas) is more favourable than the GWP recorded with alcohol (E85 & M85) fuelled vehicles.

Table 1.23 Greenhouse gases estimated on alternative vehicle tailpipe emissions (European EDC cycle).

Average	CO_2 [g/km]	CH_4 [g/km]	N_2O [g/km]	Global Warming Potential* [CO_2 equiv] [g/km]	Relative to gasoline= 100 GWP
Autogas	170	0.005	0.010	173	90
CNG	150	0.180	0.010	157	81
M85	175	0.004	(0.010)	178	92
E85	180	0.016	(0.010)	183	94

Sources: TNO; Ethanol and methanol from Office of Transport Technologies, US. Data in parenthesis estimated.
Note : GWP estimated according to the Intergovernmental Panel on Climate Change (IPCC) 1996 method with the following factors: CO_2 =1; CH_4 = 21; N_2O = 310.

1.2 AUTOGAS FUELLED HEAVY DUTY VEHICLES (HDV) EMISSIONS

1.2.1 Regulated Pollutant Emissions of Autogas HDVs

The low levels of autogas HDVs particulates, whether stoichiometric or lean-burn, are a significant factor favouring autogas for public transport vehicles. Also, spark ignited (SI) engines have better potential for lowering NO_x emissions than do diesel engines. Thus, the overall emission advantages of gaseous-fuelled engines are high.

Various studies in Europe have proven the clear advantage of autogas buses compared to the existing (EURO 2) diesel buses.

Table 1.24 Emissions performance of autogas engines on the EURO 2 (13 mode) emission test cycle.

	DI Diesel (EURO 2) 1995	autogas stoichiometric engine	optimised autogas stoichiometric engine	autogas lean burn engine	autogas optimised lean burn engine
NO_x (g/kWh)	7.0	0.4	0.42	3.5	2.5
CO (g/kWh)	4.0	0.6	0.4	2.0	0.2
HC (g/kWh)	1.1	0.03	0.01	0.55	0.2
Particulates (g/kWh)	0.15*	< 0.01	< 0.01	< 0.02	< 0.02
Reference		*DAF LT 160 + 3 way catalyst*	*DAF LT 170 + 3 way catalyst*	*Van Tilburg LP Gas Green engine*	*TNO*

Source: Manufacturer's data
**Not applicable for gaseous fuelled engines*

This environmental advantage is maintained even with the latest engine technologies.

Table 1.25 Emission performance of DAF and MAN autogas engines on the new European ETC (EURO 3) emission test cycle.

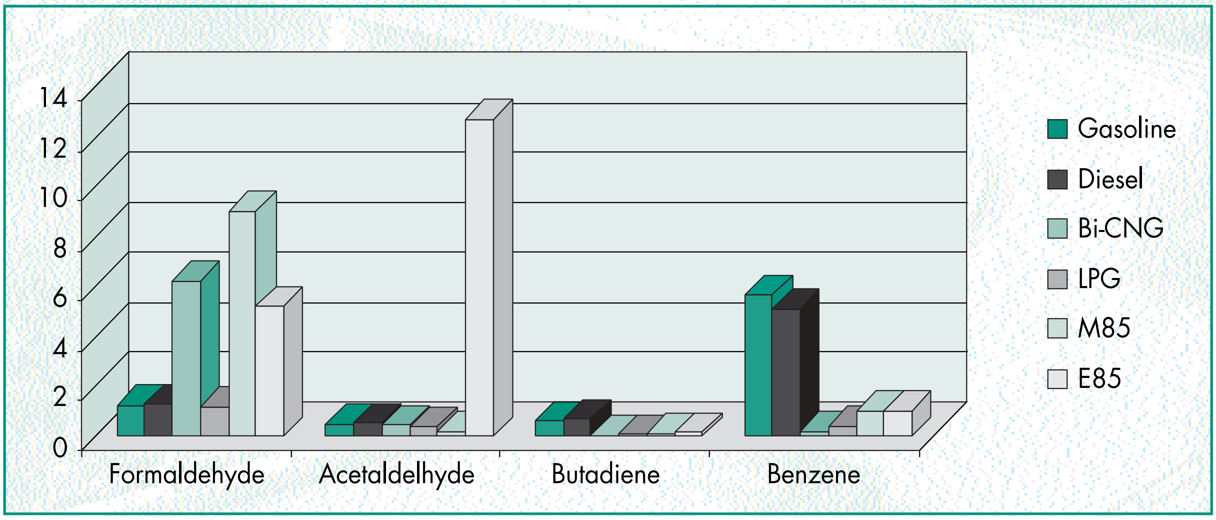
	EURO 3 2000	EURO 4 2005	EEV**	DAF Autogas DAF LP Gas GG170LPG	MAN Autogas MAN G 2866 DUH04
NO_x emissions (in g/kWh)	5.0	3.5	2.0	Less than 1.0	2.0
CO emissions (in g/kWh)	5.45	4.0	3.0	Less than 2.0	3.0
NMHC emissions (in g/kWh)	0.78	0.55	0.40	Less than 0.2	0.4
Particulates (in g/kWh) a)	0.16 *)	0.03 *)	0.02	Not measurable	Not measurable

Source: DAF and ASIG
**) not applicable for gas fuelled engines*
*** Enhanced Environmentally Friendly Vehicles*

1.2.2 Non-Regulated Pollutants Emissions Performances of Autogas HDVs

A strong advantage of autogas technology is the potential to drastically reduce the emissions of non-regulated pollutants.

Diagram 1.1 T/VOC Fractions for Downstream Emissions (%)*.

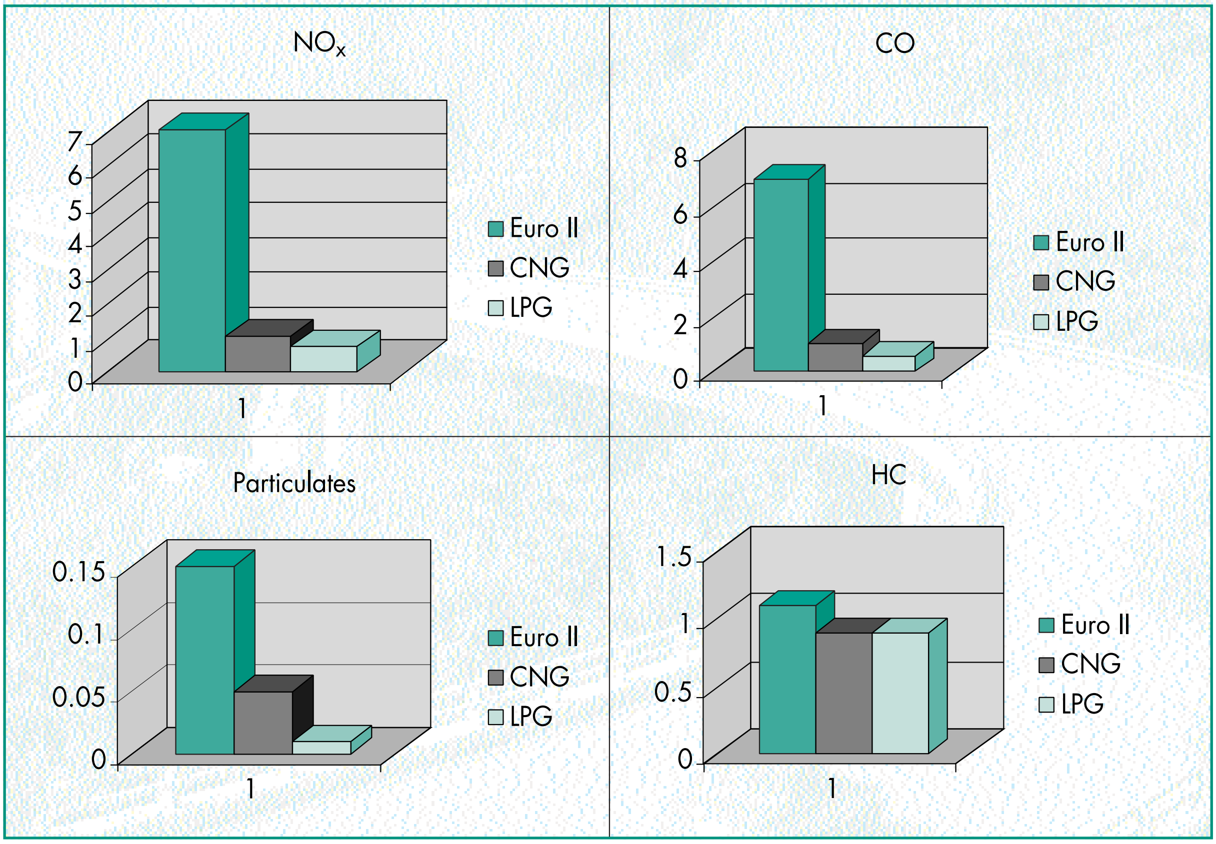


Source: US, Center for Transportation Research: Argonne National Laboratory - August 2000
**T/VOC= Toxic Component of a particular emission stream*

1.2.3 Performance of Autogas Buses in "Real Conditions"

Recent studies of real life working conditions of today's city buses (following a succession of acceleration, idling and deceleration phases) showed that even when compared to low sulphur diesel, optimised autogas vehicles are able to offer reductions of more than 50% of NO_x, and approximately 90% or more on CO, HC and particulates.

Diagram 1.2: Results of emissions tests commissioned at Millbrook Proving ground (UK) using the "London Bus cycle ("real world" dynamic test).



Source: Millbrook *Emissions in g/kWh*

1.3 Life Cycle Analysis (LCA) of Autogas versus Other Motor Fuels

Life cycle analysis integrates the effects of emissions of all pollutants through the entire energy chain-from the point of production to end-use. LCA of autogas shows advantages over all other motor fuels.

The purpose of this section is to discuss the performance of autogas compared to other motor fuels according to a renowned LCA model for transportation fuels. Called the GREET 1.5 model, it was developed by the Argonne National Laboratory, a part of the U.S. Department of Energy.

The GREET model estimates the full fuel-cycle emissions and energy use associated with various transportation fuels and advanced vehicle technologies for light-duty vehicles. The fuel-cycle emissions and total energy consumption is calculated on the basis of:

- five criteria pollutants : volatile organic compounds (VOC), carbon monoxide (CO), nitrogen oxides (NO_x), particulate matter (PM_{10}) and sulfur oxides (SO_2), and
- three greenhouse gases : carbon dioxide (CO_2), methane (CH_4) and nitrous oxide (N_2O).

Greenhouse gas emissions are estimated by the sum of CO_2, CH_4 and N_2O emissions weighted by their global warming potential as adopted by the Intercontinental Panel on Climate Change (IPCC) (CO_2 = 1, CH_4 = 21 and N_2O = 310). PM_{10} emissions include tire and brake wear as well as exhaust emissions.

Table 1.26 Short-term and long-term fuel-cycle options.

Motor fuel	Short-term options (MY 2000)	Long-term options (MY 2010)
Gasoline	Gasoline vehicle; Reformulated gasoline	Direct injection spark ignition engine; Reformulated gasoline
Autogas (LP Gas)	Dedicated LP Gas vehicle*	Dedicated LP Gas vehicle*
Diesel	Direct injection compression ignition; conventional diesel	Direct injection compression ignition; reformulated diesel
CNG	Dedicated CNG vehicle*	Dedicated CNG vehicle*

* *"Dedicated" as used in the GREET model means mono-fuelled vehicles that operate on only one fuel.*

The total fuel-cycle is divided into:

- upstream emissions and energy use of a certain fuel, and
- downstream emissions and energy use when the fuel is combusted in a certain type of engine.

Both upstream and downstream emissions are addressed in the following sections.

1.3.1 Upstream Fuel Cycle

Two different fuel-cycles are considered:

- petroleum based fuel-cycles for gasoline, diesel and autogas, and
- natural gas based fuel cycles (CNG and autogas).

Since autogas is produced both from petroleum and natural gas, it is included in both fuel cycles. Efficiencies of both processes are summarised in the tables below. In terms of energy efficiency, autogas has the highest total energy efficiency (89.3%) in the upstream fuel-cycle.

Table 1.27 Upstream fuel cycles: Energy efficiencies of petroleum based fuel-cycle stages.

Fuel	Fuel-cycle stage	Energy efficiency (%)	Total efficiency (%)
Crude oil	Recovery	98.0 (1)	(1)*(2)*(3)*(4)
	Transportation and storage	99.5 (2)	
Conventional gasoline	Refining	85.0 (3)	81.6
	Transportation, storage and distribution	98.5 (4)	
Reformulated gasoline	Refining	86.0 (3)	82.6
	Transportation, storage and distribution	98.5 (4)	
LP Gas Autogas	Refining	93.5 (3)	89.3
	Transportation, storage and distribution	97.9 (4)	
Conventional diesel	Refining	89.0 (3)	85.6
	Transportation, storage and distribution	98.6 (4)	
Reformulated diesel	Refining	87.0 (3)	83.6
	Transportation, storage and distribution	98.6 (4)	

Source: Argonne National Laboratory
*Note: Numbers in parenthesis indicate stages of the fuel cycle, * is the symbol for multiplier*

Table 1.28 Energy efficiencies of natural gas based fuel-cycle stages: upstream fuel-cycles.

Fuel	Fuel-cycle stage	Energy efficiency (%)	Total efficiency (%)
Natural gas	Recovery	97.0 (1)	(1)*(2)*(3)*(4)
	Processing	97.5 (2)	
CNG	Transportation and distribution	97.0 (3)	87.2
	Compression and storage	95.0 (4)	
LP Gas (autogas)	Production	96.5 (3)	89.3
	Transportation, storage and distribution	97.9 (4)	

Source: Argonne National Laboratory

1.3.2 Downstream Fuel-Cycle: Vehicle Economy and Exhaust Emissions

The exhaust emissions for conventional gasoline and diesel vehicles are derived from the U.S. "Mobile 5b and Part 5" models, which estimate the emission rates of on-road vehicles. It should be noted that the GREET model is based on US energy production and use patterns where roughly 45% of LP Gas comes from refining of crude oil, and roughly 55% from gas processing. Since production and distribution are key factors in the GREET model, care should be exercised in transferring conclusions to other supply scenarios. LCA emission changes between baseline vehicles and alternative fuelled vehicles are estimated in GREET on the basis of laboratory-tested emissions.

Table 1.29 Downstream Fuel Cycle: Short-term and long-term fuelling technologies, economy and emissions changes according to the GREET model.

	Change (%)							
Vehicle technology	Fuel Economy	Exhaust VOC	Evap. VOC	CO	NO_x	PM_{10}	CH_4	N_2O
Short-term technologies: % relative to National Low-Emission Vehicle (NLEV) gasoline vehicles fuelled with conventional gasoline								
Gasoline vehicle; reformulated gasoline	0	-10	-30	-20	-5	-5	-8	0
Dedicated LP Gas (autogas) vehicle*	0	-20	-90	-25	-10	-90	+30	0
Direct injection compression ignition; conventional diesel	+35	0	-100	-80	+120	+750	-90	-40
Dedicated CNG vehicle*	-7	-60	-90	-30	-10	-95	+900	-20
Long-term technologies: % relative to Tier 2 gasoline vehicles fuelled with reformulated gasoline								
Direct injection spark ignition engine; reformulated gasoline	+25	0	-10	0	0	+40	0	0
Dedicated LP Gas (autogas) vehicle*	+10	0	-90	-20	0	-80	+10	0
Direct injection compression ignition; reformulated diesel	+50	-20	-100	0	+100	0	-80	-40
Dedicated CNG vehicle*	+5	-10	-90	-20	0	-80	+400	-50

Source: Argonne National Laboratory

Note: "Dedicated" in the above table means mono-fuelled, i.e. a vehicle operating only on CNG or autogas

1.3.3 GREET Model Results: Total Fuel-Cycle

This section summarises the relative per mile Total Fuel-Cycle energy and emission results of the GREET model for the selected short-term and long-term technologies.

Note : The researchers stress that by nature, the evaluated technology options are subject to uncertainties, which will affect the outcomes of fuel-cycle assessments. The results shown below, therefore, provide a 'snapshot' of potential technology effects based on current understanding of technology advancements at a certain time. As more information becomes available the key assumptions in the GREET model will be revised on a regular basis.

Regarding technologies available on the short-term, autogas vehicles offer significant reductions of energy consumption and emissions.

Table 1.30 Percentage (%) changes in Total Fuel-Cycle of energy consumption, greenhouse gases and emissions. Short-term options relative to conventional (NLEV, model year 2001) gasoline vehicles according to the GREET model.

	Total energy consumption	Green house gases	CO_2	Total VOC	Total CO	Total NO_x	Total PM_{10}	Total SO_x
Gasoline vehicle; reformulated gasoline	+2	+1	-1	-5	-19	+15	+75	0
Dedicated LP Gas (autogas) vehicle: natural gas fuel cycle	-9	-14	-15	-65	-40	-23	-45	-75
Dedicated LP Gas (autogas) vehicle: crude oil fuel cycle	-8	-13	-13	-57	-39	-17	-35	-60
Direct injection compression ignition; conventional diesel	-30	-26	-27	-62	-95	+53	+160	-30
Dedicated CNG vehicle	+4	-11	-17	-72	-43	+18	-38	-40

Source: Argonne National Laboratory

Other results of the GREET model for the technologies available on the short term can be analysed as follows:

- The large reductions of energy consumption, greenhouse gases and CO_2 emissions for direct injected diesel vehicles are largely due to engine efficiency gains.
- The smaller greenhouse gas reduction for CNG vehicles is attributable to a large amount of CH_4 emissions during the upstream stages of the natural gas cycle.
- NO_x emissions of gasoline and autogas vehicles show a relatively small increase or decrease. Diesel vehicles will always have the challenge of reducing their NO_x emissions because of their high air-to-fuel ratio and high pressures in the combustion chamber. The increase of NO_x emissions of CNG vehicles is primarily caused by the generation of NO_x by compressors used for natural gas compression.
- The increase of PM_{10} emissions of gasoline vehicles is because the oxygenates in reformulated gasoline are ethanol based. Ethanol has high upstream PM_{10} emissions during production and corn farming.

Table 1.31 Percentage (%) changes in Total Fuel-Cycle of energy consumption, greenhouse gases and emissions. Long-term options relative to conventional (Tier II, model year 2004) gasoline vehicles according to the GREET model.

	Total energy consumption	Green house gases	CO_2	Total VOC	Total CO	Total NO_x	Total PM_{10}	Total SO_x
Direct injection spark ignition engine; reformulated gasoline	-20	-20	-20	-12	-1	-15	-10	-20
Dedicated LP Gas (autogas) vehicle: natural gas fuel cycle	-17	-23	-23	-57	-22	-40	-40	-70
Dedicated LP Gas (autogas) vehicle: crude oil fuel cycle	-16	-22	-22	-50	-21	-35	-30	-50
Direct injection compression ignition; reformulated diesel	-35	-33	-32	-62	-3	-25	-15	-35
Dedicated CNG vehicle	-8	-25	-27	-62	-20	+25	-35	-35

Source: Argonne National Laboratory

Other results of the GREET model for the technologies available on the long term can be analysed as follows:

- The reduction of energy consumption, greenhouse gases and CO_2 of direct injected gasoline vehicles in general is attributable to their improved fuel economy. Conventional spark ignition rather than direct injected spark injection engines were assumed for autogas and CNG vehicles, because no significant fuel economy benefits are offered by replacing spark ignition engines with direct injected engines for these fuels, according to the GREET researchers.

- The reduction for autogas vehicles is primarily because only a small amount of energy is consumed during autogas fractioning in petroleum refineries or in natural gas processing plants.

- The use of autogas and CNG achieves 40-60% reductions in VOC emissions, primarily because VOC evaporative emissions from baseline gasoline vehicles are eliminated.

- Because of more stringent regulations, the GREET model assumes that PM_{10} tailpipe emissions of diesel and gasoline vehicles will be equalised.

AUTOGAS VEHICLE COMPONENTS, SAFETY STANDARDS AND REGULATIONS

Autogas Vehicle Components, Safety Standards and Regulations

2.1 Status of the Existing Standards & Regulations

The environmental benefits of autogas are generally well known. Safety issues associated with using LP Gas vehicles are equally important.

The LP Gas industry has taken the lead in safety by addressing minimum local, regional or national standards for operating LP Gas vehicles safely. Overall safety, including the installation of autogas kits on vehicles as well as the delivery of product from the LP Gas refuelling facilities, remains a priority for the industry.

2.1.1 Standards and Regulations Addressing Vehicle Safety

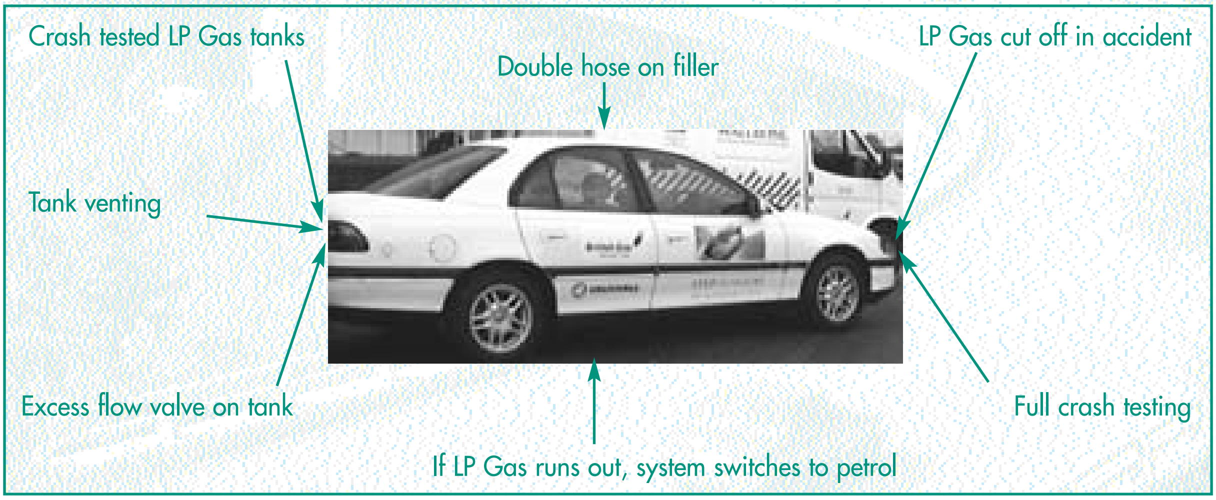
Scientific studies confirm that in Europe the frequency of accidents as well as the related risks associated to the use of autogas vehicles are extremely low, in fact, even lower than those associated to conventional fuelled vehicles. **See "References".**

Three main hazards for autogas vehicles are:

- road traffic accidents that may cause a fuel leak or autogas container rupture,
- vehicle fire that may lead to venting of the autogas container through the pressure relief valve and /or a pressure relief device (e.g. fuse),
- leakage of fuel due to a mechanical defect or human error.

To prevent and minimise these hazards, the LP Gas industry has developed stringent standards and regulations in design, manufacturing and installation of autogas parts and equipment.

Figure 2.1 Example of safety devices on a LP Gas vehicle.



Source: LP Gas Magazine (UK)

In Europe, there are currently two UN/ECE regulations to harmonise safety standards associated with autogas parts and vehicles:

- the UN/ECE Regulation 67-01 series (which entered into force on 13 November 99 in 25 ECE countries including the European Community) that define very stringent design and construction rules for the autogas parts including minimum safety rules linked to their installation on the vehicle. This regulation is based on the initial requirements shown in the draft European CEN standards for:
  - autogas containers: pr EN 12806;
  - autogas components, except the container: pr EN 12806;
  - installation requirements of autogas components: EN 12979;
  - operational requirements for autogas components: pr EN 13856;

- the UN/ECE draft regulation on "retrofit LPG and CNG vehicles" that defines for OEMs the minimum rules for the safe installation of autogas parts certified according to R67-01 series. This new regulation will be implemented after European Parliament ratification.

Implementation of these new UN/ECE regulations will now allow free trade throughout Europe of autogas vehicles and parts. In addition to the development of harmonised safety rules, the LP Gas industry may see a decrease in the production costs of equipment based on economies of scale.

Before implementation of the UN/ECE Regulation 67-01 series, each European country had its own autogas legislation usually based on national standards. This required equipment and vehicles to be developed specially for each country. This remains the case outside the ECE, for example in Japan, where compliance of autogas components must follow "The Standard of Handling and Structure for LPG Vehicle" guidelines as required by the Ministry of Construction and Transportation.

Expanding on the European experience of improved safety rules and expected lower autogas equipment prices, and in the context of the worldwide development of OEMs engines, the ISO/TC22 (International Standardisation Committee dealing with automotive matters) created Working Group 11. This Group is charged with initiating a worldwide harmonisation of rules regarding the design and manufacturing of autogas containers.

Parallel to this standardisation work, development began within the UN/ECE Transport Division of a "World Forum for Harmonisation of Vehicle Regulations", originally entitled WP29 (for further details see the UN/ECE Transport Division WP29 publication: "WP29 - How it Works - How to Join it"). Currently there are twelve countries participating. In addition, Australia, Canada, Europe, Japan, Korea, the Russian Federation, South Africa and the US may introduce in their future programmes the development of a worldwide regulation extending the implementation of the UN/ECE R67 requirements.

Table 2.1 Review of national and international standards & regulations regarding autogas equipment fitted in a vehicle (design, manufacturing and installation).

	UN / ECE R67-01 series	Examples of other national standards	
Texts dealing with autogas parts	R67 Part I		
Container	R67 Annex 10	Australia: AS/NZS 3509, AS 1210, AS 2030.1 Europe: pr EN 12805	Japan: JIS B 8242 US* : UL 644
Accessories fitted to the container[1]	R67 Annex 3	Australia: AS/NZS 1425	Europe : pr EN 12805
Vaporizer/Pressure regulator	R67 Annex 6	Australia: AS/NZS 1425 Europe: pr EN 12806	Japan: JIS B 8238 US* : UL 144
Shut-off valve	R67 Annex 7	Australia: AS 2473 Europe: pr EN 12806	Japan : JIS B 8245 US* : UL 125
Gas injection device, injector or gas mixing piece	R67 Annex 11	Australia: AS/NZS 1425	Europe: pr EN 12806
Gas dosage unit	R67 Annex 12	Europe: pr EN 12806	
Flexible hoses	R67 Annex 8	Australia/New Zealand: AS/NZS 1869 Europe: pr EN 12806	Japan: JIS B 8261, JIS K 6347-1 Part 1 US* : UL 21, ASTM D 3902, ASTM D 2513
Filling unit	R67 Annex 9	Australia: AS/NZS 1425 Europe: pr EN 12806	US*
Non-return valves	R67 Annex 7	Australia: AS/NZS 1425 Europe: pr EN 12806	Japan: JIS B 8245 US*
Gas-tube pressure relief valve	R67 Annex 7	Europe: pr EN 12806	US*
Filter unit	R67 Annex 5	Europe: pr EN 12806	
Pressure or temperature sensors	R67 Annex 13	Europe: pr EN 12806	
Fuel pump	R67 Annex 4	Europe: pr EN 12806	
Service coupling	R67 Annex 7	Europe: pr EN 12806	
Electronic control unit	R67 Annex 14	Europe: pr EN 12806	
Fuel rail	R67 Annex 11	Europe: pr EN 12806	
Pressure relief device	R67 Annex 3	Australia: AS 2613 or AS 1210 Japan: JIS B 8245	Europe: pr EN 12806 US*: UL 132
Installation requirements dealing in particular with installation of the fuel container and its accessories, requirements of the gas connections between components:	R67 Part II	Australia: AS/NZS 1425 Europe: EN 12979	US*
*US: regulations and standards for autogas equipment installed on vehicles is subject to a variety of jurisdictions and standards in addition to those listed. For a more complete listing refer to National Fire Protection # 58, "Liquefied Petroleum Gas Code" 2001 or latest edition.			
Test procedures of autogas parts[2]	R67 Annex 15	Australia: AS/NZS 1425 Europe: pr EN 12806	US*

1) Accessories fitted to the container (either separate or combined): 80% stop valve, level indicator, pressure relief, remotely controlled service valves with excess flow valve, fuel pump, multi-valve, gas-tight housing, power supply bushing, non-return valve, pressure relief device.
2) Test procedures of autogas parts other than the container: over pressure, external leakage, high temperature, resistance to dry heat, ozone ageing, creep, temperature cycle.

2.1.2 Standards and Regulations Addressing Autogas Refuelling Safety

Autogas usage is effective in reducing urban air pollution. Consumers are increasingly requesting refuelling sites in areas where the air pollution is a major concern.

On the European level, this regulatory field is currently covered by national regulations. The safety distances around autogas refuelling sites may sometimes inhibit the installation of autogas refuelling stations, especially in urban areas.

CEN standards for the installation of autogas refuelling stations are under development with the objective to harmonise as much as possible the minimum safety requirements governing installation and maintenance of new autogas filling stations: "Construction and Performance of LPG Equipment for Automotive Filling Stations - Part 1: dispensers (Work Item 51), Part 2: installation requirements (Work Item 52), Part 3: operational requirements (Work Item 53)". (CEN/TC286/working group 6)

Figure 2.2 Example of minimum safety devices required in Europe for an autogas refuelling station with underground storage.

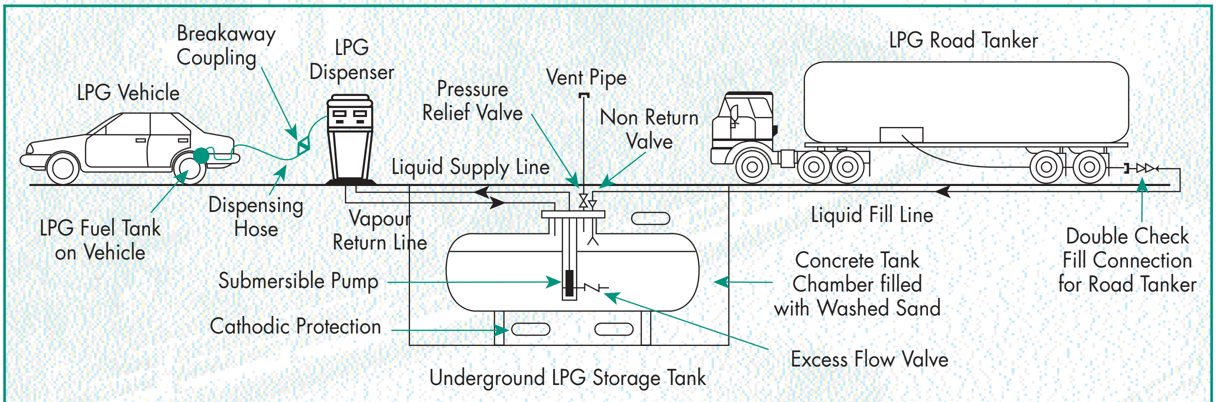


Table 2.2 Review of national and international standards related to autogas refuelling.

Equipment	ISO standard		Examples of national standards
Filling nozzles			Europe: pr EN 13760 US: NFPA 58
Rubber hoses (bulk)	ISO 2928		Japan: JIS K 6347-2 Part 2
Dispensing LPG hoses	ISO 11759		Europe: WI 52 of CEN/TC286 US: NFPA 58
Electrical systems dispensing			Australia: 2229.2; DR 99902 Europe: WI 52 of CEN/TC286 US: NFPA 58
Dispensing sites			Europe: WIs 51, 52 & 53 of CEN/TC286 US : UL 495, NFPA 58

Implementation of stringent rules in Europe resulted in other countries using self-service autogas refuelling stations in full service gasoline/diesel stations, as well as exclusive autogas self-service stations similar to conventional motor fuels. Some national rules have even been changed to allow the use of an autogas dispenser in the same area as the dispenser for the conventional motor fuels. Such actions, along with increased consumer confidence that autogas is as safe as the conventional motor fuels, allows for significant reductions in the installation costs of new autogas dispensing sites.

2.2 New Developments Regarding Autogas Components

2.2.1 Implementation of the Euro Filling Units for Light (LDV) and Heavy Duty Vehicles (HDV)

A major barrier for consumers and OEMs to the free circulation of autogas vehicles throughout Europe is the multiple type of autogas refuelling nozzles and the need for numerous specific adapters. This process was recognised by the European LP Gas industry as customer unfriendly.

Figure 2.3 Overview of the different connections of the existing vehicle filling units used for passenger cars.

Principle	ACME-thread coupling	Bayonet quick coupling	Dish Coupling
Vehicle filling unit connecting area			
Countries where this principle is mainly used	Australia, Austria, Belgium, Canada, Germany, Ireland, Poland, New Zealand, USA	Netherlands, Poland, UK	Italy, France Greece, Poland, Portugal, Spain

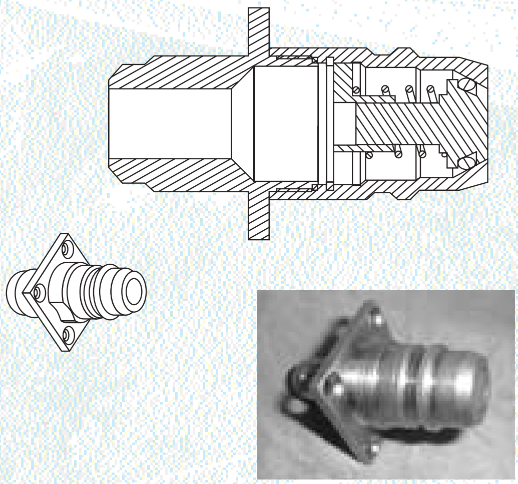
The European LP Gas industry initiated, through CEN's Technical Committee 286, Working Group 6, the development of a new European LP Gas refuelling system for light duty vehicles, the "light vehicle Euro filling system". This initiative included the description of a new vehicle filling unit and associated nozzle. The basic requirements to be complied with by this new "light vehicle Euro filling system" are:

- a minimum flow-rate of 60 l/min. (liters per minute) to achieve refuelling time similar to those of gasoline and diesel vehicles;
- release volume below 1 cc per disconnect to improve emissions so as to keep an environmental advantage over conventional vehicles;
- improved customer friendliness of the refuelling operations through the addition of specific requirements such as: definition of a limited force to connect, limited weight of the nozzle (2kg maximum), consideration of the ease with which an adapter can be connected during the implementation period of the "Euro Nozzle"; and
- improved nozzle lifetime including specific requirements regarding resistance to bad handling and dirt.

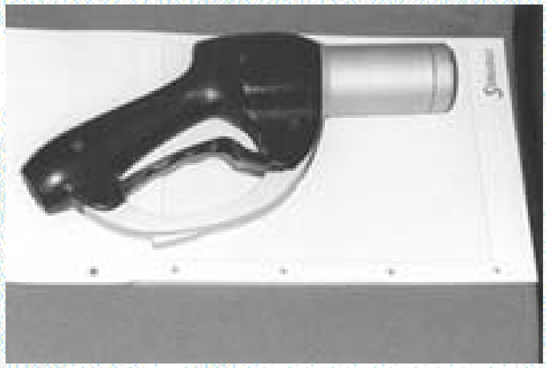
All of these requirements are fully described in two draft standards to be formally adopted by the CEN:

- vehicle filling unit: pr EN 12806 "Automotive LP Gas Components Other Than Tanks';
- filling nozzle: pr EN 13760 "European Filling Nozzles for Light Duty and Heavy Duty Vehicles"

Figure 2.4 Design principle of the new European LPG Gas filling system for the light vehicles (less than 3.5 tons).



Design principle of the Euro filling unit for light vehicles (below 3.5 tons)
Source : AEGPL



Example of future Euro filling nozzle prototype developed by STAUBLI (France)

The implementation plan of the Euro filling unit for the light vehicles (less than 3.5 tonnes) is currently in discussion within the European LP Gas Association (AEGPL) in close co-operation with car manufacturers and importers. The main item remains the definition of the transitory period during which the private owner of a passenger car will have to move from the existing vehicle filling unit to the new Euro filling unit. The following target dates are currently being considered:

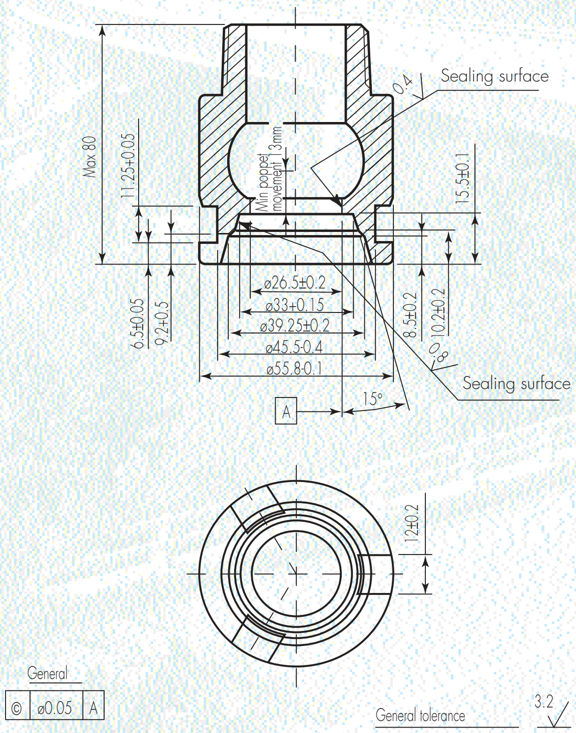
- Fall 2002: Start of the implementation of the Euro filling unit on new OEMs vehicles according to the introduction of the Euro filling unit requirements of Regulation R67-01;
- Year 2005: the Euro filling unit to be mandatory on all new LP Gas vehicles;
- Year 2008: all LP Gas vehicles shall be able to be refuelled with a Euro filling nozzle for light vehicles.

Refuelling operations of HDVs are not subject to the same design and operational criteria as for the Euro light-filling nozzle. The HDV criteria includes the:

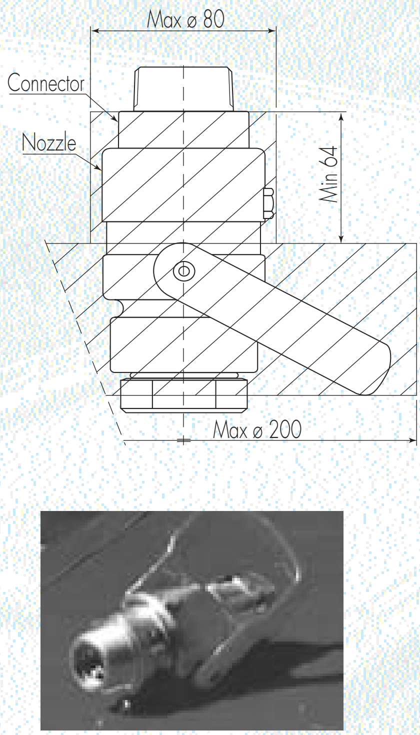
- need for higher flow rate: 200 l/mn (liters per minute);
- possibility to use a higher connecting force since the nozzle will be handled by professional people. Nevertheless, the weight of the nozzle shall not exceed 3kg.
- same discharge limits of 1 cc as for light duty vehicles at connection/disconnection.

These requirements have been considered for the development of a harmonised Euro heavy-duty vehicle (more than 3.5 tons) filling system. They have been included in the above-mentioned standards of CEN/TC286: pr EN 12806 for the HDV Euro filling unit and pr EN 13760 for the HDV Euro filling nozzle.

Figure 2.5 Drawings of the Euro filling system (vehicle filling unit & filling nozzle) for Heavy Duty Vehicles.



Drawing of the HDV Euro vehicle filling unit



Drawing of the HDV Euro filling nozzle
(picture of the TODO prototype)

Implementation of the new refuelling system for HDVs is expected in the near future. Fewer difficulties are anticipated for the harmonisation of HDVs due to the lower number of these types of vehicles than passenger cars in Europe. In addition, these vehicles are mainly operated by captive fleets that will avoid using adapters.

2.2.2 Development of New Autogas Container Designs

Safety is a driving force for the design and manufacturing of autogas containers. In Europe, the UN/ECE Regulation 67-00 series introduced in June 1987, allowed two types of automotive LP Gas containers :

- class A containers having a design pressure of 30 bar fitted with a pressure relief valve set at 25 ± 2bar (mainly used in the Dutch market);
- class B containers having a design pressure of 45 bar without pressure relief valve (mainly used in the Italian and French markets).

In 1999, following an accident involving an autogas vehicle in a fire, the European autogas experts demonstrated the need to improve the behaviour of autogas containers in fire conditions. This resulted in the implementation of new rules for autogas container design and equipment incorporated in UN/ECE Regulation 67-01 series. According to these new rules autogas containers marketed in Europe, as well as in the 25 ECE Contracting Parties to the UN/ECE R67, containers will be designed for 30 bar beginning November 2000, and be fitted with:

- a Pressure Relief Valve (PRV) : designed to limit the pressure build-up in the container and set to operate at 27±1 bar with a minimum flow-rate calculated according to the external surface of the autogas container :

$$Q \geq 10.66\ A^{0.82}$$

in which:

Q= flow of air in standard m^3/min (100 kPa absolute and temperature of 15°C)

A = exterior surface of the autogas container in m^2.

and,

- a Pressure Relief Device (PRD) mounted on the container in the gaseous zone and aimed to protect the container from burst, which can occur in case of fire, by venting the LP Gas contained. It will be designed to open at a temperature of 120 ± 10 °C and achieve a minimum flow-rate calculated as follows according to the external surface of the autogas container :

$$Q \geq 2.73\ A$$

in which:

Q= flow of air in standard m^3/min (100 kPa absolute and temperature of 15°C)
A = exterior surface of the container in m^2.

or,

- a device combining both a PRV and a PRD: for example, a pressure relief valve can be considered as a PRD if its flow is at least 17.7 standard m^3/min;

or,

- any other equivalent device, provided that it ensures the same degree of performance.

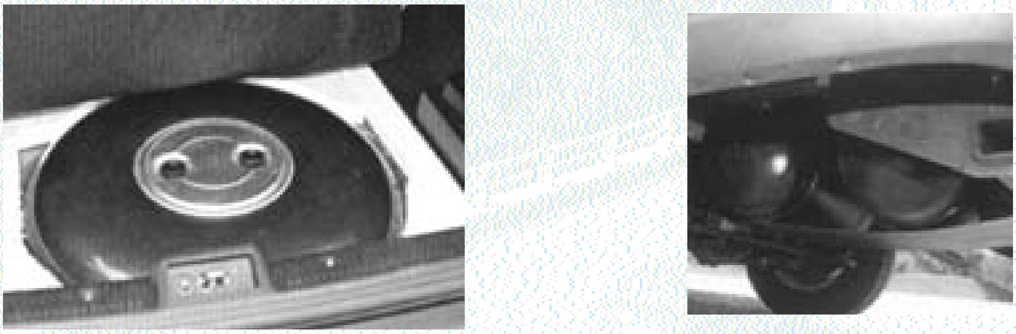
Testing remains a critical element in meeting the stringent requirements for the design and manufacturing of the autogas containers. The table below summarises the tests that autogas containers must comply with according to the new R67-01 series rules.

Table 2.3 Autogas container test requirements

Tests	Test during production	Prototype testing	Number of prototypes to be tested	
Tensile Test	x	x	2	To check the properties of the parent steel and welds of the container such as yield stress, tensile strength and elongation
Bend test	x	x	2	
Burst test		x	2	To check the container is able to support 67.50 bars pressure without fracture and limited change in volume
Hydraulic test	x	x	100 %	The container shall withstand an inner hydraulic pressure of 30 bars without leakage or becoming permanently distorted
Bonfire test		x	1	To demonstrate that the container fitted with its accessories will not burst in fire conditions
Radiographic examination	x	x	100 %	To check the quality of wells
Macroscopic examination	x	x	2	To check for any assembly fault or significant inclusion or other weld defects
Inspection of welds	x	x	100%	To check the quality of the fusion of the welded metal with the parent metal
Visual Inspection of the parts of the container	x	x	100%	

In addition to these safety considerations, autogas vehicles compared to conventional vehicles require an additional storage fuel tank. A concern to some customers is the loss of space in the vehicle boot compartment. This lead to the development of toric tanks that can be fitted in the spare wheel compartment or used in a new tank location.

Figure 2.6 Example of new autogas tank location in a vehicle.



Other factors in satisfying customer needs include:

- autogas vehicle range comparable to conventional vehicles meaning container capacity of at least the same volume as gasoline vehicles;
- improved trunk/boot compartment capacity meaning better integration of the autogas container in the design of the car, in close co-operation with the OEMs; and
- a reduction of autogas parts to improve the CO_2 emissions of the vehicles

Autogas container manufacturers are currently developing new solutions such as polymorphic and composite containers to meet these expectations.

Containers made from composite materials show some very promising benefits compared to conventional steel autogas containers, especially regarding less weight and better performance in a fire. Nevertheless, the always more stringent emissions targets requested for the evaporative emissions of the completed vehicle will require the composite manufacturers to pay special attention to the evolution of the permeability characteristics of their future composite structure.

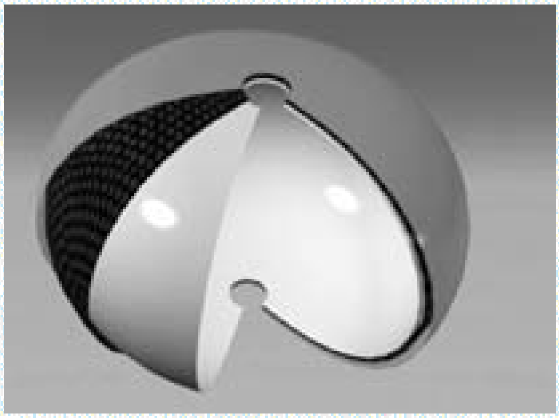
Table 2.4 Comparison of the characteristics of the steel and composite autogas containers.

	Steel Container	Composite Container
Volume (litres)	57	57
Weight (kg)	>38	8 - 9
Life-cycle Analysis, eco indicator	3, 129	688
Bonfire	Danger of explosion	No explosion
Impact resistance	Average/Good	Excellent

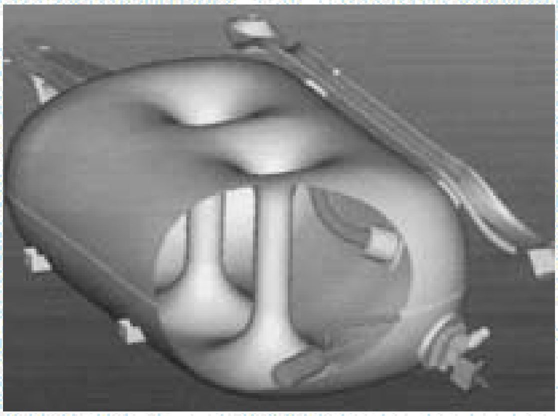
Source: ALE

Figure 2.7 Example of new autogas containers concepts.

LIOTARD : "T" tank concept
(65 litres developed for the RENAULT Espace)



ALE : composite tank concept



PORTINOX concept for stainless steel containers
(volume 77 liters - already available)

ROXER concept for the Peugeot 406
(volume 75 liters - availability year 2002)

All autogas containers must comply with minimum safety rules required for the steel autogas containers with conventional shapes (cylindrical or toric). New approval criteria will need to be considered in the above-mentioned standards and regulations in order to allow free trade worldwide of these new container types through the harmonisation of the certification procedures.

This task is one of the primary objectives of the new ISO Working Group ISO/TC22/WG11 under the Work Item 20826 "Automotive LPG Components, Containers". For ECE countries, amendments to UN/ECE Regulation 67 offered by the AEGPL Automotive Commission are already under discussion within the WP29 Forum to introduce minimum certification rules for composite LP Gas containers. Details are available from the WP29/GRPE web site.

2.2.3 Development of New Autogas Injection Systems

The different types of autogas systems currently marketed can be classified according to their technology and how the injection is controlled. Table 2.2 summarises the different options for installation of existing autogas systems according to the vehicle's exhaust after-treatment system.

Table 2.5 Classification of the current types of autogas systems.

Fuelling system	Traditional exhaust					Catalyst exhaust			
			Gaseous injection				Gaseous injection		
Electronic control	carburetor	carburetor with lambda sensor	single point	liquid injection	carburetor	carburetor with lambda sensor	single point	multi point	liquid injection
Without electronic control	1st generation								
Closed loop and/or digital linear actuator		2nd generation	2nd generation	2nd generation	2nd generation	2nd generation	2nd generation	2nd generation	2nd generation
Micro processor controlled self learning without any adjustment		3rd generation	3rd generation	3rd generation	3rd generation	3rd generation	3rd generation	3rd generation	3rd generation

(For further details on the different generations of autogas systems, see Appendix A).

Today, autogas vehicles comply with the most stringent emissions targets (Euro 4, ULEV) if fitted with 4th generation systems. This is usually in conjunction with a common rail fuel management system in order to achieve OBD compliance.

AUTOGAS FUEL COMPOSITION STANDARDS AND TEST METHODS

There is no single international fuel composition standard for autogas. The main fuel composition standards are national or continental:

- Europe: EN 589
- US: ASTM D 1835-97 (GPA standard, 2140 HD-5)
- Canada: (CAN/CGSB-3.14, Grade 1)
- Japan: JIS K 2240 "LPG specification and analysing methods, Class 2";
- Australia: draft standard under development;

These standards refer to either international (ISO), European (EN), American (ASTM) and/or Japanese test methods.

EN 589, like the European standards for petrol (EN 228) and diesel (EN 590), is implemented nationally within the European Member States. Currently, the EN 589 and the draft Australian specifications are specifically developed to address the critical parameters for autogas such as the Motor Octane Number (MON), residue, and sulphur content. In Japan class 2 of the industrial LP Gas specification is designated for autogas use. Although the US has a standard for autogas but no federal requirement for its use, some vehicle manufacturers require the HD-5 specification in order to have warranty coverage.

Since 1998, car manufacturer organisations have promoted the harmonisation of transportation fuel composition worldwide to meet vehicle needs (see the "World-wide Fuel Charter – April 2000 issued by ACEA, Alliance, EMA and JAMA). Because of continuously tighter vehicle emission requirements and increased durability requirements, limitations of sulphur and evaporation residues are being investigated. An ISO specification for autogas would improve the acceptance of autogas as a real alternative to conventional motor fuels fully exploiting its environmental potential. However, such an initiative must be responsive to the sometimes-unique requirements of a particular country, market, and sources of supply.

Autogas Fuel Composition Standards and Test Methods

3.1 Critical Autogas Fuel Composition Parameters

3.1.1 The Motor Octane Number (MON)

The MON is an important parameter to prevent premature self-ignition of the fuel creating engine knock resulting in potential engine damage. For autogas, MON is calculated on the basis of fuel composition. There are two references to MON blending calculations: ASTM D 2598-96 and EN589-2000. The calculation on the basis of the ASTM method usually gives a MON of one point higher than the calculation according to EN589.

Table 3.1 : Blending motor octane numbers according to ASTM 2598 and EN 589.
Calculation based on liquid volume % in the gas mixture.

MON	ASTM 2598-96	EN 589 2000
Ethane	100.7	95.6
Propane	97.1	95.6
Propylene	84.9	83.1
n-Butane	89.6	88.9
iso-Butane	97.6	97.1
Butylenes	not applicable	75.7
Pentane	not applicable	88.9

3.1.2 Sulphur Content

Autogas naturally has a low-sulphur content (less than 10 ppm weight). Addition of an odourant is required for safety reasons to aid in detection of a leak. Historically, these odourants contain sulphur since sulphur provides a readily recognised and unpleasant smell. However, an excessive amount of sulphur may impact the durability of exhaust gas after-treatment systems.

The LP Gas industry is investigating alternative means of odourising autogas as well as defining acceptable levels.

3.1.3 Residues After Evaporation

Residues in autogas can cause malfunctioning of the autogas equipment on board the vehicle.

Residues can be picked in the supply chain and can collect in the autogas equipment under normal operating conditions due to polymerisation of unsaturated compounds. Some sources of oily residues in the LP Gas distribution chain can be from condensate pipe lines; storage caverns (diesel fuel and oils); compressors (lube oil); new tanks and piping (protective coatings); hoses, gaskets, and pipe dopes (plasticisers).

In the vehicle, the storage tanks might be a source of rust and dirt requiring filtration before the fuel reaches the engine. Studies have shown that in some cases 60 % of the filtered material consists of metallic dirt (2 to 200 µm), 30% of sand (40 to 250 µm) and 10 % rubber plus rust. New filter media such as multi-layer glass fibre are currently available to improve the cleanliness of autogas especially for fuel injection systems. The elimination of solid particles can take place on the vehicle or at the point of use.

3.2 RELATIONSHIP BETWEEN COMMERCIAL FUELS AND VEHICLE EMISSION TESTING FUELS (REFERENCE FUELS)

Part of the vehicle approval process is compliance with emissions standards. On the UN/ECE level, this is dealt with in two international regulations:

- UN/ECE Regulation n°83 : emissions of light duty vehicles;
- UN/ECE Regulation n°49 : emissions of heavy-duty engines.

Further details on these regulations can be found on the UN/ECE Transport Division web site (see "Reference"). These regulations include the specifications for fuels required for certification, the so-called "reference fuels". These reference fuel specifications should reflect the commercial fuel characteristics that are required to achieve defined emission targets.

For autogas, two reference fuels have been defined for light duty vehicle emission testing to ensure the self-adaptability of the on-board automotive LP Gas equipment to the various automotive LP Gas fuel compositions marketed in Europe. For LP Gas heavy-duty engine emission testing, two additional reference fuels have been defined reflecting a higher MON (92.5 according to EN589).

In the US, autogas reference fuels for testing are defined as those commercially available in the marketplace.

3.3 EXAMPLES OF AUTOGAS FUEL COMPOSITION STANDARDS

3.3.1 European Specification EN 589

The European Standard EN 589 was developed for light duty automotive use. It specifies the requirements and test methods of autogas where the composition is mainly determined by the minimum Motor Octane Number of 89. Also, the minimum vapour pressure in the winter period for different climatic areas is specified. It is the intention of the European LP Gas industry to limit the sulphur content to 50 mg/kg in the next revision of EN589 (year 2003). Other critical criteria of EN589 are as follows:

Table 3.2 : Requirements and test methods of autogas according to European Standard EN 589.

Property	Unit	Limits Minimum	Limits Maximum	Test Method +
Motor octane number (MON)		89.0		Annex B (Calculation of MON)
Total dienes content	mole %		0.5	EN 27941
Hydrogen sulfide		Negative		EN ISO 8819
Total sulfur content (after stenching)	mg/kg		100	EN ISO 24260 or ASTM D 3246-96
Copper strip corrosion (1 h at 40 °C)	Rating	Class 1		EN ISO 6251
Evaporation residue	mg/kg		100	EN ISO 13757
Vapour pressure, gauge at 40 °C	kPa		1550	EN ISO 4256 or EN ISO 8973 and Annex C
Vapour pressure, gauge min. 150 kPa at a temperature of -for grade A (dependent on country) -for grade B (dependent on country) -for grade C (dependent on country) -for grade D (dependent on country)	°C		 -10 -5 0 +10	EN ISO 8973 and Annex C
Water content		No free water at 0 °C		Visual (see para. 6.2)
Methanol content	mg/kg		2000	ISO 8174
Odour		Unpleasant and distinctive at 20 % of lower flammability limit		Odour (see para.6.1) and Annex A (Odour test)

Note: There are important footnotes to these specifications not shown.

3.3.2 Draft Australian Standard

The Australian standard is currently under development and will be based on EN 589 with a slightly higher motor octane number (MON) of 90.5.

3.3.3 The US ASTM D 1835-97 Specification

The US ANSI/ASTM D 1835-97 standard specifies commercial LP Gas, and for automotive use a special-duty propane commonly referred to as "HD-5".

The US Gas Processors Association (GPA) specification 2140 "HD-5" was developed in the early 1960s to accommodate the needs of higher compression engines. This specification limits propylene content to 5% volume, butane and heavier (2.5%) and sulphur (120 ppm). The higher compression engines were never built, thus there is no federal requirement to use this specification fuel. However, California requires a specification similar to HD-5 but allows up to 10% propylene and up to 5% butane.

HD-5 is a high quality product composed mainly of propane. Although, the motor octane number is not explicitly specified, superior antiknock characteristics are guaranteed by the specification. The lower detection limit of the test method for the evaporation residues is far higher than the limit specified in EN589.

Table 3.3 : Requirements and test methods of autogas according to US Standard ASTM D1835-97.

Property	Unit	Special-Duty Propane	Test Method
Vapor pressure at 37.8 °C, maximum	kPa	1434	ASTM D 1267 or ASTM D 2598
Volatile residue: evaporated temperature, 95 %, max. or butane and heavier, max. pentane and heavier, max.	°C vol % vol %	- 38.3 2.5	ASTM D 1837 ASTM D 2163 ASTM D 2163
Propylene content, max.	vol %	5.0	ASTM D 2163
Residual matter: residue on evaporation 100 ml, max. oil stain observation	ml -	0.05 pass	ASTM D 2158 ASTM D 2158
Relative density at 15.6/15.6 °C	-		ASTM D 2598
Copper strip corrosion	rating	No. 1	ASTM D 1838
Total sulfur content (after stenching)	mg/kg	123	ASTM D 2784
Hydrogen sulfide	-	pass	ASTM D 2420
Moisture content	-	pass	ASTM D 2713
Free water content	-		
Motor octane number		not applicable	
Total dienes content		not applicable	
Methanol content		not applicable	
Odour		not applicable	

- *Note: in addition to this standard, the following test procedures are applicable: Ethyl mercaptan : ASTM D 5305-97*
- *Carbonyl sulfide : ASTM D 5303-92.*

3.3.4 THE JAPANESE INDUSTRIAL STANDARD (JIS) K2240-1991 SPECIFICATION:

The Japanese autogas standard is included in JIS K 2240-1991, class 2. The main difference between autogas specification and the industrial specification is the variation in C_3 compounds. Nevertheless, no motor octane number is specified which allows autogas with a very low MON. Other parameters, such as evaporative residues, H_2S and free water are not covered.

Tests methods are covered in JP: JIS K 2240.

Table 3.4 Requirements for the Japanese Industrial and Autogas (class 2) specifications.

	Unit	No.1	No. 2	No.3	No.4
Ethane + ethylene	mole %				
Propane + propylene	mole %	> 90	50 to 90	< 50	< 10
Butane + butylene	mole %	< 10	< 50	50 to 90	> 90
1,3 Butadiene	mole %	*	*	*	*
Sulphur content	mg/kg	< 200	< 200	< 200	< 200
Vapour pressure (40 °C)	kPa	< 1550	< 1550	< 1250	< 520
Density (15 C)	g/cm^3	0.50 to 0.62	0.50 to 0.62	0.50 to 0.62	0.50 to 0.62
Copper corrosion (40 °C, 1h)		< 1	< 1	< 1	< 1

** In the case of the use for automobiles, the content of butadiene shall not be detrimental to the using purpose.*

TECHNOLOGICAL DEVELOPMENTS

A 1. AUTOGAS EQUIPMENT TECHNOLOGY

A 1.1 Introduction

The level of technology has advanced significantly over the years. In the 1970s very simple emission control systems and the introduction of clean gasoline resulted in a major improvement in exhaust gas emissions. The introduction of clean gasoline technology (e.g. the three-way catalyst) drove autogas systems improvement resulting in the development of electronically controlled systems. Later, even more sophisticated systems were developed using self-adaptive control.

A short overview of the development stages of autogas systems is given below.

1st Generation equipment. These systems consist of a pressure regulator and one single gas mixer having no electronic control. Gasoline engines with a single carburetor without three-way catalyst can be converted with this single point system with fixed adjustment.

2nd Generation equipment. These systems consist of a gas mixer or one single point injection unit with electronic control of the gas supply. These can be applied to engines with closed loop lambda controlled three-way catalyst and an oxygen sensor in the exhaust. Gasoline engines with a single carburetor with or without three-way catalyst can be converted by using single point gaseous fuel systems. If used on gasoline engines with multipoint manifold fuel injection systems, there is a risk of severe backfire that can occur due to the relatively large intake manifolds compared with carburetted gasoline engines. A carefully tuned gas supply is needed in order to exclude the occurrence of too-lean mixtures.

3rd Generation equipment. These systems use multipoint manifold injection with continuous injection or timed simultaneous operation (all injectors injecting at the same time) and lambda (λ)-control with three-way catalyst. These systems are designed for the conversion of engines with multipoint gasoline injection systems. The risk of backfire and decreased performance compared to gas mixers are significantly reduced.

4th Generation equipment. These systems are the same as the 3rd generation multipoint equipment, however, the injection timing and duration is optimised for each cylinder (sequential multipoint injection system). The equipment is used both for gaseous and liquid autogas injection. These systems are comparable with the latest generation multipoint gasoline manifold injection systems with fuel-rail in combination with λ-control.

On-board Diagnostics (OBD)
Modern gasoline vehicles equipped with on-board diagnostics meeting stringent requirements for energy consumption and exhaust emissions can only be converted to autogas if microprocessor controlled injection systems are used in combination with the OEM engine management information. In these cases close co-operation with the OEM is necessary. See A.2 below.

A 1.2. Future Developments of Gasoline and Diesel Engines

Conventional stoichiometric gasoline engines.
As emission standards become more stringent, meeting these standards is mainly determined by engine behaviour just after cold start (temperature between 20 and 30 C). A prime strategy is fast warming of the catalyst. Autogas vehicles will benefit from these developments.

Gasoline direct injection (GDI) engines.
In order to decrease energy consumption gasoline engines use direct fuel injection. These engines are able to run

very lean at part load, having lower heat losses from the combustion chamber and lower throttling losses. At higher loads they run stoichiometric. The after-treatment system and engine management system is more complicated than with stoichiometric engines since these systems must be able to convert NO_x under lean conditions (NO_x adsorber or lean NO_x catalyst).

Optimising GDI engines to use autogas direct injection is very difficult especially in case of retrofit. Investment cost by OEMs will be very high. Therefore, it is expected that GDI engines will use manifold autogas injection operating either stoichiometric under all circumstances or lean at part load. If operating lean the mixtures will not be as lean as is possible with gasoline. Therefore some advantages of autogas will be lost.

Diesel direct injection (common-rail)
Almost all diesel engine manufacturers produce direct injection diesel engines applying conventional injection techniques (distributor pump) or common-rail technique (continuous high pressure with electronically actuated injectors).

The advantage of a direct injection diesel engine is the lower fuel consumption compared with the pre-chamber (indirect) injection technique. Common-rail engines are more flexible than conventional direct injection diesels since diesel fuel can be injected at every phase in the four-stroke cycle. Therefore, engine and after treatment system can be better matched in order to reach low emissions.

Direct injected diesel engines generally produce less CO_2. However, diesel emission standards for NO_x and particulates in Europe and Japan are much less tight than is the case for gasoline vehicles. If technology neutral standards are applied, the diesel engine will likely become more expensive since advanced after treatment systems must be used. These are described below.

Diesel after treatment systems

Diesel particulate filter (DPF). The diesel particulate filter has a high efficiency and continuously regenerating filters need no special regeneration systems that may overheat the filter and destroy it. A problem may be the minimum temperature at which the oxidation of the particulates begins, especially during urban driving.

NO_x adsorber (NO_x trap or NO_x storage catalyst). A NO_x adsorber stores nitrogen oxides during normal lean diesel operation. After 40 to 60 seconds the engine runs rich for several seconds in order to reduce the stored NO_x by the CO formed in the engine. This lean/rich cycle must be continuous. It is not easy to run a diesel engine under rich circumstances without excessive smoke emissions.

Urea (ammonia) de-NO_x system. After injection of a urea-water solution in the exhaust, ammonia is formed in the exhaust gas that reduces NO_x in a special catalyst. The amount of injected urea has to be proportional with the NO_x flow in the exhaust during all running conditions. If the amount is too high, ammonia slips through the catalyst. If the amount is too low, NO_x emission will be too high. This means that careful calibration, especially under transient conditions, is necessary.

A.2. On-Board Diagnostics (OBD)

A 2.1. Introduction.

OBD was first used by car manufacturers to detect malfunctions in the engine management system. After storing the malfunction of a specific part in a monitoring system and identifying it by a scan tool, it was easy to repair the damaged component(s). OBD I operation was based on this system, and had no relevance to the effect on emissions.

OBD II (US) and EOBD (Europe) legislation requires that the system identifies malfunctions and deterioration of components if they cause emissions to exceed specified thresholds. These are defined in the US EPA test cycle (FTP 75), and the European revised urban + extra-urban cycle (EDC or MVEG-B). Malfunctions are identified by means of fault codes stored in the computer memory. They must be indicated to the driver upon detection by a visible or audible malfunction indicator (MI).

A 2.2. OBD and Alternative Fuels

A 2.2.1 US Situation

In 1991, California introduced OBD I regulations for gasoline vehicles. In 1996, both California and EPA required OBD II systems for all fuels, but would consider annual waivers requiring alternative fuel vehicles to be equipped with OBD I systems. The advent of OBD II systems for gasoline meant that when such a vehicle was operated on an alternative fuel, the OBD II system would perceive incorrectly that a fault had apparently occurred, and a false malfunction indicator light would be set.

However, until 2004 manufacturers of alternative fuel systems may request approval of a monitoring strategy where specific monitoring requirements are disabled for which monitoring may not be reliable with respect to the use of alternative fuels. This means that selected monitors that would otherwise set a false MI and code can be disabled when operating on an alternative fuel. Different strategies can be developed depending on whether the alternative fuel conversion is carried out through a partnership between the OEM and alternative fuel system provider, or is carried out as an aftermarket conversion.

One strategy is to establish a communications link between the gasoline and alternative fuel computers. When the vehicle starts to operate on the alternative fuel, a command is sent to the OEM computer to disable ODB II monitors. For aftermarket conversions, a method can be used by which malfunction codes are cleared in the OEM gasoline computer during alternative fuel operation. In this case the alternative fuel computer must provide appropriate diagnostics.

By 2004, all OBD monitors must be active for all fuels, and no further waivers will be permitted for alternative fuels. As the emissions standards become increasingly more stringent, the OBD II systems will become more complex. Only a close relationship with the OEM will allow suppliers of alternative fuel conversion systems to achieve full OBD II capability.

A 2.2.2 European Situation

In 2000, the European Union introduced EOBD regulations for gasoline vehicles. In 2003, EOBD will be implemented for new type approved autogas and CNG fuelled vehicles and in 2004 for all new registered autogas and CNG vehicles.

As the European Directive deals only with new vehicles (OEM), aftermarket conversions are regulated by national law in the different European countries until the beginning of 2003.

Currently, amendments are proposed by OEMs and conversion system suppliers in order to adapt the European OBD legislation to gaseous-fuelled vehicles. It is believed that the existing gasoline regulation is also feasible for mono-fuelled gas vehicles, and that amendments and additions are only necessary for bi-fuelled vehicles.

A 2.2.3 Japanese Situation

In the future all vehicles have to be equipped with OBD systems similar to EOBD. Currently, the more expensive cars are already equipped with OBD.

A 2.3. OBD System Operation and Test Procedure.

A 2.3.1 OBD System Operation

For most emission control systems and components, OBD regulations require malfunctions to be identified before any problem becomes serious enough to cause vehicle emissions to exceed the standards by more than a maximum permitted factor or level (OBD thresholds). This requires manufacturers to correlate component and system performance with emission levels to determine when deterioration of the system or component will cause emissions to exceed this OBD threshold. When this occurs, the regulation requires the diagnostic system to alert the vehicle operator to the problem by activation of the malfunction indicator (MI).

For components and systems in which the emission standard criterion is not sufficient or cannot be easily applied, the regulation establishes different malfunction criteria to identify emission problems. For example, in addition to having to detect engine misfire before emissions exceed the thresholds, the regulation requires that misfire levels be detected that will cause catalyst damage due to overheating.

The OBD system must monitor several parts and systems. Examples are oxygen sensor, catalyst, engine misfire, and other systems that can have an influence on emissions, e.g. exhaust gas recirculation.

A 2.3.2 OBD Test Procedure

In order to test the performance of the OBD system, regulations prescribe tests to be carried out on a chassis dynamometer (FPT 75 test, MVEG test). The manufacturer must make available defective components and/or electrical devices that would be used to simulate failures. When measured over the test cycle, such defective components or devices must activate the malfunction indicator and not cause the vehicle emissions to exceed the OBD emission and other thresholds by a prescribed value. For the EU these values are: HC 0.4 g/km, CO 3.2 g/km and NO_x 0.6 g/km not exceeding by more than 20 % depending on the defective component.

Some examples are given below.

- In order to check the influence of the reduction in catalyst efficiency, the catalyst is replaced with a deteriorated (aged) or defective catalyst or the failure is electronically simulated.
- Induced engine misfire conditions.
- Replacement of the oxygen sensor with a deteriorated or defective oxygen sensor or electronic simulation of such a failure.
- Electrical disconnection of any other emission-related component connected to the engine management computer.
- Electrical disconnection of the electronic evaporative purge control device.

A 2.3.3 Future OBD Developments in the US and Europe

The requirements for OBD systems will change in the future. The following developments may be expected.

- The EOBD 2005 thresholds will be more restrictive
- A catalyst NO_x threshold is likely to be introduced (now HC only)
- Aging of complete catalyst system (not only the first brick of a dual catalyst system)
- Improved monitoring of misfiring
- Only CAN (Communication Area Network) mandatory
- Air conditioning system component monitoring
- Variable valve timing control system
- Direct ozone reduction monitoring

EFFECTS OF REGULATED AND NON-REGULATED EMISSIONS OF EXHAUST GASES

B 1 Regulated and Non-Regulated Environmental Components

Apart from the regulated components such as CO, HC, and NO_x for gasoline, autogas and diesel vehicles, there are also so-called non-regulated components that are not limited by law. There are a large variety of components that can be summarised according to their environmental effects.

Together with the regulated components they can be classified as causing:

- Local toxic or nuisance effects
- Long term toxic effects such as carcinogenicity and mutagenicity properties
- Regional environmental effects such as summer smog, winter smog and acidification
- Global environmental effects such as global warming and deterioration of the ozone layer

Local Toxic or Nuisance Effects

- Carbon monoxide (CO), the most known automotive pollutant, has a direct toxic effect as it blocks O_2 transport through the body.
- Nitrogen oxides (NO and NO_2 form together NO_x), SO_2 and NH_3 have a direct toxic effect; they cause eye and nose irritation and tightness of the chest.
- Total hydrocarbons (THC) consist of thousands of different components which almost all have a different yet direct effect. As pure methane (CH_4) has no direct effect, non-methane hydrocarbons (NMHC) are more representative.
- To some hydrocarbons special attention is paid: 1,3 butadiene and the lower aldehydes (formaldehyde, acetaldehyde and acrolein) are irritating to the eyes and upper bronchial tubes.
- Particulate matter (PM) is shown in several studies to have a strong correlation between particulate size and mortality.

Long-term Toxic Effects such as Mutagenic and Carcinogenic Properties

- Air toxics such as formaldehyde, acetaldehyde, 1,3 butadiene are compounds that also have a long-term toxic effect and are probable human carcinogens. Benzene has been found to cause cancers and leukemia in animals and human populations.
- Poly-aromatic hydrocarbons (PAHs) also have a long-term toxicity as several components such as benzo(a)pyrene cause cancer.

Regional Environmental Effects such as Summer Smog, Winter Smog and Acidification

Summer smog potential. Summer smog is caused by the formation of ozone (O_3) from nitrogen oxides (NO_x) and several organic components (C_nH_mO) in the atmosphere. The production of ozone is a complicated process since differing components produce differing amounts of ozone. Favourable conditions for smog formation are no wind (emissions are not moved away) and sun light (UV radiation). As the formation of ozone takes time, the rush hour in the morning is responsible for an ozone peak at about five hours later around mid-day. The evening rush hour causes less smog as the intensity of the sunlight after that time is weaker.

Summer smog potential is determined by a mixture of several hydrocarbons, aldehydes and CO. It is expressed in ethene equivalents and calculated from the POCP (Photochemical Ozone Creation Potential relative to ethene) of each exhaust gas component and its concentration.

The components O_3 and NO_2 related to summer smog have a clear effect on the mortality of elderly people and of cardiac patients. O_3 also causes eye irritation, tightness of the chest and irritation of upper bronchial tubes.

Winter smog potential. Winter smog is characterised by high concentrations of harmful components of which sulfur dioxide (SO_2) and very small particles (PM_{10}) are the most important. PM_{10} is the abbreviation for the mass of airborne particulate matter (aerosols) with a diameter smaller than 10 micro-meter and is an indication of the severity of winter smog. The particles can carry several harmful components such as aldehydes, PAH and heavy metals which are easily inhaled with the particle. Winter smog contribution of vehicles mainly comes from small particles. SO_2 contribution is very low compared to other sources. Winter smog forms a health hazard causing breathing problems and increased mortality.

Acidification equivalent. Rain is naturally slightly acid (pH < 7) caused by the fact that carbon dioxide from the air dissolves in the rain water and reacts to carbonic acid. If the pH is lower than the natural value acid rain is formed. Acid rain is formed by oxidation of SO_2, NO_x and ammonia in the atmosphere forming sulfuric acid and nitric acid that can reach the earth surface as wet deposition or dry deposition. Acid rain disturbs the conditions for healthy growing of plants and trees. The distance between emission source and deposition can be short (within a country) but also long (crossing borders).

The contribution of vehicles to acidification is from SO_2 , NO_x and ammonia emissions and is expressed in H^+ acidification equivalents: 1 gram SO_2 forms 31.5 millimol H^+ equivalent, 1 gram NO_x forms 21.5 millimol H^+ equivalent and 1 gram NH_3 forms 59.0 millimol H^+ equivalent.

Global Environmental Effects such as Global Warming and Deterioration of the Ozone Layer

Global Warming Potential (GWP) or greenhouse effect. The earth receives warmth from the sun's heat that is then trapped near the planet's surface by a mixture of gases. Some scientists in the 1970s claimed that these gases that had been in balance for millions of years, were being quickly influenced by man's activities and that a general increase in these, so called, "greenhouse gases" was resulting in the earth's surface being slowly heated. They claim this heating results in changing surface temperatures and weather patterns. The use of fossil fuels has been blamed as a major contributor to this effect. As a result of the production of carbon dioxide and other greenhouse gases, and their claimed influence on the environment, the worldwide community has decided to act immediately and limit their production and use.

A natural greenhouse effect is always present and prevents too much cooling of the earth's surface. If the energy balance is disturbed by greenhouse gases such as CO_2 (carbon dioxide), CH_4 (methane), N_2O (nitrous oxide), CFC's (chlorofluorocarbons) and O_3 (ozone), the earth and its atmosphere become warmer causing climate changes. Due to lack of knowledge still uncertainties remain on the time lag, the extent and regional patterns.

The contribution of vehicles towards global warming is based on CO_2, CH_4 and N_2O emissions. Methane is a greenhouse gas that has 21 times the effect of CO_2, however, engine out concentrations are much lower. N_2O has 310 times the effect of CO_2. (100 year time horizon, Intergovernmental Panel on Climate Change, 1996).

Deterioration of the ozone layer. Chlorofluorocarbons are threatening the ozone layer in the stratosphere (at 20 km height) by the formation of very reactive radicals turning ozone into O_2. Ozone at this height is important because it absorbs the greater part of the very harmful UV-radiation. Vehicle emissions are believed not to be a threat to the ozone layer. However, the effect of NO and N_2O is not yet clear.

VEHICLE EMISSION STANDARDS in EUROPE, US, JAPAN, AUSTRALIA and OTHER AREAS of the WORLD

C.1. Emission Standards in the European Member States

In the European Union, the Directive 98/69/EC (amending the Directive D70/220) defines the emission standards for the year 2000 (Euro 3 targets) and 2005 (Euro 4 targets) for light duty vehicles. Light duty vehicles are defined as passenger cars and light duty vehicles with a maximum mass of 3.5 tonnes. Specific requirements regarding the gaseous-fuelled vehicles have been introduced through the Directive 98/77/EC.

Table C.1 Entry into force of the Euro 3 and Euro 4 emission standards for light vehicles (less than 3.5 tonnes).

Vehicle category	New type-approval date	All types date
	Euro 3	
M (passenger cars) except > 2500 kg	1 January 2000	1 January 2001
M (passenger cars) > 2500 kg	1 January 2001	1 January 2002
N1 (light commercial vehicles) Class I	1 January 2000	1 January 2001
N1 (light commercial vehicles) Classes II and III	1 January 2001	1 January 2002
	Euro 4	
M (passenger cars) except > 2500 kg	1 January 2005	1 January 2006
M (passenger cars) > 2500 kg	1 January 2006	1 January 2007
N1 (light commercial vehicles) Class I	1 January 2005	1 January 2006
N1 (light commercial vehicles) Classes II and III	1 January 2006	1 January 2007

Category M: *Motor vehicles with at least 4 wheels and used for the carriage of passengers.*
Category N1: *Vehicles used for the carriage of goods having a maximum mass not exceeding 3500 kg.*
Reference mass: *Defined as mass of the vehicle in running order (tanks completely filled) plus 25 kg.*

Table C.2 Mandatory Euro 3 and Euro 4 tailpipe emission limits in the European Union for light vehicles (less than 3.5 tonnes).

			Reference mass (RW) (kg)	Limit Values								
				Mass of carbon monoxide (CO) (g/km)		Mass of hydrocarbons (HC) (g/km)		Mass of oxides of nitrogen (NO_x) (g/km)		Combined mass of hydrocarbons and (HC + NO_x) (g/km)		Mass of particulates (PM) (g/km)
Category		Class		Gasoline	Diesel	Gasoline	Diesel	Gasoline	Diesel	Gasoline	Diesel	Diesel
A (2000) Euro 3	M 2		All	2.3	0.64	0.20	-	0.15	0.50	-	0.56	0.05
	N_1 3	I	RW≤1305	2.3	0.64	0.20	-	0.15	0.50	-	0.56	0.05
		II	1305 < RW≤1760	4.17	0.80	0.25	-	0.18	0.65	-	0.72	0.07
		III	1760 < RW	5.22	0.95	0.29	-	0.21	0.78	-	0.86	0.10
B (2005) Euro 4	M 2		All	1.0	0.50	0.10	-	0.08	0.25	-	0.30	0.025
	N_1 3	I	RW≤1305	1.0	0.50	0.10	-	0.08	0.25	-	0.30	0.025
		II	1305 < RW≤1760	1.81	0.63	0.13	-	0.10	0.33	-	0.39	0.04
		III	1760 < RW	2.27	0.74	0.16	-	0.11	0.39	-	0.46	0.06

1) For compression ignition engines.
2) Except vehicles the maximum mass of which exceeds 2500 kg.
3) Category M vehicles that are specified in note 2.

By comparison to the previous emissions targets (Euro 1 and 2), Euro 3 and 4 emissions targets are measured over a revised test cycle of the vehicle emissions at cold start.

These directives introducing the Euro 3 and 4 emissions targets are now also placing new requirements on light vehicles including:

- Introduction of a cold start test at -7°C for new gasoline vehicle type approvals from 1 January 2002 with the following limits, 15 g/km for CO and 1.8 g/km for HC measured over the urban part of the test cycle only;
- Implementation of in-use durability requirements at 80,000 km or 5 years (whichever is sooner) for the Euro 3 stage (year 2000). However, the durability test increases to 100,000 km or 5 years (whichever is sooner) for the Euro 4 stage (year 2005).
- Implementation of OBD requirements as follows (see also Annex I, VI, X, and XI to Directive 70/220/EEC, as amended by Directive 1999/102/EC):
  - **Vehicles with positive-ignition engines**: effective 1 January 2000 for new types and from 1 January 2001 for all types, vehicles of category M_1 except vehicles the maximum mass of which exceeds 2,500 kg. Vehicles of category N_1 class I, must be fitted with an on-board diagnostic (OBD) system for emission control in accordance with Annex XI;
  - **Vehicles with compression-ignition engines**: Effective 1 January 2003 for new types, and from 1 January 2004 for all types, vehicles of category M_1 must be fitted with an on-board diagnostic (OBD) system for emission control in accordance with Annex XI, except vehicles designed to carry more than six occupants including the driver and vehicles whose maximum mass exceeds 2,500kg.
  - **For the vehicles using gaseous fuels (autogas or CNG):**
    Directive 2001/1/EC (of 6 February 2001 and amending Directive 70/220/EEC) defines the dates from which OBD systems are mandatory for passenger cars and light commercial vehicles that have positive-ignition engines running on autogas and CNG.
    - Vehicles of category M1 ≤ 2500kg and vehicles of category N1 class II: new types, 1 January 2003; all types, 1 January 2004.
    - Vehicles of category M1 > 2500 kg and vehicles of category N1 class II and III: new types, 1 January 2006; all types 1, January 2007.

    More discussion on OBD is covered in Appendix A.2.

Regarding HDVs, Directive D88/77 defines the minimum emission rules including related emission test cycles. The table below describes the status of the latest amendments to this directive that impacts the emissions performance of autogas vehicles.

Regarding HDVs, Directive D88/77 defines the minimum emission rules including related emission test cycles. The table below describes the status of the latest amendments to this directive that impacts the emissions performance of autogas vehicles.

Basic EC Directives	*subject*	*Amendments related to automotive LP Gas*	*Comments*
D70/220	*Emissions performance of light vehicles* *(Passenger Cars & LDVs)*	*- D98/69* *- D99/102* *- D2001/1* *- COM(2000)487 (adopted by the E. Council on 7th June 2001)* *- Doc. ENTR/F/5/6003)*	*- emission targets for years 2000 & 2005* *- clarification of the E-OBD implementation dates* *- derogation of E-OBD requirements for gaseous fuelled vehicles until 2003* *- exemption of autogas vehicles from the cold start emission test;* *- introduction of updated reference fuels specification for emission testing of the Euro 4 engines;*
D88/77	*Emissions performance of heavy duty vehicles*	*- D99/96* *- D2001/27*	*- defines the Euro 4 testing procedures as well as the EEV targets;* *- introduces a specific adaptation of the emission test cycles (change of the statistical criteria for the gaseous fuelled engines) and updated reference fuel specifications for autogas, CNG and methanol*
D80/1268	*Measurement of fuel consumption and CO_2 emissions*	*- D99/100*	*Introduction of the requirements specific to gaseous fuelled vehicles*
D80/1269	*Measurement of vehicle net power*	*- D99/99*	*Introduction of the requirements specific to gaseous fuelled vehicles*

(Further information on the status of these directives can be found on the European Commission web-site)

Requirements of these Directives have also been used as a basis for the discussions of updated emissions standards outside of Europe such as ECE countries. These directives, through the work within the UN/ECE/WP29, have fostered the exchange of information between the European Union and other parties such as Australia.

Table C.3: Equivalence between the UN/ECE Regulations and the European Directives dealing with the emission aspects of autogas vehicles.

European Directive	UN/ECE Regulation	Scope
D 70/220	R 83	Regulated pollutants emissions tests of passenger cars and LDVs
D 88/77	R 49	Regulated pollutants emissions tests of HDVs
D 80/1268	R 101	Measurement of fuel consumption and CO_2 emissions
D 80/1269	R 85	Measurement of net power

Note: ECE regulations are technical procedures only. The dates of their implementation may differ from country to country depending on the approval status of the respective amendment of that country. For example, the table below describes in detail the equivalence between the UN/ECE Regulation 83 (emissions of light duty vehicles) and the amendments to the EU Directive 70/220.

Table C.4 Equivalence between the amendments to UN/ECE Regulation 83 and EU Directive 70/220.

ECE Regulation	EU Directive	Stage	Cycle + Vehicle category
ECE R-83/00	88/76/EEC	1988, Euro 0	ECE cycle LD passenger cars (SI + diesel)
ECE R-83/01	91/441/EEC	1992, Euro 1	UDC + EUDC cycle LD passenger cars (SI + diesel)
ECE R-83/02	93/59/EEC	1993, Euro 1	+ Light commercial vehicles (LCV)
ECE R-83/03	94/12/EC	1996, Euro 2	LD passenger cars (SI + diesel)
ECE R-83/04	96/69/EC 98/77/EC	97/98, Euro 2 1999, Euro 2	+ LCV + autogas/NG fuelled vehicles
ECE R-83/05	98/69/EC	2000, Euro 3 2005, Euro 4	LD passenger cars +LCV (SI + diesel + autogas/CNG)

C.2. US Federal Emission Standards

The Clean Air Act Amendments were signed into law in November 1990. Once the Amendments were approved, the EPA worked with the assistance of the oil and automotive industries to develop detailed rules to put the legislation into place. The most important of these are the 'Tier I' exhaust emissions limits for light duty vehicles and was introduced progressively from 1994. The EPA determined that a National Low Emission Vehicle (NLEV) programme would result in emissions reductions. The test cycle used is the US FTP (Federal Test Procedure).

Table C.5 US Federal Tier I and NLEV emission limit values in grams/mile.

Emissions	Durability (miles)	Tier I (model year 94 →)	NLEV (model year 01 →)
NMHC	50,000 100,000	0.25 0.31	0.075[4] 0.090[4]
CO	50,000 100,000	3.4 4.2	3.4 4.2
Cold CO (-7°C)	50,000	10	3.4[5]
NO_x [1) 3)]	50,000 100,000	0.4 0.6	0.2 0.3
NO_x [2) 3)]	50,000 100,000	1.0 1.25	0.2 0.3
PM	50,000 100,000	0.08 0.10	- 0.08[2]

1) gasoline vehicles only
2) gasoline and diesel vehicles
*3) NO_x highway standard: 1.33 * NO_x city standards as listed above*
4) NMOG (non-methane organic gases) measurement instead of NMHC (non-methane hydrocarbons)
5) 3.4 g/mi CO level may be required starting 2001 pending the outcome of an EPA study

NLEV will be in place until 2004 at which time the Federal Tier II standards will take effect. The same standards as NLEV will be applicable to Tier II, but car manufacturers will have to meet a 0.07 g/mi NO_x fleet average at the end of the durability test of 120,000 mi/10 years. This standard will be phased in 25/50/75/100% from 2004 to 2007 for cars and trucks < 6000 lbs GVW and 50/100% in 2008-2009 for heavier trucks.

Eight standard "bins" of emissions limits are available. A manufacturer may choose to certify a vehicle for one of these bins as long as the manufacturer's fleet averages 0.07 g/mi NO_x (sales weighted). Bin 1 corresponds to 0.0 g/mi of any emissions. The emission standards for each bin are listed in the Table C.6.

Table C.6 US Federal Tier II emissions standards to be phased in from 2004 in grams/mile.
0.07 g/mi NO_x fleet average at 120,000 miles/10 years.

0.07 g/mi NO_x fleet average at 120,000 miles/10 years									
emissions	durability	Bin 8	Bin 7	Bin 6	Bin 5	Bin 4	Bin 3	Bin 2	Bin 1
NMOG	50,000 120,000	0.100 0.125	0.075 0.090	0.075 0.090	0.075 0.090	0.070	0.055	0.010	0
CO	50,000 120,000	3.4 4.2	3.4 4.2	3.4 4.2	3.4 4.2	2.1	2.1	2.1	0
NO_x	50,000 120,000	0.14 0.20	0.11 0.15	0.08 0.10	0.05 0.07	0.04	0.03	0.02	0
PM	120,000	0.02	0.02	0.01	0.01	0.01	0.01	0.01	0
HCHO[1]	50,000 120,000	0.015 0.018	0.015 0.018	0.015 0.018	0.015 0.018	0.011	0.011	0.011	0

[1] HCHO = formaldehyde

During the phase-in period 2004 to 2006, vehicles up to 6000 lbs gross vehicle weight (GVW) that do not follow the 0.07 NO_x fleet average must meet 0.3 NO_x fleet average. In addition to bin 1 to 8, a manufacturer may choose for that period to certify to bins 9 and 10 as shown in the next Table C.7 as long as the 0.3 NO_x fleet average is met.

Table C.7 Interim Tier II, 0.3 g/mi NO_x fleet average, emission standards in grams per mile.

0.3 g/mi NO_x fleet average			
Emissions	Durability	Bin 9	Bin 10
NMOG	50,000 120,000	0.075 0.090	0.125 0.156
CO	50,000 120,000	3.4 4.2	3.4 4.2
NO_x	50,000 120,000	0.2 0.3	0.4 0.6
PM	120,000	0.06	0.08
HCHO	50,000 120,000	0.015 0.018	0.015 0.018

For reasons of clarity, the Tier II phase-in schedule is summarised in the Table C.8 below.

Table C.8 Tier II phase-in schedule in % (vehicles < 6000 lbs GVW).

	2001	2002	2003	2004	2005	2006	2007	2008
NLEV	100	100	100					
Interim Non- Tier II, 0.3 NO_x average				75	50	25	0	0
Tier II, 0.07 NO_x average				25	50	75	100	100

Figure C.1 The US Federal Test Procedure is presented in the image below.

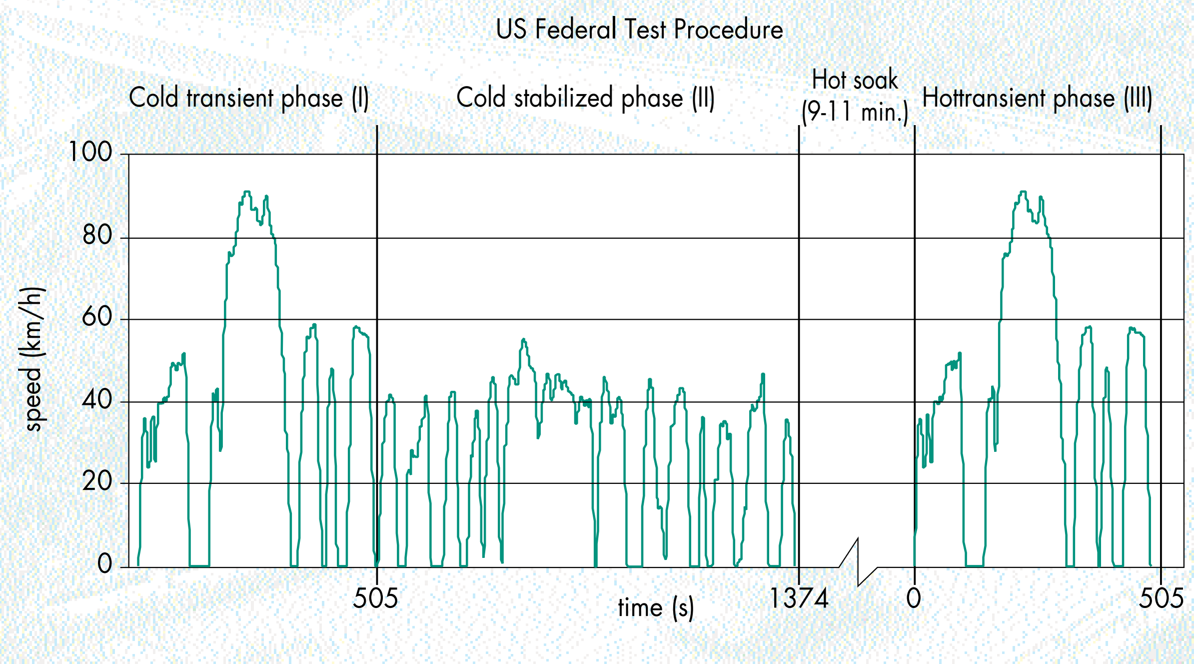


Figure C.1 Length: 11.06 miles; duration: 1877 seconds; max. speed: 56.68 mph; average speed: 21.19 miles per hour.

C.3. California Emission Standards

The Clean Air Act reaffirmed the authority of individual states to adopt more stringent emission standards if they wish to do so. However, they are only permitted to adopt the standards set by California. This restriction was imposed in order to prevent motor manufacturers having to produce individual models for each state. Instead, they only need to produce two models - one complying with Federal standards and one complying with California requirements. The California emission classes are defined as follows:

TLEV	Transitional Low Emission Vehicle
LEV	Low Emission Vehicle (LEV_1, LEV_2)
ULEV	Ultra Low Emission Vehicle ($ULEV_1$, $ULEV_2$)
SULEV	Super Ultra Low Emission Vehicle
ZEV	Zero Emission Vehicle

The corresponding emission standards are defined in two stages: the current LEV 1 standards phasing out from 2004 to 2007, and LEV 2 phasing in from 2004 onwards (Table C.9 and Table C.10).

Table C.9 Californian LEV 1 emission standards phasing out 2004-2007 in grams per mile.

Emissions	Durability	TLEV 1	LEV 1	ULEV 1	ZEV 1
NMOG	50,000 100,000	0.125 0.156	0.075 0.090	0.040 0.055	0 0
CO	50,000 100,000	3.4 4.2	3.4 4.2	1.7 2.1	0 0
NO_x	50,000 100,000	0.4 0.6	0.2 0.3	0.2 0.3	0 0
PM	50,000 100,000	- 0.08	- 0.08	- 0.04	0 0
HCHO	50,000 100,000	0.015 0.018	0.015 0.018	0.008 0.011	0 0

From model year 1996 gasoline and alcohol vehicles must also meet cold CO limits, similar to the US Federal standards.

Table C.10 Californian LEV 2 emission standards phasing in 2004 onwards in grams per mile.

Emissions	Durability	LEV 2	ULEV 2	SULEV 2	ZEV 2
NMOG	50,000 120,000	0.075 0.090	0.040 0.055	- 0.010	0 0
CO	50,000 120,000	3.4 4.2	1.7 2.1	- 1.0	0 0
NO_x	50,000 120,000	0.05 0.07	0.05 0.07	- 0.02	0 0
PM	50,000 120,000	- 0.01	- 0.01	- 0.01	0 0
HCHO	50,000 120,000	0.015 0.018	0.008 0.011	- 0.004	0 0

Manufacturers must certify their vehicle fleet each model year such that the sales-weighted NMOG fleet average is below the mandatory limits. The calculation is based on 50,000 miles standards for TLEV, LEV and ULEV, and 120,000 miles standards for SULEV. Manufacturers can obtain credits for better fleet average or buy credits from another manufacturer to balance possible emission deficits.

The NMOG fleet average limits are shown in the Table C.11.

Table C.11 California NMOG annual fleet average emission limits.

Year	1999	2000	2001	2002	2003	2004	2005	2006	2007	2008	2009	2010
g/mi	0.113	0.073	0.070	0.068	0.062	0.053	0.049	0.046	0.043	0.040	0.038	0.035

C.4. Japanese Emission Standards

The current Japanese emission standards are listed below in Table C.12.
New and converted autogas vehicles must meet the same emission standards as gasoline vehicles.

Table C.12 Current Japanese emission standards.

Vehicle type	test	emissions	unit	Standards	
				Mean[1]	Max[1]
Gasoline and autogas	11 mode	HC	g/test	2.2	4.42
		CO		19.0	31.1
		NO_x		1.4	2.5
	10.15 mode	HC	g/km	0.08	0.17
		CO		0.67	1.27
		NO_x		0.08	0.17
Diesel	10.15 mode	HC	g/km	0.40	0.62
		CO		2.1	2.7
		NO_x		0.40	0.55
		PM		0.08	0.14

[1] *All limits are given as max/mean; the maximum limits apply for production of < 2000 units/annum and the mean limits apply to production of >2000 units/annum.*

For importers, these standards are applicable from September 2002 onwards. For diesel cars, more stringent requirements come into force from October 2002 onwards for domestic producers, and from September 2004 for importers (Table C.13).

Table C.13 More stringent emission standards.

Vehicle type	test	emissions	unit	Standards	
				Mean	Max
Diesel	10.15 mode	HC	g/km	0.12	0.24
		CO		0.63	0.98
		NO_x[1]		0.28/0.30	0.43/0.45
		PM[1]		0.052/0.056	0.11

[1] *Different NO_x and PM limits for vehicles below/above 1265 kg mass.*

Figure C.2 Length: 1.021 km, duration: 120 seconds, max. speed: 60 km/h, average speed: 30.6 km/h.

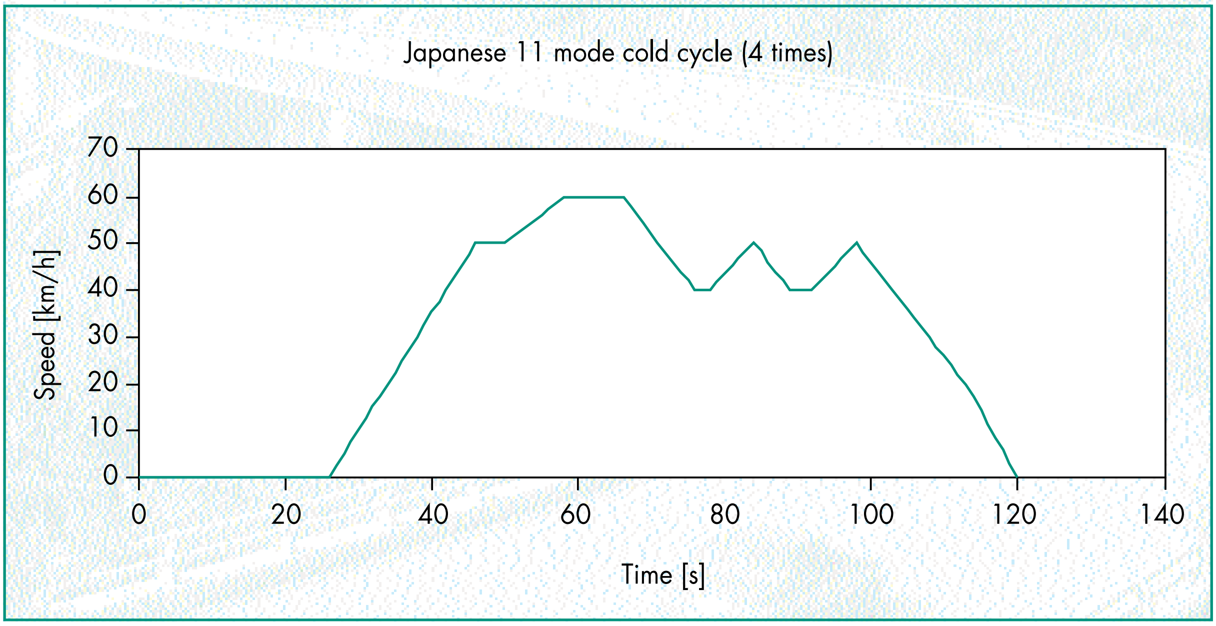
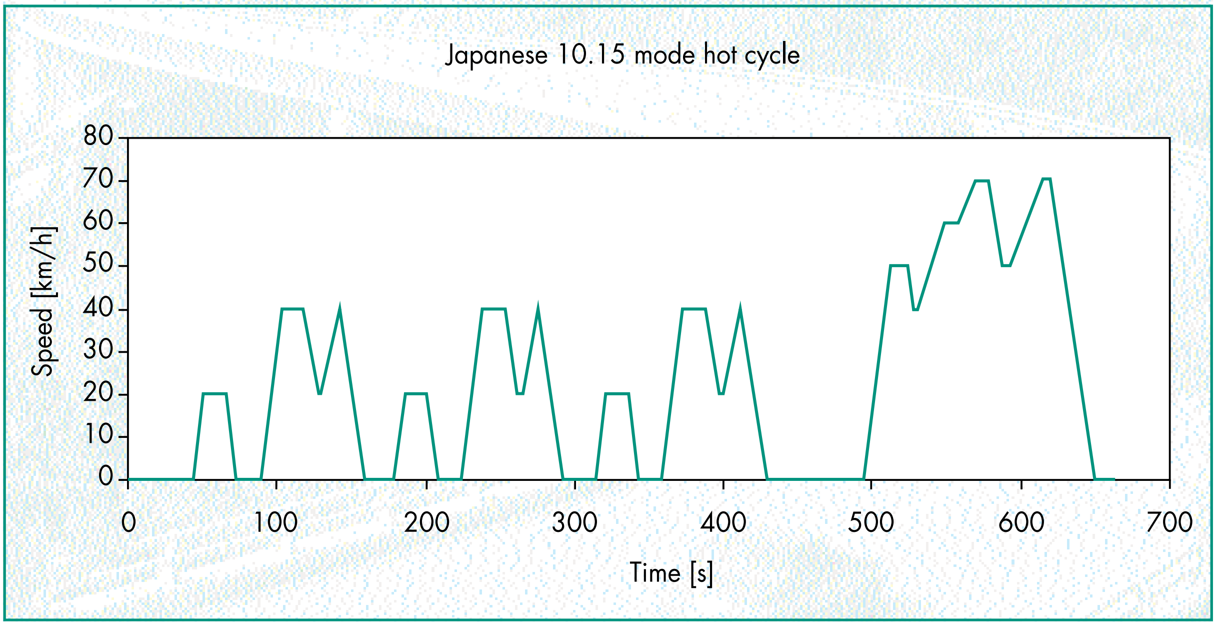


Figure C.3 Length: 4.16 km; duration: 660 seconds; max. speed: 70 km/h; average speed: 22.7 km/h.



C.5. AUSTRALIAN EMISSION STANDARDS

Australian gasoline vehicle certification standards have traditionally been based on US regulations using the US Federal Test Procedure (FTP) drive cycle. The current spark-ignition Australian Design Rule (ADR37/01) for light-duty vehicles applies only to gasoline fuelled vehicles. Gaseous fuels, therefore, are not covered by any certification standards under regulations currently in force.

Since 1995, diesel engine manufacturers have been allowed to optionally certify against one of a "menu" of international standards, including UN ECE, US Federal and Japanese regulations. Again, these standards do not currently apply to gaseous or other alternative fuels.

However, recent Australian government decisions may result in a rapid uptake of progressively more stringent standards based on the UN ECE (Euro) regulations (although in some cases allowing certification equivalent to US standards as an alternative). The changes will also result in the inclusion of all fuels covered by the UN ECE regulations.

The following Table C.14 summarises Australia's current and future spark-ignition light duty vehicle standards. Euro 2 will be implemented from January 2002, and Euro 3 from January 2005. No decision has yet been taken on possible timing for the adoption of Euro 4 or 5.

Table C.14 Regulated Emission Limits under Current and Future ADRs.

Exhaust Gas	ADR37/01 (FTP) g/km	ADR79/00 (Euro 2) g/km	ADR79/01 (Euro 3) g/km
CO	2.1	2.2	2.3
HC	0.26		0.2
HC + NO_x		0.5	
NO_x	0.63		0.15

For diesel light-duty (<3.5 tonne GVM) vehicles, the Euro 2 standard will be applied from January 2002, and Euro 4 from January 2006 for passenger and light commercial diesel vehicles. All medium and heavy-duty vehicles, i.e. all vehicles with a GVM greater than 3.5 tonnes, must comply with Euro 3 from January 2002 and Euro 4 from 1 January 2006.

Table C.15 Korea Emission Standards.

Effective Date	Vehicle Type	CO g/km	HC g/km	NO_x g/km	PM g/km	Test Cycle
2000	Gasoline and LP Gas mini cars <800 cc	2.11	0.16	0.25	–	US FTP 75
	Gasoline and LP Gas >800 cc, <3.0 tonne	2.11	0.16	0.25	–	US FTP 75
	Gasoline and LP Gas LDT< 1.7 t	2.11	0.25	0.62	–	US FTP 75
	Gasoline and LP Gas LDT 1.7 tonne to 3.0 tonne	2.74	0.29	0.43	–	US FTP 75
2004	Gasoline and LP Gas LDT<1.7 tonne	1.27	0.18	0.16	–	US FTP 75
	Gasoline and LP Gas 1.7 tonne to 3.0 tonne	1.65	0.24	0.30	–	US FTP 75

C.6 Requirements in other areas of the World

Emission test procedures and standards differ from country to country. South and Central American countries base their standards on the US regulations, e.g. US 83, US 87, and US 94. Eastern and Asian countries base their standards mainly on ECE R-83 (00 to 03) or Euro 1 and Euro 2.

- **Analogue electronic control**
  Analogue electronic control indicates a control system that operates with analogue signals, i.e. with signals that have a certain strength, e.g. in millivolts (mV). Such signals are sensitive to weakening through resistances.
- **Catalyst**
  A catalyst is a device in the exhaust of an engine that promotes chemical reactions between exhaust gas components, thereby limiting the emission of harmful or otherwise unwanted components. It is more correct to speak of a catalytic converter.
- **Closed loop control**
  Closed loop control is a term used in control technology. It indicates a type of control where the process output is measured and used as an input for the control. In the case of catalyst-equipped engines, it means that the relative air/fuel ratio is determined from the exhaust gas and adjusted through the fuelling when necessary.
- **CURE (Cancer Unit Risk Estimate)**
  This estimate is derived from the sum of contributions of each component relative to the CURE of benzene as normalising parameter. Two different methods are generally used for the estimation of the CUREs: the EPA method (US Federal Environmental Protection Agency) and the CARB method (California Air Resources Board).
- **Diesel cycle**
  Diesel cycle indicates the combustion process that is initiated by self-ignition of fuel injected in a hot high-pressure air charge. Diesel engines are also called compression ignition engines.
- **Digital electronic control**
  Digital electronic control indicates a control system that operates with digital signals, i.e. signals that represent a certain numerical value. This value does not change when the signal weakens through internal resistances. Digital control requires a microprocessor to handle the signals.
- **Dry gas**
  Dry gas indicates the exhaust gas after condensation of the water content thereof. Concentrations of exhaust gas components are higher in dry gas than in wet gas.
- **GRPE : Group of Experts on Pollution and Energy :**
  Working Party below the scope of the WP.29 with main task to develop harmonised UN/ECE Regulations for vehicles focussing on their emission aspects. This Working Party is also in charge of the evolution of the UN/ECE Regulation 67.
- **DPF**
  Diesel Particulate Filter
- **Lambda sensor**
  A lambda sensor (oxygen sensor) is a device that establishes the relative air/fuel ratio ("lambda") from a measurement of the oxygen content in the exhaust gas. In practice a lambda sensor is a bi-stable device that triggers at lambda = 1.0. It serves to establish a closed loop lambda control in the case of a stoichiometrically operating engine, i.e. an engine operating at lambda = 1.0.
- **Lean Burn**
  Lean Burn indicates an engine that operates at an air excess, usually at a quite significant air excess, so at lambda >>1.0.
- **Mobile source air toxics (MSAT)**
  Pollutant emission compounds that are presumed or known carcinogens: formaldehyde, acetaldehyde, 1,3 butadiene, benzene, polycyclic organic matter (POM or PAH), and a number of nano-particulates (nm= 10^{-9} m diameter).

- **Open loop control**

  Open loop control is the situation where a process is only regulated through forward control and no measurement of the end result is used to readjust this control. In the case of catalyst equipped engines it indicates the situation where the air/fuel ratio is not readjusted on the basis of an exhaust gas measurement.

- **Otto cycle**

  Otto cycle indicates the combustion process that is initiated by an electric spark in a premixed air/fuel mixture. Otto engines are also called spark ignition engines, or positive ignition engines.

- **Oxidation catalyst**

  An oxidation catalyst is a catalyst designed to promote oxidising reactions only. It is often used on lean burning engines that operate at a large air excess. Usually the chemical layout of three-way catalysts and oxidation catalysts is different.

- **Stoichiometric**

  The word stoichiometric in practice indicates a chemically correct air/fuel ratio, without either an excess of fuel or of air. This corresponds to lambda = 1.0.

- **Three-way catalyst**

  A three-way catalyst is the term used to indicate a catalyst that limits the emission of the three regulated exhaust gas components by promoting both oxidising and reducing reactions at the same time. In order for a three-way catalyst to function the engine has to operate strictly stoichiometrically within a narrow tolerance band. This is obtained through closed loop control over a lambda sensor. Sometimes the term "open loop three-way catalyst" is used. This indicates a catalyst that operates on average at lambda = 1.0, but where lambda control is through an open loop system. This catalyst will either oxidise or reduce at any given moment, depending on whether the engine is operating with a slight air excess or a slight fuel excess at that moment in time.

- **Turbocharger**

  A turbocharger is a device that consists of an exhaust gas driven turbine directly coupled to a compressor that pumps air into the engine. The device is used to increase the amount of air or air/fuel mixture flowing through the engine, thereby increasing the potential power output.

- **UEGO sensor**

  A universal exhaust gas oxygen sensor operates in a similar way as a lambda sensor, but gives a signal that is indicative of the actual oxygen content in the exhaust gas. Where lambda sensor triggers only around lambda = 1.0, a UEGO sensor actually measures the air/fuel ratio at lambda values at 1 and higher. A UEGO sensor can, therefore, be used in the closed loop control of a lean burn engine.

- **Wastegate**

  A wastegate is a device that limits the power of an exhaust gas driven turbine by opening a by-pass, thereby limiting the amount of exhaust gas passing through the turbine. In the case of a turbocharger this limits the amount of air pumped into the engine. A wastegate is usually applied when the turbocharger has the main aim to improve the engine power at low engine speeds, but there would otherwise be a risk that the engine would be overloaded at high engine speeds when there is substantially more exhaust gas.

- **Wet gas**

  Wet gas indicates the exhaust gas with the water that originates from combustion. Concentrations of exhaust gas components in wet gas are lower than in dry gas.

- **WP.29 :**

  World Forum for Harmonisation of Vehicles Regulations : further information on the organisation of this UN/ECE Transport Division Working Party can be found in the WP.29 document : "WP.29 : How it works, How to Join it" - see the WP.29 UN/ECE web-site.

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- UNECE/WP29/GRPE Communication.
- "LPG Fuel and Equipment Symposium 2001", CEN/TC 19 & CEN/TC 286/WG 6. Amsterdam, 1 and 2 March 2001.

Web Sites

Australian LPG Association		alpga.asn.au
European LPG Association		aegpl.com
Autogas site Australia		autogaschallenge.com.au
Brazil Sindigas		sindigas.com.br
Canadian Gas Association		cga.ca
Japan LP Gas Association		j-lpgas.gr.jp
LPG Safety Association of South Africa		gas.org.za
National Propane Gas Association US		npga.org
Propane Gas Association of Canada		propanegas.ca
Alternative Fuel Data Centre (US)	AFDC	afdc.doe.gov
Argonne National Laboratory (US)	ANL	transportation.anl.gov
Department of Transport (US)	DOT	dot.gov
Environmental Protection Agency US	EPA	epa.gov
Office of Transportation & Air Quality (US)	OTAQ	epa.gov/otaq
Office of Transportation Technologies (US)	OTT	ott.doe.gov/otu/field_ops/emiss_data.html
PowerShift Programme (GB)		est-powershift.org.uk
American Society of Mechanical Engineers	ASME	asme.org
American Society for Testing and Materials	ASTM	astm.org
Bureau of Indian Standards	BIS	bis.org.in
British Standards Institute	BSI	//bsonline.techindex.co.uk
Canadian General Standards Board		pwgsc.gc.ca/cgsb
European Committee for Standardisation	CEN	cenorm.be
Canadian Standards Association	CSA	csa.ca
German Industrial Standards Body	DIN	//www2.beuth.de
Global Engineering Documents		global.ihs.com
International Organization for Standardization	ISO	iso.ch
Japanese Industrial Standards Committee	JSA	jsa.or.jp
National Fire Protection Association (US)	NFPA	nfpa.org
South African Bureau of Standards	SABS	sabs.co.za
Standards Australia		standards.com.au
Underwriters Laboratories Inc. (US)	UL	ul.com
Standards Review (US)	UL	ulstandardsinfonet.ul.com
United Nations, Economic Commission for Europe, Transport Division, Geneva	UN/ ECE	unece.org/trans/welcome.html
Australian LPG Association	ALPGA	alpga.asn.au
European LPG Association	AEGPL	aegpl.com
Autogas site Australia		autogaschallenge.com.au
Brazil Sindigas		sindigas.com.br
Canadian Gas Association		cga.ca
Japan LP Gas Association		j-lpgas.gr.jp
LPG Safety Association of South Africa		gas.org.za
National Propane Gas Association (US)	NPGA	npga.org
Propane Gas Association of Canada	PGAC	propanegas.ca
World LP Gas Association	WLPGA	worldlpgas.com

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