European
Science and
Technology
Observatory

TRENDS IN VEHICLE AND FUEL TECHNOLOGIES

REVIEW OF PAST TRENDS

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May 2003

EUROPEAN COMMISSION
JOINT RESEARCH CENTRE

Report EUR 20746 EN

Institute for
Prospective
Technological Studies

About the JRC-IPTS

The **Joint Research Centre** (JRC) is a Directorate General of the European Commission, staffed with approximately 2,100 people, coming in the vast majority from the 15 Member States of the European Union. The Brussels Support Services (including the office of the Director General and the Science Strategy Directorate) and seven Institutes located in five different countries compose the main organisational structure of the JRC (http//:www.jrc.org). The Institute for Prospective Technological Studies (IPTS) is one of the seven Institutes making up the JRC. The mission of the JRC is to provide customer-driven scientific and technical support for the conception, implementation and monitoring of EU policies.

The Institute for Prospective Technological Studies (IPTS) is one of the seven Institutes making up the JRC. It was established in Seville, Spain, in September 1994.

The **mission of the IPTS** is to provide prospective techno-economic analyses in support of the European policy-making process. IPTS' prime objectives are to monitor and analyse science and technology developments, their cross-sectoral impact, and their inter-relationship with the socio-economic context and their implications for future policy development. IPTS operates international networks, pools the expertise of high level advisors, and presents information in a timely and synthetic fashion to policy makers (http//:www.jrc.es).

The **IPTS is a unique public advisory body**, independent from special national or commercial interests, closely associated with the EU policy-making process. In fact, most of the work undertaken by the IPTS is in response to direct requests from (or takes the form of long-term policy support on behalf of) the European Commission Directorate Generals, or European Parliament Committees. The IPTS also does work for Member States' governmental, academic or industrial organisations, though this represents a minor share of its total activities.

Although particular emphasis is placed on **key Science and Technology fields**, especially those that have a driving role and even the potential to reshape our society, important efforts are devoted to improving the understanding of the complex interactions between technology, economy and society. Indeed, the impact of technology on society and, conversely, the way technological development is driven by societal changes, are **highly relevant themes within the European decision-making context**.

The **inter-disciplinary prospective approach** adopted by the Institute is intended to provide European decision-makers with a deeper understanding of the emerging science and technology issues, and it complements the activities undertaken by other institutes of the Joint Research Centre.

The IPTS **approach** is to collect information about technological developments and their application in Europe and the world, analyse this information and transmit it in an accessible form to European decision-makers. This is implemented in the following **sectors of activity**:

- Technologies for Sustainable Development
- Life Sciences / Information and Communication Technologies
- Technology, Employment, Competitiveness and Society
- Futures project

In order to implement its mission, the Institute develops appropriate contacts, awareness and skills to anticipate and follow the agenda of the policy decision-makers. **IPTS Staff** is a mix of highly experienced engineers, scientists (life-, social- material- etc.) and economists. Cross-disciplinary experience is a necessary asset. The IPTS success is also based on its **networking capabilities and the quality of its networks** as enabling sources of relevant information. In fact, in addition to its own resources, the IPTS makes use of external Advisory Groups and operates a number of formal or informal networks. The most important is a Network of European Institutes (*the European Science and Technology Observatory*) working in similar areas. These networking activities enable the IPTS to draw on a large pool of available expertise, while allowing a continuous process of external peer-review of the in-house activities.

About ESTO

The European Science and Technology Observatory (ESTO) is a network of organisations operating as a virtual institute under the European Commission's – Joint Research Centre's (JRC's) Institute for Prospective Technological Studies (IPTS) - leadership and funding. The European Commission JRC-IPTS formally constituted, following a brief pilot period, the European Science and Technology Observatory (ESTO) in 1997. After a call for tender, the second formal contract for ESTO started on May 1st 2001 for a period of 5 years.

Today, **ESTO is presently composed of a core of twenty European institutions**, all with experience in the field of scientific and technological foresight, forecasting or assessment at the national level. These nineteen organisations have a formal obligation towards the IPTS and are the nucleus of a far larger network. Membership is being continuously reviewed and expanded with a view to match the evolving needs of the IPTS and to incorporate new competent organisations from both inside and outside of the EU. This includes the objective to broaden the operation of the ESTO network to include relevant partners from EU Candidate Countries. In line with the objective of supporting the JRC-IPTS work, ESTO **aims** at detecting, at an early stage, scientific or technological breakthroughs, trends and events of potential socio-economic importance, which may require action at a European decision-making level.

The ESTO **core-competence** therefore resides in prospective analysis and advice on S&T changes relevant to EU society, economy and policy.

The **main customers** for these activities is the JRC-IPTS, and through it, the European policy-makers, in particular within the European Commission and Parliament. ESTO also recognises and addresses the role of a much wider community, such as policy-making circles in the Member States and decision-makers in both non-governmental organisations and industry.

ESTO members, therefore, **share the responsibility** of supplying the IPTS with up-to-date and high quality scientific and technological information drawn from all over the world, facilitated by the network's broad presence and linkages, including access to relevant knowledge within the JRC' Institutes.

Currently, ESTO is engaged in the following **main activities:**

- A series of **Specific Studies**, These studies, usually consist in comparing the situation, practices and/or experiences in various member states, and can be of a different nature a) *Anticipation/Prospective analysis*, intended to act as a trigger for in-depth studies of European foresight nature, aiming at the identification and description of trends rather than static situations; b) *Direct support of policies in preparation* (ex-ante analysis); and c) *Direct support of policies in action* (ex-post analysis, anticipating future developments).
- Implementation of **Fast-Track** actions to provide quick responses to specific S&T assessment queries. On the other hand, they can precede or complement the above mentioned Specific Studies.
- To produce input to **Monitoring Prospective S&T Activities** that serves as a basis of experience and information for all other tasks.
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- Support the production of **"The IPTS Report"**, a monthly journal targeted at European policy-makers and containing articles on science and technology developments, either not yet on the policy-makers' agenda, but likely to emerge there sooner or later.

For more information: http//:www.jrc.es Contacts: esto-secretary@jrc.es

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Institute for Prospective Technological Studies

IPTS Technical Report Series, EUR 20746 EN

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Seville, Spain, 2003

Published by:
EUROPEAN COMMISSION
Joint Research Centre
IPTS- Institute for Prospective Technological Studies
W.T.C. Isla de la Cartuja s/n
E-41092 Seville, Spain
http:\\www.jrc.es

Printed in Spain

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EXECUTIVE SUMMARY

The objective of this study was to review past trends and anticipate future developments in vehicle and fuel technologies, mainly in relation to passenger transport. The study provided an overview of trends in the main families of conventional and alternative technologies and fuels, covering the evolution of their major technical characteristics, fuel economy, user costs and environmental impacts.

The technologies covered include internal combustion engines, on both conventional fuels (gasoline or diesel) and on alternative fuels (LPG, natural gas, hydrogen, alcohols, biodiesel, DME and synthetic fuels), electric vehicles, hybrid vehicles and fuel cells. Extra attention has been given to alternatives that can provide hydrogen for fuel cells. The time-scale of the study covers the last 20 years of trends and extends until the year 2020 in the anticipation of possible developments. It covers developments on a worldwide scale, with particular emphasis on the potential for introduction of new technologies in Europe, North America and Japan. The results of the study will be used as input for the transport and energy models maintained and developed by JRC-IPTS. The study will also provide input to relevant JRC-IPTS activities such as the Sustainable Energy Technology Reference and Information System (SETRIS).

Vehicle and fuel technologies have undergone important developments in the last 30 years. The volatility of oil prices and increasing concerns about the environment have influenced user choices and initiated government intervention (e.g. emission limits) in many countries. As a result, car manufacturers have had to accelerate the introduction of new engine and fuel technologies. In terms of fuel efficiency and emissions, technological development has been fast, but not fast enough to meet the growing demand for transport. Car ownership and car use are reaching saturation levels in Europe, USA and Japan, but their expected growth in the rest of the world will probably outweigh the efficiency gains achieved through technological solutions.

Gasoline was the prime fuel for propulsion of passenger cars until the 1970s. The oil crisis of 1973 led to an increase in awareness of the need for better fuel economy, and alternative fuels and propulsion systems received more attention. In the late 1980s and early 1990s environmental concerns began to increase, leading to the introduction of emission limits. The spark-ignited ***gasoline engine*** is still the main option for passenger cars and light-duty vehicles. Emissions from gasoline engines have been reduced dramatically with the introduction of the three-way catalyst, coupled with electronically controlled gasoline injection (in the throttle body). With a renewed emphasis on fuel economy and CO_2 emissions (linked to the fear of global warming), fuel-saving technologies such as gasoline direct injection (GDI) and variable valve actuation are gaining interest.

Diesel engines were mainly used in the past for stationary purposes or for heavy-duty vehicles. The shift from indirect injection to turbo diesel direct injection and the introduction of electronic diesel control (i.e. common rail), led to significant improvements in terms of fuel economy and emissions. Noise and performance, once the main drawback of diesel engines, have also improved tremendously in the latest diesel models.

The advantages of diesel in terms of fuel economy and durability have made it very popular in Europe over the last 10 years with sales reaching 50% of the European market. In the United States, however, diesel passenger cars are not popular, due to different fuel pricing strategies, different emission legislation and the poor image of “smoking” diesel engines.

Alternative fuels came into the picture in the 1970s for reasons of security of energy supply. By the end of the 1980s growing concern about the environmental impact of automobiles stimulated the interest in alternative fuels. The most popular alternative fuels at the moment are LPG, alcohols (ethanol and methanol), natural gas, and - for diesel engines - biodiesel. Other fuels that have not so far reached the commercialisation stage are hydrogen (particularly for use in fuel cells), DME and synthetic fuels. Most vehicles operating on alternative fuels are also capable of using conventional fuels such as gasoline (in the case of LPG, natural gas, alcohols) or diesel (in the case of biodiesel). These vehicles are often referred to as bi-fuel, dual-fuel or flexible fuel vehicles. The two-fuel option increases their functionality, since alternative-fuel filling stations may be rare. On the other hand, this may cause people to operate these ‘alternative fuel vehicles’ only with conventional fuels.

The 1973 oil crisis also initiated a belief in ***electric vehicles***. Numerous projects were launched in the 1970s, based on the assumption that batteries could be improved rapidly. Batteries have remained a major drawback for purely electric vehicles, however, and the EV-market remained well below expectations. By the end of the 1990s, hybrid vehicles had been introduced to the market. These do not have the major drawbacks of battery electric vehicles (low range, long recharging), and at the same time are both environmentally friendly and attain better fuel economy than do conventional vehicles. Hybrid vehicles show good market potential.

Emerging technologies such as electric cars, fuel cells or cars fuelled by natural gas or bio-fuels have to compete with established fuels (gasoline and diesel) and with the proven technology of the internal combustion engine. The emerging alternatives still lag in terms of maturity, infrastructure and fuel availability, safety and public perception, and are not yet considered as alternatives by consumers. Whether they will eventually become such, when their cost falls to competitive levels, remains an open question.

In the EU, fuel is taxed at relatively high levels (compared with the USA) to encourage consumers to purchase and operate vehicles with acceptable fuel economy. As a consequence, fuel economy figures are seriously better than they are in the USA. Furthermore, to achieve Kyoto targets to lower CO_2 emissions, the ACEA made a voluntary agreement with the European Commission to reduce CO_2 emissions from new cars by around 25% by 2008 (in comparison with the 1995 figures). In the USA, Corporate Average Fuel Economy (CAFE) mandates manufacturers to sell a mix of vehicles whose weighted average fuel economy meets specified annual targets. As CAFE regulations have remained unchanged over the past 10 years, there has been no incentive for manufacturers to improve fuel economy figures.

The main trends of vehicle and fuel technologies over the last 30 years can be summarised as follows:

- Significant improvement of fuel economy, performance and emissions for both gasoline and diesel fuelled passenger cars
- Increase of the share of diesel in Europe
- Increase in total transport demand has grown faster than improvements in fuel economy and emissions
- Changing user preferences / lifestyles can lead to an increase in higher consuming and polluting cars (e.g. Sport Utility Vehicles)
- Electric vehicles have not managed to overcome technical and economic barriers
- Some alternatives (i.e. hybrid vehicles, natural gas, bio-fuels) are promising options for the medium term.
- Emission control and taxation can significantly influence technological development in the automotive sector

CONTENTS

ABBREVIATIONS

Fuels and chemical substances

CFC	Chlorofluorocarbons	LNG	Liquefied Natural Gas
CGH_2	Compressed Gaseous Hydrogen	LPG	Liquefied Petroleum Gas
CH_4	Methane	M85	85% Methanol, 15% Gasoline
CHF	Clean Hydrocarbon Fuel	MTBE	Methyl Tertiary Butyl Ether
CNG	Compressed Natural Gas	N_2O	Dinitrogen Oxide
CO	Carbon Monoxide	NG	Natural Gas
CO_2	Carbon Dioxide	NiMH	Nickel Metal Hydride
DME	Dimethyl Ether	NMHC	Non-methane Hydrocarbons
E85	85% Ethanol, 15% Gasoline	NMOG	Non-Methane Organic Gases
E95	95% Ethanol, 5% Gasoline	NO_x	Nitrogen Oxides
ETBE	Ethyl Tertiary Butyl Ether	PM	Particulate Matter
FAME	Fatty Acid Methyl Ester	RFG	Reformulated Gasoline
GHG	Greenhouse Gases	RME	Rapeseed Methyl Ester
GTL	Gas-to-Liquid	SOF	Soluble Organic Fraction
H_2	Hydrogen	SO_x	Sulphur Oxides
HC	Hydrocarbons	TBA	Tertiary Butyl Alcohol
HCHO	Formaldehyde	VOC	Volatile Organic Compounds
LH_2	Liquefied Hydrogen		

Technical terms

4WD	4-wheel drive	LDV	Light-Duty Vehicle
A/F	Air to Fuel ratio	LEV	Low Emission Vehicle
ABS	Anti-lock Braking System	MCFC	Molten Carbonate Fuel Cell
AFC	Alkaline fuel cell	MDPV	Medium-Duty Passenger Vehicle
APU	Auxiliary Power Unit	MDT	Medium-Duty Truck
BEV	Battery Electric Vehicle	MIL	Malfunction Indicator Light
CAFE	Corporate average fuel economy	MPI	Multi-Port Injection
CAGR	Corporate Average Growth Rate	MTA	Manual Transmission
CAN	Controller Area Network	MY	Model Year
Cd	Drag Coefficient	NA	Naturally aspired
CI	Compression Ignition	NEDC	New European Driving Cycle
CIDI	Compression Ignition Direct Injection	NGV	Natural gas vehicle
CR	Compression Ratio	OBD	On-Board Diagnostics
CRT	Continuously Regenerating Trap	OEM	Original Equipment Manufacturer
CVT	Continuously Variable Transmission	PAFC	Phosphoric Acid fuel cell
DFI	Digital Fuel Injection	PCU	Power Control unit
DI	Direct injection	PCV	Positive Crankcase Ventilation
DISI	Direct injection spark ignition	PEM-FC	Polymer Exchange Membrane Fuel Cell
DMFC	Direct methanol fuel cell	PFI	Port fuel injection
DPF	Diesel Particulate Filter	POX	Partial Oxidation
ECE	Urban Driving Cycle (EU)	P-ZEV	Partial Zero Emission Vehicle
ECU	Engine (electronic) Control Unit	RVP	Reid Vapour Pressure

EDC	Electronic Diesel control
EFI	Electronic Fuel Injection
EGR	Exhaust gas recirculation
EUDC	Extra-Urban Driving Cycle (EU)
EV	Electric Vehicle
FC	Fuel Cell
FCV	Fuel Cell Vehicle
FFV	Flexible Fuel Vehicle
FPFC	Fuel Processed (reformer) fuel cell
FSI	Fuel Stratified Injection
FT	Fisher-Tropsch Processed
FTP	Federal Test Procedure (US)
GDI	Gasoline Direct Injection
GVW	Gross Vehicle Weight
HCCI	Homogeneous Charge Compression Ignition
HEV	Hybrid Electric Vehicle
HSDI	High Speed Direct Injection
HVAC	Heating, Ventilation and Air-Conditioning
ICE	Internal Combustion Engine
IDI	Indirect injection
IMA	Integrated Motor Assist
ISAD	Integrated Starter Assist Damper
ISG	Integrated Starter Generator
LAN	Local Area Network
SA	Starter Alternator
SCR	Selective catalytic reduction
SI	Spark ignition
SOFC	Solid Oxide Fuel cell
SR	Steam Reforming
SULEV	Super Ultra Low Emission Vehicle
SUV	Sport Utility Vehicle
TBI	Throttle Body Injection
TC	Turbo charged
TD	Turbo diesel
TDI	Turbocharged Direct Injection
TLEV	Transitional Low Emission Vehicle
TTW	Tank-to-wheel
TWC	Three-Way Catalyst
ULEV	Ultra-Low Emission Vehicle
ULSAB	Ultra Light Steel Auto Body
ULSAC	Ultra Light Steel Auto Closure
ULSAS	Ultra Light Steel Auto Suspension
VMT	Vehicle Miles Travelled
VVA	Variable Valve Actuation
VVT	Variable Valve Timing
WTT	Well-to-tank
WTW	Well-to-wheel
ZEV	Zero Emission Vehicle

Organisations and workgroups

AAA	Association Auxiliaires de l'Automobile
ABI	Austrian Biofuels Institute
ACEA	European Automobile Manufacturers Association
AECC	Association for Emissions Control by Catalyst
AFDC	Alternative Fuels Data Centre (US)
AMAA	American Automobile Manufacturers' Association
AMI	American Methanol Institute
APME	Association of Plastics Manufacturers in Europe
CAA	Clean Air Act
CAAA	Clean Air Act Amendment
CARB	California Air Resources Board
CEC	California Energy Commission
DOE	United States Department of Energy
DOT	United States Department of Transportation
EAA	European Aluminium Association
EIA	United States Energy Information Administration
EPA	United States Environmental Protection Agency
EU	European Union
EU15	15 member states of the European Union
IANGV	International Association for Natural Gas Vehicles
IEA	International Energy Agency

INEE	Instituto Nacionàl de Efficiéncia Energética (Brazil)
IPCC	Intergovernmental Panel on Climate Change
JAMA	Japan Automobile Manufacturers Association
MEET	Methodologies for Estimating Air Pollutant Emissions from Transport
NAEI	National Atmospheric Emissions Inventory (UK)
NAVC	Northeast Advanced Vehicle Consortium
NLEV	National Low Emission Vehicle Program (US)
OTT	Office of Transportation Technologies (US DOE)
PNGV	Partnership for a New Generation of Vehicles
SAE	Society of Automotive Engineers
SMMT	Society of Motor Manufacturers and Traders
UFOP	Union zur Förderung von Öl- und Proteinpflanzen (Germany)

INTRODUCTION

In recent years there has been considerable growth in road transport, and this trend is set to continue for the foreseeable future. Today's transport is based almost exclusively on the consumption of petroleum products such as gasoline and diesel, and is responsible for producing over 20% of overall anthropogenic CO_2 emissions. The contribution of transport to greenhouse gas levels will continue to grow as demand for cars worldwide remains high and the potential for reducing CO_2 emissions from conventional vehicles reaches its limits.

Sustainable mobility represents a major challenge for policy-makers, and vehicle technologies for individual mobility are recognised as having the potential to make a significant contribution. In particular, they could provide continued personal freedom with reduced energy consumption and improved environmental performance.

In recent decades vehicles have undergone a number of changes aimed at achieving more environmentally friendly transport. Some of these changes have resulted from technology developments and cost optimisation, but many were driven by government actions such as emission legislation. There are several technical options for future vehicles, all of them cleaner because they will have to comply with stricter emission levels. In particular, developments towards fuel-cell vehicles seem attractive in the long-term, when fossil resources are slowly but surely diminishing.

The objective of this ESTO study was to review past trends and anticipate future developments in vehicle and fuel technologies, mainly in relation to passenger transport. The study provided an overview of the trends in the major families of conventional and alternative technologies and fuels, covering the evolution of their main technical characteristics, fuel economy, user costs (variable and fixed) and environmental impacts.

The technologies covered include internal combustion engines, on both conventional fuels (gasoline or diesel) and on alternative fuels (LPG, natural gas, hydrogen, alcohols, biodiesel, DME and synthetic fuels), electric vehicles, hybrid vehicles and fuel cells. Extra attention has been given to alternatives that can provide hydrogen for fuel cells.

The time-scale of the study covers the last 20 years of trends and extends until the year 2020 in the anticipation of possible developments. It covers developments on a worldwide scale, with particular emphasis on the potential for introduction of new technologies in Europe, North America and Japan.

The results of the study will be used as input for the transport and energy models maintained and developed by JRC-IPTS. The study will also provide input to relevant JRC-IPTS activities such as the Sustainable Energy Technology Reference and Information System (SETRIS).

1 MAIN TRENDS OF VEHICLE AND FUEL TECHNOLOGIES

by Luc Pelkmans (Vito), Gotzon Azkarate (INASMET) & Staffan Hultén (MERIT)

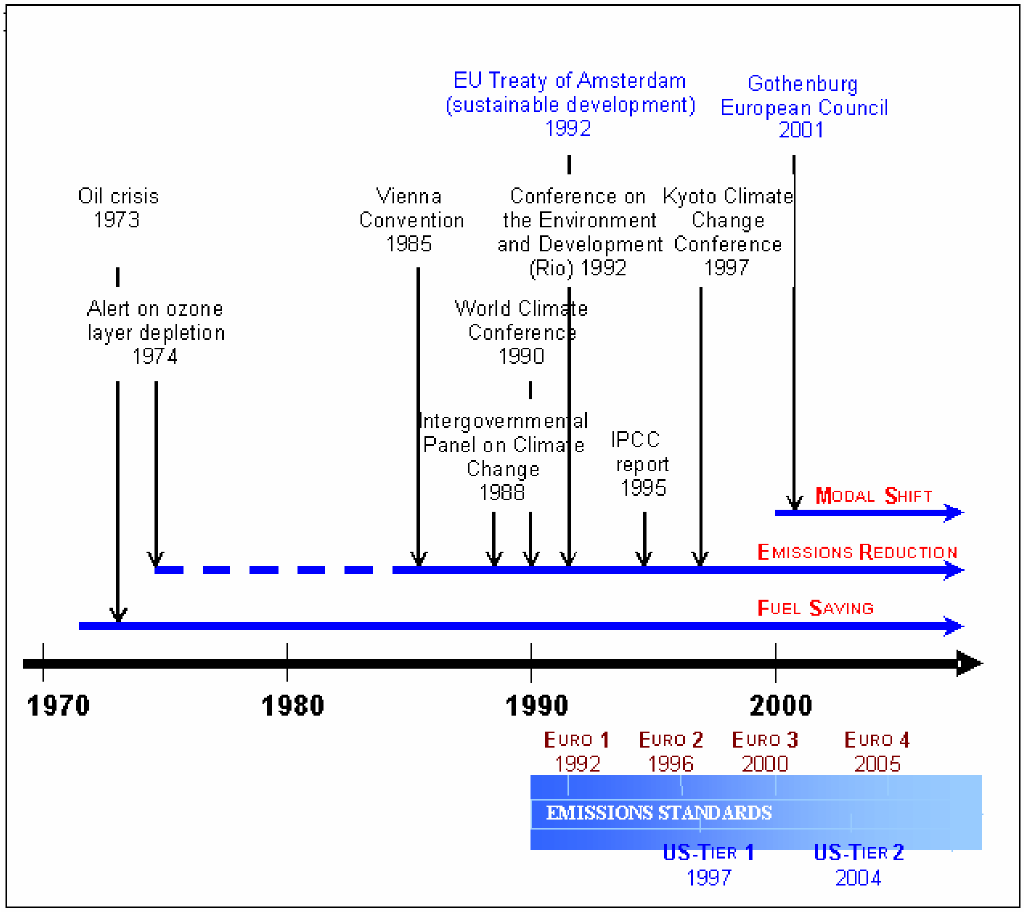
1.1 Introduction

This chapter highlights the main trends in vehicle and fuel technologies up to the year 2000. The study has focused on engine technology, but trends concerning transmission, aerodynamics, materials and electronics are also discussed.

The technical evolution of the world of the automobile since 1980 has been marked by certain historical events. From the first oil crisis in 1973 to the Johannesburg meeting in August 2002, different guidelines have been indicated for the reduction of both fuel consumption and emissions to the atmosphere, as well as for sustainable development. Some of these events are shown in the graphic below.

The first oil crisis came in 1973. Oil importing states realised that they were energy dependent and a new, until then unconsidered, idea took shape – fuel saving. Many governments set limits on speed and fuel consumption, while manufacturers began to make engines that were less polluting.
In June 1974 the magazine *Nature* published an article by Paul Crutzen and Maria Molina (1995 Nobel Prize for Chemistry). This article alerted the international community to the way in which the Earth's ozone layer was being depleted. In March 1985 the Vienna Convention for the Protection of the Ozone Layer lent a formal framework to the impetus for global action. It drew up an international timetable for first reducing, then eliminating by 2000, the chlorofluorocarbons (CFCs) used in industry. In 1988 it set up a new body, the 2000-strong Intergovernmental Panel on Climate Change (IPCC) to gain further understanding of the way in which the greenhouse effect worked. Its task was to assess scientific data on climate change, appraise social, economic and ecological impacts, and to draw up prevention and response strategies.
In June 1992, in Rio de Janeiro, the UN held its second Conference on the Environment and Development. This represented a milestone for the sheer scope of the principles it was to adopt in a final declaration, which emphasised that development and environmental protection were inseparable. The Rio Declaration urged nations to co-operate as global partners in order to conserve, protect and restore the health and the integrity of the Earth's ecosystem. In 1990, two years before Rio, the second World Climate Conference in Geneva had already recognised climate change as a worldwide problem on an unprecedented scale. In 1995 the IPCC's second report confirmed the fears voiced at Rio. The international negotiation calendar drawn up at Rio went ahead and in December 1997, the Kyoto Climate Change Conference took place with the objective of arriving at a protocol agreement on targets for cutting greenhouse gases.

Figure 1.1: Global milestones with impact on emissions and fuel consumption



1.2 Internal Combustion Engine

1.2.1 Introduction to engine evolution

From the early stages of automobile design, the internal combustion engine (ICE) had been the heart of the car. The earliest automobile engine was modified from an industrial-use internal combustion engine.

The first internal combustion engine was invented by the Italians Barsanti and Matleucci in 1856; it was a stationary engine powered by coal gas from a railway station.

In 1876, Nicolas Otto made the first four-stroke coal oil engine, which cut fuel consumption as much as 75% compared with contemporary engines. His student, Daimler, created his own gasoline engine in 1883 and within two years had raised maximum engine speed to 900 rpm, four times higher than Otto's engine. In 1885, Benz's engine adopted the battery, coil and spark-plug ignition system. In 1888, Edward Butler of the UK designed the carburettor that was adopted for all cars for 100 years.

In 1890, the German Rudolf Diesel invented the diesel engine. Early engines were all single-cylinder, with a large rotating flywheel to avoid misfire. Later, multi-cylinder engines were mostly arranged in-line, although from time to time there were horizontally opposed engines.

1.2.2 Spark ignition engine (Otto)

The spark ignition (SI) engine, invented by Nicolas Otto, was the sole basis for automobile transport until the 1970s, and is still the major power source for current light-duty vehicles.

The main characteristics of spark-ignited engines are:

- The SI engine injects fuel to the air as it is drawn into a cylinder. This principle changes, however, in the current development of gasoline direct injection.
- The fuel-air mixture is compressed and is ignited by a spark.
- The power output of an SI-engine is controlled by a throttle, which varies the amount of fuel-air mixture drawn into a cylinder. In the future this may also be changed by variable valve control.
- An SI-engine usually runs stoichiometrically – the fuel-air ratio is fixed so that there is just enough air to burn all the fuel. This is particularly important when a three-way catalyst is matched to the exhaust. This principle has also been changed in the current development of lean-burn SI engines.

It is useful to regard an engine as a set of interconnected systems. Four of the systems of a spark-ignited engine will be covered here – the air, fuel, exhaust and control systems. The air system delivers the intake air-fuel mixture to the engine. The fuel system provides for fuel storage in the vehicle, delivers fuel to the intake air system and mixes the air and fuel in the correct proportion so the mixture burns well in the engine. The exhaust system routes the combustion gases to the atmosphere. In modern vehicles, a complex, computerised control system balances the often conflicting goals of high power, good fuel economy and low emissions.

Everything, of course, starts with the fuel.

The possible fuels for spark-ignition engines include:

- Gasoline
- Natural gas (mostly methane)
- Propane / butane (LPG)
- Hydrogen
- Methanol and derivatives (e.g. MTBE), possibly blended with gasoline
- Ethanol and derivatives (e.g. ETBE), possibly blended with gasoline
- Synthetic gasoline fuel

Gasoline fuel (also called petrol) is made from petroleum and consists of a number of hydrocarbons along with some additives to improve the properties of the fuel. It is liquid and has a high energy content. In the early years of the automobile, naturally occurring gasoline was expensive and often sold in small quantities in pharmacies. Gasoline began to be produced inexpensively with the advent of petroleum refining technologies such as thermal cracking and eventually catalytic cracking. As a result, gasoline became the fuel of choice for internal combustion engines. Spark-ignited engines are therefore often referred to as gasoline engines.

The properties of gasoline have evolved somewhat over the past decades to improve performance and driveability (e.g. octane number), but also to lower its impact on the environment (lead content, sulphur content, oxygenates, etc.). The composition is prescribed by governmental regulations. The evolution of these regulations will be discussed in a following chapter.

Effects of gasoline composition and properties on vehicle emissions [MED (2001)]:

- Sulphur content affects the performance and durability of catalysts. Advanced catalyst formulations being developed for Euro 4 compliance are particularly sensitive and can only be used with a very low sulphur fuel (50 ppm or lower).
- Fuel parameters such as volatility and aromatics content affect engine emissions as follows, but do not directly affect emissions control technology.
- Reducing the volatility of gasoline through reduced Reid Vapour Pressure (RVP) and/or lower distillation temperatures has a significant impact on VOC emissions.
- Addition of oxygenates reduces CO emissions.
- Reduction of the aromatics content reduces emissions of air toxics, hydrocarbons and CO.
- Reduction of olefins significantly reduces butadiene emissions.

The other fuels mentioned will be discussed in the section covering alternative fuel vehicles.

The use of methanol, ethanol and their derivatives should also be mentioned here, however, as, from the 1990s, they have been added on a large scale to gasoline as oxygenates. Oxygenates are organic compounds containing carbon, oxygen and hydrogen. They serve three basic objectives: boosting octane value, serving as a fuel substitute (e.g. ethanol in Brazil), and providing an efficient means of reducing harmful emissions (especially CO and hydrocarbon emissions).

The commonly used oxygenates in gasoline blends are methanol, ethanol, isopropanol, tertiary butyl alcohol (TBA), methyl tertiary butyl ether (MTBE) and iso-butyl alcohol.

MTBE, the most popular oxygenate, has been widely used in the United States for a number of years. In response to recent concerns about groundwater contamination, however, the use of MTBE and other oxygenates (except ethanol) will be banned in California from December 2002 [MED (2001)].

Air is drawn into the engine through the intake system. An air filter is used to keep dust and contaminants (e.g. insects) out of the engine. To control engine speed, a throttle is mounted in the air intake. This is simply a disk attached to a shaft to block air flow into the engine. The accelerator pedal is mechanically linked to the throttle. Depressing the accelerator pedal tilts the disk, reducing the blocked area and allowing more air to enter the engine. With more air, the engine can use more fuel and produce more power to accelerate, climb a hill or maintain a higher cruising speed.

A recent development has been to replace the mechanical link between the accelerator pedal and the throttle by an electric link. This is called ‘drive by wire’.

An engine that uses intake air at atmospheric pressure is said to be naturally aspirated. The amount of air a naturally aspirated engine can use is limited by the local air density (barometric pressure) and pressure losses in the intake system. To get more air into an engine, small compressors are sometimes used to pressurize the intake air. If the compressor is driven off the engine crankshaft, it is called a supercharger. Another way to power the compressor is to put it on a common shaft with a turbine driven by the engine's exhaust gas. This arrangement is called turbo-charging. Turbochargers are more compact than superchargers and can be used on all sizes of engines. To maintain boost pressure at a relatively constant amount over a wide range of engine speeds, some sort of pressure regulator is needed. A waste gate is the typical solution. The waste gate opens to divert some of the exhaust flow around the turbine when boost pressure is at the desired level.

Engines generally are separated into two distinct pieces, the cylinder head and the block. The head, or top of the modern vehicle engine, controls the gas flow through the engine and also holds the spark plugs. Intake valves and exhaust valves allow for precisely timed intake and exhaust flows. The movement of the valves is controlled by means of a shaft with elliptical lobes and is named a camshaft. As the camshaft rotates, the lobes push against the rocker arms to open the valves against spring pressure either directly or via pushrods. Engines with a camshaft mounted in the head above the valves are of an overhead cam (OHC) design, and engines with the camshafts mounted below the valves, on the block, are of a pushrod design.

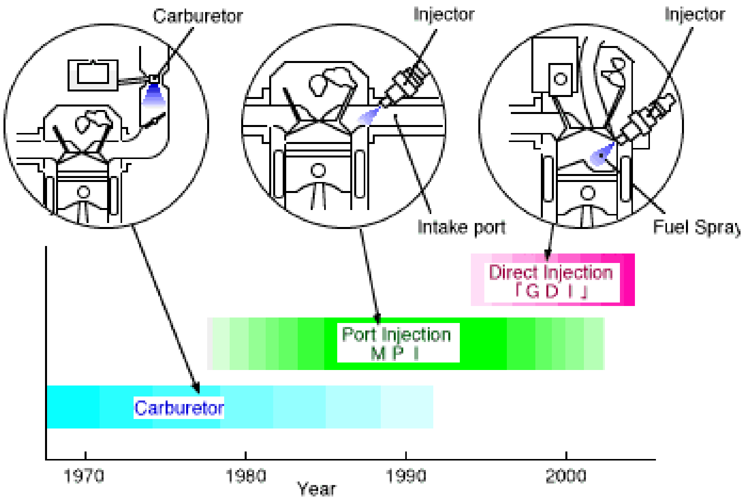
Currently engines typically have one to three intake valves and one or two exhaust valves per cylinder. An engine with two intake and two exhaust valves per cylinder is of a four-valve head design. More valves per cylinder are preferred for better breathing. Usually the exhaust valves are slightly smaller in diameter than the intake valves. It is easier to push out exhaust gases pressurised above atmospheric pressure than to draw in the air-fuel mixture at atmospheric pressure.

Progress in fuel control and their combination with after-treatment devices have made a particular difference in the emissions and the fuel consumption of gasoline engines.

The following figure offers a general overview of the fuel injection milestones in gasoline engines for passenger cars.

As a result of emission and fuel efficiency laws, the fuel system in modern cars has changed a lot over the years. The 1990 Subaru Justy was the last car sold in the United States to have a carburettor. But fuel injection has been around since the 1950s, and electronic fuel injection was used widely in European cars starting around 1980. Now, all gasoline cars sold in the United States and Europe have fuel injection systems.

Figure 1.2: Gasoline injection evolution graph



source: Mitsubishi, 1997

Carburettor

For much of the existence of the spark-ignited internal combustion engine, the carburettor was the device that supplied fuel to the engine. On many other machines, such as lawnmowers and chainsaws, it still is.
The goal of a carburettor is to mix just the right amount of gasoline with air so that the engine runs properly. If insufficient fuel is mixed with the air, the engine "runs lean" and either will not run or risks damage. If too much fuel is mixed with the air, the engine "runs rich" and either will not run (it floods), runs very smoky, runs poorly (bogs down, stalls easily), or at the very least wastes fuel. The carburettor is in charge of getting the mixture just right.
As the automobile evolved, the carburettor became increasingly complicated in order to handle all of the operating requirements. For instance, to handle these tasks, carburettors had five different circuits:

- **Main circuit** – Provides just enough fuel for fuel-efficient cruising
- **Idle circuit** – Provides just enough fuel to keep the engine idling
- **Accelerator pump** – Provides an extra burst of fuel when the accelerator pedal is first depressed, reducing hesitation before the engine speeds up
- **Power enrichment circuit** – Provides extra fuel when the car is going up a hill or towing a trailer
- **Choke** – Provides extra fuel when the engine is cold so that it will start

In order to meet stricter emission requirements, catalytic converters were introduced in the mid-1970s. Very precise control of the air-to-fuel ratio was required for the catalytic converter to be effective. Oxygen sensors monitor the amount of oxygen in the exhaust, and the **engine control unit** (ECU) uses this information to adjust the air-to-fuel ratio in real-time. This is called **closed loop control** – it was not feasible to achieve this control with carburettors. There was a brief period of electrically controlled carburettors before fuel injection systems took over, but these electrical carburettors were even more complicated than the purely mechanical ones.

In 1981, carburettors were doomed to disappear in the USA when changes in regulations required a huge decrease in tailpipe emissions.

Electronic fuel injection (EFI)

The main reason for the introduction of fuel injection was because it provided a better way to meet government fuel economy and emission standards. The fact, however, that fuel injection is an all-round better fuel delivery system is equally important.

Fuel injection has no choke, but sprays atomised fuel directly into the engine. This eliminates most of the cold-start problems associated with carburettors. Electronic fuel injection also integrates more easily with computerised engine control systems because the injectors are more easily controlled than a mechanical carburettor with electronic add-ons. Multiport fuel injection (where each cylinder has its own injector) delivers a more evenly distributed mixture of air and fuel to each of the engine's cylinders, which improves power and performance. Sequential fuel injection (where the firing of each individual injector is controlled separately by the computer and timed to the engine's firing sequence) improves power and reduces emissions. So there are some valid engineering reasons as well for using fuel injection.

History

The developments in gasoline fuel injection began during World War II with fuel injection for aviation purposes. Electronic fuel injection had its beginnings in Italy when an engineer named Ottavio Fuscaldo incorporated an electrical solenoid as a means of controlling fuel flow – this was a modern electronic fuel injection development.

At the end of the 1940s and in the early 1950s, externally driven gasoline injection systems were developed for application in automobiles, surprisingly for the low-price categories. The application of gasoline injection for bigger and more expensive cars began with the use of a Bosch *direct* injected fuel system in the Mercedes-Benz 300SL. Up until 1968, line pumps, similar to diesel injection pumps, had been used. Apart from Bosch, other companies, such as Kugelfischer/Schäfer, Simms, Scintilla and Lucas, produced gasoline injection systems for direct and indirect injection.

In 1967 Bosch introduced the D-Jetronic electronic gasoline injection system, replaced from 1973 by the L and K Jetronic. The K-Jetronic in particular was renowned for its accurate fuel dosing and high reaction speed with a changing engine load.

In 1976 gasoline injection was combined with lambda control and the three-way catalyst. In 1979 Bosch integrated gasoline injection and ignition control in the Motronic system, introducing the first digital engine management system on the world market [Bosch (1992)].

USA

In 1949 an Indy race featured a fuel-injected Offenhauser. The system was developed by Stuart Hillborn and featured an indirect injection system.

Chevrolet introduced the Rochester Ramjet in 1957. This was also used in the 1957 Pontiac Bonneville and employed a number of systems designed by Hillborn. The system was not popular with the general public and, after 1959, was dropped with the exception of the Corvette which used it as an option until 1965.

In 1975 GM introduced the first mass-produced US fuel injection system on the 1976 model of the Cadillac Seville. This was a system consisting of a throttle body, eight fuel injectors mounted on a fuel rail directing fuel into the intake, a crude analogue computer and various sensors. It had been developed by Bendix, Bosch and General Motors.

Later in 1980 the first digital computerised control was introduced for Cadillac. Named Digital Fuel Injection (DFI), it had originally been conceived as a multipoint injection. Cost constraints again limited it as a throttle body system with two fuel injectors. The introduction of a digitally controlled system made it possible for better refinement of fuel control via various sensors, to make minor adjustments on the fly and to be able to store codes indicating malfunctions that could be recalled by a technician in troubleshooting.

(Source: http://chevythunder.com/fuel injection history.htm).

Types of fuel injection

Throttle body injection (TBI) is much like a carburettor except that there is no fuel bowl, float, needle valve, venturi, fuel jets, accelerator pump or choke. That's because throttle body injection does not depend on engine vacuum or venturi vacuum for fuel metering. Fuel is sprayed directly into the intake manifold instead of being siphoned in by intake vacuum.

A TBI fuel delivery system consists of a throttle body with one or two injectors and a pressure regulator. Fuel pressure is provided by an electric pump. It is a relatively simple set-up and causes few problems – but does not provide all of the advantages of a multiport or sequential fuel injection system.

The next step up from TBI was multiport injection (MPI). Engines with multiport injection have a separate fuel injector for each cylinder, mounted in the intake manifold or head just above the intake port. Thus, a four cylinder engine would have four injectors, a V6 would have six injectors and a V8 would have eight injectors.

Multiport injection systems are more expensive because of the added number of injectors. But having a separate injector for each cylinder makes a big difference in performance. The same engine with multiport injection will typically produce 7 to 30 kW more than one with TBI because of better cylinder-to-cylinder fuel distribution. Injecting fuel directly into the intake ports also eliminates the need to preheat the intake manifold since only air flows through the manifold. This, in turn, provides more freedom for tuning the intake plumbing to produce maximum torque. It also eliminates the need to preheat the incoming air by forcing it to pass through a stove around the exhaust manifold.

There are other differences between multiport injection systems. One is the way in which the injectors are pulsed. On some systems, all the injectors are wired together and pulse simultaneously (once every revolution of the crankshaft). On others, the injectors are wired separately and are pulsed sequentially (one after the other in their respective firing order). This system is called sequential multiport injection. The latter approach is more complicated and requires more expensive electronic controls, but provides better performance and throttle response by allowing more rapid changes in the fuel mixture.

Gasoline Direct injection (GDI)

Except for some of the early vehicle models, gasoline-powered engines with fuel injection have always used "indirect" injection systems that spray fuel either into the intake manifold or head ports. Diesel injection systems, on the other hand, use "direct" injection and spray fuel directly into the combustion chamber (or prechamber). Being able to inject gasoline directly into a high compression spark-ignited engine should theoretically improve fuel economy and performance. But until recently, attempts to make a practical direct injection gasoline engine have failed because of detonation and emission problems.

Mitsubishi was the first manufacturer to introduce GDI engines in cars (1996 in Japan, 1998 in Europe and 2000 in the USA). Based on type approval values, Mitsubishi's Carisma S 1.8 LX GDI emits 18% less CO_2 than the Carisma 1.8 GLX. However, a comparative test of the two versions of the Carisma performed by the Swedish MTC according to the European test cycle (NEDC) resulted in only 10% fuel reduction, and when driving according to the American FTP-75 test cycle, the difference was only 8% [Ahlvik, 1998].

One of the keys to making this work is the way in which air is directed into the cylinders. Most engines have horizontal intake and exhaust ports so air and fuel enter past the intake valve, blow past the spark plug and swirl back around the cylinder in a circular path before being ignited. In the GDI engine, the intake port is almost vertical. Air flows down from the top, enters past the intake valve and injector, flows down the side of the cylinder until it hits a cup-shaped pocket in the piston dome that redirects it back up towards the spark plug. This "reverse flow" arrangement combined with relatively late injection timing in the compression stroke allows the engine to handle very lean mixtures at idle without misfiring. When more power is needed, injector timing is advanced earlier in the compression stroke and more fuel is injected into the cylinder to create a more conventional fuel mixture.

Like all the fuel injection systems that have come before it, the new direct injection engines will still require replacement parts and will likely suffer from similar injector woes that plague today's engines. In fact, direct injection injectors may prove to be even more troublesome than indirect injectors because they are exposed directly to the heat of combustion.

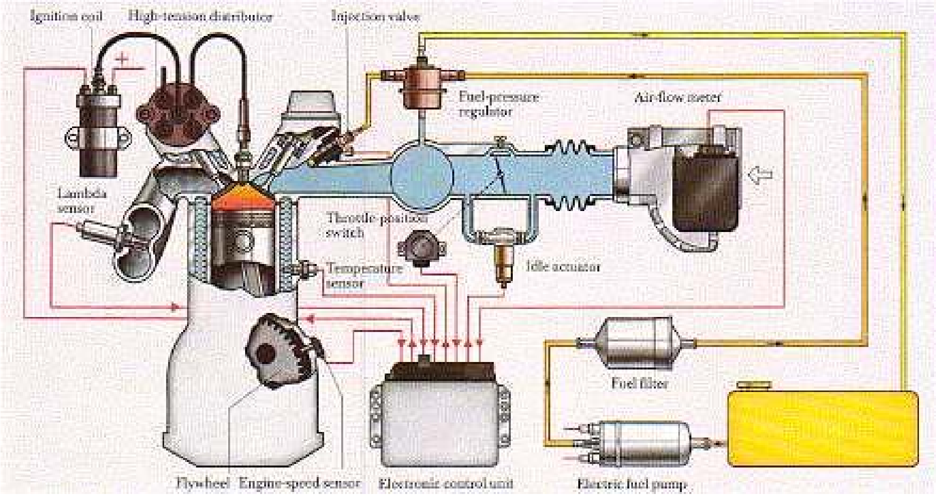
1.2.2.1 Electronic control unit

Until the 1970s, all control of fuel, air or ignition happened mechanically. It was the introduction of electronic fuel injection that meant the start of engine management systems.

The electronic control unit (ECU) is an important part of the fuel injection system as it controls the fuel injection and consequently the strategy to reduce automotive pollution. The microcomputer controls the quantity of fuel injected and ignition timing precisely to the various operating conditions, such as idle, part load, full load, warm-up, overrun and load change. A very basic modern engine system could monitor and control: mass air flow, fuel flow, ignition timing, exhaust oxygen (lambda oxygen sensor), knock (vibration sensor), EGR, exhaust gas temperature, coolant temperature, engine speed and intake air temperature. Based on the information from these sensors, the ECU determines the injector pulse width.

The basic function of the ECU is to control the pulse width of the injector. In engine management systems, however, the ECU also controls additional functions, such as idle speed, ignition timing, fuel pump operation, speed limiting, exhaust gas recirculation, variable intake manifold or evaporative emission container.

Figure 1.3: Gasoline engine with electronic fuel injection



Source: Bosch, 1992

Table 1.2-1: Monitored conditions and controlled functions by the Electronic Control Module (ECM)

Conditions that may be monitored	**Functions that may be controlled**
• Mass flow of intake air* • Intake manifold air pressure • Intake manifold air temperature • Throttle position • Angular rate of change of throttle position • Engine speed • Camshaft or crankshaft position • Quantity of oxygen in the exhaust • Spark knock • Engine coolant temperature • Vehicle speed • Gear selection • Transmission controller • State of air conditioner	• Mass of fuel injected for steady state, accelerating and enrichment conditions • Idle speed • Cold start injector, if equipped • Evaporative emissions control system (e.g. when to purge the charcoal canister) • Amount of exhaust gas recirculation (EGR) • Spark timing • Amount of boost for turbocharged vehicles • Input to the Automatic Braking System (ABS) computer for traction control • Transmission shift points

* Measuring the mass of the intake air eliminates the need to compensate for the change of air density with altitude

1.2.3 Compression ignition engine (Diesel)

The development of the internal combustion engine began in the late 18th century. Slow but steady progress was made over the next hundred years. By 1892, Rudolf Diesel received a patent for a compression ignition reciprocating engine. But his original design, which used coal dust as the fuel, didn't work. Diesel, recognizing that the liquid petroleum by-products might be better engine fuels than coal dust, began to experiment with one of them. This fuel change, coupled with some mechanical design changes, resulted in a successful prototype engine in 1895. Today, both the engine and the fuel still bear his name.

The first commercial diesels were large engines operating at low speeds. They were used to power ships, trains, and industrial plants. By the 1930s, diesels also were powering trucks and buses. An effort in the late 1930s to extend the engine's use to passenger cars was interrupted by World War II. The real breakthrough of diesel engines in passenger cars began in the 1970s. The automotive diesel became very popular in Europe, but has not enjoyed comparable success in the United States.
Today, diesel engines are used worldwide for transportation, manufacture, power generation, construction and farming. The types of diesel engines are as varied as their uses – from small, high-speed, indirect-injection engines to low-speed direct-injection behemoths with cylinders one meter in diameter. Their success is due to their efficiency, economy, and reliability.

Diesel engines are similar to spark-ignited engines in many ways. Both are internal combustion engines and most versions of both use a four-stroke cycle. The following four principles are typical for diesel engines and are different from SI engines:

- The diesel engine draws air into a cylinder and injects fuel after the air has been compressed (SI engines compress the air/fuel mixture).
- The diesel engine relies on high temperature alone for ignition (not a spark). Since this high temperature is the result of compressing air above the piston as it travels upward, diesel engines are also referred to as compression-ignition engines.
- A diesel engine does not throttle the intake air; it controls the power output by varying the amount of fuel injected into the air, thereby varying the fuel-air ratio. This is one of the primary reasons why diesel engines are more fuel efficient than spark-ignition engines.
- A diesel engine runs lean – there is always more air than is needed to burn the fuel.

1.2.3.1 Fuels

Possible fuels for compression ignition engines are:

- Diesel oil
- Biodiesel (usually RME), possibly blended with diesel oil
- DME (dimethyl-ether)
- Dual fuel (ethanol + diesel or natural gas + diesel), in which the diesel fuel serves as ignition starter
- Synthetic diesel fuel

<u>Diesel oil</u> is also made from petroleum and consists of a mixture of hydrocarbons and some additives to improve the properties of the fuel. Compared to gasoline, diesel oil

consists of a somewhat higher C-fraction of hydrocarbons. It is therefore less volatile and has a somewhat higher energy density than gasoline. The composition of diesel oil has changed somewhat over the years by legislation. The sulphur content in particular is a hot topic in recent adaptations of legislation.

Effects of diesel composition and properties on vehicle emissions [MED, 2001]:

There is a clear correlation between some diesel properties and regulated emissions, but drawing general conclusions is somewhat difficult due to such factors as inter-correlation of different fuel properties, different engine technologies or engine test cycles.

- Sulphur increases particulate emissions in both light-duty and heavy-duty diesels. It also degrades the performance of nearly all emission control equipment. In particular, de-NO_x catalysts and continuously regenerating particulate traps require very low sulphur levels.
- In heavy-duty diesels engines, increasing cetane number reduces HC, CO and NO_x emissions. Reducing fuel density reduces NO_x and PM but increases HC and CO emissions.
- Light-duty diesels show different fuel sensitivity to heavy-duty diesels.

The properties of the other fuels will be discussed in the section on alternative fuel vehicles.

1.2.3.2 Fuel injection

Indirect injection via a prechamber

Series production of the first diesel passenger-car engine began in 1976.

The diesel engine had an indirect injection system via a prechamber until the Direct Injection (DI) technology was developed.

In this kind of indirect injection, fuel is injected into a small prechamber connected to the cylinder via a narrow passage that enters the prechamber tangentially. During the compression process, air is forced through this passage, generating a vigorous swirling motion in the prechamber. Then fuel is injected into the prechamber and ignition occurs there. The combination of rapidly swirling air in the prechamber and the jet-like expansion of combustion gases from the prechamber into the cylinder enhances the mixing and combustion of the fuel and air.

The high velocity flow of air through the narrow passage connecting the main cylinder to the prechamber, as well as the vigorous swirling motion in the prechamber itself, causes the air to lose significantly more heat during compression than it does in a Direct Injection (DI) engine. Coupled with a pressure drop from the main chamber to the prechamber, this results in an air temperature in the prechamber after compression that is lower than that in a similar DI engine.

Since rapid fuel auto ignition requires a certain air temperature, an Indirect Injection (IDI) engine needs a higher compression ratio to achieve the desired air temperature in the prechamber. IDI engines operate at compression ratios of about 20:1 to 24:1; while

DI engines operate at ratios of about 15:1 to 18:1. IDI engines typically achieve fuel efficiencies that are 10% to 20% lower, on a relative basis, than comparable DI engines.
Even with the higher compression ratios, IDI engines may still be hard to start. Most IDI engines use glow plugs to heat the air in the prechamber in order to make starting easier. Glow plugs, which are small resistive heaters, are usually powered for only the first few minutes of engine operation.

With the negative attributes of harder starting and lower efficiency, one may wonder why IDI diesel engines are used at all. The answer is engine speed. As an engine gets smaller, generally it must operate at higher speeds to generate the desired power. As engine speed increases, there is less time per engine cycle to inject, vaporize, mix, and combust the fuel. As a result, the higher mixing rates afforded by IDI designs become necessary to achieve good combustion at higher engine speeds. IDI diesels were most commonly used in smaller automotive and light-duty truck applications.

Turbocharger

It was evident that higher power would be needed in the next development stage of diesel engines. Imminent environmental requests speeded up the transition to forced aspiration by a turbocharger in the early 1980s; by 1982 the Turbodiesel (TD) had appeared and developed.

Since the power output of diesel engines (or for that matter, gasoline engines) is limited by the amount of air they take in, it is common practice to employ some form of forced air induction to increase maximum power. In turbo-charging or supercharging, a compressor is used to raise the pressure and, therefore, the density of the air entering the engine. Increasing the total mass of air inducted per cycle allows more fuel to be injected and burned without increasing the fuel-air ratio to the point that particulate emissions become excessive (smoke limit).

Even at equal power, a forced-air diesel engine has an advantage over a naturally aspirated engine. The increased air mass decreases the fuel-air ratio and, thereby improves the engine's thermal efficiency (fuel economy). In addition, the decrease in fuel-air ratio at part power can also improve emissions performance, depending on other factors.

Direct Injection (DI)

At the beginning of the 1990s, Volkswagen, together with its Audi brand, took a further most decisive step forward by introducing direct injection. The first four-cylinder diesel engine with this form of fuel injection appeared in 1991 and was known as the TDI, the initials standing for Turbocharged Direct Injection. Once again, the major problem to be overcome initially concerned the engine's noise emissions, but despite this it was clear that direct injection was the only practicable way to access all the performance reserves inherent in the diesel combustion principle. In comparison with comparable indirect injection engines, the TDI had a fuel-saving potential of up to 15%, and as the noise problem was brought under control the TDI engines were able to achieve their rightful lead over competitors.

A further development stage led to the adoption of the variable-geometry turbocharger, which further improved the flexibility of the four-cylinder TDI engine and enabled the power output of what was by now a 1.9-liter unit to be boosted from 90 to 110hp. This development progress was marked by colouring the "I" red in the TDI logo.

EDC (Electronic Diesel Control)

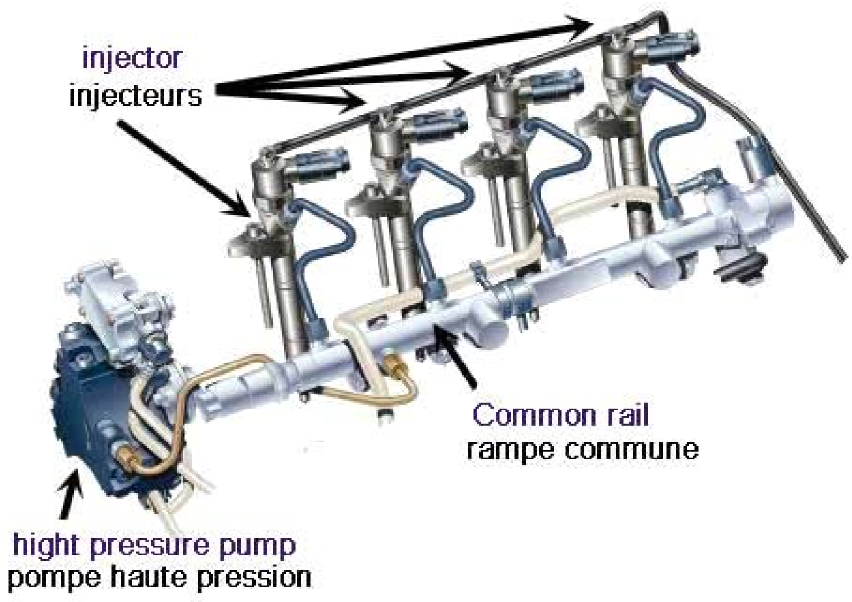
Another major step ahead was taken in May 1993 when the first car diesel engine with electronic engine management – termed "Electronic Diesel Control" (EDC) – appeared on the scene in the shape of the new Mercedes C-class.
With the use of electronic data-collecting sensors, it is possible to adjust the start of injection and exhaust gas recirculation more accurately and flexibly to the engine requirement and operating conditions. EDC also carries out functions such as cylinder balancing, idle speed control, active surge damper, protection against overheating, boost pressure control and self diagnostics.

EDC improves fuel economy and reduces the amount of pollutants in the exhaust. EDC also allows constant speed cruising, which is crucial for high tonnage hauling. In addition, since data are available in digitised form, the EDC system can be easily interconnected with other vehicle systems such as the anti-lock braking system (ABS) and traction control (ASR).

Common rail direct injection

While the Japanese industry is leading in gasoline direct injection technology, Germany's Bosch, working in conjunction with several European car makers, pioneered Common-Rail Direct Injection for diesel engines. This was first introduced in 1997 in Alfa Romeo (156).
Compared with gasoline, diesel is the lower quality ingredient of the petroleum family. Diesel particles are larger and heavier than gasoline, thus more difficult to pulverise. Imperfect pulverisation leads to more unburnt particles, hence more pollutants, lower fuel efficiency and less power. Common-rail technology is intended to improve the pulverisation process.
To improve pulverisation, the fuel must be injected at a very high pressure, so high that normal fuel injectors cannot achieve this. In a common-rail system, the fuel pressure is implemented by a strong pump instead of fuel injectors. The high-pressure fuel is fed to individual fuel injectors via a common rigid pipe (hence the name of "common-rail"). In the current first generation design, the pipe withstands pressure as high as 1,350 bar or 20,000 psi. Fuel always remains under such pressure even in stand-by state. Therefore, whenever the injector (which acts as a valve rather than a pressure generator) opens, the high-pressure fuel can be injected into the combustion chamber quickly. As a result, not only pulverisation is improved by the higher fuel pressure, but the duration of fuel injection can be shortened and the timing can be precisely controlled.
Benefiting from the precise timing, the common-rail injection system can introduce a pre-combustion to create a small-scale combustion before normal combustion takes place. The main benefit of this is a serious reduction in engine noise. After the main injection, a post-combustion injection is introduced, which injects a small amount of fuel during the expansion phase. This will further reduce the unburnt particles and will also increase the exhaust flow temperature, thus reducing the pre-heat time of the catalytic converter. In short, "post-combustion" cuts pollutants.

Figure 1.4: Common rail system



PSA, 1999

According to PSA's press release (1999), its HDI common-rail engine (in addition to other improvement) cuts fuel consumption by 20%, doubles torque at low engine speeds and increases power by 25% (compared with indirect injection engines). It also brings a significant reduction in the noise and vibrations of conventional diesel engines. For emissions, greenhouse gases (CO_2) are reduced by 20%. At a constant level of NO_x, carbon monoxide (CO) emissions are reduced by 40%, unburnt hydrocarbons (HC) by 50%, and particle emissions by 60%.

Diesel common rail system advantages

- Compact design: the compact design of the injector outline enables the common rail system to be used on two or four valves per cylinder.
- Modular system: with one electronically driven injector per engine cylinder, the system is modular and can be used on three, four, five and six cylinder engines.
- Low drive torque: as the pumping of the pressure rail is not phased with the injection, the common rail system requires a low drive torque from the engine.
- Independent injection pressure: the injection pressure is independent of the engine speed and load, so enabling high injection pressures at low speed if required.
- Lower NO_x emissions: injection sequences which include periods both pre and post the main injection can be utilised to reduce emissions, particularly NO_x, enabling the system to meet the stringent emission levels required by EURO-3 and US-98 legislation and beyond.
- Noise reduction: The inclusion of pilot injection results in a significant reduction in engine noise.
- Full electronic control: Common rail offers all the benefits of full electronic control fuel metering and timing, as well as the option of interfacing with other vehicle functions.

Latest TDI – pump injector

Volkswagen once again scaled new heights in diesel engine development by adopting high-pressure fuel injection in 1998. Knowing that combustion quality depends directly on the absolute pressure at which fuel can be injected into the cylinders, VW decided to adopt the pump-injector principle, which from the very start was able to guarantee the necessary high injection pressures. At the same time, a defined volume of fuel was injected as a pilot stroke before the main injection stroke, the ideal method of achieving a smooth combustion process in a high-performance diesel engine. The two red letters "DI" in the logo are a sign that the pump-injector principle is being used.

Despite an identical 1,896 cc capacity, the performance of the 1.9 TDi unit now has an output of 150 hp at 4,000 rpm (compared with 90 hp for the same indirect injected TD engine). This increased performance is largely due to the advanced new injection system using pump injector units.

Each cylinder is fed fuel by a pump injector unit that delivers injection pressures of between 400 and 2,050 bar, considerably higher than common rail systems used in engines under 2.0 litres. Thanks to these high pressures, the fuel that enters the cylinders is finely atomised, ensuring more complete combustion. The optimised design of the injector nozzles also facilitate the combustion process, by improving the flow of fuel and the formation of the mixture.

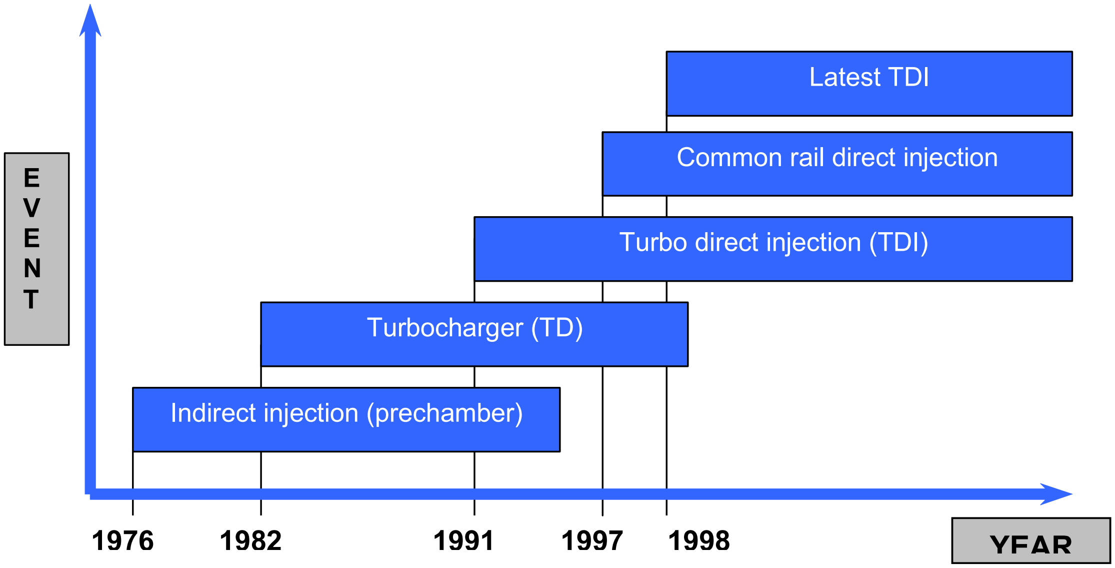
Precise electronic control of the pump injector units ensures delivery of the ideal amount of fuel at all times. This results in greater engine efficiency and a reduction of close to 25% in particle emissions. The engine is also more refined: pre-injection of small amounts of fuel raises the internal pressure of the combustion chamber slightly, thus reducing the diesel's characteristic noise.

Other elements of the engine have also been modified in order to deliver 150 hp. Intercooler performance has been improved, and new pistons fitted. Most significantly, the turbocharger features a turbine with variable geometry which allows the engine to achieve its high performance level without sacrificing response at low engine speeds. The maximum pressure delivered is 1.5 bar.

Overview of the milestones in diesel fuel injection

The following figure shows an overview of the evolution of diesel injection in the automotive world from the 1970s.

Figure 1.5: Overview of the main developments in diesel injection technology



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1.3 Emission control

1.3.1 Introduction

Complete combustion of gasoline and diesel (as for most hydrocarbon fuels) would result in carbon dioxide (CO_2) and water vapour (H_2O) emissions. Although CO_2 is quite inert and harmless in direct inhalation, it is, however, gaining importance given its role in the greenhouse effect.

Due to incomplete combustion, exhaust gases will also contain carbon monoxide (CO) and unburnt hydrocarbons (HC). Moreover, apart from the nitrogen (N_2) which was already present in the intake air, oxidation products of this nitrogen, namely nitrogen oxides (NO_x), will also be present in the exhaust gases.

In addition, other regulated or unregulated emissions may also be present:

- The emission of particulate matter (PM) is rather low for the gasoline engine, certainly when total mass of PM is considered. Due to more difficult pulverisation of the heavy diesel droplets and because of non-homogeneous distribution of the diesel fuel over the combustion chamber, diesel engines have always produced more particulate (smoke) emissions.
- Until recently, the sulphur content of gasoline was also much lower than that of diesel, leading to lower sulphur oxide (SO_x) emissions. In coming legislation, the sulphur content of both gasoline and diesel will be reduced to comparable levels.
- In the past, lead (Pb) was also present in exhaust gases because of the use of anti-knock (or octane improving) products containing lead in the gasoline fuel.
- Phosphorus, chlorine, bromine and boron compounds which can be present in the fuel or lubricating oil, can also be found in the exhaust gases as dioxins.

Automotive emissions are controlled in three ways.

One is to promote more complete combustion so that there are fewer by-products; the second is to reintroduce excessive hydrocarbons back into the engine for combustion; and the third is to provide an additional area for oxidation or combustion to occur. This additional area is called a catalytic converter.

Honda always was one of the pioneers in environmental developments. In the 1973 Honda Civic compound vortex combustion chamber technology was used to lower engine-out emissions. It was soon clear, however, that catalyst technology would take over.

Environmental catalyst technologies stem from the air pollution problems associated with light-duty vehicles, mainly gasoline fuelled passenger cars. Following the adoption of the Clean Air Act (CAA) in the USA and the resulting vehicle emission standards, oxidation catalysts have been commercialised in the USA since the mid-1970s in order to control emissions of CO and HC from spark-ignited gasoline engine applications.

Three-way catalysts, introduced in the 1980s, also made it possible to control NO_x emissions from SI engines at very low levels.
In the 1990s, oxidation catalysts were introduced to diesel-fuelled cars in Europe. From as early as the 1970s, diesel catalysts have also been used in some occupational environments, such as underground mining.

1.3.2 Catalytic converter

Catalyst-equipped cars were first introduced in the USA in 1974 but only appeared on European roads in 1985 and were legislated for in 1993. Now more than 275 million of the world's 500 million cars and over 85% of all new cars produced worldwide are equipped with autocatalysts. Catalytic converters are also increasingly fitted on heavy-duty vehicles, motorcycles and off-road engines and vehicles.

Three-way catalyst technology, operating on the principle of catalytic reduction of NO_x by CO and HC, requires that the engine is operated with a nearly stoichiometric air-to-fuel (A/F) ratio. This created the need for an electronic control system for the air/fuel ratio. In 1981 the first self-adjusting engines, called feedback fuel control systems, were introduced,. An oxygen sensor was installed in the exhaust system and would measure the oxygen content of the exhaust stream. The signal can be related to the lambda value, which is the air/fuel ratio compared with the stoichiometric value.
The “lambda sensor” would then send a signal to a microprocessor, which would analyse the reading and operate a fuel mixture or air mixture device to create the correct air/fuel ratio. As computer systems progressed, they were able to adjust ignition spark timing as well as operate the other emission controls that were installed on the vehicle.

In the presence of oxygen, the three-way catalyst becomes ineffective in reducing NO_x. For this reason three-way catalysts cannot be employed for NO_x control on diesel applications, which are lean-burn engines containing high concentrations of oxygen in their exhaust gases in all operating conditions.

Oxidation catalysts convert carbon monoxide (CO) and hydrocarbons (HC) to carbon dioxide (CO_2) and water and decrease the mass of diesel particulate emissions, but have little effect on nitrogen oxides (NO_x) and particulate numbers. They were used in the 1970s in the USA for gasoline cars until they were replaced by three-way catalysts.
Recently oxidation catalysts have been mainly employed for diesel vehicles.

The first automotive application of diesel oxidation catalysts was the diesel-fuelled Volkswagen “Umwelt” in 1989. The use of a catalyst was not necessary to meet European regulations at that time. Rather, it was introduced as a sign of an environmentally responsible attitude of the car maker.
Since the introduction of the Euro II emission standard in the mid-1990s, the diesel oxidation catalyst has become a standard component of the diesel-fuelled car in Europe. On top of a reduction in CO, HC and PM, certain commercial diesel catalysts developed for the Euro III standard (year 2000) incorporate a “passive $DeNO_x$” function and are capable of 5-15% NO_x reduction in addition to their oxidation activity.

Fast light off catalysts allow the catalytic converter to work sooner by increasing the exhaust temperature. Untreated exhaust emitted at the start of the legislated emissions test and on short journeys in the real world is curtailed. Changes to the thermal capacity of substrates and type and composition of the active precious metal catalyst have together effected big improvements.

More thermally durable catalysts with increased stability at high temperature allow the catalytic converter to be mounted closer to the engine and increase the life of the catalyst, particularly during demanding driving. Precious metal catalysts with stabilised crystallites and washcoat materials that maintain high surface area at temperatures around 1000°C are needed. Improved oxygen storage components stabilise the surface area of the washcoat, maximise the air/fuel 'window' for three-way operation and indicate the 'health' of the catalyst for On Board Diagnostic (OBD) systems.

Substrates

Technology of the substrates on which the active catalyst is supported has seen great progress. In 1974, ceramic substrates had a density of 200 cells per square inch of cross section (31 cells/cm^2) and a wall thickness of 0.012 inch or 12 mil (0.305 mm). By the end of the 1970s, the cell density had increased from 300 to 400 cpsi and wall thickness had been reduced by 50% to 6 mil. Now 400, 600 and 900 cpsi substrates are available and wall thickness can be reduced to 2 mil - almost 0.05 mm. In the late 1970s, substrates derived from ultra-thin foils of corrosion-resistant steels came on to the market. In the beginning, the foils could be made from material only 0.05 mm thick allowing high cell densities to be achieved. Complex internal structures can now be developed; 800 and 1000 cpsi substrates are available and wall thickness is down to 0.025 mm. This progress in ceramic and metal substrate technology has major benefits. A larger catalyst surface area can be incorporated into a given converter volume and this allows better conversion efficiency and durability. The thin walls reduce thermal capacity and avoid the penalty of increased pressure losses. Alternatively, the same performance can be incorporated into a smaller converter volume, making the catalyst easier to fit close to the engine as cars are made more compact [AECC, 2002].

Optimised systems incorporating these new technologies are in production. The use of additional catalytic converters close to the exhaust manifold reduces the time to light-off in the cold start and, therefore, the total emissions. Light-off times have been reduced from as long as one to two minutes to less than 20 seconds. Improved substrate technology, combined with highly thermally stable catalysts and oxygen storage components, allows the close-coupled catalyst approach to meet the European Union 2000 (Euro 2) and 2005 (Euro3) standards as well as the California Low Emission Vehicle (LEV), Ultra Low Emission Vehicle (ULEV) and Super Ultra Low Emission Vehicle (SULEV) regulations.

Maintenance and durability of emissions performance is crucial for maximum environmental benefit from the application of advanced emissions control technology. The technology used should be durable for the defined, reasonable life of the vehicle and the vehicle should be checked regularly to ensure that the installed systems are working properly and that they have not been abused or inadequately maintained.

Following the USA in the mid 1990s, Europe adopted OBD systems from 2000 to monitor operation of the engine management and emissions control components, including the conversion efficiency of the catalytic converter. The performance and durability of the catalytic converter are very dependent on the engine and fuel management systems, of which the converter is a key part.

1.3.3 Particulate traps

Ceramic wall flow filters (or traps) remove over 90% by weight of the total particulate matter contained in diesel exhaust. Current limit values are set on the mass of particulate in grams per kilometre. However, recent work on the ultra-fine particulates (smaller than PM1 or 1 micron = 1 millionth of a metre in diameter) produced by diesels, concentrates on the number and size of particulates, which are thought to be more critical indicators of health impact. Trap-based after-treatment can reduce the numbers of particulates including ultra-fine ones (PM 0.01-PM 1) with 99.9% or greater filtration efficiency over a wide range of engine operating conditions. Since the wall flow filter would readily become plugged with particulate material in a short time, it is necessary to 'regenerate' the filtration properties of the filter by burning off the collected particulate on a regular basis. The most successful methods of achieving regeneration include:

- Electrical heating of the trap either on or off the vehicle
- Incorporating a catalytic coating on the filter to lower the temperature at which particulate burns to normal exhaust temperatures
- Using very small quantities of a fuel-borne catalyst such as ceria. The catalyst, when collected on the filter as an intimate mixture with the particulate, allows the particulate to burn at normal exhaust temperatures to form CO_2 and water, while the solid residues of the catalyst are retained on the filter.
- Incorporating an oxidation catalyst upstream of the filter that, as well as operating as a conventional oxidation catalyst, also increases the ratio of NO_2 to NO in the exhaust. Trapped particulate burns off at normal exhaust temperatures using the powerful oxidative properties of NO_2.

The Peugeot 607 HDi is the first modern car equipped with a particle filter as standard. The filter is regenerated through the use of cerium fuel additive and a sophisticated management strategy of the common-rail engine. PSA brought the Peugeot model to the market in early 2000.

A long-term emission durability test of a particulate filter-equipped Peugeot 607 HDi passenger car has been completed by the Allgemeine Deutsche Automobilclub (ADAC) and the Umweltbundesamt (UBA - the German Federal Environmental Agency). The particulate filter was found to function reliably over the 80,000 km test. Emission tests conducted after the 80,000 km showed that the particulate filter removed more than 99.9% of the fine diesel particles. The UBA said that the Peugeot 607 HDi tested emitted on average 10,000 times fewer particles than a comparable vehicle without a particle filter.

1.3.4 Next generation technology for emission after-treatment

Hydrocarbon Adsorber Systems incorporate special materials, such as zeolites, into or ahead of the catalyst. Hydrocarbon emissions are collected when exhaust temperatures are too low for effective catalyst operation. The hydrocarbons are then desorbed at higher temperatures when the catalyst has reached its operating temperature and is ready to receive and destroy the hydrocarbons. This technology has the potential to reduce hydrocarbons to less than half the levels emitted from a three-way catalytic converter.

Electrically Heated Catalyst Systems use a small catalyst ahead of the main catalyst. The substrate, onto which the catalyst is deposited, is made from metal so that, when an electric current is passed, it will heat up quickly. This brings the catalyst to its full operating temperature in a few seconds.

DeNO$_x$ (or Lean NO$_x$) Catalysts use advanced structural properties in the catalytic coating to create a rich 'microclimate' where hydrocarbons from the exhaust can reduce the nitrogen oxides to nitrogen, while the overall exhaust remains lean. Further developments focus on increasing the operating temperature range and conversion efficiency.

NO$_x$ adsorbers (NO$_x$ traps) are a promising development as results show that NO$_x$ adsorber systems are less constrained by operational temperatures than DeNO$_x$ catalysts. NO$_x$ traps adsorb and store NO$_x$ under lean conditions. A typical approach is to speed up the conversion of nitric oxide (NO) to nitrogen dioxide (NO$_2$) using an oxidation catalyst so that NO$_2$ can be rapidly stored as nitrate on alkaline earth oxides. A brief return to stoichiometric or rich operation for one or two seconds is enough to desorb the stored NO$_x$ and provide the conditions for a conventional three-way catalyst mounted downstream to destroy NO$_x$.

Selective Catalytic Reduction (SCR) was originally introduced on stationary power plants and engines but is now being used on heavy-duty diesel engines and in development for light-duty diesel vehicles. Ammonia or ammonia precursors are used as a selective reductant, in the presence of excess oxygen, to convert more than 70% of NO$_x$ to nitrogen over a special catalyst system. Particulate emissions are also lowered. SCR systems on commercial road vehicles have operated successfully for hundreds of thousands of kilometres.

1.3.5 On-Board Diagnostics (OBD)

On-Board Diagnostics systems (OBD) were created to detect faults in certain emission-critical components. When a defect is detected, the ECM turns on a *malfunction indicator light (MIL)* – often the "check engine" light – on the dashboard and stores a fault code in the computer memory. The purpose of the system is to alert the driver immediately, so that he or she knows to have the vehicle checked as soon as possible. Another reason behind the OBD development is the system's capability of pinpointing the specific component that has malfunctioned, saving substantial time and cost in comparison with guess-and-replace repairs.

The so-called OBD-II system has been required in the USA for all cars built since January 1, 1996. In Europe, the EOBD (European On-Board Diagnostics) has been required for new certifications since January 1, 2000, and for all new vehicles since January 1, 2001 [Nylund, 2002]

The systems that California requires the second-generation on-board diagnostic analyser (OBD-II) to monitor for malfunction are [Carley, 2000]:

- Overall catalyst system efficiency
- Evaporative control system leakage (fuel tank vapour space and vapour lines)
- Ignition misfire
- Secondary air injection system operation
- Fuel delivery system effect on emissions
- Oxygen sensor performance
- EGR system flow rate
- Electronic powertrain components that can affect emissions or are used for
- emission diagnostic strategies
- Air conditioning system refrigerant loss

1.3.6 Other means of emission control

1.3.6.1 Exhaust Gas Recirculation (EGR valve)

Exhaust Gas Recirculation (EGR) is a strategy employed on many modern gasoline and diesel engines to reduce NO_x emissions. The principle is relatively simple. Exhaust gas, being already burned, is essentially inert. If some of this exhaust gas is introduced into the intake manifold (recirculated) along with air and fuel, it won't participate in the combustion reactions. However, the exhaust gas can absorb some of the heat produced, thereby lowering the cylinder temperature. Since NO_x production is favoured strongly by higher temperatures, EGR reduces NO_x emissions substantially. The mechanics of EGR involve appropriate piping between the engine's exhaust and inlet systems and a control valve to regulate the amount of exhaust that is recirculated.
Since EGR action reduces performance by diluting the air /fuel mixture, the system does not allow EGR action when the engine is cold or when the engine needs full power.

The EGR system can be simple or quite complex. Early versions (1970s) were simple. They used EGR bleed ports inside the intake manifold, supplying a fairly constant volume of exhaust gas to the cylinders. These early versions resulted in an engine that ran horribly, particularly at idle. As the systems improved, they also became more complicated. Some of the EGR system's controls are computer-driven while others are purely mechanical in operation. All are critical to good engine performance and satisfactory driveability. Since the EGR system protects the engine from destructive pinging or detonation, in addition to lowering emissions, it should never be disconnected.

1.3.6.2 Positive Crankcase Ventilation (PCV valve)

Positive Crankcase Ventilation (PCV) was one of the first techniques employed to reduce unburned VOC emissions from gasoline-powered vehicles. It was required initially on California vehicles in 1961. Since the gases in the combustion chamber are under high pressure while combustion is taking place, a small fraction leaks past the rings that seal the gap between the piston and the cylinder wall. These *blow-by gases* end up in the crankcase. They are a mixture of unburned fuel, air and combustion products. As the blow-by gases accumulate in the crankcase, they must be vented to avoid pressurizing the crankcase, which would force oil out of the engine. PCV systems consist of tubing and a control valve that meters the flow of the blow-by gases from the crankcase back into the engine's intake system, from which they are drawn into the cylinders and burned. Prior to the use of PCV, blow-by was vented to the atmosphere, providing a significant source of VOCs.

1.3.6.3 Evaporative controls

Gasoline fuel evaporates quite easily. In the past these evaporative emissions were vented into the atmosphere. Twenty per cent of all HC emissions from the automobile are from the fuel tank. In 1970 the USA passed legislation prohibiting venting of gas-tank fumes into the atmosphere. An evaporative control system was developed to eliminate this source of pollution. The function of the fuel evaporative control system is to trap and store evaporative emissions from the fuel tank and carburettor. A charcoal canister is used to trap the fuel vapours. The fuel vapours adhere to the charcoal, until the engine is started, and engine vacuum can be used to draw the vapours into the engine, so that they can be burned along with the fuel/air mixture. This system requires the use of a sealed gas-tank filler cap. This cap is so important to the operation of the system that a test of the cap is now being integrated into many state emission inspection programs. Pre-1970 cars released fuel vapours into the atmosphere through the use of a vented gas cap. Today with the use of sealed caps, redesigned gas tanks are used. The tank has to have the space for the vapours to collect so that these can then be vented to the charcoal canister. A purge valve is used to control the vapour flow into the engine. The purge valve is operated by engine vacuum. One common problem with this system is that the purge valve goes bad and engine vacuum draws fuel directly into the intake system. This enriches the fuel mixture and will foul the spark plugs. Most charcoal canisters have a filter that should be replaced periodically. This system should be checked when fuel mileage drops.

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1.4 General evolution of conventional technologies

1.4.1 Diesel vehicles

1972: EGR

Exhaust Gas Recirculation (EGR) valves appear to reduce fuel consumption and (especially NO_x) emissions.

1980: Modern diesel engines

Diesel engines use less fuel and therefore emit less greenhouse gas, CO_2. NO_x and CO level are also lower but the problem to be cleared is the excessive particles emitted. These are mostly carbon or large hydrocarbon particles, contributing to smog and dark smoke

1988: Direct injection (Fiat Croma)

The advantage is a better combustion, lower consumption and gas emission.

1989: TDI

The Volkswagen turbocharged direct injection diesel engine (TDI) is quieter, smoother, more responsive and almost entirely free of diesel odour. It is also more energy efficient and cleaner.

1997: Common rail direct injection

Common rail direct injection for diesel engines was first introduced in Alfa Romeo (156). To improve pulverization of diesel particles the fuel is injected at a very high pressure by individual fuel injectors via a common rigid pipe, introducing a "post-combustion". At a constant level of NO_x, carbon monoxide (CO) emissions are reduced by 40%, unburnt hydrocarbons (HC) by 50%, and particle emissions by 60%.

1998: Pump injector

Volkswagen introduced the pump injector for diesel engines (VW Passat). This structure eliminates fuel tubes which limit high pressure needed for a better combustion.

2000: Particle filter

PSA's particle filter, introduced in Peugeot 607 HDI, is a porous silicon carbide unit, comprising passageways, which has the property of easily trapping and retaining particles from the exhaust gas flow. Before the filter surface is fully occupied, these carbon / hydrocarbon particles should be burnt up, becoming CO_2 and water, and leave the filter in company with exhaust gas flow. This is called "regeneration".

1.4.2 Gasoline vehicles

1973: Honda Civic: compound vortex combustion chamber

1974: Catalytic converter

GM introduces the catalytic converter.

1975: Turbo pressure control

Porsche controls turbocharger pressure by the wastegate in 911 Turbo.

1976: Three-way catalyst

Volvo introduces 3-way catalytic converter.

1978: Intercooler

Porsche introduces an intercooler system for supercharged engine in 911 Turbo.

1980: Turbo management

Saab introduces turbocharger electronic management (APC).

1984: Lean burn engine

Lean-burn engine, first introduced by Toyota, can operate in very lean air / fuel mixture.

1985: Saab direct ignition

Ignition system without spark-plug wire allows higher voltage for a better engine start.

1994: Mazda's Miller Cycle engine

The Miller Cycle engine differs from the Otto cycle by delaying the inlet valves closing well into the compression stroke. The intake valves remain opening, thus air flows out without compression. Compression ratio is decreased from 10:1 to slightly less than 8:1.

1995: Honda's ZLEV engine

Honda's ULEV engine ZLEV ("Zero" Low Emission Vehicles) engine deals comfortably with cold start emission. ULEV (Ultra Low Emission Vehicles) engine is similar but without the HC-absorbing catalyst.

1996: Mitsubishi GDI engine

Direct Injection Gasoline engine - Mitsubishi GDI is one of the branches of "Lean Burn Technology" differing from Lean Burn in the adoption of directly fuel injection system. Mitsubishi claimed GDI consumes 20% to 35% less fuel, and generates 20% less CO_2 emissions and 10% more power than conventional engines.

1998: BMW Valvetronic

BMW's Valvetronic engine is the world's first engine to get rid of throttle butterfly, saving around 10% fuel.

1999: Renault IDE

Direct Injection Gasoline engine - Renault IDE. Instead of pursuing ultra-lean air / fuel mixture, these adopt ultra-high EGR (Exhaust Gas Recirculation). This reduces fuel consumption by decreasing pumping loss as well as by reducing the effective engine capacity during light or part load.

1.4.3 Variable valve timing

Mid 80s: VVT

Variable valve timing (VVT) first appeared in an Alfa Romeo model. Valves activate the breathing of the engine. The timing of breathing (that is, the timing of air intake and exhaust) is controlled by the shape and phase angle of cams. To optimise the breathing, the engine requires different valve timing at different speeds. When the engine speed increases, the duration of intake and exhaust stroke decreases so that fresh air becomes too slow to enter the combustion chamber, while the exhaust becomes too slow to leave the combustion chamber.

Late 80s: Cam-Changing VVT

VTEC system (Valve Timing Electronic Control) launched by Honda in the 3-stage VTEC is formed by 2 sets of cams having different settings.

1991: Cam-Changing + Cam-Phasing VVT

VVT improves torque delivery at low / medium speed. Variable lift and lift duration at high rev power but it is more complex and expensive. Porsche's Variocam Plus system used it for first time.

1992: Cam-Phasing VVT

Cheap and simple, continuous VVT improves torque delivery across the whole engine speed range. It was first introduced by BMW's Vanos. The disadvantage is the lack of variable lift and variable valve opening duration, thus less top end power than cam-changing VVT.

1995: Variable Valve Control

Variable Valve Control introduced by Rover provides continuously variable timing and the duration of opening achieves both drivability and high speed power but with a lack of variable lift, expensive for V6 and V8, and impossible for V12.

1.4.4 Other events and milestones

Mid 80s:

- Honda and Toyota made 4-valve engines standard in virtually all mainstream models where head is increasingly being used.
- Toyota Variable Intake System (T-VIS) accelerating low-speed air flow to the manifold.
- Twin-spark: Alfa Romeo insisted on putting two spark plugs in each cylinder. As ignition takes place in two locations rather than one, this enable more efficient combustion and cleaner emission.

Late 80s - early 90s:

- Boost control: While wastegate just set the upper limit of boost pressure, Electronic Boost Control governs the boost pressure throughout the whole engine speed range.
- 1991 - First generation VR6: Engines for small cars have to be mounted transversely, but even mounting transversely cannot guarantee the installation of a V6. Volkswagen developed a narrow-angle (15°) V6 displacing as much as 2.8 litres
- 1992 - Light Pressure Turbo (LPT). This was the standard engine with a smaller turbo and lighter boost pressure improving torque without adding much cost . It was introduced by Saab in the Saab 9000 2.3 turbo Ecopower.

Mid 90s:

- The Variable Intake Manifold improves torque delivery at low speed without hurting high-speed power and is cheaper than variable valve timing although it has bit space engaging and not much benefit in high-speed output.
- Weight reduction: Aluminium head and block engines such as the Rover K-series and plastic or magnesium intake manifolds are increasingly popular.
- Reduction of friction and inertia: Aluminium pistons and cylinder liner (including Nikasil and FRM), titanium connecting rods and forged components.
- On-Board Diagnostic systems: OBD2 provides almost complete engine control and also monitors parts of the chassis, body and accessory devices, as well as the diagnostic control network of the car, controlling CO, HC and NO_x emissions.
- Ram air creates a slightly higher pressure than normal aspiration providing additional power.

Late 90s:

- 1999 - 24-valve VR6. 4 camshafts are fitted into the small piece of cylinder head in a perfect design allowing cam-phasing VVT.
- 1999 - W18 engine by Volkswagen where among the three banks of 6-cylinders there are two large V angles.
- Mercedes' 3-valve approach to cut cold-start emission to reduce the time taken to bring the catalyst to its operating temperature Mercedes tried to reduce the surface area of the exhaust port by using a single exhaust valve in each cylinder rather than two. The drawback is some power loss.
- Variable back-pressure exhaust: This low pressure actually helps drawing more air / fuel mixture into the cylinder from intake manifolds, optimising high and low speed output and reducing noise at low speed.

2000:

- Variable Compression Ratio: Saab SVC enhances efficiency for turbo/supercharged engines across the whole engine-speed range, thus enabling the engine to be smaller and lighter, highly adaptable to different grades of fuel, and with cleaner emissions possible through the implanting of a complicated sliding cylinder head and cylinder.
- W16 engine: Bugatti 16.4 Veyron. This comprises two exceptionally narrow V8 cylinder blocks combined at an angle of 90 degrees.

2001:

- W12 engine (Volkswagen) is formed by three banks of 4-cylinders in-line.
- Continuously variable intake manifold - BMW (745i): This system increases the torque in a wider engine-speed range by changing the intake manifold width or volume to create a two-stage resonance. The result is an improvement of power, consumption, gas emission and driveability.

2002:

- 2002 – The W8 engine was first introduced in Volkswagen Passat W8. W8 consists of a pair of 15° VR4 engines joined to a common crankshaft at 72°.

1.4.5 References

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1.5 Alternative fuel vehicles

1.5.1 Introduction

Alternative fuels are defined as all fuels that can be used for motor vehicles apart from the petroleum-derived gasoline and diesel fuel. The main objective for using these fuels is achieving lower environmental impact.
The most popular alternative fuels at this moment are the gaseous fuels LPG and natural gas, the alcohols ethanol and methanol, and, for diesel engines, biodiesel. Current

research is also directed towards hydrogen (especially for use in fuel-cell engines), DME and synthetic fuels.

Most vehicles operating on alternative fuels, are also capable of using conventional fuels such as gasoline (in the case of LPG, natural gas, ethanol or methanol) or diesel (in the case of biodiesel). These vehicles are often referred to as bi-fuel, dual-fuel or flexible fuel vehicles. The two-fuel option increases their functionality, since alternative fuel-filling stations may be rare. On the other hand, this may cause these 'alternative fuel vehicles' to operate merely on conventional fuels.

Table 1.5-1: Advantages and disadvantages of alternative fuels

Fuel	Advantages	Disadvantages
Natural gas	• Very low particulate emission compared with diesel • Low NO_x emissions compared with advanced diesel engines	• More complex refuelling system • Four times larger tank size requirement • Engine efficiency in bus operation is approximately 20% lower for diesel • Lean-burn engines often have problems with methane emissions
Alcohols	• High octane number • Low NO emissions • Low evaporative losses	• Cold start problems • Increased aldehydes • More corrosive than hydrocarbons • Larger fuel tanks • Safety and handling problems
Biodiesel	• Higher cetane number • Good lubricity • Zero sulphate and SO_2 emission • Particulates of lower toxicity (same mass emission)	• Corrosion properties • Lower heating value • Higher freezing point • Increased NO_x emission • Increased odour
Dimethyl ether (DME)	• Little modification to the diesel engine required • Very low particle emission • Lower engine noise • Low NO_x levels without after-treatment	• Lower well-to-wheel efficiency • Lower viscosity • The injection system needs to be developed

Source: Joumard, 1999

Before the introduction of gasoline as a motor fuel in the late 1800s, vehicles were often powered by what are now considered alternative fuels. For example, coal gas, which is a form of methane or natural gas, was used in early prototype internal combustion engines in the 1860s. Electricity, stored in lead acid batteries, was a popular energy source for vehicles from as early as the 1830s until the 1920s. In the 1880s, Henry Ford fuelled one of his first automobiles on ethanol, often called "farm alcohol" because it was made from corn. His early Model Ts were designed with an adjustable carburettor to allow them to run on alcohol fuel. Liquefied petroleum gas (commonly called propane) has been used as a transportation fuel since the 1930s. Because of the low fuel prices of mass-produced, petroleum-derived products as gasoline or diesel, alternative fuels merely disappeared from the automotive market.

After the oil crisis in 1973, alternative fuel vehicles came back into the picture. The LPG and ethanol market, in particular, grew from the 1970s. By the end of the 1980s increasing concern regarding the environmental impact of automobiles stimulated interest in alternative fuels (and also in electric vehicles).

Table 1.5-2: U.S. Alternative Fuel Vehicles by Manufacturer for 2002 Model Year

Manufacturer	**Fuel**	**Models**
Ford Motor Co.	CNG	Crown Victoria, bi-fuel-F-150 or dedicated Econoline & F-150
	Propane	Bi-fuel F-150
	Ethanol	Flex-fuel Explorer, Ranger & Taurus
	Electric	Ranger & THINK City
Daimler-Chrysler	CNG	Ram Van, Wagon
	Ethanol	Flex-fuel Chrysler Town & Country, Voyager (& Grand), Caravan (& Grand)
General Motors	CNG	Bi-fuel Cavalier, Express/Savanna, Silverado/Sierra
	Propane	Chevrolet/GM medium duty truck
	Ethanol	Flex-fuel Chevrolet S-10, GMC Sonoma, Tahoe/Yukon, Suburban
Honda	CNG	Civic
	Hybrid Electric	Insight
Toyota	CNG	Camry
	Hybrid Electric	Prius
	Electric	RAV-4 EV

Source: http://www.afdc.doe.gov/pdfs/wModel_Year2002AFVs.pdf

Cost concerns do not, of course, involve just the vehicle and the fuel itself. Fuel distribution and tank stations must follow and this creates an additional cost.

The cost of retrofitting an existing refuelling station's or retail outlet's gasoline/tank for ethanol (E85) ranges from $5,000 to $30,000. For a new underground tank and pump, the price ranges from $50,000 to $70,000. For LPG, the installation cost of a new outlet is $25,000 to $40,000. For CNG, the installation cost of an initial outlet is $250,000 to $500,000.

1.5.2 LPG

1.5.2.1 Introduction

LPG (liquid petroleum gas) is a combination of hydrocarbons such as propane, ethane and butane. In the USA, LPG is often referred to as propane (since LPG contains at least 90% propane in the USA). It is obtained as a by-product of crude oil refining and natural gas processing. LPG is gaseous at ambient conditions, but liquefies at moderate pressures (6 to 8 bar). Although stored on board vehicles as a liquid, it is returned to a gaseous form before being burned in the engine.

Experiments using propane as a motor fuel were first conducted around 1910. During the 1950s, the conversion of conventional vehicles to AFVs became popular. A taxi firm in Milwaukee boasted a fleet of nearly 300 taxis running on propane at that time, and the Chicago Transit system operated more than 500 propane-fuelled buses. From the end of the 1970s conversion of gasoline vehicles to LPG became popular, and in Europe too.

For on-road use, LPG is currently used in both light and medium duty vehicles as well as in heavy-duty trucks and buses (especially in the USA). LPG is also a popular choice for off-road vehicles, such as forklifts, where the reduction of exhaust gases is important as this type of vehicle is often used indoors.

Worldwide, some 4,500,000 cars and vans use LPG as a fuel. Larger markets include Italy with well over one million vehicles, Australia, with over 500,000, and the Netherlands with 400,000 - the highest percentage (~10%) of the total number of vehicles of any country. Nearly all taxis in Japan run on LPG, and India, Brazil, Turkey and the USA all have a significant number of such vehicles.

As LPG is a by-product of crude oil refining, it can be produced at low cost. This, however, also creates a counterpart - namely that its potential is limited to the amount available from crude-oil refining and natural-gas processing (some 5% of crude oil input). It will not be produced as a total replacement for the other fossil fuels. The available amount, however, is far from being reached at the moment.

Most light-duty LPG vehicles are conversions, with conversion costs typically ranging from €1,000 for early systems up to € 2500 for the newest.

1.5.2.2 LPG Technology

In many respects technology for LPG engines resembles that for conventional gasoline spark-ignition engines. This is especially the case for light-duty vehicles. Modern light-duty LPG vehicles and conversion kits commonly employ three-way catalytic converters and stoichiometric air-fuel ratio control systems with feedback control via an oxygen sensor. Apart from differences in the fuel metering hardware and the absence of cold starting aids (although new systems commonly use gasoline for starting the engine), these systems closely resemble those used in modern light-duty gasoline vehicles. The same can be said for natural gas conversion systems.

One frequent complaint about bi-fuel LPG passenger vehicles is the loss of trunk space due to the installation of the LPG tank. An advantage, however, is that LPG engines are reported to last longer than gasoline engines. Although initial costs are higher, the long-term savings on fuel costs and maintenance usually outweigh the short-term costs.

LPG vehicles can either be dedicated vehicles, which operate exclusively on LPG, or bi-fuel vehicles which have fuel systems for both LPG and gasoline. In light-duty applications most LPG vehicles are bi-fuel. Until recently most light-duty vehicles were retrofitted from gasoline in the aftermarket business. With the increasing complexity of gasoline engine management systems and the requirement for On Board Diagnostics, OEM manufacturers increasingly directly offer bi-fuel vehicles from the showroom. Examples of this include General Motors, Volvo, Ford, Rover and Daewoo.

Gaseous fuels occupy more volume than the same amount of gasoline, yet have the same energy. As a result, the volumetric energy content of a stoichiometric gas/air mixture is less than that of gasoline-air mixture. In addition, gaseous fuels do not benefit from the practice of power enrichment – the best power output from gas engines occurs at essentially the stoichiometric air-fuel ratio.
When a gasoline engine is converted, the combination of these two effects typically results in a loss of maximum power output of approximately 10%. For LPG, these effects are smaller than for natural gas, and the power loss is typically only a few %. In dedicated engines, the reduction in power output with gaseous fuels can be compensated by increasing the compression ratio.

Gaseous-fuel vehicles require precise control of the air-fuel ratio to minimise emissions while maintaining good performance and fuel economy. Until about 1990, nearly all gaseous-fuel metering systems relied on mechanical principles, analogous to the mechanical carburettors used in gasoline engines until the 1980s. Although these mechanical systems can be designed to give good engine performance and efficiency, they are susceptible to fuel metering errors due to wear, drift, changes in elastomer properties, changes in fuel and air temperature, changes in fuel properties, etc. These mechanical systems are thus unable to meet the requirement of modern three-way catalytic converter systems for very precise control of the air-fuel ratio.

In the 1980s air-fuel ratio control systems for light-duty gasoline vehicles evolved from mechanical systems to digital electronic fuel injection. Gaseous fuel metering systems have recently undergone a similar evolution. The fuel metering and engine control systems installed on new LPG vehicles are essentially identical to the multi-point sequential fuel injection systems installed on production gasoline vehicles, except for details of the fuel rail and injectors. Several manufacturers of gaseous-fuel retrofit kits now also offer systems using electronically controlled fuel injection.

Three evolutions of LPG systems can be mentioned [De Keukeleere, 1998]:

1. *First generation systems* with mechanical fuel control and carburettor.
2. *Second generation systems* in which the LPG dosing is controlled electronically. In contrast with the first-generation systems, this type of system can be used in combination with gasoline injection and closed loop three-way catalyst. These systems were introduced in the early 1990s and the technology is still frequently used for retrofit systems.
3. *Third generation systems* are microprocessor controlled, incorporate adaptive learning and require no manual adjustments. Such systems can be either carburetted (central mixer) or fuel injected. The most recent developments utilise LPG sequential multi-point injection, in either liquid or gaseous form.

Modern vehicles equipped with On Board Diagnostics (OBD) can be converted to LPG use only when microprocessor-controlled LPG systems are used in combination with the original engine-management information database. For these applications, close co-operation with the vehicle manufacturer is a necessity.

Developments in the field of modern LPG fuel systems have been rapid, with the Netherlands and Italy taking the lead in Europe. The technology is also available from Japan, the USA and Canada, and there is international co-operation with car manufacturers.
In countries where stringent emission standards are not required, conventional mechanical LPG systems (first generation) are still employed.

The leading technologies in Europe are the Dutch GENTEC-VIALLE and KOLTEC-NECAM systems, which are electronically controlled fuel multi-point injection systems [see Annex]. In Italy, FIAT is actively involved in adapting some of its cars to LPG/CNG. In France, Renault has performed various tests in light-duty vehicles. In Germany, Mercedes Benz has launched a sophisticated multi-point LPG system for its new models.

1.5.3 Natural gas

1.5.3.1 Introduction

Natural gas is a fossil fuel that can be found all over the world. It is not a petroleum product and is primarily composed of methane (CH_4), with minor amounts of ethane and higher hydrocarbons. Depending on the source, the natural gas can also contain CO_2, nitrogen and water. Because it is a fossil fuel, there is a finite supply with reserve estimates of 120 years at current levels of consumption.
Natural gas can also be produced as a by-product of landfill operations – in this case it is called biogas. The engine technology is the same for biogas.
Natural gas is transported to end users through a gas pipeline system. For storage and use as an alternative fuel in vehicles, natural gas is either compressed (CNG) or liquefied (LNG). LNG is only used in heavy-duty vehicles, so only CNG vehicles will be discussed here.

1.5.3.2 CNG technology

Natural gas has been used for many years in stationary internal combustion engines. The major difficulties with natural gas in transportation applications have been on-board fuel storage and vehicle range. Because of its very low energy density as a gas, natural gas must be either compressed (CNG) or liquefied (LNG), increasing its energy density, to make it a viable transportation fuel.

There are two types of light-duty CNG vehicles or fuel systems currently being produced: dedicated vehicles that operate exclusively on natural gas, and bi-fuel vehicles that have fuel systems for both natural gas and gasoline.

The fuel system for CNG is very similar to LPG systems. There are three types:

- Mechanically controlled systems with carburettor
- Systems with electronic control
- Self-learning systems with microprocessor

The latter two are usually equipped with fuel injection. The main difference between an LPG system and a CNG system is the storage pressure (up to 200 bar) and the controllers, reducing to pressure down to about 5 bar before the fuel is discharged or injected into the engine intake manifold..

The natural-gas engine is a spark-ignited engine, and current light-duty natural-gas engines are stoichiometric with lambda control and three-way catalyst (heavy-duty natural-gas engines are very often lean-burn controlled). Catalysts used for gasoline engines deteriorate quickly when used for natural gas. This is because of the presence of methane, a relatively stable gas, which is more difficult to convert. The conversion efficiency of the catalyst is reduced quite quickly, not just for methane but also for other hydrocarbons. The application of dedicated three-way catalysts for natural gas is therefore necessary to keep exhaust gas emissions low.

Because of the very high research octane number (RON), a higher compression ratio is possible, which may lead to higher engine efficiency. Bi-fuel vehicles cannot utilise this advantage as they should also be suited to gasoline use.

In general it can be said that dedicated CNG vehicles are more optimised to the use of natural gas and will achieve better fuel efficiency and lower emissions than bi-fuel CNG vehicles.

Dedicated light-duty NGVs cost about €3,500 to €7,000 more than their gasoline counterparts [De Keukeleere, 1998].

Some of the expense is due to the need for specialised storage tanks. As demand increases and more NGVs are sold, prices will most likely decrease. NGVs generally have lower exhaust emissions than do gasoline vehicles. Evaporative emissions are also reduced when refuelling an NGV. If any natural gas escapes from the refuelling nozzle, the gas will not lie on the ground or enter sewage systems because the natural gas is lighter than air. Driving range remains one of the drawbacks of dedicated CNG vehicles.

Depending on the make and model, 1999 CNG vehicles in the USA have a driving range of approximately 200 - 300 km, which is about half that of their gasoline counterparts. For bi-fuelled natural-gas vehicles, driving range is less of a problem as they are equipped with two separate fuel systems.
(http://www.eia.doe.gov/cneaf/alternate/issues_trends/altfuelmarkets.html)

1.5.3.3 Statistics

Natural gas as a vehicle fuel has a long and established record in Europe, North America, Argentina, New Zealand and Australia. Other countries are planning to expand the use of natural gas vehicles. A detailed overview of the number of natural-gas vehicles and fuelling stations can be found in the Annex [IANGV, 2002].

NGV technology development and commercialisation began in Italy, where conversion systems attached to gasoline vehicles became an alternative to using expensive and scarce gasoline that was diverted for military vehicles during World War II.
Currently Italy has about 370,000 NGVs. The Italians have a network of 280 filling stations to support their use of compressed natural gas (CNG). Russia has about 75,000 NGVs and a fuelling network of some 250 stations. Outside these countries, there are now several thousand NGVs in Europe and a slowly growing fuelling station infrastructure.
Argentina has 700,000 NGVs - the largest fleet in the world - it is converting more than 3,000 vehicles a month and has over 500 fuelling stations in operation or under development. Venezuela has a national NGV programme and will be installing 60 fuelling stations and converting vehicles.
Canada has about 36,000 vehicles converted to natural gas, and the government-supported NGV programme has created a number of incentives. The Canadian Government provides cash incentives for fleets to convert their vehicles and hopes to use CNG for 10% of the entire country's future vehicle fuel requirements.
In the USA there are now about 68,000 vehicles fuelled on natural gas. Natural-gas vehicles have been in use there since the late 1960s, but comparative prices with gasoline and state-of-the-art technologies are only now making natural gas economically and technologically competitive with gasoline vehicles. There are about 1,200 private and public refuelling stations for CNG and 44 for LNG. Natural-gas refuelling stations are usually located in urban areas near the major concentrations of natural-gas vehicles and are frequently constructed on a company site to serve fleet vehicles.
The majority of NGVs in use in the USA are non-dedicated, light-duty CNG vehicles. The EIA collected data on nearly 35,000 CNG vehicles in use in 1998 (almost one-half of the total CNG vehicles estimated to be in use in 1998). Of the vehicles reported on, 63 % were light-duty, non-dedicated vehicles.

1.5.4 Hydrogen

Hydrogen is the most abundant chemical element, comprising about 75% of the mass of the universe. When combusted it creates only water vapour as a by-product.
Although hydrogen is abundant as an element in many compounds, it must be in its uncombined form to use as a fuel. Generating hydrogen typically requires significant

amounts of energy or has energy conversion losses that increase its cost. Hydrogen can be produced through several methods [CEC, 1999]:

1. Natural gas steam reforming. Conversion efficiency is about 70% to 75%. This is the most common method of producing hydrogen. Naphta and LPG can also be used as a feedstock for this process in which syngas (CO and H_2) is produced at high temperatures in the presence of a catalyst.
2. Electrolysis. Electricity produced from renewable sources, such as solar, wind and hydro-power can be used. The electrolysis process itself is emission free and has an efficiency of around 80-90%. Some sources, however, mention that process conversion efficiency appears to be less than 65% at best.
3. Biomass gasification and pyrolysis.
4. Photo-electrolysis
5. Photo-biological process.

Beyond hydrogen's use in the NASA space programme, its use in transportation has only been in experimental and prototype vehicles. In 1997, it was estimated that in the USA there were less than 20 vehicles that relied on hydrogen as a fuel. Germany, however, has been experimenting with hydrogen-fuelled vehicles since the 1920s. In the past two decades both DaimlerChrysler and BMW have invested research into hydrogen internal combustion vehicles. Now many in the automotive industry are looking toward hydrogen fuel cells as the next generation vehicle [Bradley, 2000].

Major issues with the use of hydrogen as a fuel are production, infrastructure costs and on-board vehicle storage.

Hydrogen gas can be applied in spark-ignited internal combustion engines. Its main application in the future, however, will be in fuel cells (see next chapter).

The 'HyWEB' website offers an overview of hydrogen cars (both internal combustion engines and fuel cells): http://www.hydrogen.org/h2cars/overview/index.html.

The main industrial promoter of hydrogen as a fuel for internal combustion engines is BMW. They suggest engine efficiency around 35-36%. Vehicle models are restricted, however, to demonstrations and are not commercially available.
BMW began to address the question of hydrogen drive in the late 1970s. Development has now reached the 5th generation of hydrogen-driven cars, presently on the basis of the latest 7-Series model.

Whereas the basic engine is series-produced, hydrogen drive as part of the fuel system calls for certain modifications in the mixture process. For this purpose, an electronic fuel mixture system has been developed. This exactly regulates the hydrogen intake and the charge cycle. The combustion process generally involves a surplus of air (lean combustion). This absorbs heat in the combustion chamber and keeps flame temperature below the critical limit at which uncontrolled ignition can occur. NO_x emissions can still be an issue as these are related to combustion temperature. Therefore, combustion of hydrogen should be kept at very lean levels. Since the lean limit is much higher than for gasoline and big varieties of lambda are acceptable, powering the vehicle can be achieved by fuel control (as for a diesel engine) - in this case a throttle is not necessary [BMW, 1999].

A major factor limiting the use of hydrogen is the ability to safely store and transport this highly volatile fuel. Hydrogen is generally stored as either a compressed gas or as a liquid. Both approaches present volume and weight problems due to low energy density. Another option that has been investigated is storing hydrogen as a metal hydride. The fuel is than released when needed, usually with heat. Unfortunately, this technique is currently the most expensive way to store hydrogen and thus imposes losses in fuel economy.

1.5.5 Ethanol

1.5.5.1 Introduction

Ethanol (C_2H_5OH), also called ethyl alcohol or grain alcohol, is a liquid derived from corn, grains or from a variety of other agricultural products, residues and waste. As such it is considered a renewable energy source. Over four million vehicles have operated on ethanol in Brazil as a result of a government programme to produce the fuel from sugar cane [CEC, 1999].

In high concentrations ethanol is most typically used as a blend of 85% ethanol and 15% gasoline, known as E85, which is appropriate for light-duty vehicles. Ethanol, however, is most commonly used as a blending component with gasoline in a combination of 10% ethanol and 90% gasoline, commonly known as gasohol or E10. Ethanol can be blended in even lower concentrations with gasoline to produce oxygenated gasoline. In the future, ethanol may be used as a component of ethyl tertiary butyl ether (ETBE), a different type of oxygenate.

Ethanol's history as a transportation fuel began with Henry Ford and other transportation pioneers. In the 1880s, Ford built one of his first automobiles, the quadricycle, and fuelled it with ethanol. The Ford Model T had a carburettor adjustment that could allow the vehicle to run on ethanol fuel produced by farmers [CEC, 1999].

Rising taxes on ethanol limited its use as a fuel. Low gasoline prices, and a "propaganda campaign" by oil producers were factors that kept ethanol and other alternatives from catching on as transportation fuels. During World Wars I and II in both the United States and Europe, alcohol fuels were used as a supplement to oil-based fuels (usually around 20%). Following WWII, ethanol was unsuccessful as an economically competitive transportation fuel due to the reduction in oil prices. In Brazil and in the USA in particular, the 1970s oil crises gave birth to a governmental ethanol support strategy.

1.5.5.2 Ethanol markets

United States

There are currently 121 ethanol (E85) refuelling sites in the USA, up from 37 in 1995 [US DOE, 2002]. Ethanol refuelling sites can be found predominantly in the Midwest, close to the major supplies of ethanol. Although the trend in alternative fuels is in the direction of E85 use, the infrastructure has been slow to develop because these vehicles can use conventional fuel. Further, studies have shown that refuelling stations need at least 200 steady customers for any single grade in order to make profitable use of the facilities. Though large numbers of flexible-fuel vehicles are being sold, they are spread out over the entire nation, and reaching a "critical mass" of 200 that use a single refuelling station is still difficult to achieve.

Table 1.5-3 shows an overview of ethanol consumed in the USA as E95, E85 and in gasohol. The comparison is also made with the consumption of the oxygenate MTBE (see later) and gasoline.

Table 1.5-3: Estimated US consumption of fuel ethanol, MTBE and gasoline (Thousand Gasoline-Equivalent Gallons)

	1994	1996	1998	2000	2002 (projected)
E85	80	694	1.727	*7.074*	10075
E95	140	2,699	59[a]	*13*	0
Ethanol in Gasohol (E10)	845.900	660.200	889.500	*1.106.300*	1.118.900
MTBE in Gasoline	2.108.800	2.749.700	2.903.400	*3.087.900*	2.531.000
Gasoline[b]	113.144.000	117.783.000	122.849.000	*125.720.000*	130.735.000

Source: EIA, 2002

[a] A major drop in E95 consumption occurred between 1997 and 1998 because of a significant decrease in the number of E95-fueled vehicles in operation (347 to 14), due to the elimination of an ethanol-fuelled bus fleet in California.

[b] Gasoline consumption includes ethanol in gasohol and MTBE in gasoline.

Approximately 1.7 million gasoline-equivalent gallons (GEG) of E85, and 59,000 GEG of E95 were consumed in 1998, mostly in Midwestern states. One reason for the relatively low consumption of E85 and E95 is that there are relatively few vehicles on the road that operate on these fuels. In 1998, approximately 14,000 ethanol-fuelled vehicles were in use compared with some 210 million gasoline and diesel fuelled vehicles on the road in 1996 [EIA, 2002)].

Brazil (see also par. 3.8.2)

Ethanol has been promoted in Brazil as a response to the oil shock of 1973 and partly as an alternative to oil to promote self-sufficiency. In 1975 the government created the

Brazilian National Alcohol Program to regulate the ethanol market and encourage the production and use of fuel ethanol from Brazilian sugar cane.

A lot of government support was given to the ethanol sector and tax incentives were created so that ethanol would cost less to the consumer than gasoline. The first alcohol vehicles were manufactured in 1979. As the main technical problems were solved, sales of these vehicles boomed. Market penetration averaged 92% between 1983 and 1988. By 1990 more than five million alcohol-fuelled vehicles were in circulation, representing an estimated 50% of the fleet [Buarque de Holanda & Dougals Poole, 2001].

An ethanol shortage in 1989 reduced the confidence of customers and sales of ethanol vehicles dropped dramatically. In 2001, there were still 3.7 million older ethanol vehicles in circulation and the distribution network is still in place.

Currently the reduction in hydrated ethanol (for dedicated ethanol vehicles) has been compensated for in part by an increasing demand for anhydrous ethanol, which can be blended up to a proportion of 24% with gasoline.

While Brazil is still the leading country in ethanol use at present, the USA is expected to catch up, using ethanol as an oxygenate.

Europe

Other than in Sweden and France, the use of bioethanol has not yet been developed on a major scale in the EU, and initiatives have been aimed at the production of ETBE as a replacement for MTBE in unleaded gasoline. France is the primary producer of bioethanol in Europe, followed by Italy and Spain.

Sweden has programmes to promote the use of bioethanol in FFV-vehicles and the use of diesel-ethanol emulsions and also neat ethanol fuels for diesel engines. Stockholm City Transport runs the world's largest fleet of ethanol buses, currently some 250 Scanias.

At the end of September 2002, Scania decided it would not continue its work on ethanol vehicles.

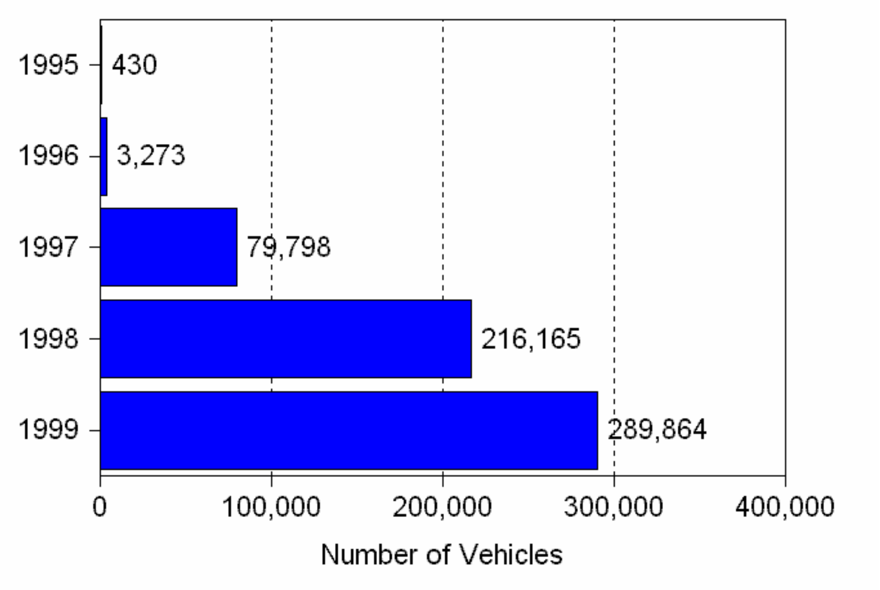
1.5.5.3 FFV-Technology

A flexible fuelled vehicle (FFV) has a single fuel tank, fuel system, and engine. The vehicle is designed to run on unleaded gasoline and an alcohol fuel (usually ethanol) in any mixture. The engine and fuel system in a flex-fuel vehicle must be adapted slightly to run on alcohol fuels because alcohols are more corrosive. There must also be a special sensor in the fuel line to analyse the fuel mixture and control the fuel injection and timing to adjust for different fuel compositions.

The small amount of gasoline added to the alcohol helps prevent corrosion of engine parts, it aids ignition to help start engines in cold weather and to ensure that flames are visible. Ethanol FFVs have modern microprocessor technology that continually adjusts the engine operation, fuel to air ratio, as required by the ratio of ethanol and gasoline in the fuel tank.

Ethanol FFVs can therefore operate on any combination of the two fuels. FFV technology for ethanol and methanol are similar, but may use different materials for the fuel system and are calibrated differently to match the fuel's energy content.

Figure 1.6: Number of FFV vehicles in the USA



Source: Joyce, 2000

Flex-fuel technology was created by Ford Motor Company in the mid-1980s. Since 1997 vehicle suppliers in the USA have produced increasingly more flexible-fuelled E85 vehicles. In June 1997, Ford Motor Company announced it would make E85 flexible-fuel capability a standard on its 3.0 litre Ford Ranger pick-up trucks, starting in the autumn of 1998. At the same time, Ford also announced plans to "offer other high-volume FFV car and truck lines, including Windstar" in later years. Shortly after Ford's announcement, Chrysler Corporation announced it would provide E85 flexible fuel systems as standard equipment on all of its 3.3-litre engine mini-vans, also beginning in 1998. As a result, the E85 vehicles available grew from about 400 in 1995 to more than 200,000 in 1998. In 1999 it was announced that Ford would begin producing the Taurus EX as an E85 flexible-fuelled vehicle and General Motors would offer a line of flexible-fuelled E85 pick-up trucks in model year 2000.

FFVs generally are more expensive than conventional vehicles, although this margin has decreased in recent years with newer technology.

The most significant barrier to wider use of fuel ethanol is its cost. Even with tax incentives for ethanol producers, the fuel tends to be more expensive than gasoline per gallon. Furthermore, since fuel ethanol has a somewhat lower energy content, more fuel is required to travel the same distance. This energy loss leads to an approximate 3% decrease in miles-per-gallon vehicle fuel economy with gasohol (E10). For E85 the difference is much more.

Blends of up to 10% ethanol with gasoline can be used in all gasoline-powered automobiles, without engine or carburettor modification. This makes ethanol very suitable for use as oxygenate.

1.5.5.4 Ethanol as oxygenate

Ethanol's chemical properties make it very useful for some applications, especially as an additive in gasoline fuel. Major stimulants for the use of ethanol have been the oxygenate requirements of the Reformulated Gasoline (RFG) and Oxygenated Fuels programs of the Clean Air Act in the USA. Oxygenates are used to promote more complete combustion of gasoline, which reduces carbon monoxide and volatile organic compound (VOC) emissions. In addition, oxygenates can replace other chemicals in gasoline, such as benzene, a toxic air pollutant.

The two most common oxygenates are ethanol and methyl tertiary butyl ether (MTBE). MTBE, primarily made from natural gas or petroleum products, is preferred to ethanol in most regions because it is generally much less expensive, is easier to transport and distribute, and is available in greater supply. Because of different distribution systems and blending processes (with gasoline), substituting one oxygenate for another can lead to significant cost increases.
Despite the cost differential, there are several possible advantages of using ethanol over MTBE. Ethanol contains 35% oxygen by weight - twice the oxygen content of MTBE. Furthermore, since ethanol is produced from agricultural products it has the potential of being a sustainable fuel, while MTBE is produced from natural gas and petroleum, fossil fuels. In addition, ethanol is readily biodegradable, eliminating some of the potential concerns about groundwater contamination that have surrounded MTBE (see the section on MTBE). In California, MTBE has been banned as oxygenate from the end of 2002 [Urbanchuck, 2000].
If MTBE is banned as a gasoline additive and fuel producers replace MTBE with ethanol, it is uncertain whether there will be sufficient refinery capacity both to replace MTBE and to fuel flexible-fuel vehicles a substantial part of the time with E85.

Ethanol can also be blended into otherwise non-oxygenated gasoline to raise the octane rating of the fuel, and therefore improve its combustion properties. High-performance engines and older engines often require higher octane fuel to prevent early ignition, or "engine knock". Other chemicals may be used for the same purpose, but some of these alternatives are highly toxic. Furthermore, since these additives do not contain oxygen, they do not result in the same emission reductions as oxygenated gasoline.

1.5.6 Methanol

Methanol is a clean-burning liquid alternative fuel. Its chemical formula is CH_3OH. Because methanol can be produced from natural gas, coal or even biomass, it offers energy security benefits and a clean alternative to petroleum-based fuels.
The most typical application today is M85, a mixture of 85% methanol and 15% gasoline, which is primarily used as an alternative fuel in light-duty vehicles. M100 (pure methanol) works best in heavy-duty vehicles. Methanol is also being tested as a source of hydrogen to power fuel cells in electric vehicles. In another transportation

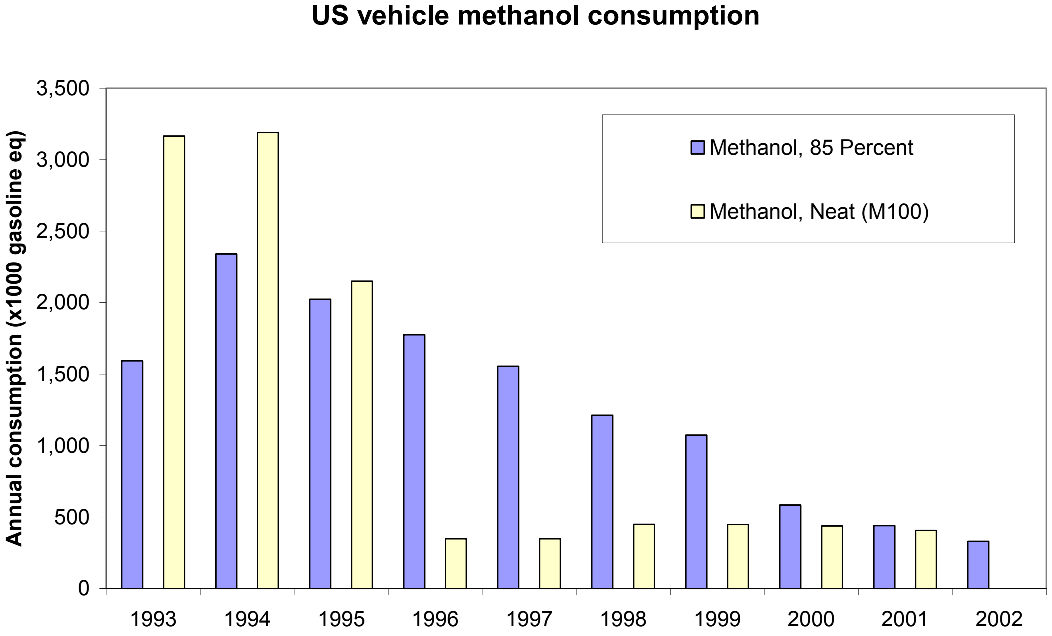
application, methanol is used to produce the oxygenate, methyl tertiary butyl ether (MTBE). Flexible-fuel vehicles can use methanol or gasoline in any combination from the same tank. That means these vehicles can use alcohol fuel when it is available or regular gasoline when it is not.

Methanol's power, performance and safety have also made it the fuel used in Indianapolis-type racing cars since 1965. Since 1978, the California Energy Commission - in association with Chrysler, Ford Motor Company, General Motors, Honda, Mazda, Mercedes-Benz, Mitsubishi, Nissan, Toyota, Volkswagen and Volvo - have sponsored demonstration programmes to test M85-powered vehicles in public and private fleets. The Commission also teamed with major oil companies to provide M85 fuel at strategically placed gasoline stations around the state. In the 1980s and 1990s several thousand methanol-powered vehicles were operated by California fleets as part of CEC-sponsored programmes conducted in partnership with the automobile industry. The numbers increased most dramatically after 1987, when the first flexible-fuelled autos designed for M85 were commercially produced. To support methanol programmes, the CEC (California Energy Commission) provided assistance in the development of a methanol reserve to supply fuel and a refuelling infrastructure to distribute the fuel in California. At its peak, more than 100 locations in California hosted methanol fuelling facilities. Methanol fuel use has decreased significantly from the mid 1990s. A sharp increase in the price of methanol in 1994 and another less severe one in 1997 contributed to the decline in methanol use as an alternative fuel. Currently there are only two methanol (M85) refuelling sites in the US, significantly down from 88 in 1995. Both of these sites can be found in California [US DOE, 2002].
While two American auto companies offered M85 fuel-flexible vehicles for sale to fleets and the public in the 1995 model year,, only one was offering FFVs in the 1996 model year. None of the auto companies offered methanol-powered vehicles after the 1998 model year, shifting their focus to ethanol-based alcohol fuels.

Figure 1.7 also shows that methanol consumption for vehicles in the USA peaked around 1994 and has declined since.

If methanol is to have a significant role in future AFV markets, it is likely to be in methanol fuel cell vehicles. The American Methanol Institute (AMI) suggests that further development of methanol fuel cell technologies will offer potential growth for methanol demand. The AMI also states that "a clear consensus has now been reached that methanol is the automotive industry's preferred energy source for fuel cell vehicles". [AMI, 2000].

Figure 1.7: Evolution of methanol consumption as vehicle fuel in the USA



Source: EIA, 2002

1.5.7 Biodiesel

Biodiesel is the generic name for a variety of diesel fuel alternatives based on methyl esters of vegetable oil or fats. Biodiesel fits into the category of a renewable fuel because it is made from agricultural feedstocks such as rapeseed or soybean. Research on rapeseed derived biodiesel takes place in Europe, while the USA has been focusing on soy-based biodiesel. Other possible feedstocks for biodiesel include bio-oils from corn, cottonseed, peanut, sunflower, canola, and rendered tallow (animal fat). Used frying oils are also taken into consideration.

The fuel is made by a catalytic chemical process named trans-esterification, using an alcohol (such as methanol) and a catalyst. The final fuel closely resembles conventional diesel fuel, with a comparable cetane number. The energy content is a little lower, and viscosity somewhat higher (although the esterified biodiesel has far lower viscosity than the vegetable oil itself).

A big advantage of biodiesel is that it can be used in normal diesel engines without any major adaptation of engine settings. Vehicle fuel lines and other components that would come in contact with the fuel may have to be changed, however, because biodiesel can dissolve some rubber. The fuel also clouds and stops flowing at higher temperatures than diesel, so fuel-heating systems or blends with diesel fuel would be needed in lower temperature climates.

The fuel is essentially sulphur-free and emits significantly less visible smoke, hydrocarbons and carbon monoxide. Nitrogen oxide (NO_x) emissions are similar to or slightly higher than those of diesel. Biodiesel has a high flash point and has very low toxicity if digested. It is also biodegradable.

As early as 1892, when Rudolf Diesel secured his patent for the diesel engine, he claimed that the engine could operate on vegetable or animal oil.
After some experiences with vegetable oils, notably in WWII, it was not until 1975 that experiments were conducted with vegetable oils and their esters.
The first commercial RME (rapeseed oil methyl ester) was produced in 1988, although it was characterised as a single-feedstock product of then questionable quality. By 1991 the first biodiesel fuel standard was issued in Austria for RME. This was the basis for numerous diesel engine warranties issued by all key tractor companies. This standard was followed in 1997 by a standard for FAME (Fatty Acid Methyl Ester), to define the quality of a fuel not by its feedstock source, but by what is filled into the tank. National standards were established in Germany, the CSSR, France, Italy, Sweden and the USA.
From 1994, 5% RME was officially allowed to be mixed with normal diesel fuel in France.

This was the necessary basis for building customer confidence, obtain warranties from many diesel engine manufacturers (e.g. Mercedes-Benz, Peugeot, Volkswagen) and injection pump producers, to provide transport reliability and to create a positive image in the marketplace. The most recent development is the completion of a CEN-draft standard for biodiesel with validity all over Europe. This work is still in progress and a final CEN-standard may be published by the end of 2002.

In total, 1,500 filling stations in Germany provide neat RME [Bockey, 2002].

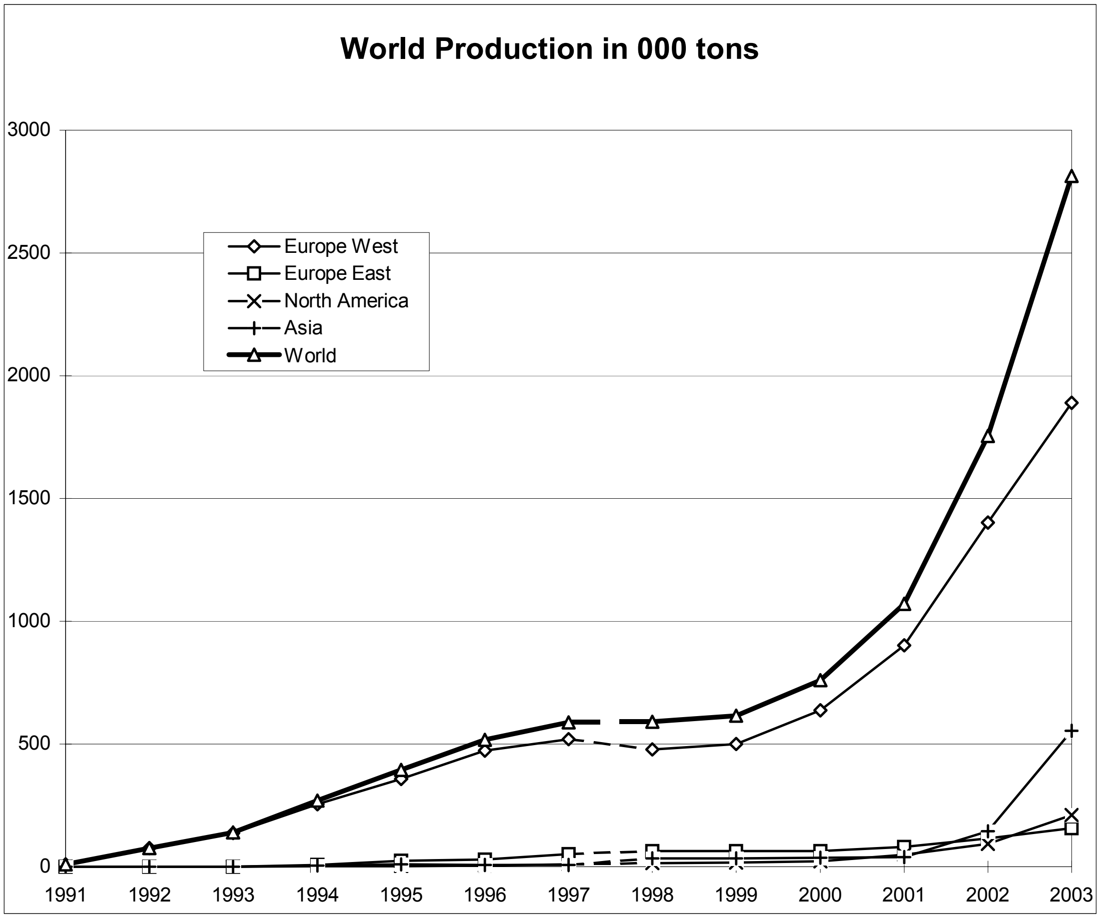
Although it can be used in common diesel engines, some manufacturers do not allow the use of 100% biodiesel because of concerns about fuel quality and concerns about increase in NO_x emissions.

After beginning in 1988 with a rather small Austrian farmers' co-operative biodiesel plant with a capacity of approximately 500 tons a year, other production plants followed quickly and the first industrial scale biodiesel production plant with a capacity of 10,000 tons a year went into operation in Austria in 1991. Over the next few years larger plants were established all over Europe – e.g. in Livorno, Italy (capacity up to 80,000 tons), in Rouen, France (capacity 120,000 tons and to date the largest Biodiesel production plant of the world), in Germany and in Sweden. The Czech Republic completed a programme to establish 16 biodiesel plants, making this country the leader for numbers of production sites.

The study *"Review on Commercial Biodiesel Production Worldwide"* as commissioned by the International Energy Agency, completed by the Austrian Biofuels Institute and published in April 1998, had identified 21 countries around the world in which biodiesel projects with a commercial objective had been implemented. Despite these many worldwide initiatives, Europe kept the lead by far and only in recent times has US production increased, with the location of the most modern MFS-Biodiesel plant of Griffin Industries in Kentucky.

In 1998-99 the biodiesel production community experienced a very difficult period when non-food oilseeds were grown at minimum acreages, food vegetable oil prices soared to extreme heights and at the same time the crude mineral oil price reached a record low level of around $9 a barrel, leading many producers into a loss position.
With the European Commission resetting the set-aside percentage back to 10% non-food crops, larger volumes of non-food oil at reasonable prices became available again, triggering a renaissance for biodiesel producers. This is especially true in Germany, where an increase in production capacity from today's 90,000 tons a year up to an impressive 1,000,000 tons a year by the year 2003 is forecast, most of it located in Eastern Germany [Körbitz, 2002].

Figure 1.8: Worldwide biodiesel production



Source: Körbitz, 2002

1.5.8 DME (Dimethyl Ether)

DME is an oxygenated hydrocarbon (CH_3OCH_3), which is the simplest compound in the class of ethers. It is generally produced from natural gas, but almost any carbon-based feedstock can be used, including crude oil, coal, crop residues, oil sands, wood, or straw. Throughout the world, about 100,000 to 150,.000 tons of DME are produced annually [CEC, 1999].

Currently, the main use for DME is as a propellant in aerosol spray cans. However, its environmental characteristics and its high cetane number (> 55) make DME a viable alternative to diesel fuel in compression-ignition engines. As a motor fuel, when compared with diesel, DME is a clean fuel due to its lower particulate matter emissions. DME contains no sulphur and when used in a diesel engine, its NO_x emissions can be significantly reduced by modified fuel injection systems and through using exhaust gas recirculation. DME has approximately one half the energy content of diesel fuel.

Under standard atmospheric pressure, DME is a gas. Under moderate pressure, however, it becomes a liquid, similar to LPG. Like LPG, DME requires a pressurised vehicle fuel system and a pressurised fuel distribution system. LPG storage tanks are adequate for DME. Compared with diesel fuel, DME has poor lubricity and poor viscosity. Research is being conducted on the use of commercial lubricant additives.

Some experiments have been undertaken in heavy-duty applications, especially by Volvo [Hansen & Mikkelsen, 2001].
No commercial applications have been reported.

1.5.9 Synthetic fuels

Synthetic fuels (diesel, gasoline or methanol) can be made from carbon-containing feedstocks such as natural gas or coal, but can also be produced from biomass or a range of petrochemical by-products (refinery bottoms, bitumen, tars, coke). This process is referred to as the “Fischer-Tropsch” process or GTL for converting gases into liquids yielding synthetic fuels. Synthetic diesel fuel appears to be the most economical fuel product from the GTL process, compared with the production of other fuels such as gasoline and methanol.

The FT process was named after two German scientists who developed it in the 1920s: Franz Fischer and Hans Tropsch. Shortly afterwards, the process was employed by German companies in full-scale industrial plants to manufacture synthetic fuels, mainly diesel, from coal for use by the Germans during WWII. With Germany's very limited crude oil resources it became critical to find a means of obtaining fuel for tanks, aircraft and motor vehicles. The Fischer-Tropsch synthesis, based on abundant coal resources as feedstock, was the solution. It is estimated that some 4,500,000 barrels of synthetic fuels were made during each of the war years in Germany [Howard, 1998].

Another important thread in the development of FT technology started in South Africa in the late 1940s when the South African Government began research in the field. That work was conducted through a company, which became later the South African Coal, Oil and Gas Corporation, or "Sasol". The first Sasol plant was build in 1955 and additional plants were started in the 1980s. All plants used coal as a feedstock. Sasol's main objective was to make gasoline from local coal resources, as, at the time these plants were built, South Africa was subject to an international embargo and was unable to import gasoline. The South African plants are still in operation, producing around 160,000 barrels per day of FT products [Howard, 1998].

Since the oil crisis in the 1970s interest in the technology and the amount of research dollars spent have followed fluctuations in crude oil prices. The most technologically advanced players are Exxon and the Royal Dutch/Shell Group. Exxon has recently been studying FT plants in several locations around the world, including in Qatar and Alaska.

Table 1.5-4: Worldwide production capacities of synthetic fuels

Project	Capacity (barrels/day)	Status
Rentech	800 – 1000	Potential
Mossgas	23,000	Operating
Sasol, I, II, III	150,000	Operating*
Shell Bintulu	12,500	Existing
Syntroleum Sweetwater	10,000	Announced
Sasol/Philips/QGPC Qatar	20,000	Potential
Shell Bangladesh	50,000	Potential
Exxon Alaska	100,000	Potential
Exxon Qatar	100,000	Potential
Chevron/Sasol Escravos	20,000,.000 – 30,000,000	Potential
Aurora Project	50,000,000 – 200,000,000	Potential
Texaco Petrobas	N/A	Potential
Statoil/Sasol	N/A	Potential

* Coal feedstock

Source: Agee, 1999

A very important feature of synthetic diesel fuels is their compatibility with existing diesel engines. The only adjustment that may be required is increasing the lubricity of fuel in order to prevent excessive wear of the fuel injection system. This can be achieved using commercial lubricity additives. Doping the FT fuel with biodiesel, which has excellent lubricity properties, is under investigation.

A number of experimental studies showed emission benefits when comparing FT diesel fuels with petroleum based diesel. These findings are in agreement with the known fuel effects on emissions. High cetane numbers and low sulphur, the basic properties of FT fuels, favour reductions in the emissions of several diesel exhaust pollutants in both heavy- and light-duty engines.

1.5.10 References

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1.6 Alternative propulsion vehicles

Electric cars appeared in the 1860s before the arrival of the internal combustion car. The first electric cars were pure prototypes because the batteries could not be recharged. Electric cars reappeared with the arrival of the modern car in the 1890s. At that time electric cars, steam cars and internal combustion cars co-existed. Electric cars sold particularly well in the USA.

1.6.1 Electric and hybrid vehicles

1.6.1.1 Electric vehicles

In a counter-factual history, 1899 could have been a crucial year in a story of how the electric vehicle won the competition for the automobile market. The market for automobiles in the USA was principally divided between electric and steam. In 1899, 1,575 electric vehicles, 1,681 steam cars and 936 gasoline cars were sold.[1] In February of that year the Electric Vehicle Company ordered 200 vehicles and the next month announced that it would introduce electric taxi-cabs on a massive scale.[2] The producers of electric vehicles had easy access to commercially obtainable components, since they used the same motors, controllers, switches and batteries as the streetcars, albeit in smaller size.[3] T.A. Edison promised that the problem of the battery's poor capacity to store energy was about to be solved. The crucial patent for the gasoline car industry — the so-called Selden patent — was purchased by the Electric Vehicle Company.[4] The following year it began a successful legal case against the then leading producers of gasoline automobiles. Furthermore, the electric car seemed more technically advanced than its rivals: that year an electric vehicle "La Jamais Contente" became the first car to reach 100 kph.

All this looked promising for the future prospects of the electric vehicle, but the early promise did not last. While sales of electric vehicles more than doubled in the USA from 1899 to 1909, the sales of gasoline cars increased more than 120 times. The Selden patent did not deter new firms from producing gasoline cars. The trade association ALAM, which was formed by a small group of manufacturers to exploit the patent, was never able to stop infringement, and in 1911 they finally lost a decisive patent infringement case against Henry Ford.[5] By the early years of this century, the gasoline car had surpassed its competitors in the US market. The same development had taken place in France, Great Britain and Germany a few years earlier.

The electric car nearly disappeared except as a delivery vehicle in the UK where up to 45,000 were used. The oil crises in 1973-74 in particular promoted the creation of electric vehicle programmes in many advanced free-economy states. One of the most ambitious programmes was launched in France. In the 1970s a network of big French

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[1] J.J. Flink (1970).

[2] R. Schallenberg (1982).

[3] R. Schallenberg (1982, p. 255).

[4] According to R. Schallenberg (1982, p. 266) the Electric Vehicle Company bought the Selden patent after the firm started to have problems with the batteries in its first generation of electric cabs.

[5] The Court found that Ford had not infringed the Selden patent because he (and nearly all other gasoline car manufacturers) had used the Otto 4-stroke engine while the Selden patent mentioned a 2-stroke engine. See J.J. Flink (1970, p. 325).

firms aided by state funding sought to construct a market for electric vehicles in France. The most active company was the French electric energy producer EdF. This firm initiated the creation of a group of public organisations that were potential users of electric vehicles. Members of the group were the French Post Office, EdF, Paris airport, SNCF, the local transport organisation in Paris RATP, among others. The goal of the work in the group was to evaluate the needs of potential users thus enabling the industry to specify its possibilities in relation to the requests and measure the gap between required performance and the technically possible. It quickly became apparent that the demands were impossible to meet with the existing battery technology.[6]

In 1976 in the USA, the Senate authorized the Energy Research and Development Association to launch a federal programme for the development of electric and hybrid vehicles. The programme had a budget of $160 million which was to be used to develop nickel-iron and nickel-zinc batteries on the one hand and vehicles on the other. The aim was to facilitate the building of 2,500 electric and hybrid cars between June 1978 and December 1979, and later to increase production to 5,000 and to 50,000 vehicles yearly. The programme never fulfilled the ambitious plans and it was stopped by the Reagan Administration for budgetary reasons in 1982-83.[7]

Japan began a redevelopment programme for electric vehicles in 1965. This was considered a fundamental technical research programme. From 1971 to 1976, 19 million dollars was spent in a large national project headed by MITI. During this period, two generations of electric vehicles were developed and some 300 vehicles of different types were constructed. In 1976 the Japanese Electric Vehicle Council fixed an objective of 200,000 electric vehicles in 1986.[8] This objective was, of course, not reached.

Similar research projects were carried out in many other countries. Nowhere, in the 1970s and the 1980s, did the projects result in mass production of electric vehicles. The majority of projects launched in the 1970s built on the assumption that the batteries could be improved rapidly. This did not happen and electric and hybrid vehicles remained uncompetitive. The electric vehicle market was, until 1980-85, dominated by the pillars of: 1) simple delivery vans in Great Britain; 2) golf carts; 3) indoor trucks and small vehicles for indoor use and; 4) home-made cars. The technology used in these cars was essentially the same as the technology used in 1910-20.

The total number of electric vehicles worldwide is still insignificant compared with the ownership of gasoline cars. Switzerland, the leading European country in electric vehicles in the 1990s, had nearly 2,000 vehicles registered in 1993 while Germany had just over 1,800. In Switzerland the vehicles were to a large extent owned by individuals, but sales declined in the 1990s from 686 vehicles in 1991 to 220 vehicles in 1992.

Table 1.6-1: The number of electric vehicles in some European countries 1993

Great Britain	20-25000
Switzerland	1500-2000

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[6] A. Nicholon (1984). For a social constructivist interpretation of the efforts to develop the electric vehicle see M. Callon (1986).

[7] A. Nicholon (1984, p. 54-55).

[8] A. Nicholon (1984, p.51-53).

Sweden	2-300*
France	600-1000
Germany	3-4000

Sources: Cowan and Hultén, 1996

Projections in 1993-94 were very optimistic. Renault planned to produce 4,000 electrics in 1995, 3,000 of them to be Clios. Peugeot aimed at producing 50,000 electrics in 1998. In reality about 4,500 electric vehicles sold in Europe from 1990-98.

One reason why electric cars sold poorly was that they never reached a threshold of sales that could have generated the development of a new design. Another reason was that it proved difficult to move a vehicle design from prototype stage to model. When the prototype was transformed a lot of performance disappeared. (Table 1.6-2 below provides data on the first and second Impact.)

Table 1.6-2: Differences between the first and the second GM Impact

	The first Impact (1990) Aero Vironment's Impact	**The Second Impact (1996) GM's EV1**
Inverter	MOSFET (analogue)	IGBT (digital)
Air-conditioning	no	yea
Charger	On-board	Off-board
Top speed	120 km/h	130 km/h
Acceleration	7.9 sec (0-96 km/h)	9 sec (0-96 km/h)
Range	200 km (at 88 km/h)	145 km (EPA highway)
Curb weight	1000 kg	1350 kg
Battery	383 kg Lead-acid	533 kg Lead-acid
Motor	2xAC-induction	1xAC-induction
Max. power	85 kW	102 kW

Source: Maruo (2000)

PSA Peugeot Citroen is the leading European manufacturer of electric vehicles. The firm became actively involved in electric vehicle (EV) research and development in 1989 and was the first major manufacturer to supply electric vehicles to corporate and municipal fleets in 1995. The company undertook this initiative because of the interest shown by municipalities, institutions and companies in enhancing the quality of urban life. As of May 2001, PSA Peugeot Citroen had accumulated sales of more than 9,000 electric vehicles. In order to limit the costs inherent in the creation of this new market, the French Government helps to subsidise the acquisition of EVs through rebates and grants.

Developed in partnership with Via GTI and Alcatel, LISELEC is a self-service electric vehicle rental program currently underway in La Rochelle, France. The two vehicles available for rent are the electric versions of the Peugeot 106 and Citroen Saxo. Upon taking out a subscription, a driver accesses a vehicle using a non-contract card. The vehicle may be returned to any of the seven LISELEC stations in the city. Five hundred customers were using LISELEC in 2001.

Projections about the future continue to be optimistic. PSA sees a first application in electric-powered commercial vehicles in 2005-2010 with small on-board hydrogen fuel cells used to back up the battery-driven powertrain. This approach is illustrated by the Peugeot Partner TAXI PAC demonstrator. PSA Peugeot Citroen has been developing fuel cell technology for more than 30 years and participates in many European research programmes, such as Hydro-Gen, Nemecel and Bio H_2. It is also active in French programmes such as Predit, and in projects backed by the French Ministry for National Education, Research and Technology.

PSA predicts that fuel cells will be the main source of energy for vehicles in the period from 2010 to 2020. This progress will be achieved with an on-board hydrogen-producing system using a bioethanol or syngas reformer. After 2020, PSA envisages the development of hydrogen fuel that will make it possible to offer electric vehicles with long-range capability, as illustrated by the Hydro-Gen demonstrator, also based on the Peugeot Partner.

The General Motors EV1, introduced in 1996, is a ground-up production vehicle designed specifically as a totally electric vehicle. The two-passenger car has an aerodynamic design and brisk performance; the 137-horse-power electric motor provides 0 to 60 miles per hour acceleration in 8 seconds and a top speed of 120 miles per hour. The lightweight body consists of composite body panels attached to an aluminium frame. The standard lead acid batteries have a range of up to 95 miles per charge; the optional advanced nickel-metal hydride battery pack provides a range of 100-plus miles per charge.

GM subsidised lease rates for EV1s. The vehicles were priced at $43,995, and all those on the road were leased. The lease rate was $499 per month. GM leased EV1s from 1996 through to 2001. As leases expire for the approximately 600 EV1s in operation, GM will take all the battery-powered vehicles off the road [Automotive News, November 11, 2002].

1.6.1.2 Hybrid electric vehicles

One of the most ambitious efforts to produce a hybrid car was the Swedish-led Clean Air project. The prototype car won an important competition in California organised by the LA Department of Water and Power in the early 1990s, but when entrepreneurs in the project tried to move to full-scale production they ran out of funding. Modern parallel HEVs are equipped with a small internal combustion engine and a small battery pack. The weight of the vehicle is thus lower and the performance better than an electric vehicle. Both the internal combustion engine and the electric engine can be used for a quick overtake. Prototype HEVs that got a lot of attention in 1991-92 were exhibited by Volvo and Renault.

In 1998, Toyota started mass production of its HEV Toyota Prius. By early 2002 Toyota had sold more than 100,000 hybrid vehicles, most of them the Prius. Sales of hybrid vehicles have started to climb since the Prius was launched on international markets.

Table 1.6-3: Worldwide hybrid vehicle sales

Year	Sales per year	Sales per month
1997	332	
1998	17,656	1,470
1999	15,255	1,270

2000	19,026	1,585
2001	36,928	3,075
2002	13,770 (3 months)	4,590

Source: Toyota

The road to this milestone largely began in December 1997, when Toyota marketed in Japan the gasoline/electric Prius passenger sedan, the world's first mass-produced hybrid vehicle. With more than 33,000 units sold by the end of 1999, the proven technology of the Prius debuted in the North American market in June 2000, followed by the start of sales in Europe in September the same year. The Prius is now sold in more than 20 countries.

Since the arrival of the Prius, TMC's hybrid vehicle line-up in Japan has grown to include the Estima Hybrid mini-van, which came out in June 2001, and a mild hybrid version of the Crown luxury sedan, released the following August.

Key hybrid components in the Prius include an Atkinson cycle engine, a drive-power-supplying nickel-metal hydride battery and an electrically controlled transmission that serves as a continuously variable transmission. The Estima Hybrid's performance-enhancing electric 4WD and comprehensive four-wheel drive-and-braking control are world firsts for a mass-produced vehicle, and so is the Crown mild hybrid's practical application of a 42V electrical system.

1.6.1.3 The battery problem

Batteries that can be recharged are today being used in numerous applications, ranging from satellites in orbit around the Earth to trucks being used at airports and on railway platforms. Storage batteries come in many shapes and sizes. They can either be acid or alkaline. A battery for a mobile telephone may weigh less than 50 grams, a battery for a laptop computer 400-500 grams and a battery pack for an electric vehicle more than 500 kilograms.

In 1800, shortly after Volta announced his invention of the primary battery, a number of scientists experimented with electrochemical polarisation. It took more than 75 years, however, for a commercial storage battery to appear. There were many reasons for this - the primary battery pre-empted the role of storage battery since, in a manner of speaking, it is a storage battery; and every battery stores electrical energy in the form of its deposits. Only when dynamos replaced primary cells as the principal generators of current were the function of generation and preservation separated.

Alkaline primary batteries started to be developed in the late 1870s. Batteries were at this point used mostly by industry. The industries that used batteries were electroplating and telegraphy. In 1870 consumer markets started to grow - for example, doorbells, telephones, burglar alarms, and sewing machines.

Early in the 20th century, when the electric vehicle was one of the three prospective technologies, research on battery technology effected significant improvements in their capacity. In the 1890s battery capacities were in the vicinity of 10 watt-hours per kilogram (Wh/kg). By 1901 this had been improved to 18 Wh/kgm and by 1911 was close to 25 Wh/kg. This trajectory of technological improvement was stopped at that point and it took almost another 80 years to double the capacity. A key factor in the halt of progress was the introduction of the starting-lighting ignition into the gasoline car.

This technology meant that every gasoline car would use a battery, and it was introduced at a point where sales of gasoline cars were beginning to grow very rapidly.
R&D programmes spurred by World War II and the oil crisis of 1973 effectively changed nothing. The lead-acid battery kept its position, the traction system remained the same, and small scale production was omnipresent.

Many hundreds of millions of dollars have been spent on R&D that aims at new batteries tailor-made for electric vehicle. Advances in the 1990s suggested that battery technologies may become commercially viable for electric and hybrid cars. According to information from organisations that market nickel-cadmium batteries, their batteries could compete on cost in 2000 with diesel vehicles - in co-operation with Renault, a test was conducted with light utility transport vehicles and is said to prove the cost competitiveness of electric vehicles.
Test results from Germany in the 1990s indicated that zinc-air batteries had moved from theoretically interesting to high-performance batteries. A major problem with zinc-air battery technology at the moment, however, is that the storage battery needs to be rebuilt after each run. Zinc remains a favourite for the primary battery anodes, many storage battery engineers have experimented with zinc but it will not recharge well.

Table 1.6-4 describes the development of battery technology in the last 100 years and the theoretical possibilities for some combinations of primary materials.

Table 1.6-4: Development of the storage capacity of batteries

Type	**Year**	**Storage capacity**
Lead	1901	18 Wh/kg
Lead	1943	24 Wh/kg
Lead	1950	27 Wh/kg
Lead	1978	33 Wh/kg
Nickel-cadmium	1984	35 Wh/kg (test)
Lead	1990	40 Wh/kg
Nickel-cadmium	1993	55 Wh/kg
Nickel-cadmium	1995	65 Wh/kg (planned)
Nickel Metal Hydride	1997	80 Wh/kg
Lithium-Ion	1999	100-120 Wh/kg
Zinc-air	1993	120-300 Wh/kg (test)
Zinc-air	theoretical possibility	1070 Wh/kg
Aluminium-oxygen	theoretical possibility	4030 Wh/kg
Gasoline		13000 Wh/kg

www.saft.fr

A government-sponsored battery consortium was founded in the USA (USABC). In 1994 it had spent $262 million on development projects. The most favoured project aimed at developing a Lithium Polymer battery. From 1993-98 this project received $85 million and was aimed at developing a new type of battery that partly used plastics as a component. In 1998 a problem with this battery was that it heated up (60-100°C). The goal of the project was to build a storage battery that would cost as much as a lead-acid battery for the user but would have a performance up to five times better.

Lithium-Ion storage batteries are today being used in portable electronic devices. A pack suitable for a portable computer costs $250-500. A battery for a handset costs $100. A less expensive but also lower performing battery is the nickel-metal hydride battery. When a battery pack of this battery is built for an electric vehicle it costs

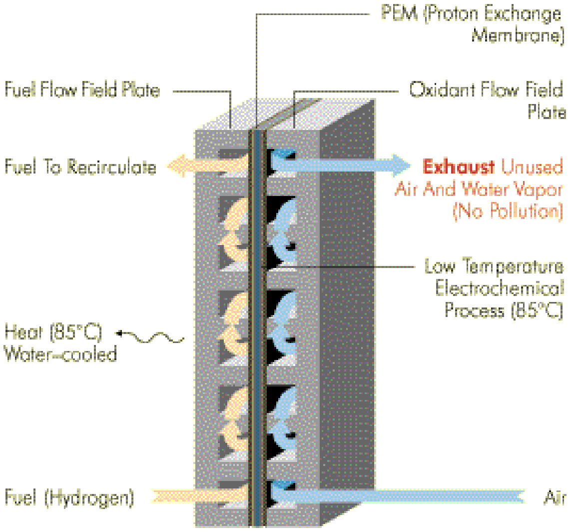
$20,000-$25000. This is two to three times more than the price of a nickel-cadmium battery. The cost of such batteries make the price of a four-seater car many times higher than that of the gasoline version.

1.6.2 Fuel cell vehicles

The basic theories and fundamentals of fuels cells have been researched from the middle of the 18th century. In 1839 the principles were established by William Robert Grove. Application fields are power generation onboard space craft and power plants. The new challenge is to package the available and well understood technology to fit into the engine compartment of standard automobiles and to provide enough power for a comparable performance of the vehicle in respect to available internal combustion (IC) engine cars. The idea is to provide power for individual transportation on demand without inflicting damage on the environment and without using limited fossil resources.

Fuel cells operate on completely different principles than IC engines. The closest technology is the common battery. In a fuel cell, a fuel, usually hydrogen, is oxidised. The result of this process is water, an electrical potential difference and heat.
Daimler-Benz describes the energy conversion process as follows: "A fuel cell is an electrochemical device that produces electricity silently and without combustion. Hydrogen fuel, which can be obtained from natural gas or methanol, and oxygen from the air are electrochemically combined in a fuel cell to produce electricity and heat with pure water as the only by- product. It is important to prevent the two gases coming into direct contact and they are therefore separated by means of an electrolyte membrane. The various types of fuel cell are identified by the different electrolytes used.
A PEM fuel cell consists of two electrodes, the anode and the cathode, separated by a polymer electrolyte. Each of the electrodes is coated on one side with a platinum catalyst. Hydrogen fuel dissociates into free electrons and protons (positive hydrogen ions) in the presence of the platinum catalyst at the anode. The free electrons are conducted in the form of usable electric current through the external circuit. The protons migrate through the membrane electrolyte to the cathode. At the cathode, oxygen from the air, electrons from the external circuit and protons combine to form pure water and heat, to obtain the desired amount of electrical-power-generated individual fuel cells in a stack. Increasing the number of cells in a stack increases the voltage, while increasing the surface area of the cells increases the current."

Figure 1.9: PEM fuel cell schematics



Source: ***http://autozine.kyul.net/technical_school/engine/alternative_fuel.htm#Fuel%20Cell***

The technology is readily available, and only recently the package size of the fuel cell engine and the fuel storage problems were solved. The difficulty at this time is to find a manufacturing process that will crush the products' cost and, therefore, the price for the end consumer. Today prototype engines cost around 100 times more than an IC engine of comparable characteristics.

Table 1.6-5 shows an overview of the main activities concerning fuel cell applications in ground transport up to 1999.

Table 1.6-5: Overview of fuel cell vehicle prototype developments up to 1999

Year	**Company**	**Vehicle type**	**Fuel cell type**	**Fuel, Power**
1959	Allis Chalmers	Tractor	Alkaline	15 kW, fuel cell weight 917 kg
1967	General Motors	Van	Alkaline	160 kW, fuel cell weight 1500 kg
1993	Ballard Power Systems	Bus	PEM	Hydrogen, 120 kW
1994	Daimler-Benz	Van (NECAR I)	PEM	Hydrogen, 50 kW
1994	City Bus project, Belgium	Bus	Alkaline	Hydrogen
1994	EnergyPartner	Car	PEM	Hydrogen, 15 kW
1994	DOE, H-Power and Fuji	Bus	PAFC	Methanol, 60 kW
1996	Daimler-Benz	Van (NECAR II)	PEM	Hydrogen, 50 kW
1997	Daimler-Benz	Bus (NEBUS)	PEM	Hydrogen, 250 kW
1997	Daimler-Benz	Car (NECAR 3)	PEM	Methanol, 50 kW
1997	Toyota	Car (RAV-4)	PEM	Methanol, 20kW
1997	Mazda	Car (Demio)	PEM	Hydrogen, 20 kW
1998	General Motors	Car (Zafira)	PEM	Methanol, 50 kW
1998	Renault	Car (Fever)	PEM	Hydrogen, 30 kW
1999	DaimlerChrysler	Car (NECAR 4)	PEM	Hydrogen, 55 kW
1999	Ford	Car (P2000)	PEM	Hydrogen, 60 kW
1999	Nissan	Car (R'nessa)	PEM	Methanol, 60 kW
1999	Honda	FCX-V1 (EV Plus)	PEM	Hydrogen, 60 kW
1999	Honda	FCX-V2 (EV Plus)	PEM	Methanol, 60 kW

Source: Steinemann, 1999

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1.7 Other vehicle aspects

Apart from the prime mover (engine or electric motor), other aspects such as transmission, aerodynamics and materials also have an impact on vehicle load, and therefore on fuel consumption and emissions.

1.7.1 Transmission

The transmission system of the vehicle is an elaborate assembly of gears, shafts and other parts that transfers selected amounts of engine to the vehicle’s wheels. The transmission enables the vehicle to accelerate forward or backward or to maintain high cruising speeds - all while the engine operates at efficient speeds and within safety limits. In the development of cars, transmission evolution veered the vehicle towards comfort and convenience.

1.7.1.1 Manual Transmission

In 1927 Warner Gear introduced a four-speed manual gearbox. The extra gear made high-speed cruising more comfortable due to less noise and vibration, increased fuel economy and reduced engine wear. Oddly, the H-shaped gear pattern was opposite to today's pattern. In 1929 Cadillac launched synchromesh transmission, but it was the Porsche 356's cylindrical sychromesh that became the world standard. It is still using it today.

The manual transmission was, by the 1930s, a fairly mature and reliable technology. But the opportunity to improve on its operation took auto-makers in different directions. An unusual clutch spring was used in the Buick Series 40 for 1939. The cone-shaped spring was claimed to exert a high-pressure on the clutch plates to prevent slipping, while at the same time give a light clutch pedal feel for extended stop-and-go driving. It was an effective, but short-lived solution, doomed by durability problems.

Chrysler took an even more radical approach, with the adoption of its "fluid drive." Although the vehicle had a clutch pedal, it operated two vaned plates that transmitted power through shearing action in low-viscosity mineral oil. The design allowed drivers to stop without using the clutch, even leaving the gear selector in high. Providing quick acceleration was also not needed. Chrysler touted the design as being easier to drive, quieter, smoother, less prone to stalling and safer. Yet fluid drive flopped.

The simplest manual transmission used in some cars, especially the smaller ones, is the sliding-spur gear type with three or more forward speeds and reverse. The desired gear ratio is selected by manipulating a shift lever that slides a spur gear into the proper position to engage the various gears. Early devices of this type required considerable skill on the part of the operator to shift the gears smoothly and without clashing the teeth.

Ease of shifting was improved by the use of synchronising clutches that caused the two portions of a positive clutch to turn in unison before the driving and driven gear teeth touched each other during engagement. The only difficulty remaining in the operation of the sliding-gear transmission was the need for simultaneously operating the accelerator pedal, the clutch pedal and the gearshift lever. The automatic transmission was developed to eliminate this manipulation.

1.7.1.2 Automatic Transmission

Automatic transmission systems consist of an arrangement of gears, brakes, clutches, a fluid drive and governing devices that automatically change the speed ratio between the engine and the wheels of an automobile. Gears are shifted in an automatic transmission by changes in hydraulic pressure, in some cases the pressure of transmission oil created by the impeller. A governor valve routes the pressurised oil to shift valves. The shift valve, in turn, controls the clutches and bands that shift and hold gears in place. Shift valves also contain pistons that move in and out, depending on the amount of hydraulic pressure. As the vehicle's speed changes, the governor valve changes the hydraulic pressure at the appropriate shift valves to cause a gearshift.

Since its introduction in 1939, the fully automatic transmission has become optional or standard equipment on most passenger cars. When the transmission is in the drive position, the driver has only to depress the accelerator pedal, and as the car gathers speed the transmission will shift automatically through its entire forward range of gears from low to high, until the two shafts are directly connected through the oil in the fluid drive, which may be either a two-element fluid coupling or a three-element torque converter. When the car loses speed, the transmission automatically shifts back from high to low gear.

Enter the 1980s, and the development of transmission suddenly accelerated. It was then that computerised automatic (some even incorporated fuzzy logic to learn driving habits), CVT (pioneered by Subaru), semi-automatic gearbox (Porsche's Tiptronic), traction control, sequential manual, button-operated semi-auto, etc. emerged.

In 1995 GM Powertrain revealed its newest innovation in the Dexron line of transmission fluid. DEXRON III is a transmission fluid that is so durable that it never needs replacing under normal driving conditions. It is touted to be the long-life automatic transmission fluid.

1.7.1.3 Manual versus automatic transmission

Automatic transmissions have refined gearing, lock-up torque converters, and variable displacement oil pumps to improve efficiency and fuel economy. CVT (continuously variable transmissions) are another step in improving economy because of their capability of allowing the engine to operate at optimum rpms.

Manual transmission systems continue to be installed in 50% of the cars produced worldwide, especially the economy models. Apart from the price factor, a number of drivers prefer the manual transmission to automatic for greater control over shifting and a more physical sense of operating the vehicle. Other drivers prefer automatics for the convenience of not having to think about shifting forward gears.

Most drivers consider manual systems to be more reliable than the complex automatics. Manuals are also considered to be more fuel-efficient.

Even though some diehard drivers continue to sneer at the automatic systems as the mark of a novice, there is little doubt that the automatic may soon become the norm, rather than the exception.

1.7.1.4 Transmission milestones

1545: Gerolamo Cardano (engineer) invented the universal joint.
1827: Onésiphore Pecqueur (engineer) invented the differential.
1898: Renault developed the manual gearbox.
1900: Louis Bonneville (engineer) invented the automatic gearbox.
1910: Föttinger (engineer) invented the hydraulic torque converter.
1924: Miller Junior 8 developed the front-wheel drive.
1926: Jean Fenaille and Jean Grégoire (engineers) invented the constant velocity joint.
1934: Citroen (Traction avant A7) developed the front-wheel drive with double universal joint.
1951: Porsche made the manual transmission with ring synchronmesh.
1968: DAF (Alexandre Horowitz) marketed the continuously variable torque transmission (CVT).
1995: Saab Sensonic made the automatic clutch on manual gearbox.
1999: Nissan (Cedric and Gloria) marketed the CVT-Extroid transmission.
2000: Audi (A6 multitronic) marketed the CVT transmission with a chain.
2001: BMW (7 serie ZF) marketed the six-speed automatic transmission.

Source: http://www.auto-innovations.com/en/itransmission.html

1.7.1.5 References

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1.7.2 Aerodynamics

Drag

Aerodynamic efficiency of a car is determined by its Coefficient of Drag (Cd). Coefficient of drag is independent of area and simply reflects susceptibility to aerodynamic drag due to the shape of the object. In theory, a circular flat plate has Cd 1.0, but after adding the turbulence effect around its edge, it becomes approximately 1.2. The most aerodynamically efficient shape is a water drop, whose Cd is 0.05. A car like this, however, cannot be made. The Cd of a typical modern car is around 0.30. It has been estimated that a 10% reduction in Cd can lead to a 5%-6% improvement in fuel economy at highway speeds and a 1%-2 % improvement at urban speeds.

Lift

Another important aerodynamic factor is lift. Since air flow above the car travels a longer distance than air flow beneath the car, the former is faster than the latter. According to the Bernoulli's Principle, the speed difference will generate a net negative pressure acting on the upper surface, which we call "lift".
Like drag, lift is proportional to area (but surface area instead of frontal area), the square of vehicle speed and Lift Coefficient (Cl), which is determined by the shape. At high speed, lift may be increased to such an extent that the car becomes very unstable. Lift is particularly serious at the rear, since a low pressure area exists around the rear screen. If the rear lift is not adequately countered, rear wheels slip easily.

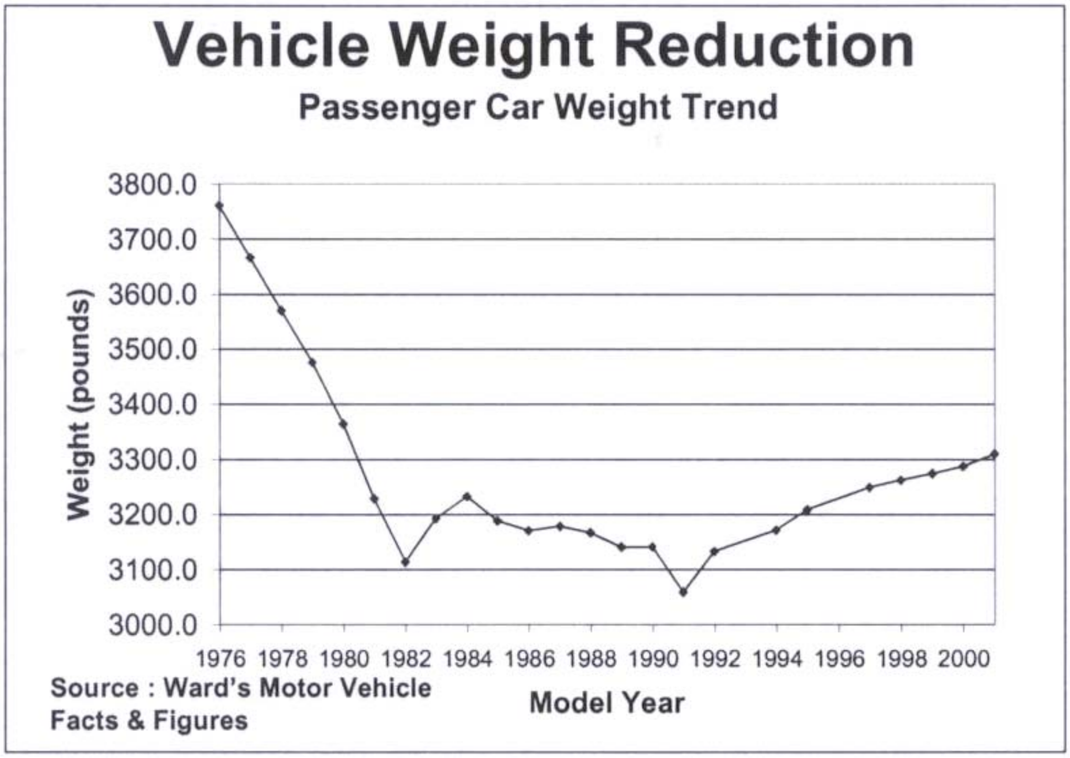
source: http://autozine.kyul.net/technical_school/aero/tech_aero.htm#Drag and Lift

1.7.3 Materials

1.7.3.1 Introduction

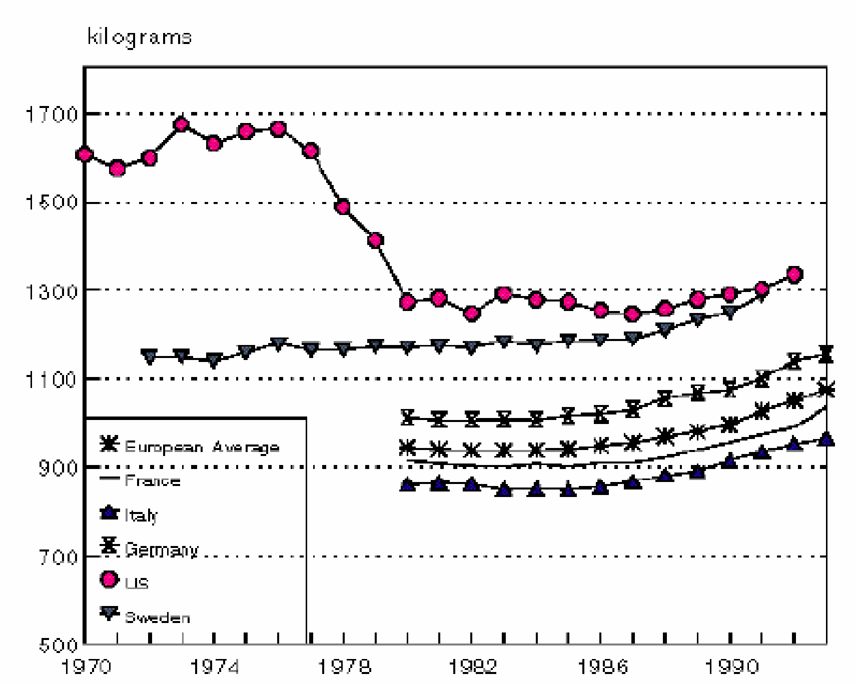
As the automotive industry addresses environmental concerns, the problem of fuel consumption and weight reduction has come to the fore.
Reducing the weight of automobiles is one of the primary means by which fuel consumption is lowered. The two basic approaches are in automotive design and in materials selection, and they are closely related.

Figure 1.10: Weight reduction has been the main trend in the last decades.



In recent years a slight increase in weight occurred due to the introduction of electronic safety systems in passenger cars.

Figure 1.11: Average new car weight in Europe & the USA.



Source: Schipper, 1997

In the field of materials, there has been a trend toward the use of light metals and their alloys in automotive components, particularly automotive bodies. The most commonly used materials are aluminium and magnesium, and their alloys, although some research has also been done on the use of titanium, zinc, and non-metallic materials.

On the other side, there has been strong competition from the steel industry, which for obvious reasons would prefer that steel be retained as the primary automotive material. Both sides face important design issues. On the steel side, one primary problem is to find new ways of designing automotive components that permit the use of less material while not sacrificing strength and safety - such research efforts as the Ultra-Light Steel Auto Body (ULSAB) project exemplify the attempt to optimise the use of steel in automobile design. Also of importance are efforts to develop new high-strength steels as replacements for (usually) carbon steels. On the light metals side, the design issue is similarly twofold: not only do automotive components have to be designed in new ways in order to provide safe and reliable components, but, since light metals in their pure form do not have the same desirable mechanical properties as even carbon steel, the alloys themselves must also be designed for optimum strength.

As a result, there are a host of new light alloys (and composites based on such alloys) intended for automotive use, together with new designs especially adapted for these alloys -- and also a host of new steel-based designs that make more efficient use of steel than was formerly typical.

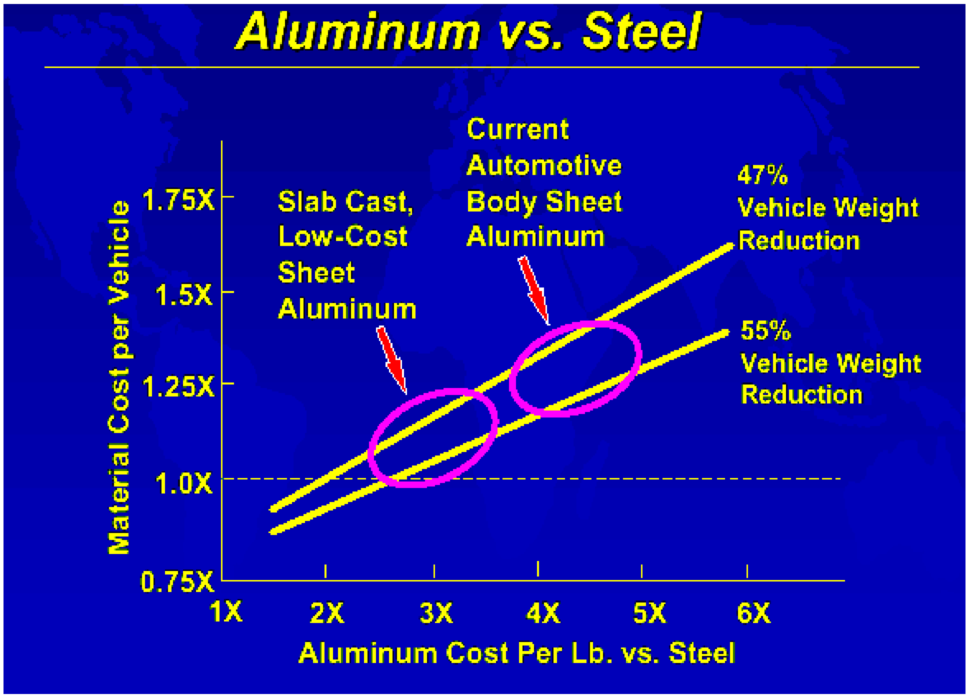
Related issues include the design of production and fabrication processes (e.g. casting, forming, welding) suitable for use with such materials. Hydroforming, for example, shows promise in the fabrication of lighter-weight steel components, allowing the formation of a chassis component as a single part rather than as a piece spot-welded together from up to six different stampings. Hydroforming eliminates the flanges ordinarily required for welding, and maintains stiffness by eliminating the welds themselves. And for aluminium components, techniques such as the brazing of honeycomb panels, the production of lightweight squeeze castings and the extrusion of large-scale shapes have shown promise.

The rivalries are not limited to automotive bodies but extend to other components as well. For engine and other components, magnesium is arguably the prime candidate as a lightweight alternative to cast iron and steel. Typical uses of magnesium and its alloys include seat frames, instrument panels, steering wheels, and engine and transmission components. The most common production process for such components is die casting, a process for which magnesium is well-suited. Some research efforts have focused on improving the die-casting process (for example, to fabricate large thin-walled parts), and others on the development of optimal welding processes for such castings. Also of importance is the corrosion protection of such components, as untreated magnesium has poor corrosion resistance.

In all of the foregoing there is also an economic trade-off: aluminium and magnesium are significantly more expensive than steel. In some cases a combination of materials may therefore be desirable for reasons of cost, and so some research efforts have focused on the joining of dissimilar metals (e.g. aluminium alloys and stainless steels) in the fabrication of hybrid auto bodies.

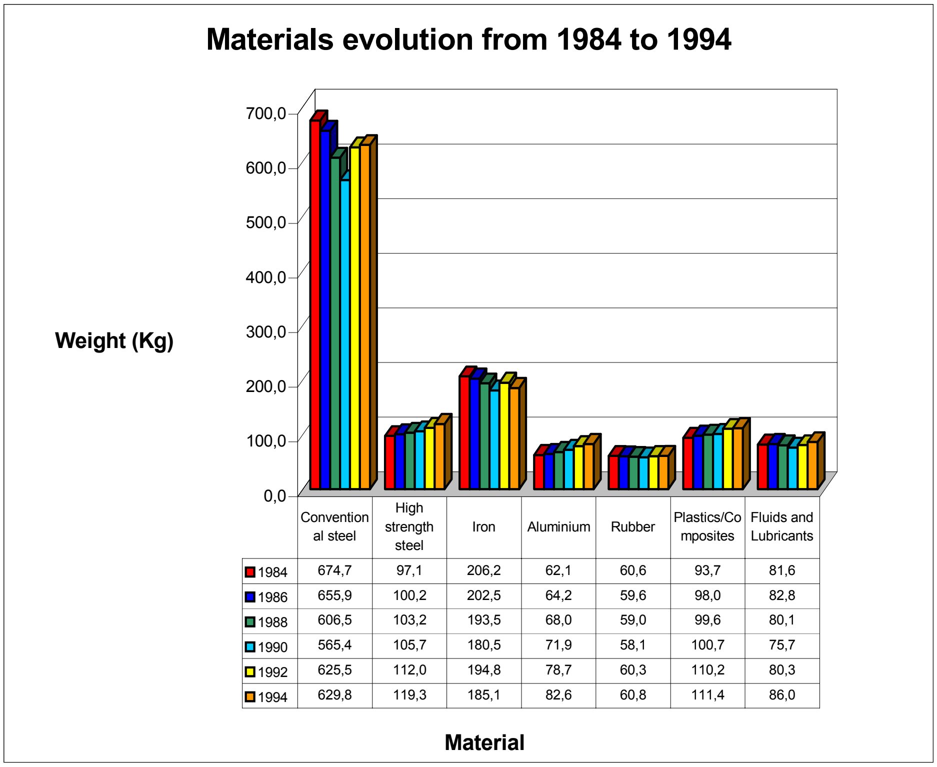
It seems likely that these developments, and with them the competition between steels and light metals in automotive applications, will continue into the foreseeable future.

Figure 1.12: Aluminium versus Steel graphic.



Source: Sherman, 2000

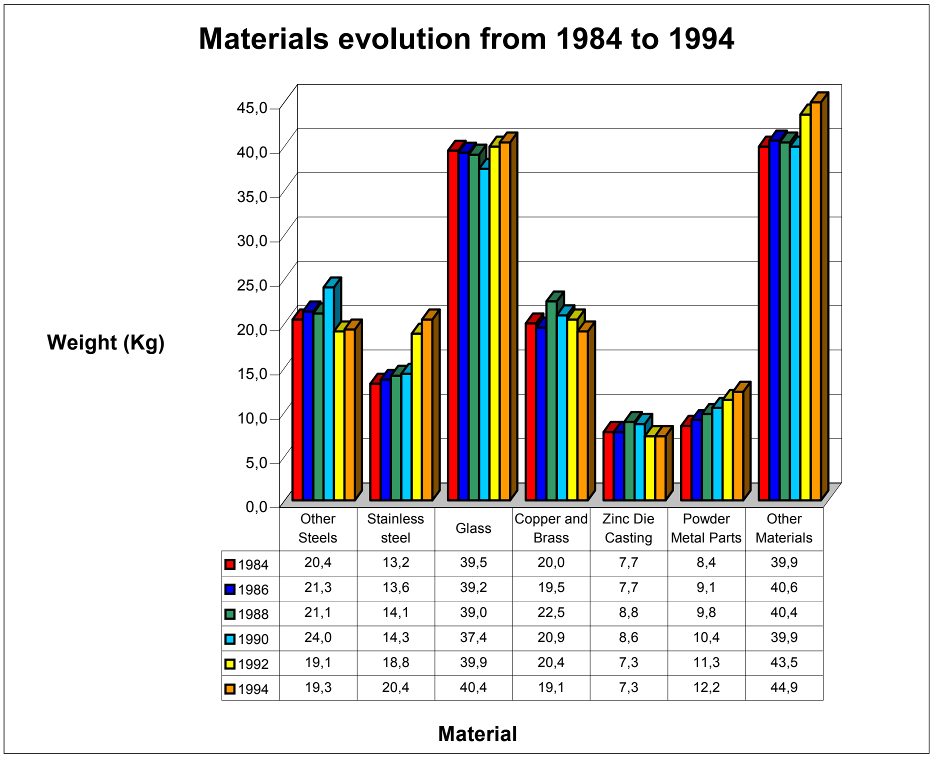
Figure 1.13: Heaviest main materials evolution from 1984 to 1994



	Conventional steel	High strength steel	Iron	Aluminium	Rubber	Plastics/Composites	Fluids and Lubricants
🟥 1984	674,7	97,1	206,2	62,1	60,6	93,7	81,6
🟦 1986	655,9	100,2	202,5	64,2	59,6	98,0	82,8
🟩 1988	606,5	103,2	193,5	68,0	59,0	99,6	80,1
🟦 1990	565,4	105,7	180,5	71,9	58,1	100,7	75,7
🟨 1992	625,5	112,0	194,8	78,7	60,3	110,2	80,3
🟧 1994	629,8	119,3	185,1	82,6	60,8	111,4	86,0

Source: EPA, 1995

Figure 1.14: Additional materials evolution from 1984 to 1994



	Other Steels	Stainless steel	Glass	Copper and Brass	Zinc Die Casting	Powder Metal Parts	Other Materials
🟥 1984	20,4	13,2	39,5	20,0	7,7	8,4	39,9
🟦 1986	21,3	13,6	39,2	19,5	7,7	9,1	40,6
🟩 1988	21,1	14,1	39,0	22,5	8,8	9,8	40,4
🟦 1990	24,0	14,3	37,4	20,9	8,6	10,4	39,9
🟨 1992	19,1	18,8	39,9	20,4	7,3	11,3	43,5
🟧 1994	19,3	20,4	40,4	19,1	7,3	12,2	44,9

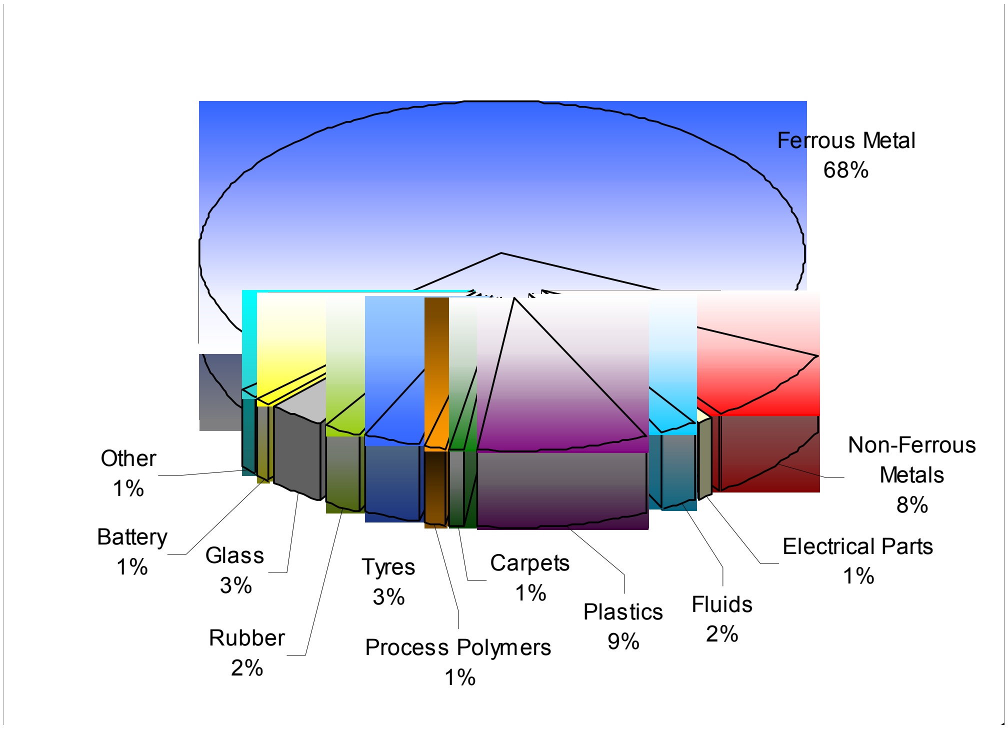
Source: EPA, 1995

1.7.3.2 Multi-material manufacture

Multi-material manufacture, sometimes known as hybrid construction, incorporating a whole raft of materials, including steel, aluminium, magnesium as well as plastic mouldings for application in the vehicle body structure, is gaining ground over single metal body systems either in steel or aluminium. For example, the latest Mercedes CL body-in-white has been constructed in the way. Steel has been used in regions highly stressed in the frontal and side impact situation, such as the roof pillars, and longitudinal and body cross members. Aluminium has been used for large surface panels for the roof, bonnet, rear panels and rear wings. Magnesium has been employed for the inner door panels and seat frames and plastics mouldings have been used for secondary components such as the boot lid, spare wheel well and front wings. A weight saving of 50 kg over the previous version of the model was achieved while the whole vehicle is 340 kg lighter than its predecessor - an impressive endorsement for the construction technology and the performance and engineering requirement for weight reduction.

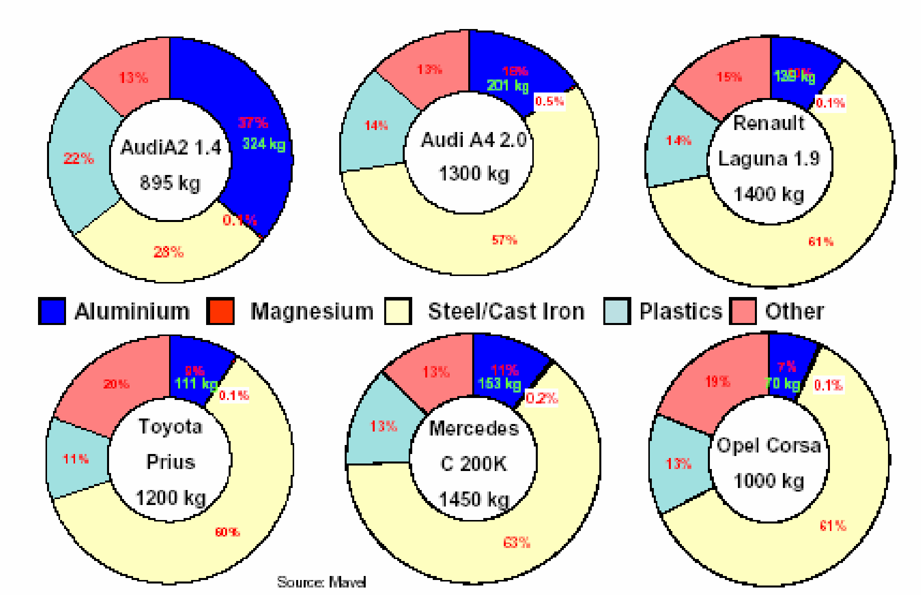
Clearly, this approach to body construction also brings joining technology to the fore. This would allow novel welding techniques such as "Friction Stir Welding", which has the ability to weld dissimilar materials together, to be investigated further. The hybrid construction method also allows the adaptation of other more common joining techniques like adhesive bonding, riveting and even old fashioned bolting techniques to be developed to a new level.

Figure 1.15: Material content in a current passenger car



Source: ACORD, 1999

Figure 1.16: Current use of materials in cars.



Source: Wolfensberger, 2002

1.7.3.3 Aluminium

For many years the biggest end-use market for aluminium has been the transportation sector with a major share of this going into car manufacturing. There has therefore been a long history of co-operation between the car industry and the aluminium industry.

Weight reduction is not only based on the need to reduce emissions by requiring less fuel, but also on the need to meet consumer demands, since the trend for add-ons such as air-conditioning, combined with the increasing popularity of light trucks as substitutes for conventional cars, is actually making vehicles heavier.

Accordingly, the forecast is for the amount of aluminium used in each car to increase from about 90 kg at present to 130 kg in the year 2005.

The development of aluminium automotive applications continued in 2000 with the introduction by several French car manufacturers of new models with aluminium front hoods for reasons of light weighting and better weight balance between the front and the rear of the car. In Germany, the amount of light metal used in the newly-introduced Mercedes C Class rose to 7.1%, as opposed to 4.4% in its predecessor.

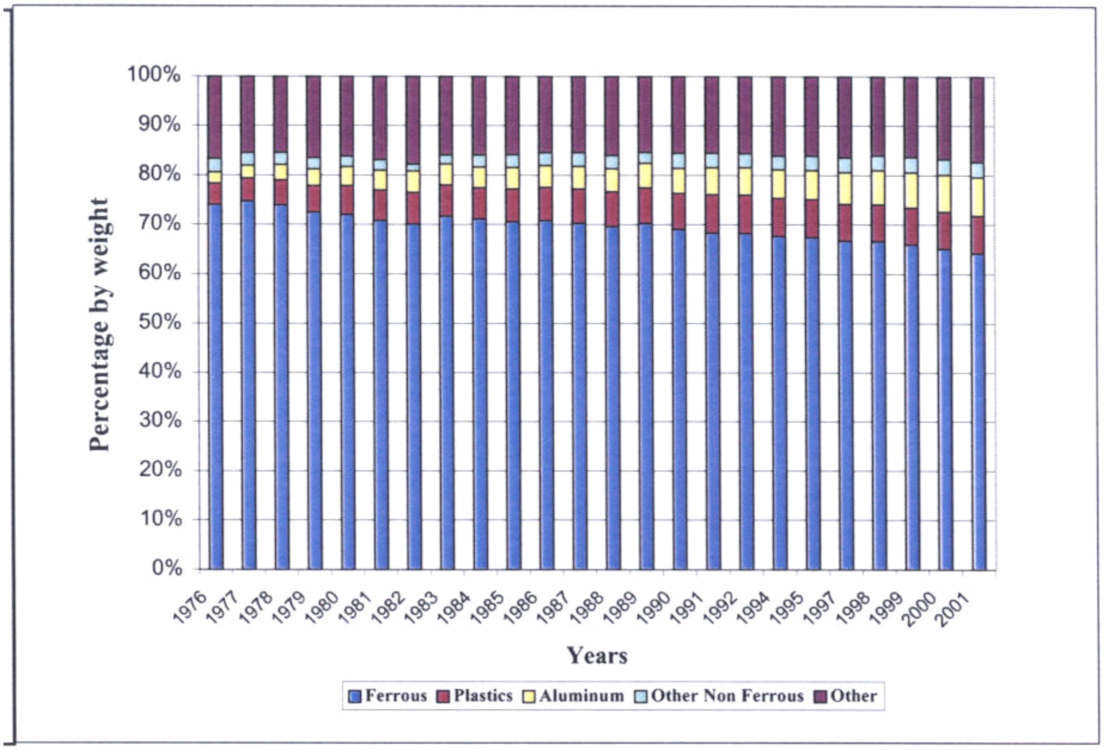
The aluminium industry has continuously improved technologies for metal recovery in end-of-life parts. The industry assists the automotive sector to achieve sustainable development as a result of aluminium's excellent recycling potential.

Aluminium's recycling record is outstanding: it can be recycled indefinitely, without quality loss. Ninety-five per cent of aluminium in cars is currently collected and recycled. After recycling, the majority of aluminium is re-used in automotive applications.

Aluminium can be easily separated from other materials, so ensuring a balance in the recycling - shredding and dismantling - of car materials.

Aluminium recycling is profitable: its high used value ensures self-supporting reclamation and recycling. Aluminium accounts for over 50% of the material value of a car at the end of its life. Anticipated increased demand for aluminium in transport applications also guarantees a full market outlet, irrespective of the quantities recovered after use.

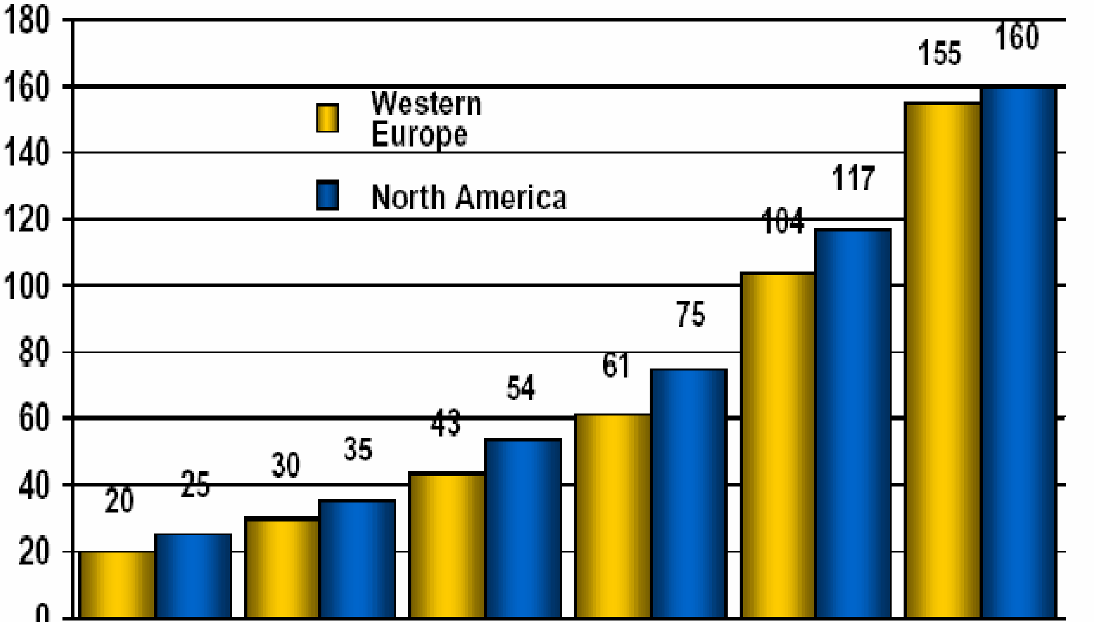
Figure 1.17: Material content changes in the last 25 years.



Source: http://www.me.mtu.edu/~apbandiv/pres2.pdf

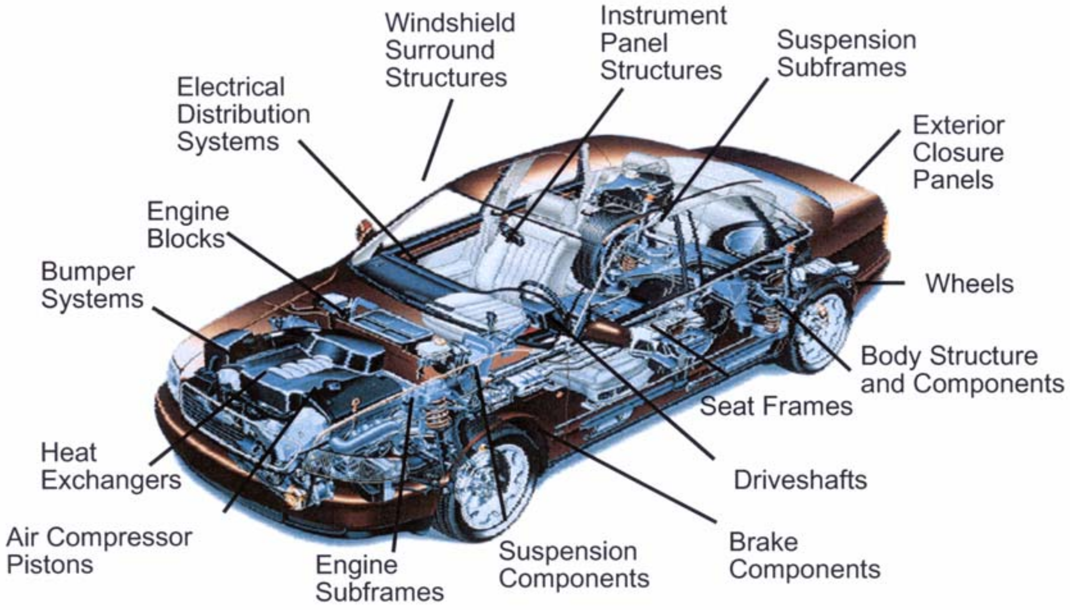
Aluminium and plastics use are increasing, while use of ferrous materials is decreasing.

Figure 1.18: Use of aluminium per light vehicle (kg).



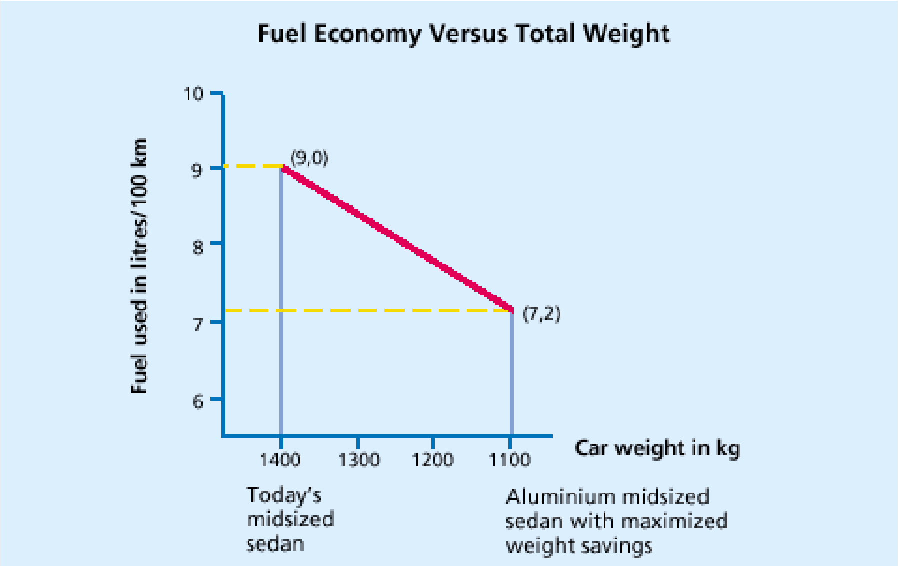
Source: Wolfensberger, 2002

Figure 1.19: Representative uses of aluminium today



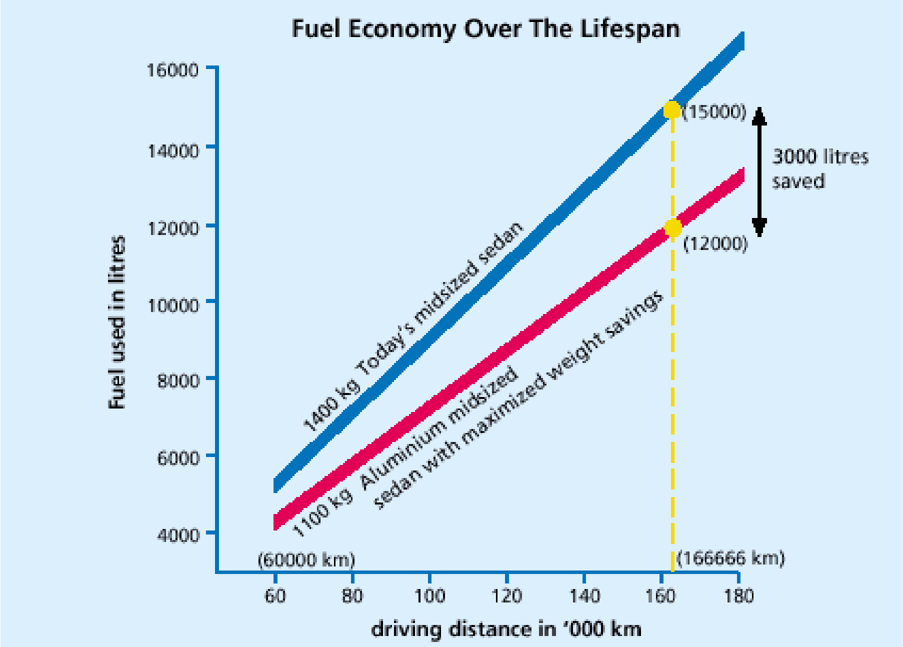
Source: Wolfensberger, 2002

Figure 1.20: "Fuel Economy" versus "Total Weight". Aluminium utilisation



Source: http://www.eaa.net/downloads/auto.pdf

Figure 1.21: Fuel Economy over the lifespan. Aluminium utilisation



Source: http://www.eaa.net/downloads/auto.pdf

1.7.3.4 Ultra-light steels

ULSAB

The Ultra Light Steel AutoBody (ULSAB) project is an intensive, multi-phase study to demonstrate steel's capability of substantially reducing the weight of a vehicle's body structure and, at the same time, ensuring safety with improved comfort and driving performance, all at affordable cost. ULSAB is being undertaken by a consortium of 35 leading steel producers from 18 countries.

The ULSAB concept confirms steel's main attributes: It is inexpensive and strong, easy to form into complex shapes and structures and is highly suited for mass production of vehicles. Its proven ability to absorb energy in a crash is unparalleled. An Ultra Light Steel Auto Body (ULSAB) structure has been assembled, weighed and tested, validating results from the concept phase of a global steel industry study and satisfying the project goals. ULSAB has proven to be lightweight, structurally sound, safe, executable and affordable.

The ULSAB structure weighs just 203 kg, 25% less than the average benchmarked in the concept phase of the study. Physical tests of the structure reveal similar remarkable results: torsion and bending tests showed improvements over benchmarks of 80% and 52% respectively, and 1st body structure mode indicates a 58% improvement. Analyses also show ULSAB satisfies mandated crash requirements, even at speeds exceeding the requirements. In addition to reduced weight and superior performance, ULSAB costs no more to build than typical auto body structures in its class and can even yield potential cost savings, according to economic analysis.

ULSAC

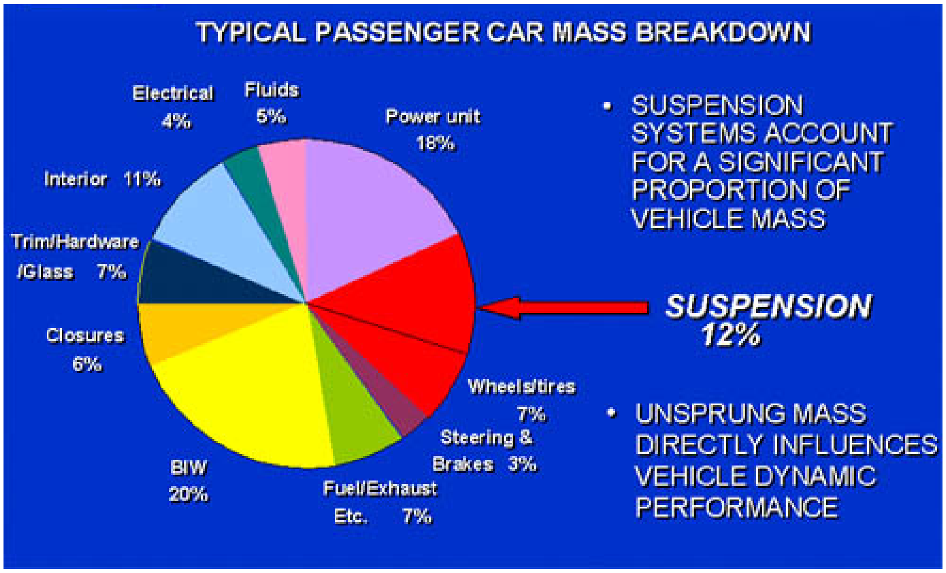
The Ultra Light Steel Auto Closure Program is a study undertaken by global steel producers to demonstrate the effective use of steel in producing lightweight, structurally sound steel automotive closures that are manufacturable and affordable. ULSAC began as a concept development programme, producing lightweight concept designs for doors, hoods, deck-lids and hatches. The programme continued to the manufacture of steel frameless door demonstration hardware that is 42% lighter than the average of benchmarked frameless doors. ULSAC meets or exceeds stringent safety and structural performance targets and can be manufactured at affordable costs.

ULSAS

The Ultra Light Steel Auto Suspension (ULSAS) project was undertaken by the global steel industry to demonstrate the effective use of steel in producing lightweight, structurally sound steel automotive suspensions that are manufacturable and affordable. Through the intelligent application of steel and the use of near-reach materials and technologies, the five ULSAS suspension design concepts achieved:

- Up to 34% mass reductions over conventional steel systems
- Up to 30% cost advantages over a benchmarked aluminium system
- Equal or better performance results.

Figure 1.22: Typical passenger car mass breakdown



TYPICAL PASSENGER CAR MASS BREAKDOWN

- SUSPENSION SYSTEMS ACCOUNT FOR A SIGNIFICANT PROPORTION OF VEHICLE MASS
- UNSPRUNG MASS DIRECTLY INFLUENCES VEHICLE DYNAMIC PERFORMANCE

Source: http://www.ulsas.org/presentation/slide6.html

From a mass point of view, there are three areas of a vehicle that dominate. Together, these account for about 50% of the total mass of a vehicle. The areas include:

- The body structure, with about 20% of total vehicle mass
- The powertrain, with about 18%
- The suspension system with 12%.

1.7.3.5 Magnesium

Although a small amount of magnesium has been used in automobiles for many years (the first 1000 Minis had magnesium sumps and VW used die-cast crankcases and transmission housings for the 'Beetle') its low density (about 1800 kg/m^3 compared to about 2,700 kg/m^3 for aluminium) and the constant search for weight savings are encouraging designers to evaluate more potential applications. The ease with which die castings can be produced make this the favoured manufacturing route for most applications. Automotive applications of magnesium currently include: instrument panel assemblies; seat structures; brake, clutch, accelerator and steering wheel assemblies; valve and cam covers; intake manifolds and manifold covers; transmission cases and covers; pistons; and various brackets and housings.

The benefits of using magnesium die castings are:

- Lower specific weight than other options
- Better elongation than the other die casting metals
- 20%-30% shorter cycle times than aluminium die casting
- Longer die life (about double) than aluminium die casting
- Ability to produce thinner walls than aluminium die casting
- Magnesium price stability

1.7.3.6 Plastics

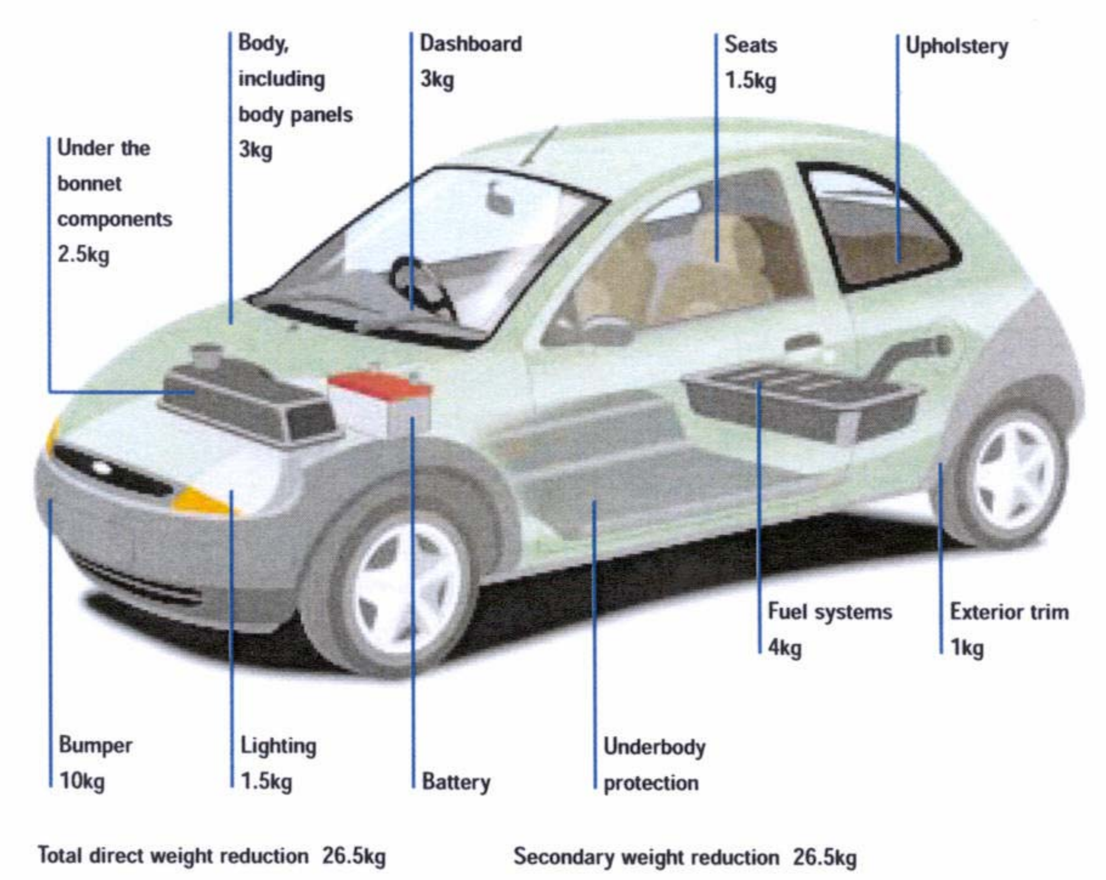
Plastics used in the car industry have risen from 70kg per car in 1977 to 100kg in 1997. Compared with 20 years ago, the use of plastics in automotive manufacturing has grown by 1,096,000 tonnes (or 114%), representing an average increase of 30 kg per car. Today‘s cars contain around 100 kg of plastics and synthetic rubber which replace approximately 360 kg of metal. The proportion of plastic in the weight of a car has changed from 3% to 14% in 20 years. A car has almost 1,000 plastic components. This reduction in weight of private cars saves 3.5 million tonnes of fuel a year in Europe. Plastics are used for their distinctive qualities, such as corrosion resistance, low weight and cost, improved reliability and safety, greater comfort, fuel efficiency, style and, increasingly, reassurance about environmental impact. According to the British Plastics Federation, "105 kg of plastics, used as a replacement for metals, in a car weighing 1,000 kg could make possible a fuel saving of up to 7.5%".

From bumpers to door panels, light-weight plastic gives cars better gas mileage and allows designers and engineers the freedom to create innovative concepts that otherwise would never be possible. Traditionally, metal alloys were used in manufacturing automobile exteriors. However, these alloys are easily susceptible to dents, dings, stone chips, and corrosion. They are also heavier and more expensive than plastic. By using plastics, manufacturers have the possibility of adopting modular assembly practices, lowering production costs, improving energy management, achieving better dent resistance and using advanced styling techniques for sleeker, more aerodynamic exteriors. Plastics first clothed the interior of the passenger compartment where safety, durability and appearance play an essential role. For components under the bonnet (headlamp housings, radiator grille, etc.), the polymers must have good dimensional stability under heat, as well as resistance to fuels and lubricants. For external components, they must have good resistance to bad weather and impact, low thermal expansion and good stability in ultraviolet.

Automobile design engineers face many constrictions when designing with metal. Low-cost, single-unit production of large automobile sections, such as a front grille, is nearly impossible when using metal. Plastic offers auto engineers a variety of practical, cost-effective alternatives, as well as tremendous advantages over traditional automobile production materials. Plastics allow auto engineers to have greater freedom in styling, building and placing components, and give them the opportunity to combine several complex parts into a single, integrated piece. Plastics make this possible, while lowering manufacturing costs.

New processes enable manufacturers to re-use scrap plastic and recycle used plastic cost-effectively. Also, plastic components weigh approximately 50% less than their steel counterparts. This enables automobile components to be substantially lighter, while retaining needed strength, and contributes to an overall lighter vehicle and therefore fewer emissions and improved gas mileage. Better gas mileage helps us responsibly manage natural resources such as gasoline, while reducing emissions released into the environment.

Figure 1.23: Examples of plastic use and related weight savings in main car components



Source: APME, 1999

The strength and durability of the plastics have also played an important part in expanding the average life span of car to over 12 years - for example by providing batter protection against corrosion. Innovative car-body developments are seeing an increase in the plastics content of cars. Approximately 100 kg of plastics replace 200 to 300 kg of traditional materials in a modern car. In recent years, increased safety and comfort features have led to a slight rise in the overall weight of the average car from 1,015 kg in 1990 to 1,132 kg in 1998. But plastics components have ensured that the balance between safety and lightweight efficiency is maintained by consistently reducing weight without compromising safety features.

Thanks to their strength and impact properties, plastics provide essential safety features, from shock absorption for bumpers to air bags, side impact protection and seat belts. Plastics replacing glass in windows and lights are 250 times stronger.
By using plastics, manufacturers have been able to reduce vehicle assembly time and costs. Bumpers, fenders and dashboards can now be moulded as single parts. In the past, these elements were made of traditional materials which required the production of many parts and multi-component assembly.

1.7.3.7 References

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1.7.4 Electronic System

1.7.4.1 Introduction

The past three decades have witnessed an exponential increase in the number and sophistication of electronic systems in vehicles.

In 1974, 55 technologies were identified as probable automobile electronic applications by a group of pioneering automotive engineers during the first Convergence Transportation Electronics Association conference. By 1982, 37 of those, including vehicle electronic subsystems such as automatic door locks, guidance, four-wheel antilock brakes, on-board diagnostic systems, service interval reminder, trip fuel consumption and cruise control were in production [Wiggins, 2000].

By 1996, some 93% of those applications had become a reality. In addition, many others had appeared that the engineers involved in the original 1974 forecast could not possibly have imagined. Applications such as heads-up displays, voice synthesis/voice recognition, four-wheel steering, traction control, electrical load management, back-up warning, heated windshield and electronically tuned manifolds were new to the market.

Today, the cost of electronics in luxury vehicles can amount to more than 23% of the total manufacturing cost. Analysts estimate that more than 80% of all automotive innovation now stems from electronics. To gain an appreciation of the change in the average dollar amount of electronic systems and silicon components, such as transistors, microprocessors, and diodes, in motor vehicles, we need only note that in 1977 the average amount was $110, while in 2001 it had increased to $1,800.

By the end of the 1970s, digital ICs, offering immense functional capacity, overtook the temperature and environmentally sensitive analogue versions. Then, in 1980, the next evolution started with the progression from 4 and 8 bit to 16-bit microprocessors. As the operational core of a microcomputer, microprocessors set the stage for such vehicle improvements as electronic engine controls, trip computers, antilock braking, hard-soft suspension and electronic climate control. Compared with the earliest microprocessors used in vehicles, today a considerably downsized packaged contains about 25 times more functional capability.

Another significant area affecting the application of electronics was the development of smart sensors during the 1990s. This has enabled the design of subsystems like integrated power train traction control, onboard diagnostics, navigation and integrated electronic braking, steering and suspension.

The next phase for automotive electronics includes the introduction of 42-volt system architectures, 32-bit microprocessors, standardised multiplexing, microwave communications, micromachined advanced sensors packaged with micro electromechanical systems, brake-by-wire and throttle-by-wire.

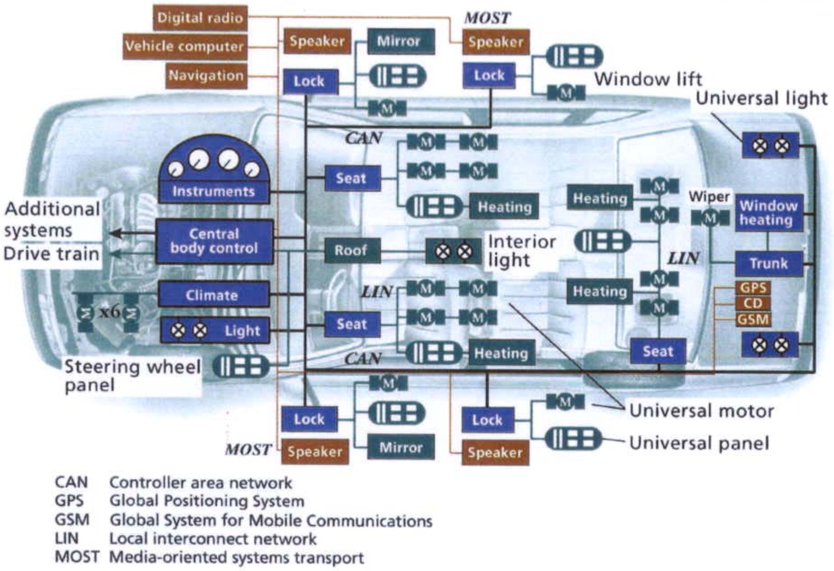
In the past decades, electronics for vehicle communications and information subsystems did not link with the outside world, other than via a few mobile telephones. Today, in ever increasing numbers, vehicles achieve cellular phone, navigation guidance and emergency communications and many other information-transfer functions through radio-frequency and microwave connections, using a network of fixed antennas or satellite links.

The resulting demands on power and design have led to innovations in electronic networks for automobiles. Researchers have focused on developing electronic systems that safely and efficiently replace entire mechanical and hydraulic applications, and increasing power demands have prompted the development of 42-V automotive systems.

1.7.4.2 In-vehicle networks

Just as LANs (Local Area Networks) connect computers, control networks connect a vehicle's electronic equipment. These networks facilitate the sharing of information and resources among the distributed applications.
The next figure shows the sheer number of systems and applications contained in a modern automobile's network architecture.

Figure 1.24: One subset of a modern vehicle's network architecture, showing the trend toward incorporating ever more extensive electronics



Source: Leen & Hefferman, 2002

1.7.4.3 Controller area network

In the mid-1980s Bosch developed the controller area network, one of the first and most enduring automotive control networks.
CAN is a robust, cost-effective general control network, but certain niche applications demand more specialised control networks. For example, X-by-wire systems use electronics, rather than mechanical or hydraulic means, to control a system. These systems require highly reliable networks.

1.7.4.4 Emerging automotive networks

X-by-wire solutions form part of a much bigger trend - an ongoing revolution in vehicle electronics architecture. To accommodate the broad and growing spectrum of vehicle network applications, research engineers are developing many specialised network protocols, including the following:

Domestic Data Bu:. Matsushita and Philips jointly developed the Domestic Data Bus (D2B) standard more than 10 years ago. D2B was designed for audio-video communications, computer peripherals, and automotive media applications.

Bluetooth: Bluetooth is an open specification for an inexpensive, short-range (10,100 meters), low-power, miniature radio network.

Mobile media link: Designed to support automotive multimedia applications, the mobile media link network protocol facilitates the exchange of data and control information between audio-video equipment, amplifiers and display devices for such things as game consoles and driver navigation maps.

Media-oriented systems transport: The applications of MOST, a fibre-optic network protocol with capacity for high-volume streaming, include automotive multimedia and personal computer networking.

Time-triggered protocol: Designed for real-time distributed systems that are hard and fault tolerant. The protocol has been proposed for systems that replace mechanical and hydraulic braking and steering subsystems.

Local interconnect network: A master-slave, time-triggered protocol, the local interconnect network is used in on-off devices such as car seats, door locks, sunroofs, rain sensors, and door mirrors.

Byteflight: A flexible time-division multiple-access (TDMA) protocol for safety-related applications.

FlexRay: FlexRay is a fault-tolerant protocol designed for high-data-rate, advanced control applications, such as X-by-wire systems.

Time-triggered CAN: As an extension of the CAN protocol, time-triggered CAN has a session layer on top of the existing data link and physical layers. TTCAN's intended uses include engine management systems and transmission and chassis controls with scope for X-by-wire applications.

Intelligent transportation systems data bus: Enabling plug-and-play in off-the-shelf automotive electronics, the intelligent transportation systems data bus eliminates the need to redesign products for different makes.

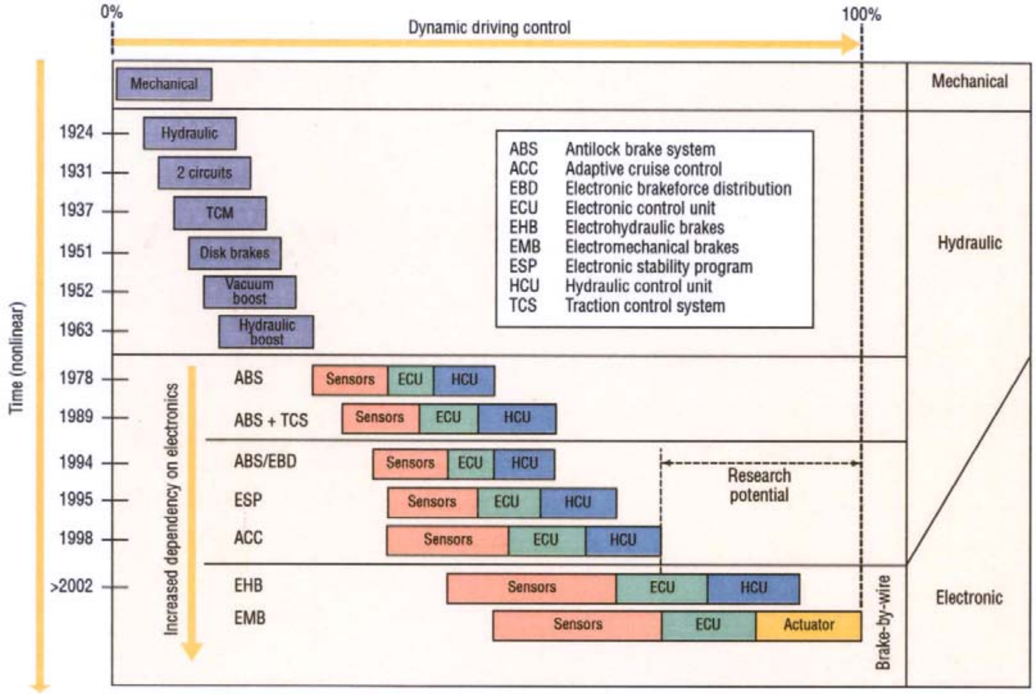
1.7.4.5 X-by-wire solutions

Today's vehicle networks are not just collections of discrete, point-to-point signal cables, they are transforming automotive components, once the domain of mechanical or hydraulic systems, into truly distributed electronic systems.

Highly reliable and fault-tolerant electronic control systems, X-by-wire systems do not depend on conventional mechanical or hydraulic mechanisms. They make vehicles lighter, cheaper, safer, and more fuel-efficient. Such systems can eliminate belt drives, hydraulic brakes, pumps, and even steering columns.

The next figure shows how dynamic driving-control systems have been steadily adopted since the 1920s, with more on the way.

Figure 1.25: Past and projected progress in dynamic driving control systems



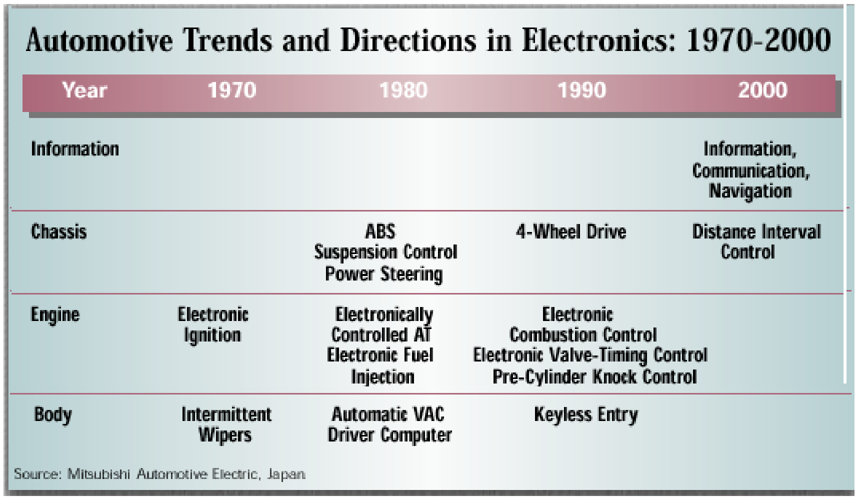
Source: Leen & Hefferman, 2002

1.7.4.6 The 42-V solution

To meet the increasing demand for power, a belt-less engine with an integrated alternator-starter on the flywheel operating at a 42-V potential offers the most promising proposed solution. The motive for the new 42-V system is clear: 79% of the energy entering a conventional engine does not make it to the driveline. The new 42-V systems are expected in new cars by 2003 [Leen & Hefferman, 2002].

1.7.4.7 General trends

Figure 1.26: Automotive trends in electronics

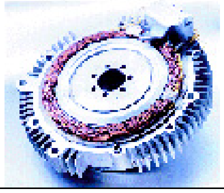


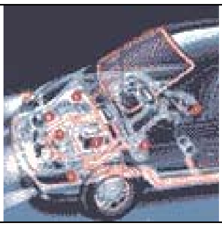
Automotive Trends and Directions in Electronics: 1970-2000

Year	1970	1980	1990	2000
Information				Information, Communication, Navigation
Chassis		ABS Suspension Control Power Steering	4-Wheel Drive	Distance Interval Control
Engine	Electronic Ignition	Electronically Controlled AT Electronic Fuel Injection	Electronic Combustion Control Electronic Valve-Timing Control Pre-Cylinder Knock Control	
Body	Intermittent Wipers	Automatic VAC Driver Computer	Keyless Entry	

Source: Mitsubishi Automotive Electric, Japan

Table 1.7-1: Latest innovations related to the comfort and driving

1996	**Telematic device**	Motorola/Ford (Lincoln)	
1999	**Keyless-go**	Mercedes (S Class)	
1999	**Autonomous Cruise Control**	Mercedes (Distronic on S/SL Class)	
1999	**Voice control integrated phone**	Mercedes (Linguatronic)	
2001	**Door without definite opening location**	BMW (Series 7)	
2001	**E-mail and internet**	Cadillac Infotaitement	
2002-2004	**Integrated Starter/ Alternator/ Damper (ISAD)**	Continental (Developed in 1997)	
	Bluetooth technology (vocal control)		

	Active noise control	Faurecia (2004)	
	14/42 volts system	(2004)	
2005-2010	**Drive-by-wire steering wheel**		
	Car periphery Sensing Radar		
	42 volts system	(2007)	

Source: http://www.auto-innovation.com/en/icomfort.html

1.7.4.8 References

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2 NEW PASSENGER CARS: ECONOMIC RATES EVOLUTION AND TRENDS IN FUEL CONSUMPTION AND EMISSIONS

by Gotzon Azkarate (INASMET) & Luc Pelkmans (VITO)

2.1 Introduction

The need for passenger transportation in today's world has increased the fleet of vehicles all over the world, leading to higher numbers of produced and sold vehicles. One of the events that confirms this trend is the aim of the biggest manufacturers to open new production factories in non-producer countries.

Even if the EU is now a reality, the Euro and the common market influence have still not given results in price convergence. This is due to various reasons, such as implemented taxes in each country or life cost.

Maintenance costs have decreased in recent years because of better and higher quality of materials employment. Production costs for diesel-engine cars are higher than gasoline engined cars, as opposed to running costs, which are lower for diesel cars.

The development in new materials used for vehicle construction has increased the vehicles´ life-time.

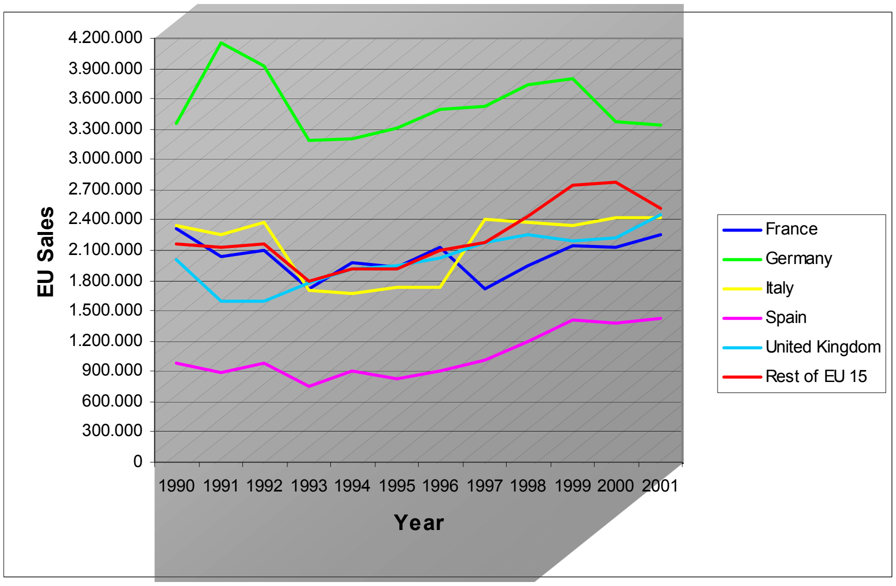
2.2 Sales & production

2.2.1 Sales

Taking passenger cars first, total sales have barely changed over the last 10 years. The Japanese home market has declined by some 20% since 1990 as consumer confidence continues to be fragile. The North American market has also declined by some 10%. This is in part due to the fact that the American consumers have shown more appetite for buying vans and pick-ups rather than passenger cars in recent years. Future growth is expected to occur largely in the emerging markets of Eastern Europe, South Asia, South America and Africa.

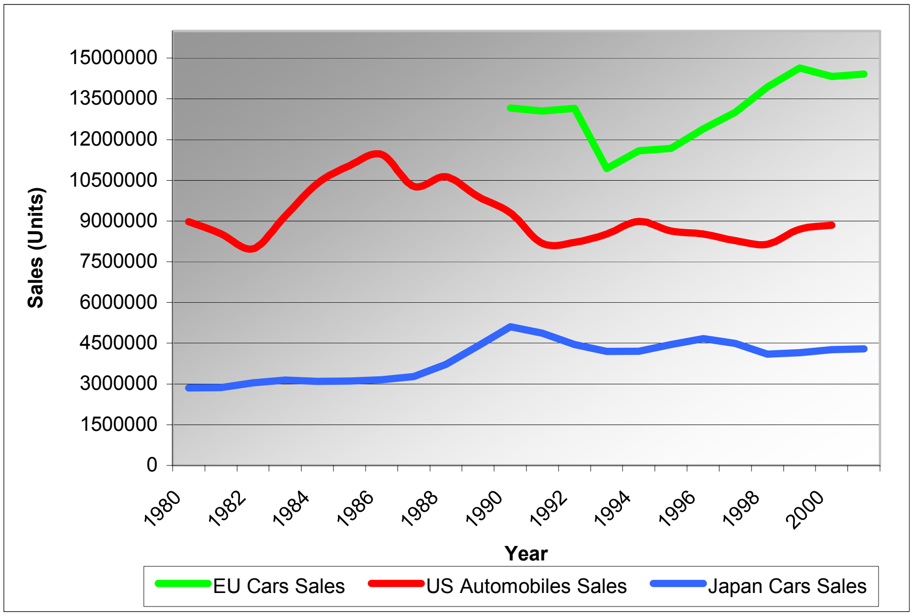
The graphs below show the data of passenger car sales evolution in the European countries and a comparison of the EU-15 with the USA and Japan.

Figure 2.1: Car sales evolution in EU-15 (1990-2000) – see Table 6.2-1



Source: ACEA, 2002

Figure 2.2: Car sales evolution in EU-15, USA and Japan (1980-2001) – see Table 6.2-1, Table 6.2-2, Table 6.2-3



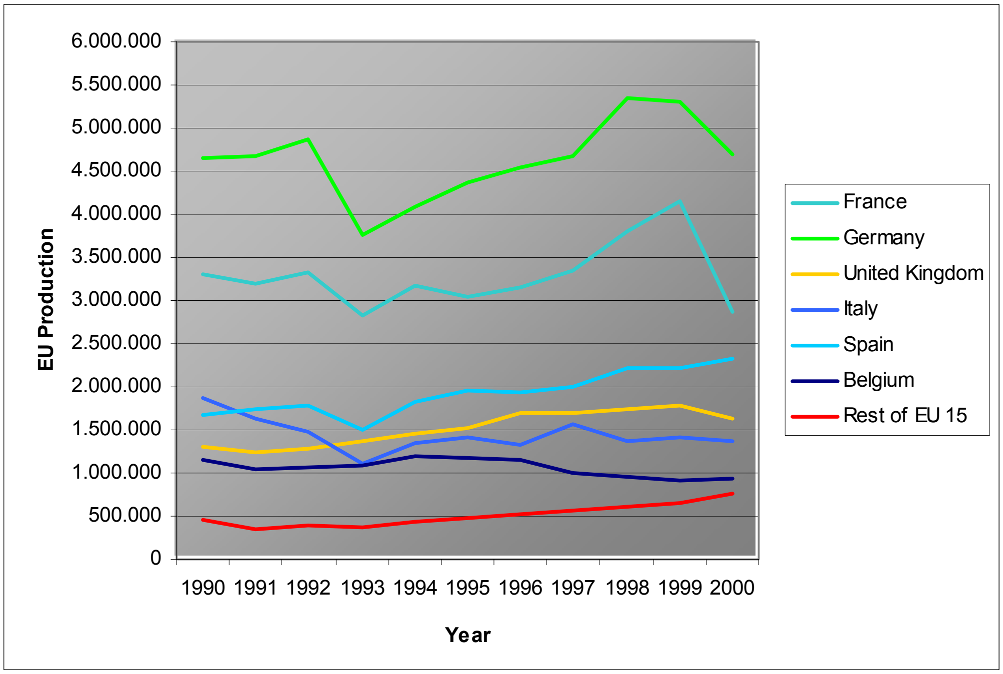
Source: ACEA, AMAA, JAMA, 2002

2.2.2 Production

Overall production levels are on a rising trend but subject to the general level of economic activity. This can be seen in the pattern since 1990 which shows a gradual dip in production during the world slow-down of the early 1990s with the gross trend resuming from 1994 onwards. Over the past decade Western Europe has maintained its position as the world's largest producer of passenger cars making approximately twice as many as the next largest region, the North American Free Trade Association.
Two significant trends over the 10-year period have been the decline in Japan's share of world production and the increase in Asia, other developing markets and, to a lesser extent, Eastern Europe. The decline in Japanese production is to some extent the result of deliberate decisions by Japanese makers to invest in production facilities closer to their main markets. In recent years, however, the Japanese home market has been weak a fact that has also contributed to this trend. Over the next decade it is expected that production growth will continue to occur mainly in a merging market with production in the more mature economies of Western Europe, North America and Japan remaining broadly stable.

In Europe, overall production levels have followed the economic cycle with a low point in 1993 and a steadily rising trend thereafter. Two countries, Germany and France, have historically accounted for roughly 50% of vehicle production despite its high cost base. Germany increased its share during the 1990s with strong growth in production, while Italy was the only major producer to see volumes fall, as the Fiat Group's traditional dominance of the small car market came under threat from Asian and Japanese competition.

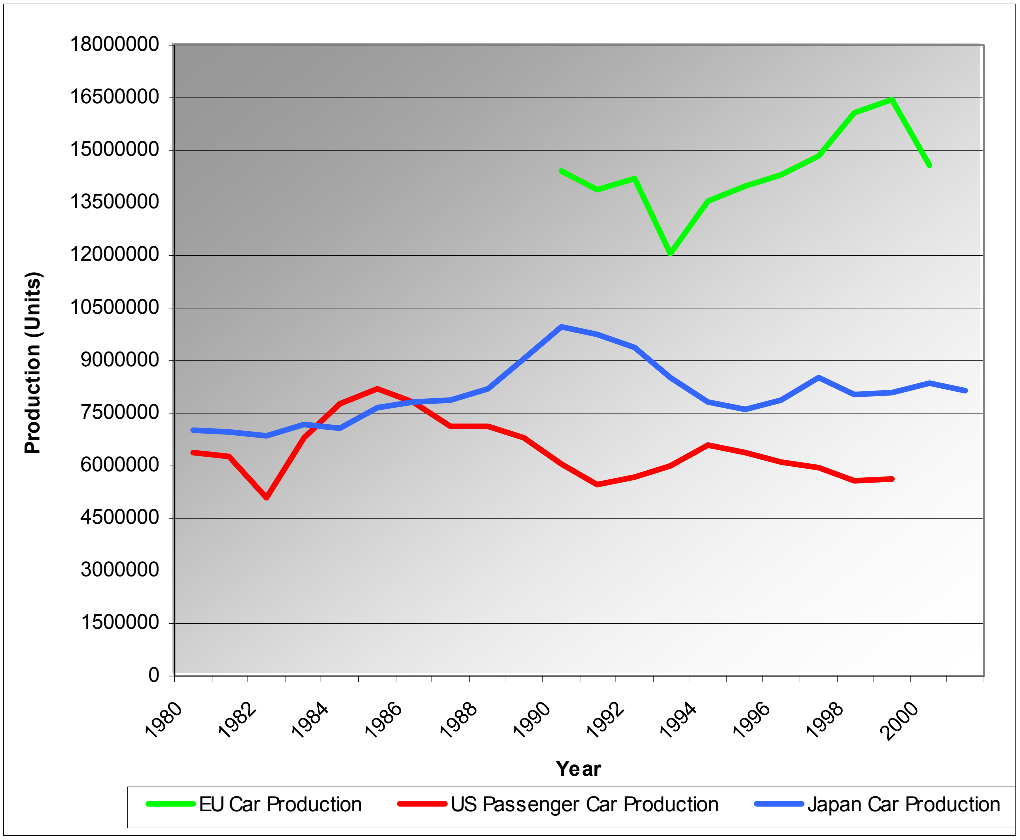
Figure 2.3: Cars production evolution in EU-15 (1990-2000) – see Table 6.2-4



Source: Economist Intelligence Unit (EIU), 2001

The following figure compares car production in the EU-15 with the USA and Japan.

Figure 2.4: Car production evolution in EU-15, USA and Japan (1980-2001) – see Table 6.2-4, Table 6.2-5, Table 6.2-6



Source: EIU, ACEA, AMAA, JAMA, Wards (1999)

2.2.3 References

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2.3 Automobile cost

2.3.1 Car prices and production cost

2.3.1.1 Prices in the EU

In its latest report on car prices, the European Commission has found that price differentials for new cars in the internal market are still substantial, despite the introduction of the Euro. For the moment, enhanced price comparability due to the Euro has not led to greater price convergence.

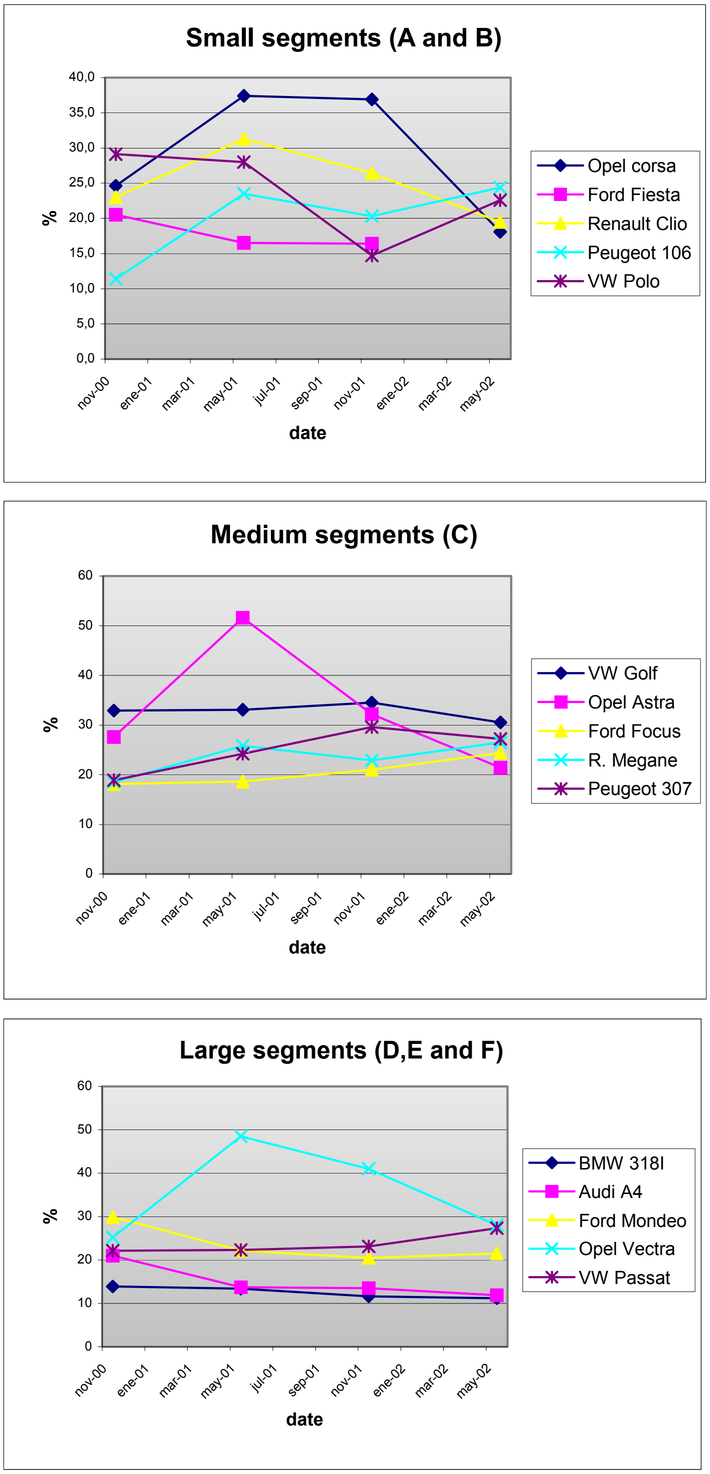
Within the Euro zone, Germany and, to a lesser extent, Austria, still remain the most expensive markets. In Germany, a total of 41 models are sold to consumers at the highest prices in the euro zone and 36 of these are between 42% and 20% more expensive than in at least one other national market. In fact, differentials of more than 20% also appear for 23 models in Austria. The cheapest markets in the Euro zone are Finland, with no differential above 20% for the models surveyed, and the Netherlands with only one differential above 20%.

In absolute values, the price differential on a car in the middle of the segment spectrum (Fiat Marea, segment D) may in certain cases reach as much as 4,600 Euro within the Euro zone and 6,000 Euro within the European Union as a whole. These values provide a relevant indication of the potential savings that consumers may obtain by exploiting price differences in the European Union. The new rules governing car distribution should simplify these purchases. (Data from 2002.)

As regards the United Kingdom, it should be noted that this market continues to be the most expensive for more than half of the models examined. Since prices in the UK are still much higher than elsewhere, many British consumers continue to try to buy cars from Continental dealers. In the worst-case scenario, certain cars are 60% more expensive in the UK than elsewhere. A Fiat Bravo is £3,806 cheaper in Denmark, a Ford Focus Ghia is £5,250 cheaper in Belgium and a Megane Scenic costs £4,300 less in the Netherlands (taking into account pre-tax prices in 2001). But car-makers and dealers say that the pre-tax price comparisons are not fair and that prices have fallen. And the EU acknowledges that while UK prices are still often higher than the rest of Europe, prices have come down by 5% since November 2000.

The car industry says that the EU is quoting pre-tax prices, and that the prices were not a fair reflection of the prices actually being paid by consumers. In Denmark, for example, VAT can account for two-thirds of the total cost of the car, while VAT usually makes up about one -fifth of the total cost of a car in the UK.

Figure 2.5: Price differences for a selection of best-selling cars (expressed as percentages of prices in Euro before tax, comparing the most expensive with the cheapest Euro zone market). – see Table 6.2-7



Source: EU, July 2002

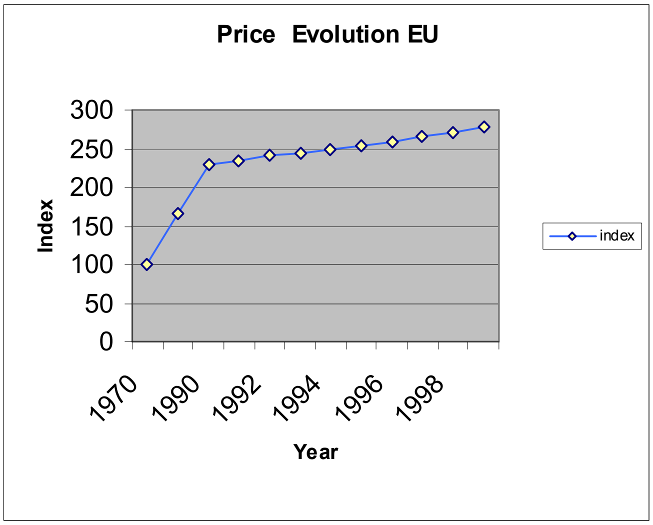
Table 2.3-1: Difference of car prices across Europe.

Prices in euro, pre-tax from November 2001	**United Kingdom**	**France**	**Germany**	**Spain**
Ford Fiesta	10,203	8270	9103	7821
Toyota Yaris	10,169	8164	9639	9175
MGF	23,060	17,519	17,567	16,367
Honda Accord	18,431	16,364	18,076	16,222
Vauxhall Vectra	14,990	13,737	16,847	13,344
Peugeot 206	10,148	9063	9603	8910

Source: http://www.cec.org.uk/wales/press/pr/0204.htm

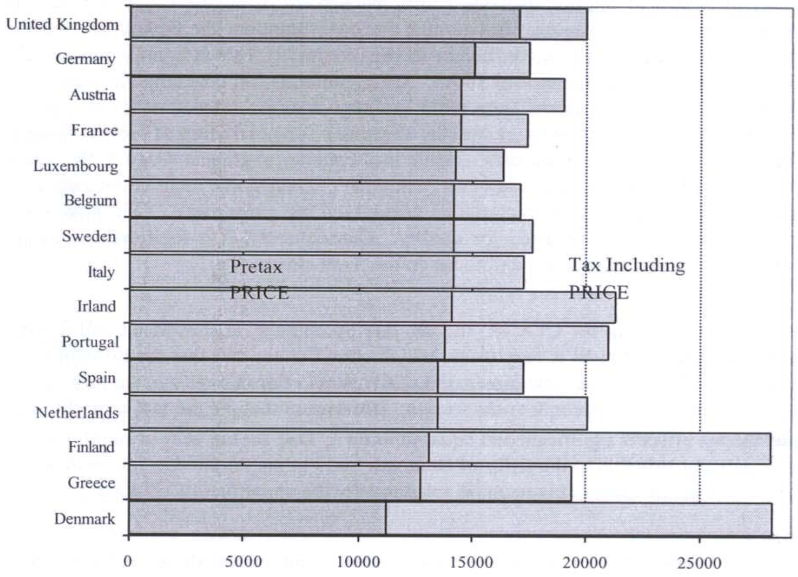
Contrary to popular belief, price differentials for cars are among the lowest compared with other products and services in Europe. And these differentials certainly do not find their origin in the selective and exclusive distribution system. They are the result of differing national markets that have not yet grown together, of different taxation systems and of currency fluctuations. With the introduction of the Euro and the growing integration of markets in the Eurozone, price differentials will grow appreciably smaller, particularly if excessive registration taxes are abolished and annual car taxes harmonised in their structures.

Figure 2.6: Passenger Car Price Index evolution in The EU 15. – see Table 6.2-8



Source: EU, 2001

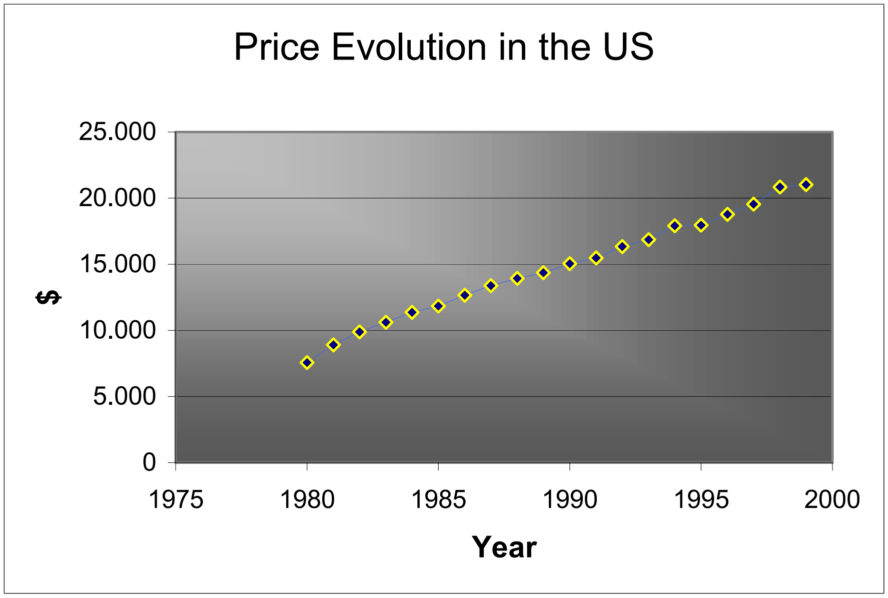
Figure 2.7: Automobile prices in EU 15, first semester of 1999.



Source: Gaulier & Haller, 2000

2.3.1.2 Prices in the USA

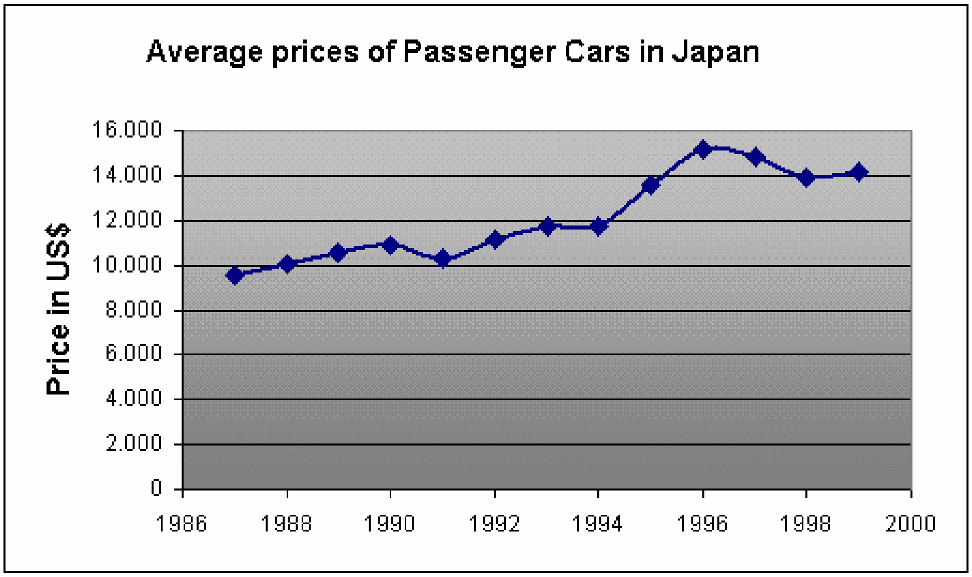
Figure 2.8: Passenger car price evolution in the USA – see Table 6.2-9



Source: Transportation Energy Data Book, 21

2.3.1.3 Prices in Japan

Figure 2.9: Passenger car price evolution in Japan.– See Table 6.2-10



Source: Industry Canada, 2001

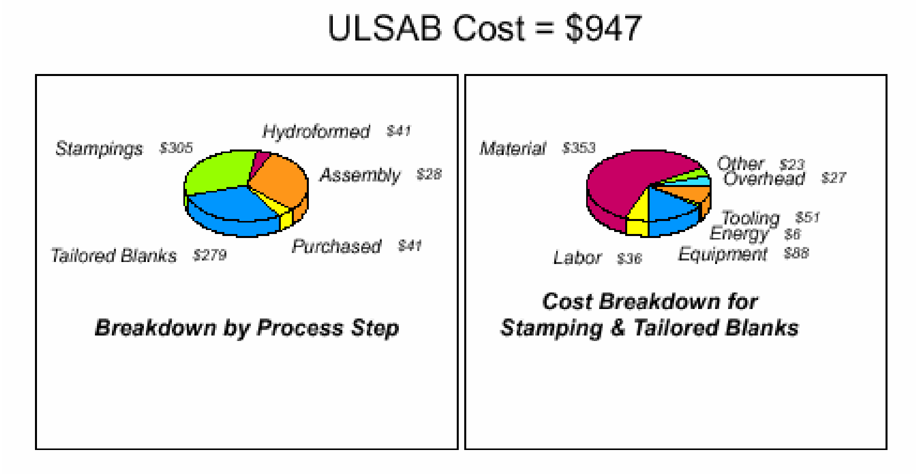
2.3.1.4 Economical analysis of fabrication - ULSAB

ULSAB (UltraLight Steel AutoBody)

Although lightweighting without sacrificing performance was ULSAB's priority, affordability was also important. A Porsche-led team of analysts developed a detailed cost model that included all aspects of fabrication and assembly. The cost model can be used to analyse ULSAB costs in comparison with other options and also to generate costs associated with alternative designs. http://www.ulsab.org/public/techinfo/graphics/slide79_big.jpgThis model comprehends United States manufacturing costs, including investments for both plant and tooling, piece fabrication costs and assembly costs, through to the end of the body shop.

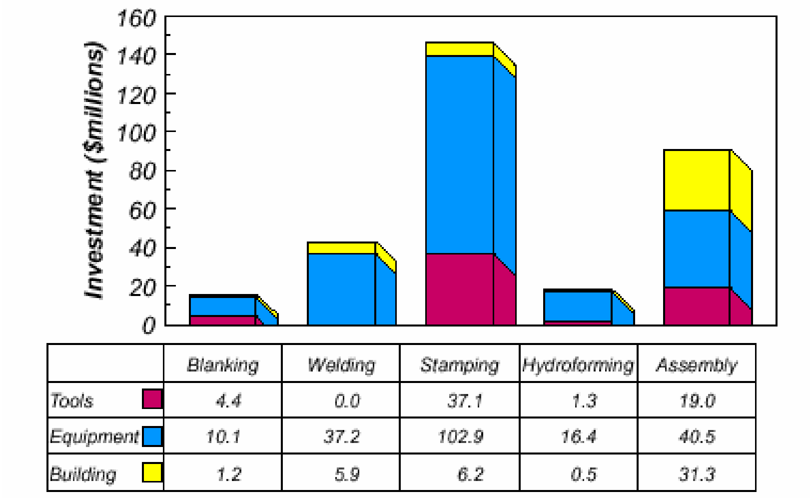
The cost model showed the ULSAB body structure to cost $947 each to manufacture and the 2000 Year structure to cost $979 each, demonstrating that sophisticated design of a steel body structure can achieve lightweight at no cost penalty and with potential cost savings.

Figure 2.10: ULSAB Cost Distribution



Source: MIT, 1999

Figure 2.11: ULSAB Investment distribution



	Blanking	Welding	Stamping	Hydroforming	Assembly
Tools 🟥	4.4	0.0	37.1	1.3	19.0
Equipment 🟦	10.1	37.2	102.9	16.4	40.5
Building 🟨	1.2	5.9	6.2	0.5	31.3

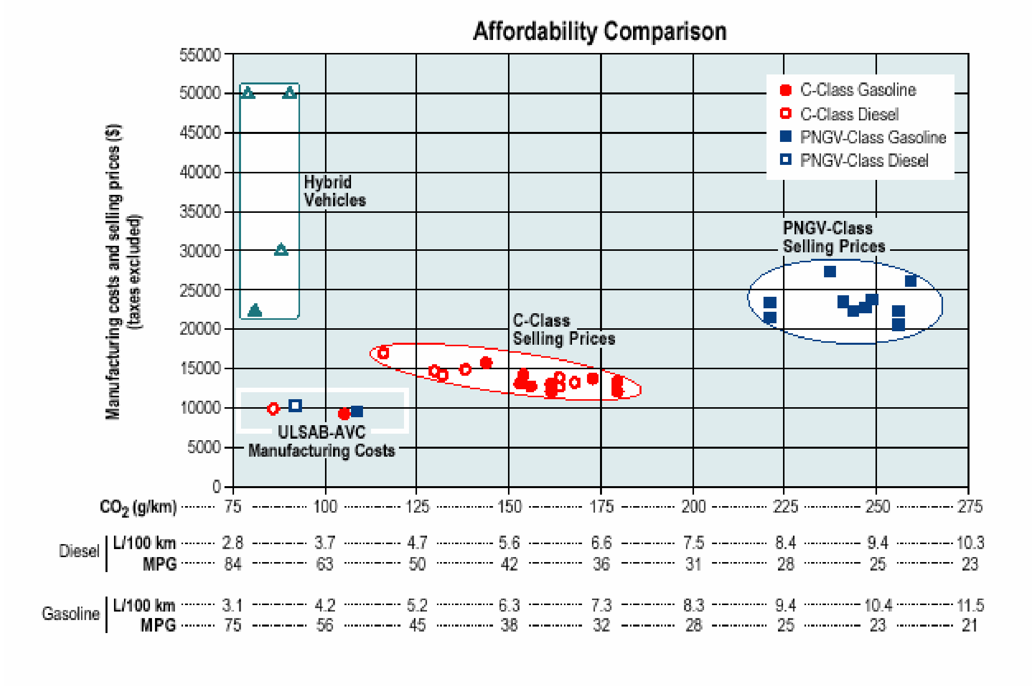
Source: MIT, 1999

Affordability of ULSAB-AVC (Advanced vehicle concepts)

ULSAB-AVC approaches high volume, STEEL-intensive C-Class and PNGV-Class (similar-to Midsize-Class) vehicle concepts.

Many decisions were made during the development process to ensure that ULSAB-AVC would be affordable, both to the manufacturer and the consumer. Modular assembly (like the front-end module) fewer body-in-white parts through part integration, and use of conventional powertrain technology all contributed to keep manufacturing costs down. Key to affordability is the steel-intensive design steel, which continues to be the most cost-effective structural material for automobile manufacturing.

Figure 2.12: ULSAB-AVC Manufacturing costs affordability comparison chart



Source: ULSAB-AVC, 2002

A detailed economic analysis, performed by leading cost analysts, was conducted to assess how much it would cost an automobile manufacturer to build the ULSAB-AVC vehicles. The economic analysis included development of a detailed cost model, which provides a platform for understanding the costs of all aspects of manufacturing an entire vehicle.

The cost model tracks the costs of all parts in the vehicle, the production of subassemblies and the final assembly process. Emphasis was placed on understanding the costs of steel part fabrication and assembly processes, like stamping, tailored blanks or hydroforming, which are modelled in considerable detail. The remaining parts costs, like the electrical system or seats, which auto manufacturers normally purchase, were estimated via supplier quotes, industry information and other cost estimates. Automotive assembly plant activities, such as painting and final assembly/trim line, were modelled using industry data concerning these processes.

To account for varying opinions as to what should be included in manufacturing costs, the spreadsheet cost model was developed so that individual users can input their company-specific assumptions to arrive at their own cost conclusions.

The assessment results show that advanced steel vehicle concepts, which have the potential to achieve four or five star crash ratings, are fuel efficient, and can be built in high volume at affordable costs.

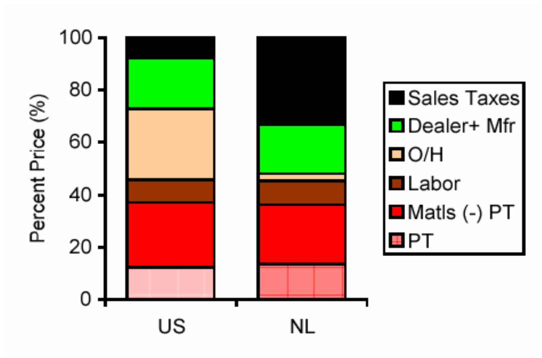
An additional study, which benchmarked the selling price of current production vehicles, revealed that ULSAB-AVC vehicles are affordable compared to benchmarks. Also, the data clearly indicates that ULSAB-AVC concept vehicles' selling price could be far below the selling price of current hybrid-engine concept vehicles, while offering substantial reduction in CO_2 emissions over conventional vehicles.

2.3.1.5 Cost aspects of Hybrid cars

Production costs

Hybrid vehicles cost more to manufacture than do conventional vehicles due to higher cost propulsion systems (used synonymously with "powertrains"). Estimates of additional cost range from $ 2,000 (~2,080 EUR) for a "mild" parallel hybrid to $ 10,000 (~10,400 EUR) for a full-performance series hybrid with substantial electric range. The powertrain in a typical $20,000 car in the USA costs about $2,500 or 12.5% of the price. And as shown in the comparison of Figure 2.13, the powertrain costs are similar in the Netherlands. Materials other than powertrain and assembly labour are also similar. When added to powertrain costs, they equal roughly half the selling price. The similarity continues in the dealers' and manufacturers' shares of the price. The typical dealer's share (roughly 18% in the US) accounts for their costs and profit. Although it is not evident in this breakdown, the smallest share of the price is the manufacturer's profit – roughly 2.5% ($500) for a $20,000 car in the USA.

Figure 2.13: Hybrid Vehicle cost/price structure [IEA-HEV, 2001]



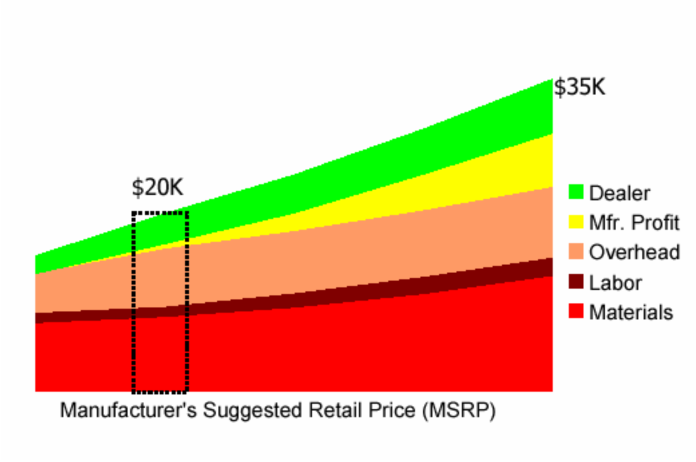
The apparent differences in the comparison are overhead (O/H) and sales tax. The difference in overhead is at least partly due to different assumptions in the two data sets. The US estimate includes all corporate costs – engineering, development, investment and all other operating costs plus vehicle destination (shipping) charges, warranty funds and litigation expenses. The data from Netherlands is based on plant costs – primarily machinery and buildings. The difference would not be so substantial if the additional corporate elements of overhead were included.

Profitability

Hybrid vehicles must be profitable to manufacturers. The previous discussion of a typical $20,000 car included a manufacturer's profit of approximately $500, leaving little flexibility to incorporate a more costly powertrain. Vehicle profitability, however, improves substantially as the price increases. As illustrated in Figure 2.14, material costs, labour and overhead do not increase proportionally with the price. The dealer's share grows somewhat, remaining substantial throughout the product line, but the manufacturer's profit grows to as much as 10,000 EUR for a 35,000 EUR Sport Utility Vehicle (SUV) or luxury car in the USA. This profit difference across the vehicle portfolio fostered the marketing approach of introducing new features on premium vehicles, then rolling down the options to lower-priced vehicles as investment is recovered and costs decrease. If hybrid vehicle marketing uses the same approach, the obvious opportunity for hybridisation in the USA is the SUV due to the high fuel consumption, high profit levels and substantial market share.

The large range of profitability shown in Figure 2.14 is not as pronounced in Asia or Europe since smaller vehicles are generally more profitable in those regions. The conclusion from this simple analysis is that there is a greater opportunity to insert hybrid propulsion components in higher-priced vehicles because there is more room to absorb the costs – but the manufacturers have to give up profit. The corporate-level decision to "subsidise" hybrid vehicles in this manner is a matter of pricing policy. These companies believe that the corporate pride and marketing value of being perceived as "green companies" justifies the subsidy, at least in the short term.

Figure 2.14: Cost elements versus price



Source: IEA-HEV, 2001

2.3.2 Automobile ownership and operating costs

The annual costs of an automobile are divided into fixed costs and variable costs. The fixed costs are the costs of ownership and are independent of the miles done. The operating costs are variable and related to the amount of travel. Fixed costs for new cars are much higher. As cars grow older and fixed costs decline, however, variable costs, which include taxed fuel, become larger and more conspicuous shares of the total.

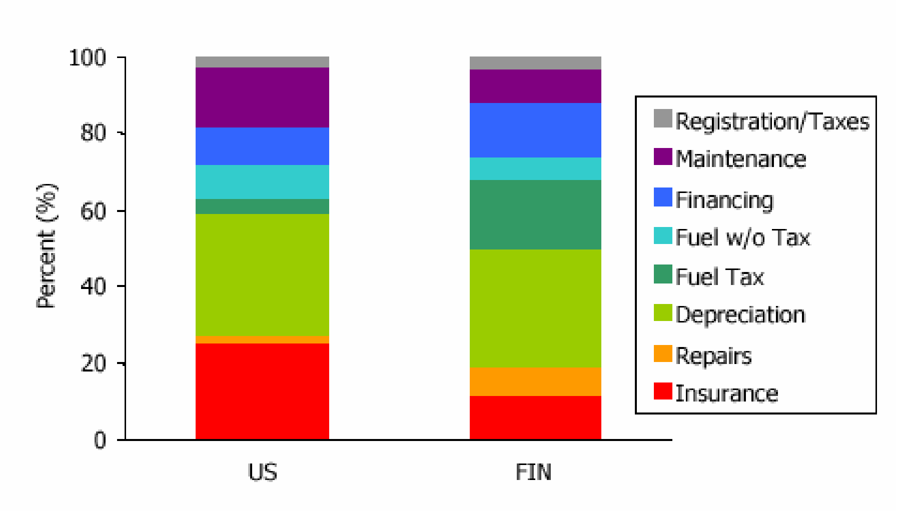
In the costs of automobile ownership we can find the depreciation of the automobile, the insurance, the finance charge and the license fees. These costs are not the same in each country.

The operating costs are gas, oil, maintenance and tyres. These costs are related to the miles driven. Costs of fuels are the sum of three steps in the fuel cycle: costs of raw materials, costs of converting raw material to final fuels and costs of distribution (delivering those fuels to the tanks of customer vehicles).

2.3.2.1 Operating costs

An often-used selling point of high-fuel economy vehicles, including hybrids, is that operating costs could be lower due to substantially lower fuel costs. This is more apparent in Asia and Europe than is the case in the USA. The higher fuel costs in Europe are evident in the following figure, which compares the USA and Finland. If the Netherlands and Finland are representative, 18%-30% of total operating cost is fuel.

Figure 2.15: Comparison of operating costs



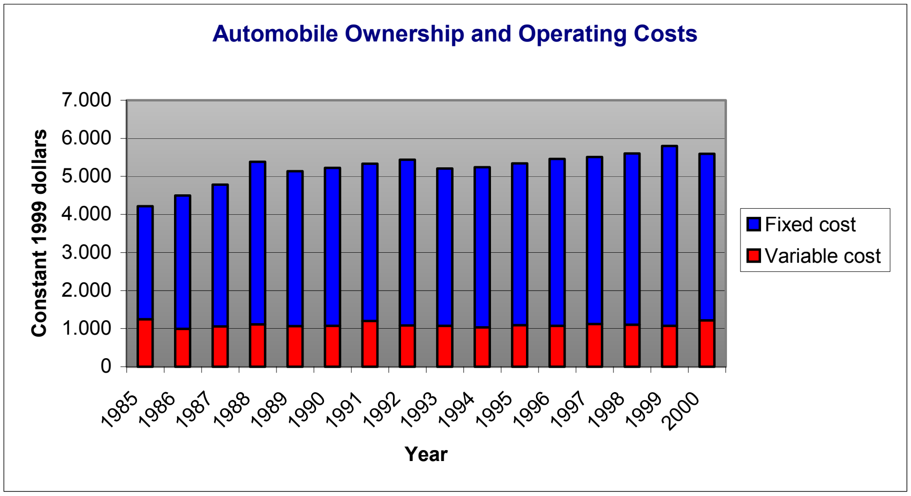
Source: IEA-HEV, 2001

In the USA, 15%-20% of the operating costs of an intermediate-sized vehicle are fuel, based on Federal Highway Administration and Intellichoice data. The US data in Source: are based on a total operating cost of 0,395$US /mi (0,257 € /km).
The comparison also reveals notable differences from lower insurance costs in Finland as well. For reference, the Finland vehicle is priced at FIM 140.000 (23.500 EUR).

2.3.2.2 Evolution of annual costs

Analysing the data of operating costs in the USA in Table 6.2-11, it is possible to follow the evolution of these costs year on year. The variable costs are almost the same year by year. This is because the maintenance and tyre costs have increased while the gas and oil costs are lower now.

Figure 2.16: Automobile Ownership and Operation Costs - see Table 6.2-11

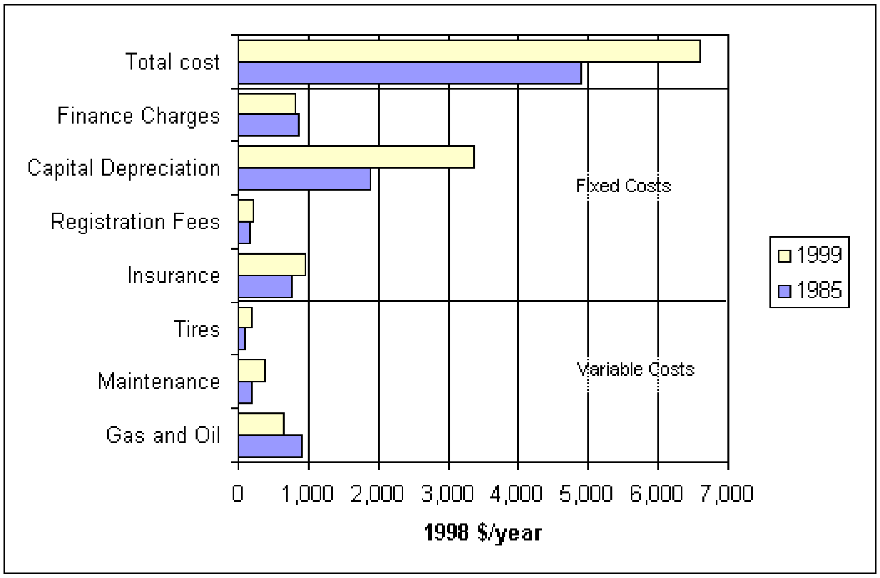


Source: Transportation Energy Data Book, 21

The comparison between 1985 and 1999 shows the changes in each cost. The next figure shows how the fixed costs increases from 1985 to 1999, while the variable costs are more or less the same.

The average 1999 model year automobile costs $5,674 per year to own and operate, up to 38% in real terms compared to 1985. The vehicle purchase price, depreciated over six years, constituted the largest portion of this cost in both of the years (27% in 1985 and 47% in 1999). In 1999, the second largest cost was insurance (17%), followed by finance charges (14%). Gasoline and oil were the fourth largest portion at 10%. For a 1985 car, gasoline and oil were the second largest part of costs (23%) followed by finance charges (21%) then insurance (19%).

Figure 2.17: Costs of Ownership and operation distribution - see Table 6.2-12.



Source: Transportation Energy Data Book, 19

Notes:

- Variable costs assume annual mileage of 10,000.
- Fuel cost for 1999 was based on early year gasoline prices averaging $1.098 per gallon and does not reflect price increases later that year.
- Fixed costs are based on a six-year or 60,000 mile depreciation period.
- Insurance costs are based on deductibles of $100 (fire and theft, 1985), $250 (fire and theft 1999), $250 (collision 1985), $500 (collision 1999), and property damage/liability coverage of $100,000/$300,000.

2.3.2.3 Evolution of automobile costs per mile

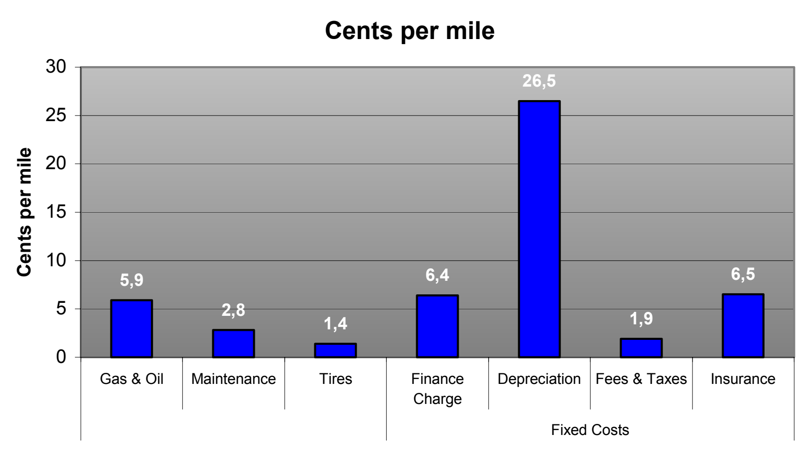
The increase of the total costs per mile is evident in the data from Table 6.2-11.

Figure 2.18: Total costs per mile - see Table 6.2-11: Automobile Ownership and Operation Costs

Source: Transportation Energy Data Book, 21

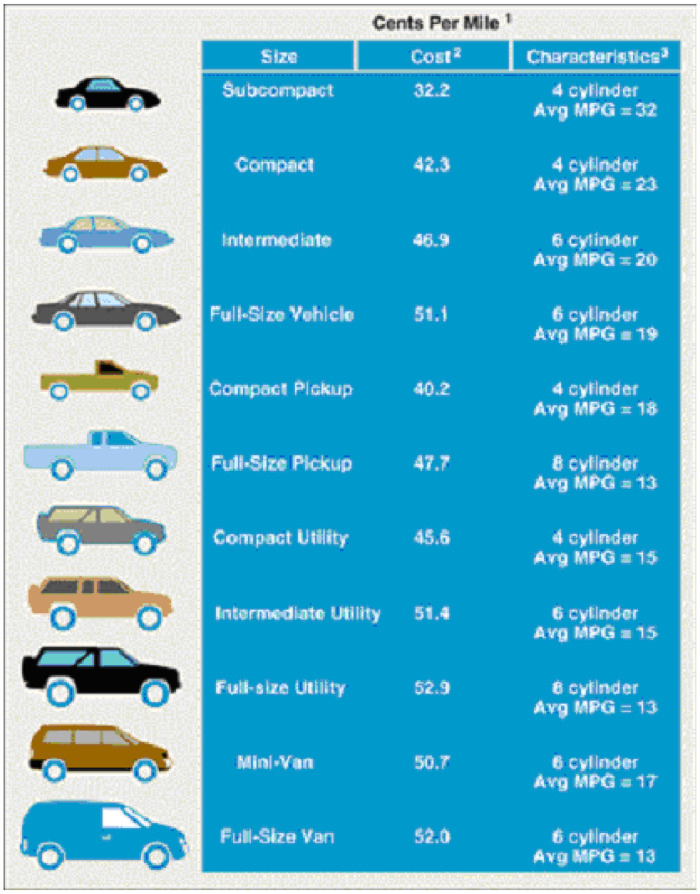
It is possible to analyse the different costs of a specific year and study how much each amounted to. In 1996 the total cost of operating a passenger car was about 51 cents per mile, taking into account depreciation and finance charges. Variable costs included gas & oil (5,9 cents per mile), maintenance (2,8 cents per mile) and tyres (1,4 cents per mile). Fixed costs included insurance (6,5 cents per mile), fees and taxes (1,9 cents per mile), depreciation (26,5 cents per mile) and finance charges (6,4 cents per mile).

Figure 2.19: Automobile costs per mile



Source: AAMA, 1996

Figure 2.20: Operating costs by automobile size



Cents Per Mile[1]

Size	Cost[2]	Characteristics[3]
Subcompact	32.2	4 cylinder Avg MPG = 32
Compact	42.3	4 cylinder Avg MPG = 23
Intermediate	46.9	6 cylinder Avg MPG = 20
Full-Size Vehicle	51.1	6 cylinder Avg MPG = 19
Compact Pickup	40.2	4 cylinder Avg MPG = 18
Full-Size Pickup	47.7	8 cylinder Avg MPG = 13
Compact Utility	45.6	4 cylinder Avg MPG = 15
Intermediate Utility	51.4	6 cylinder Avg MPG = 15
Full-size Utility	52.9	8 cylinder Avg MPG = 13
Mini-Van	50.7	6 cylinder Avg MPG = 17
Full-Size Van	52.0	6 cylinder Avg MPG = 13

Source: US DOT, 2002

[1] Total costs over 5 years, based on 70,000 miles.

[2] Includes depreciation, financing, insurance, registration fees, taxes, fuel maintenance, and repairs.

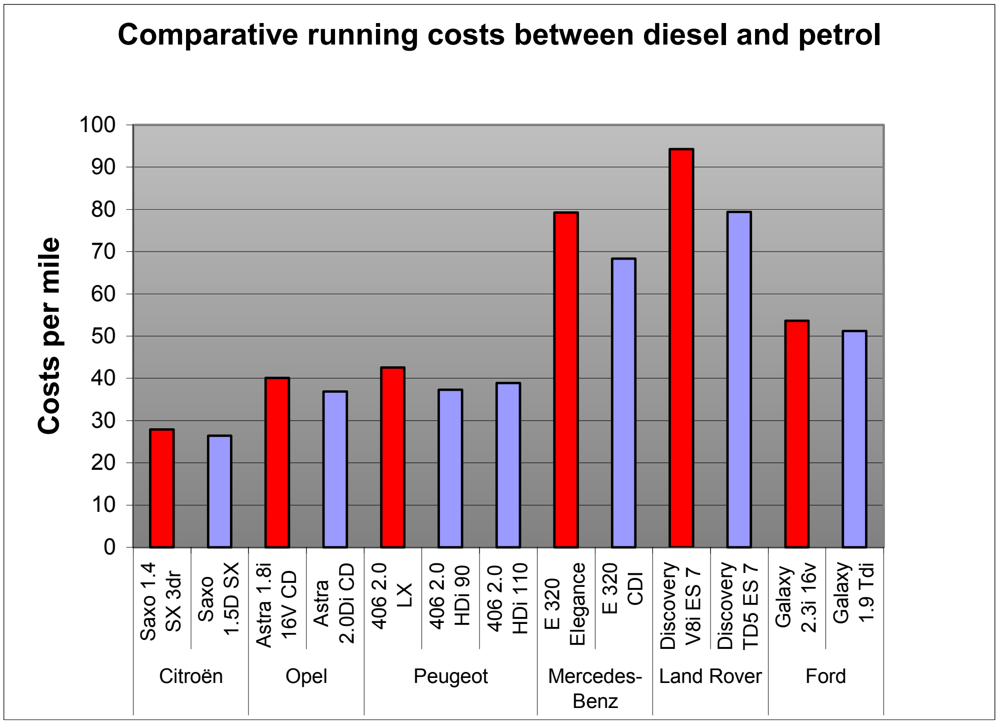
[3] Average mpg reflects city, excluding highway.

2.3.2.4 Comparative operating costs between diesel and gasoline

As shown in Table 6.2-13, operating costs are different for diesel and gasoline automobiles. Analysing the comparative study between similar models for different manufacturers, it is concluded that operating costs for diesel automobiles are lower than those for gasoline cars.

In the next figure the difference between similar diesel and gasoline automobiles are shown and likewise, the comparison between the different operating costs per mile for some manufacturers and automobile sizes.

Figure 2.21: Comparative running costs between diesel and gasoline automobiles – see Table 6.2-13,



Source: http://www.smmt.co.uk/downloads/Dieselfactsandfigures.ppt

2.3.3 Taxes

This chapter gives an overview of the specific taxes that are levied on motor vehicles. These include in particular:

- Taxes on acquisition: taxes paid once only, by each vehicle owner, for each vehicle purchased and entered into service (sales tax, registration tax).
- Taxes of ownership: taxes paid annually, regardless of how the vehicle is used.
- Taxes on motoring: taxes on the sale of fuels.

2.3.3.1 Fuel tax

Fuel taxes in industrialised countries now vary widely. The next table shows the taxes on Highway Fuels for different countries.

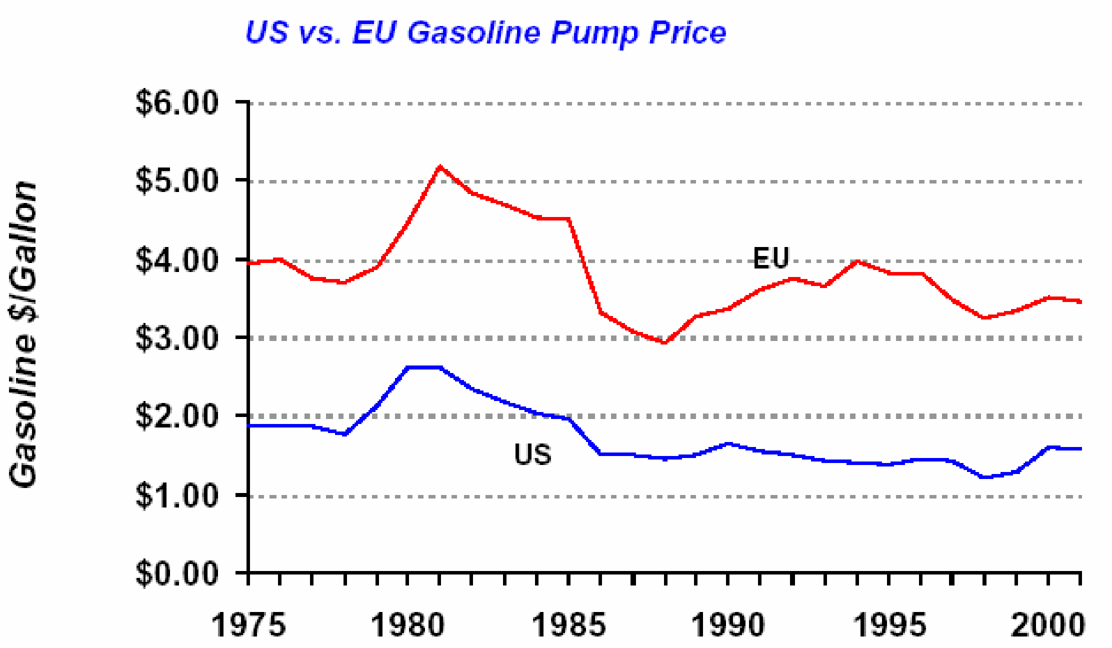
Table 2.3-2: Fuel taxes (US$/gallon, early 2000)

	GASOLINE	DIESEL
USA	0.40	0.46
Canada	0.79	0.61
Japan	2.03	1.25
Germany	2.48	1.29
France	2.87	1.53
UK	3.53	3.04

Source: IEA 2000

In the USA responsibility for better fuel economy is laid at the manufacturers' door. In Europe high taxes are applied to automotive fuels to encourage consumers to purchase and operate vehicles with acceptable fuel economy. shows the average pump price evolution of gasoline in the USA vs. the EU between 1975 and 2001. In general it can be said that fuel prices for gasoline in the EU are double those in the US.

Figure 2.22: USA vs. EU gasoline pump price

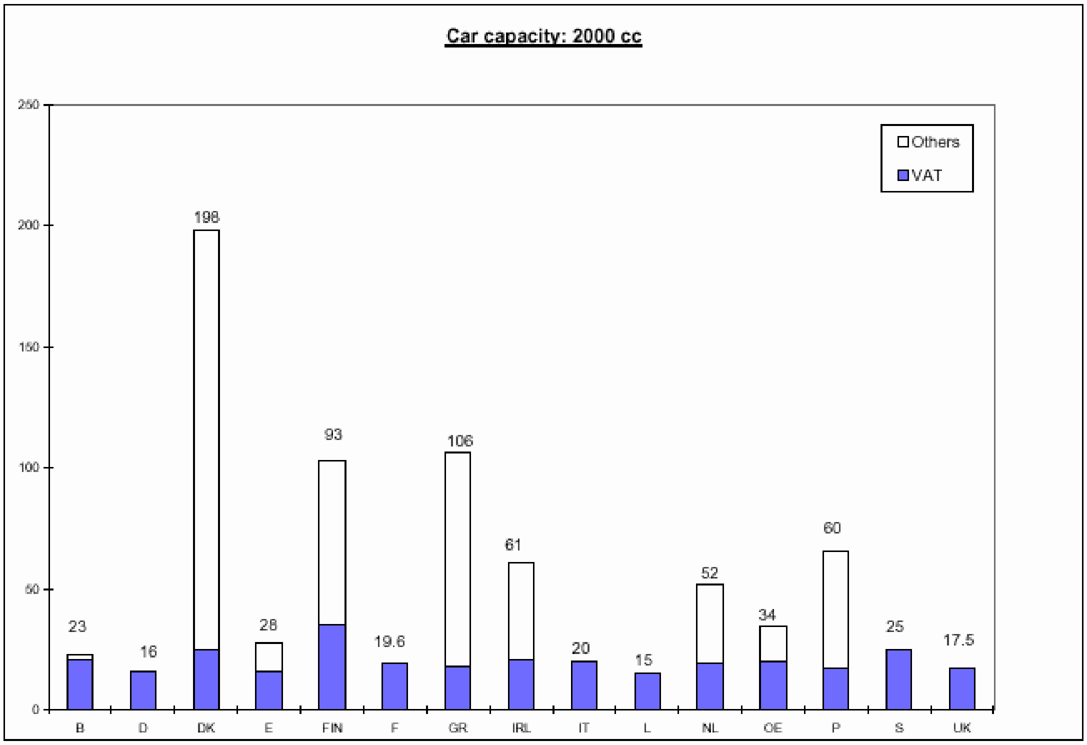


Source : Martec, 2002

2.3.3.2 Sales tax

Continuing the discussion of , sales tax in the Netherlands is comprised of the “BPM” (tax on passenger and motor vehicle) plus the VAT (value added tax). The BPM is 45.2% of the pre-tax price – minus 1,540 EUR for gasoline-fuelled cars or plus 328 EUR for diesel-fuelled cars. VAT, ranging from 13%-25% in the EU, is 17.5% in this case. Sales taxes vary widely in the EU ranging from the lowest VAT of 12% to more than 200% of the pre-tax price.

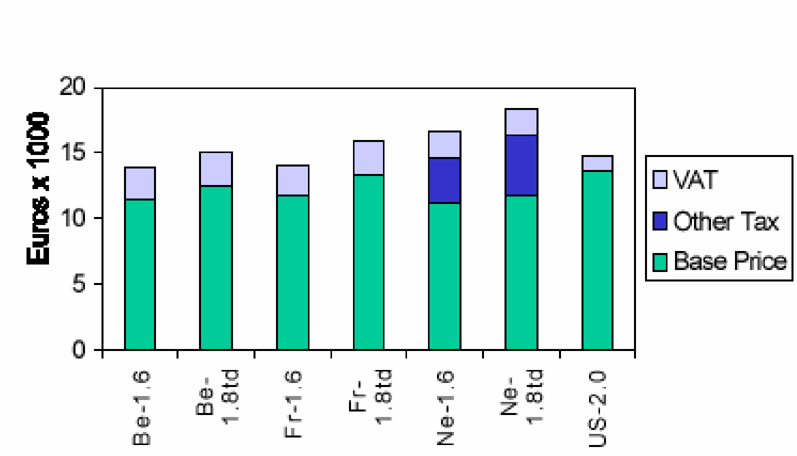
Figure 2.23: Taxes on passenger vehicles in Europe (for 2000 cc capacity)



Source: ACEA, 2002

In the USA, sales taxes vary by state and range from 0% to 8%. Considering a specific global vehicle, such a Ford Focus, illustrates the relative importance of taxes. Figure 2.24 compares prices in Belgium, France, the Netherlands and the USA. Apparently the price can vary by several thousand EURO (>20%) between Belgium and the Netherlands (with shared borders). The price comparison between the European countries and the USA is not quite as clear because engine options differ - 1.6-liter gasoline and 1.8-liter turbodiesel engines are available in Europe (i.e. “1.6” and “1.8td”) while only 2.0-liter gasoline engines are available in the USA. The lower contribution of taxes in the USA is apparent, however.

Figure 2.24: Ford Focus price comparison



Source: IEA-HEV, 2001

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2.4 Vehicle lifetime

2.4.1 Life-cycle assessment

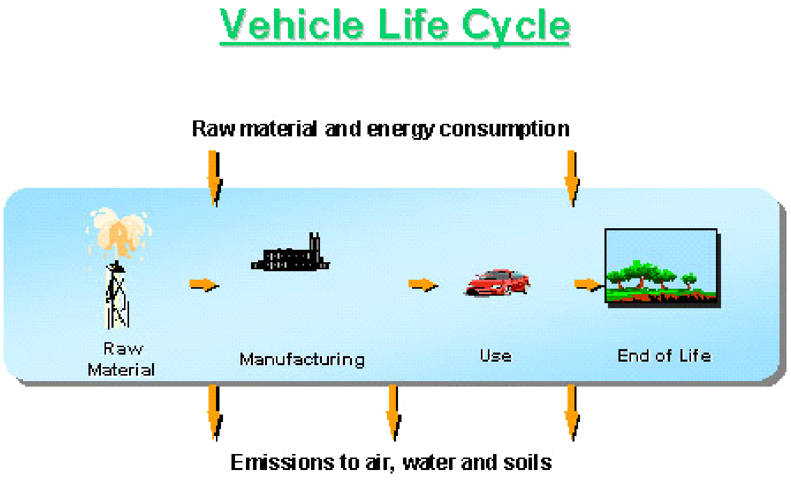
Life-cycle assessment is a process that considers the whole automobile life, from the recognition of a need, through design and development, production, distribution, usage and disposal/recycling. Taking an economic life-cycle view, each stage of the vehicle's life is assessed in terms of cost.
The life cycle of an automobile begins with the *materials production* and finishes at the *end of life stage*. In this period of time there are included the *manufacturing stage* and the *use and service stage*.

The first stage is *materials production;* this period includes resource extraction and materials processing activities. The *manufacturing stage* starts with the fabrication of product material into automotive parts (e.g. an engine block). The next steps are the manufacturing and assembly of parts into components (e.g. an engine) and the final auto assembly (e.g. power-train automobile).
The *use and service stage* includes overall environmental impacts. Beside the fuel consumption this phase includes:

- Components for running an automobile such as oil, additives and lubricants.
- Replacements parts such as tyres, batteries and filters.
- The need for infrastructure such as service and gas stations.

The final stage is the *end of life stage* of an automobile, where it enters the recycling infrastructure. In the following figure the life cycle is shown, including materials inputs and emissions.

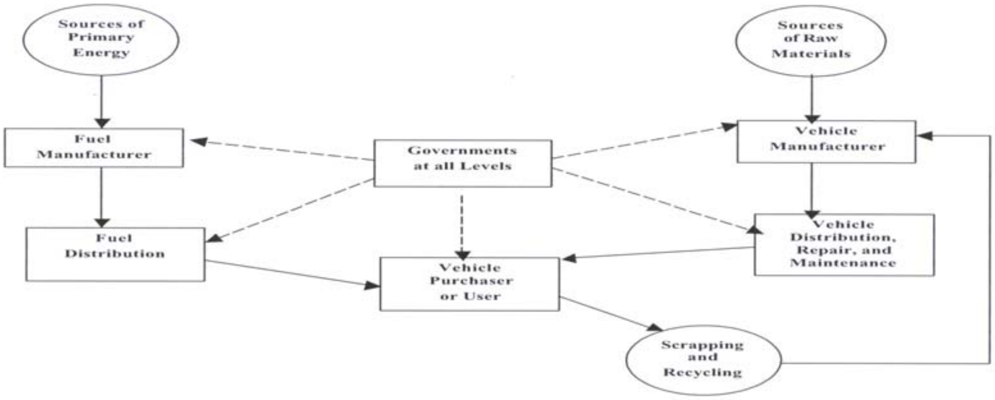
Figure 2.25: Vehicle Life cycle



Source: ITRI, 2001

The materials production and manufacturing stages depend on the manufacturers' conditions. The end of life stage is close to materials properties. It is necessary to study the use and service stage if analysis of the automobile fleet evolution is wished.
The key steps in the life cycle are shown in the next figure:

Figure 2.26: Steps in the Life Cycle of Automobile Technology



Source: Weiss, 2000

"Primary energy sources" such as petroleum or natural gas are considered from the point of their recovery from underground resources through transportation to refineries or manufacturing plants where those sources are converted to fuels for vehicles. The fuel must then be distributed up to deposit in the vehicle's tank. The total of these steps is defined as the "fuel cycle" or "well-to-tank." Analogously, the vehicle cycle begins with ores or other raw materials necessary to make the parts included in a vehicle, fabrication, and assembly of those parts, and distribution of the finished vehicle to the customer. The vehicle is then operated by the first or subsequent customer, with maintenance and repair requirements, until the end of its lifetime when the vehicle is scrapped and recycled.

2.4.2 Scrapping and survival rates

The automobile useful lifetime covers the time when the end-user owns the vehicle. It starts when the costumer buys the vehicle and finishes at the end-of-life stage. This stage will define the improvements in the automobile lifetime.
Some aspects that assist in analysing the lifetime are the scrappage and survival rates. With these rates it is possible to estimate the median lifetime of the automobile fleet. The survival rate can offer the percentage of cars that will survive with a specific age.

2.4.2.1 Automobile lifetime in the USA

Automobile scrappage and survival rates.

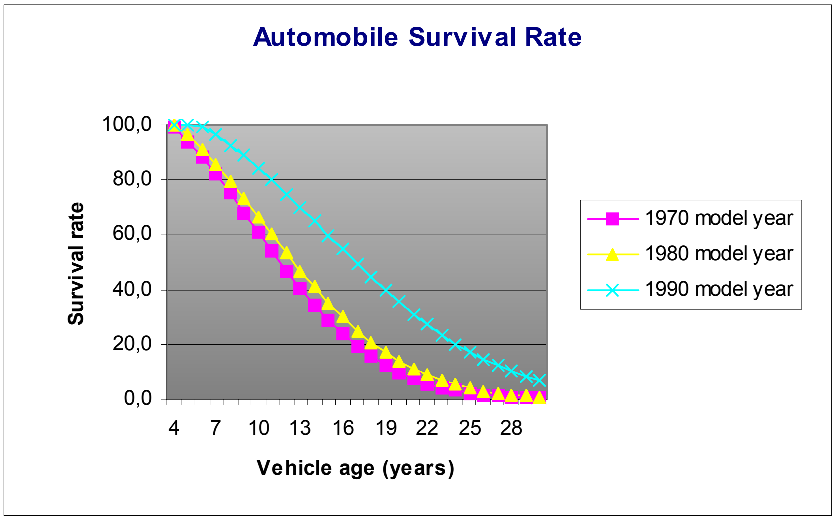
With the analysis of these rates automobiles median lifetime is obtained. These rates are shown in a year by year percentage.

- Survival rate measures the percentage of automobiles that will be in use at the end of a given year.
- Scrappage rate shows the percentage of automobiles that will be retired from use at the end of a given year.

It was assumed that scrappage for vehicles less than four years old is 0.

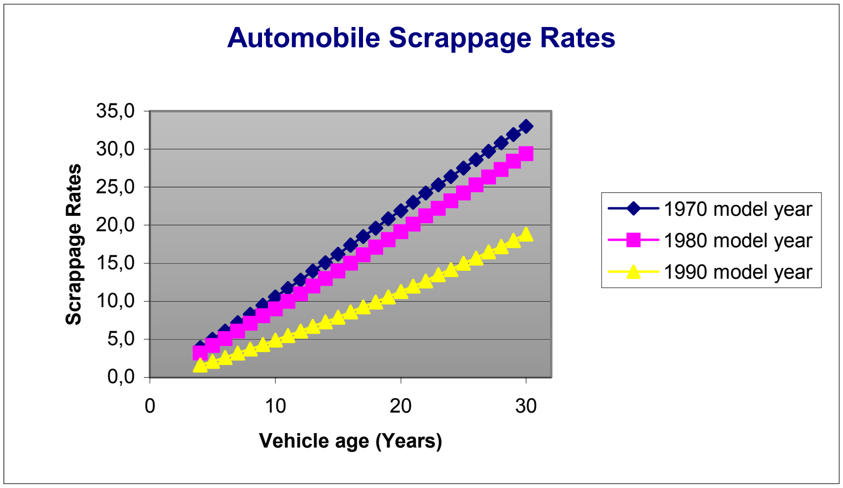
In the next figures the evolution of survival and scrappage rates and the rising life expectation of the automobiles are shown. Analysing the dates in Table 6.2-18 it is possible to obtain the medium automobile lifetime for each model year, as shown in the next figure.

Figure 2.27: Automobile Survival Rate (USA), see Table 6.2-18.



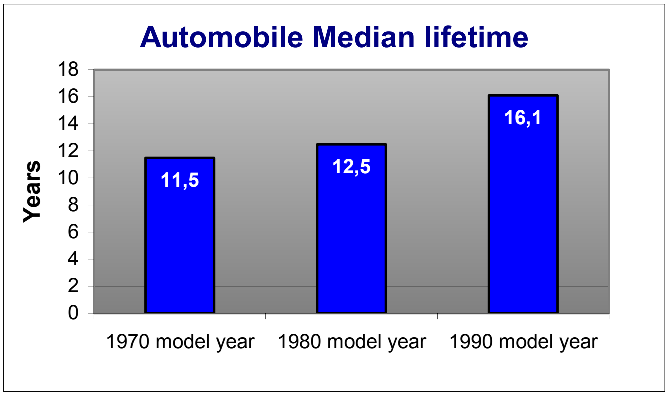
Source: Transportation Energy Data Book, 21

Figure 2.28: Automobile Scrappage Rate – see Table 6.2-18



Source: Transportation Energy Data Book, 21

Figure 2.29: Automobile Medium Lifetime– see Table 6.2-18,



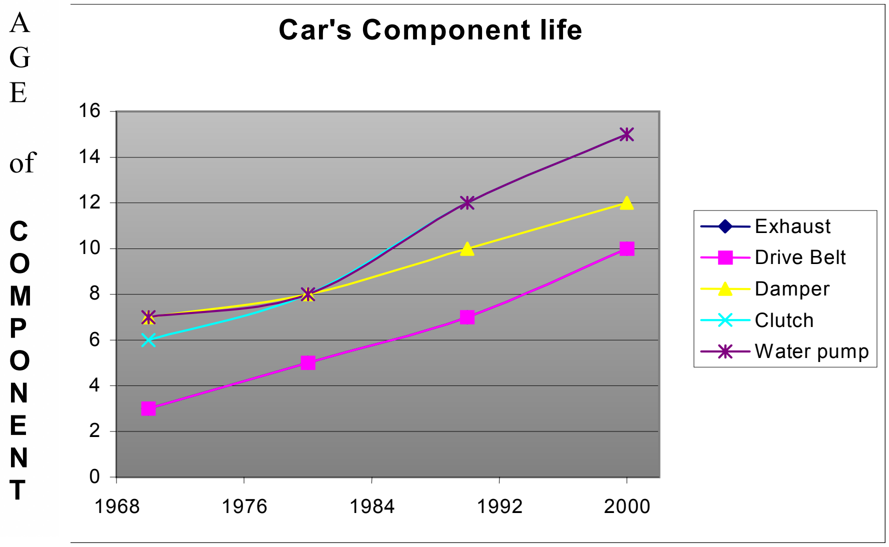
Source: Transportation Energy Data Book, 21

From the Automobile Medium lifetime figure it can be concluded that the automobile lifetime increased in the last three decades from 11.5 to 16.1 years.

Component life

The automotive industry has achieved high improvements in the quality of vehicles and in the durability and reliability of their components and systems. In the next table the life evolution of some specific components from 1970 to now is shown. The dates are in years of life.
The evolution of the component's life gives some clues as to how the automobile lifetime will develop.

Figure 2.30: Car's Component life– see Table 6.2-19

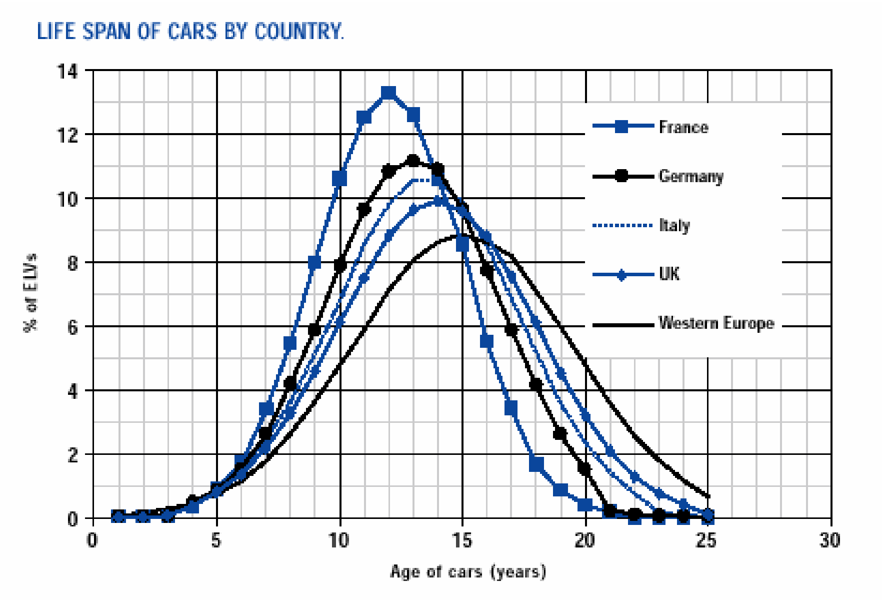


Source: Autopolis, November 2000

2.4.2.2 Automobile lifetime in Europe

The figure below shows the percentage of cars that become waste at a given age. For example, across Western Europe only 1% of end-of-life cars are aged five years, while 8% of end-of-life are cars aged 13 years.
The most important percentage of vehicles are between 10 and 17 years. The average lifetime of European automobiles is in this range.

Figure 2.31: Life Span of Cars by Country



Source: APME, 1999

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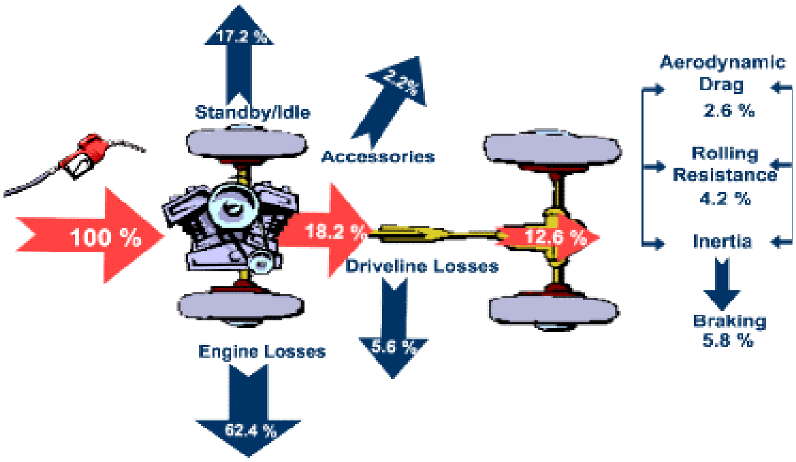
2.5 Fuel economy

2.5.1 Introduction

Only about 15% of the energy in the fuel you put in your fuel tank is used to move your car along the road or run useful accessories such as air conditioning or power steering. The rest of the energy is lost. Because of this the potential to improve fuel economy with advanced technologies is enormous.

Figure 2.32: Schematic overview of the energy flows in automobiles



Source: http://www.fueleconomy.gov/feg/atv.shtml

Motor vehicles need energy to accelerate (overcome inertia), to push the air out of their way (aerodynamic drag) and to overcome the friction from tyres, wheels and axles (rolling resistance). Fuel provides the needed energy in the form of chemicals that can be combusted (oxidised) to release heat. Engines transform heat released in combustion into useful work that ultimately turns the vehicle's wheels, propelling it along the road.

Even modern internal combustion engines convert only one-third of the energy in fuel into useful work. The rest is lost to waste heat, the friction of moving engine parts or to pumping air into and out of the engine. All of the steps at which energy is wasted are opportunities for advanced technologies to increase fuel economy.

The figure above illustrates the paths of energy through a typical gasoline-powered vehicle in city driving. Of the energy content in a litre of gasoline, 62% is lost to engine friction, engine pumping losses and to waste heat. In urban driving, another 17% is lost to idling at stop lights or in traffic. Accessories necessary for the vehicle's operation (e.g. water pump) or for passenger comfort (e.g. air conditioning) take another 2%.

Just over 18% of the energy in gasoline makes it to the transmission. Losses in the drive train to friction and slippage claim more than 5%, leaving something less than 13% to

actually move the vehicle along the road. The laws of physics will not permit all of these losses to be eliminated entirely, but improvements are possible at every step.
The 12.6% of original fuel energy that makes it to the wheels must provide acceleration (5.8%) and overcome aerodynamic drag (2.6%) and rolling resistance. In stop and go city driving it is not surprising that acceleration is the biggest need, rolling is next, followed by aerodynamic drag. On the highway the order is reversed: aerodynamic drag, which increases at an increasing rate with speed requires the most energy (about 10.9%). Each of these final uses of energy also represents an opportunity to improve fuel economy. Substitutions of high strength lightweight materials can reduce vehicle mass and thus the energy required for acceleration. Smoother vehicle shapes have already reduced drag significantly, but further reductions of 20%-30% are possible. Advanced tyre designs can cut rolling resistance.

Since most literature on the subject is found in the USA, many figures on fuel economy are expressed in mpg (miles per gallon), The following table shows the relation between fuel economy [mpg] and fuel consumption [l/100km].

Table 2.5-1: Conversion between mpg and l/100km

Fuel economy mpg	Fuel consumption l/100km
10	23,7
15	15,8
20	11,8
25	9,5
30	7,9
35	6,8
40	5,9
45	5,3
50	4,7

2.5.2 Average fuel economy (per model year) in the USA and the EU

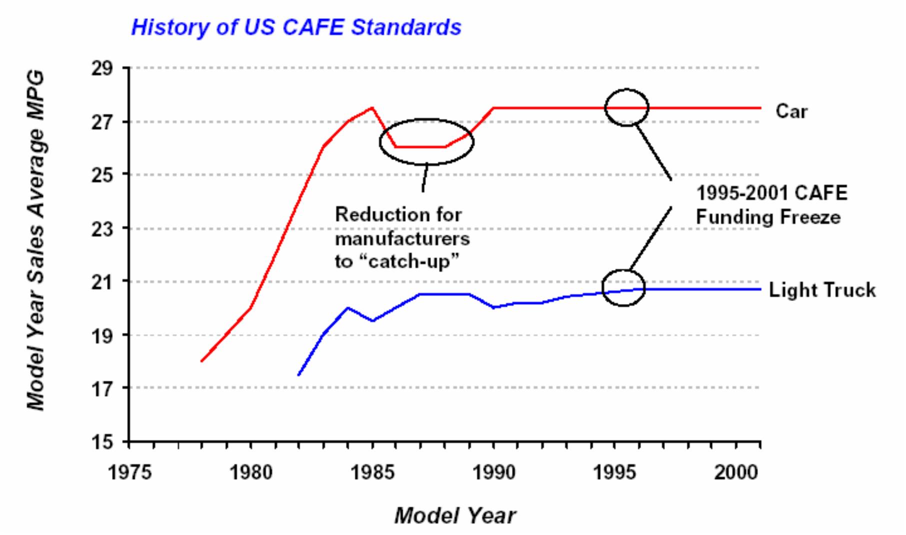
USA

In the USA, Corporate Average Fuel Economy (CAFE) mandates manufacturers to sell a mix of vehicles whose weighted average fuel economy meets specified annual targets.

- Cars and light trucks are evaluated independently.
- Incentives for alternative fuels are in place.
- Failure to comply with this Federal regulation is unlawful.

shows the history of CAFE standards in the USA for cars and light trucks.

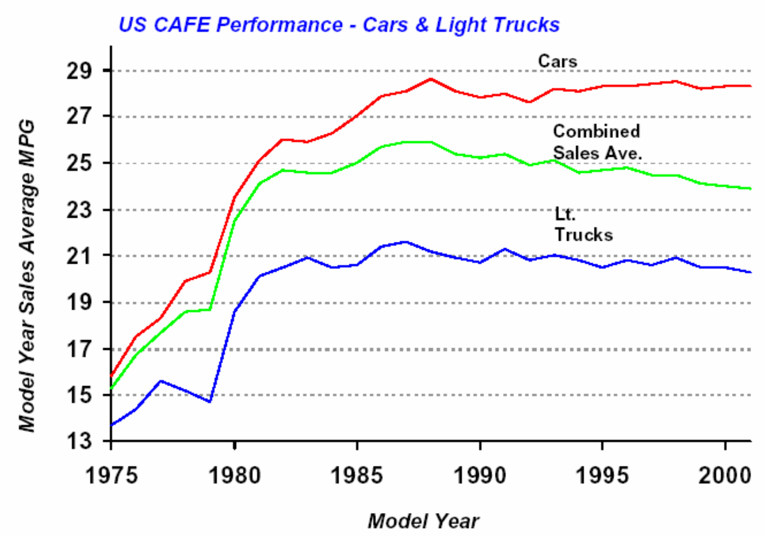
Figure 2.33: History of US CAFÉ Standards



Source: Martec, 2002

Figure 2.33 shows the actual average fuel economy values reached in the USA by car manufacturers. As the CAFE regulations remained unchanged in the past 10 years, there was no incentive for manufacturers to improve fuel economy figures.

Figure 2.34: US CAFE performance



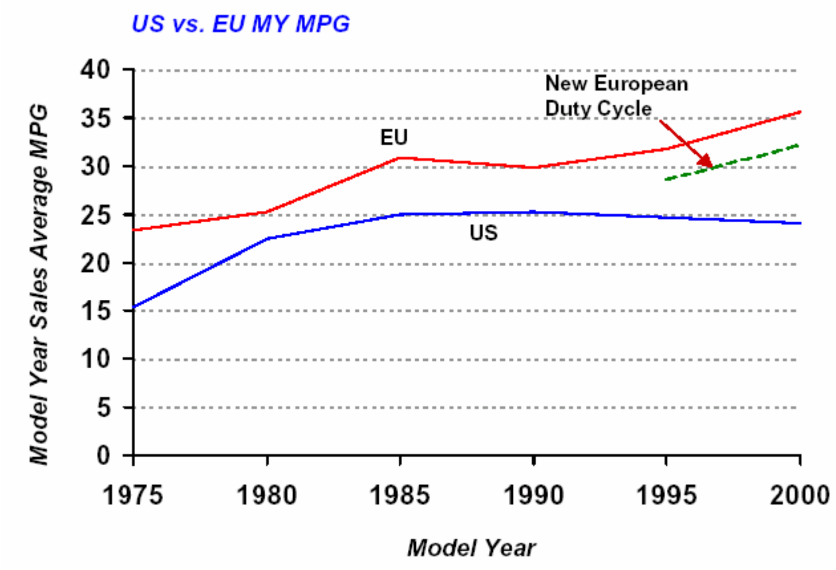
Source: Martec, 2002

European Union

In the EU, there are no federal or national limits on fuel consumption of vehicles manufactured and sold in Europe. Fuel is instead taxed at relatively high levels (compared with the USA) to encourage consumers to purchase and operate vehicles with acceptable fuel economy.

As a consequence, fuel economy figures were seriously better than in the USA.
The fuel consumption figures were obtained from the official certification tests. These results may be very different from real-world fuel consumption. In addition, the test cycles are different in the USA (FTP) and the EU (ECE). The average load in both cycles, however, is comparable, so the tendencies and differences expressed in the following figures should be realistic.

Figure 2.35: USA vs. EU average fuel economy (per model year)



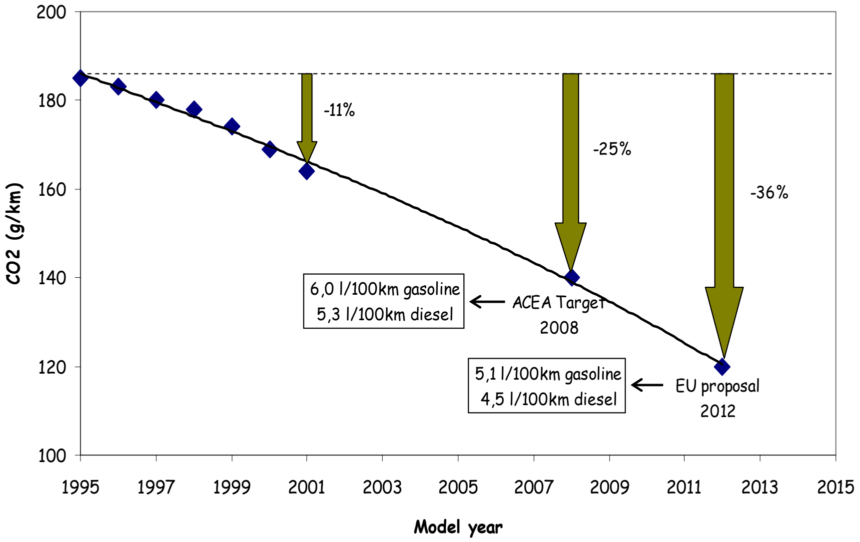
Source: Martec, 2002

The average rated fuel economy for all vehicles sold in the USA has been drifting lower since 1987 as consumers have shifted from cars to SUVs and other light trucks.
The US model year fleet average CAFE peaked in 1987 at 26.2 mpg (cars and light trucks) and has fallen ~6.5% to 23.9 mpg in 2001.

EU average fuel economy climbed steadily from 1975-2000: 1.7% CAGR.
The "pause" in EU fuel economy gains shown from 1985-1990 was due to the introduction of new emission standards, which temporarily curbed fuel economy improvement

In July 1998, the European Automobile Manufacturers Association (ACEA) made a voluntary agreement with the European Commission to reduce CO_2 emissions from new cars by around 25% by 2008 (to an average of no more than 140g CO_2/km). This of course is directly linked to fuel consumption.

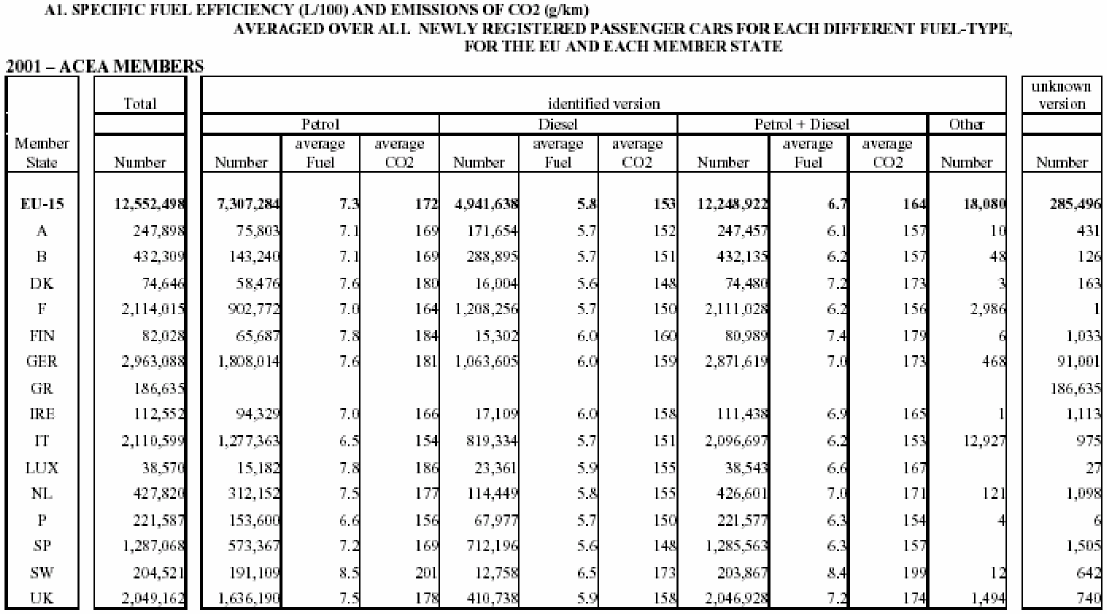
Figure 2.36: ACEA agreement



Source: ACEA, 2002

Over the period 1995 and 2001, new European gasoline cars and new diesel cars reduced their average fuel consumption from 7.9 l/100km to 7.3 l/100km and 6.6 l/100km to 5.8 l/100km, respectively. The average fuel consumption for gasoline and diesel fuelled cars combined fell from 7.6 l/100km (31mpg) to 6.7 l/100km (35mpg) [ACEA, 2002].

Table 2.5-2: Specific fuel consumption and CO_2 emissions of the ACEA newly registered passenger cars in the EU and each EU member state.



A1. SPECIFIC FUEL EFFICIENCY (L/100) AND EMISSIONS OF CO2 (g/km)
AVERAGED OVER ALL NEWLY REGISTERED PASSENGER CARS FOR EACH DIFFERENT FUEL-TYPE, FOR THE EU AND EACH MEMBER STATE

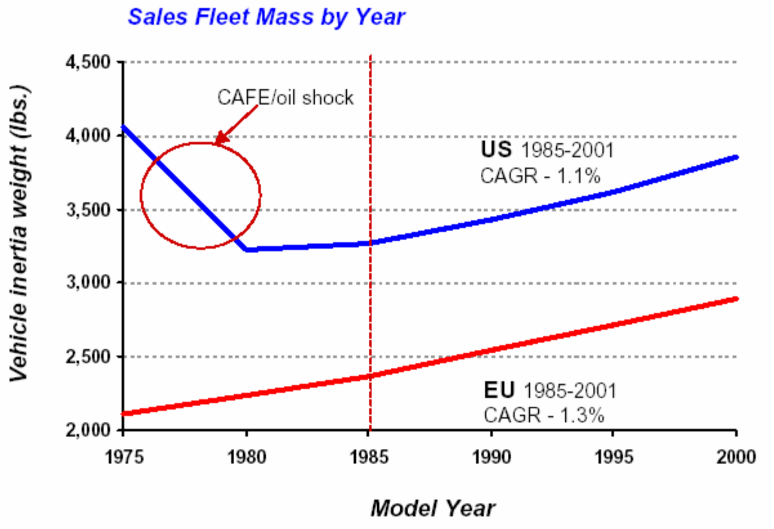
2001 – ACEA MEMBERS

Member State	Total	identified version										unknown version
		Petrol			Diesel			Petrol + Diesel			Other	
	Number	Number	average Fuel	average CO2	Number	average Fuel	average CO2	Number	average Fuel	average CO2	Number	Number
EU-15	**12,552,498**	**7,307,284**	**7.3**	**172**	**4,941,638**	**5.8**	**153**	**12,248,922**	**6.7**	**164**	**18,080**	**285,496**
A	247,898	75,803	7.1	169	171,654	5.7	152	247,457	6.1	157	10	431
B	432,309	143,240	7.1	169	288,895	5.7	151	432,135	6.2	157	48	126
DK	74,646	58,476	7.6	180	16,004	5.6	148	74,480	7.2	173	3	163
F	2,114,015	902,772	7.0	164	1,208,256	5.7	150	2,111,028	6.2	156	2,986	1
FIN	82,028	65,687	7.8	184	15,302	6.0	160	80,989	7.4	179	6	1,033
GER	2,963,088	1,808,014	7.6	181	1,063,605	6.0	159	2,871,619	7.0	173	468	91,001
GR	186,635											186,635
IRE	112,552	94,329	7.0	166	17,109	6.0	158	111,438	6.9	165	1	1,113
IT	2,110,599	1,277,363	6.5	154	819,334	5.7	151	2,096,697	6.2	153	12,927	975
LUX	38,570	15,182	7.8	186	23,361	5.9	155	38,543	6.6	167		27
NL	427,820	312,152	7.5	177	114,449	5.8	155	426,601	7.0	171	121	1,098
P	221,587	153,600	6.6	156	67,977	5.7	150	221,577	6.3	154	4	6
SP	1,287,068	573,367	7.2	169	712,196	5.6	148	1,285,563	6.3	157		1,505
SW	204,521	191,109	8.5	201	12,758	6.5	173	203,867	8.4	199	12	642
UK	2,049,162	1,636,190	7.5	178	410,738	5.9	158	2,046,928	7.2	174	1,494	740

Source: ACEA, 2002

2.5.3 Vehicle mass

Figure 2.37: Average mass of new sold vehicles



Source: Martec, 2002

USA:

- Japanese manufacturers (using smaller-sized vehicles) increased their US car market share from 10% in 1975 to 23% in 1983 primarily due to the high fuel economy of their product offering.
- As the oil shock subsided beyond 1985 (Saudi Arabia increases output 44%), US average vehicle mass began to grow at a 1.1% CAGR (1985-2001)

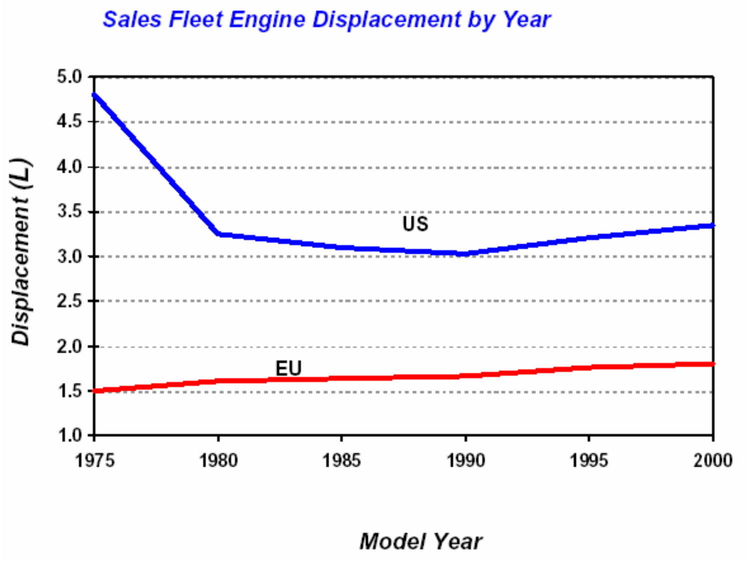
EU:

European vehicle mass has climbed steadily over 25 years from a much lower absolute base. This increase is attributable to such factors as:

- Generally increasing societal affluence; demanding more space and comfort in the vehicle.
- Additional features and functionality included across the vehicle offering, such as air conditioning, air bags, emissions equipment, etc.

2.5.4 Engine displacement

Figure 2.38: Average engine displacement of new sold vehicles



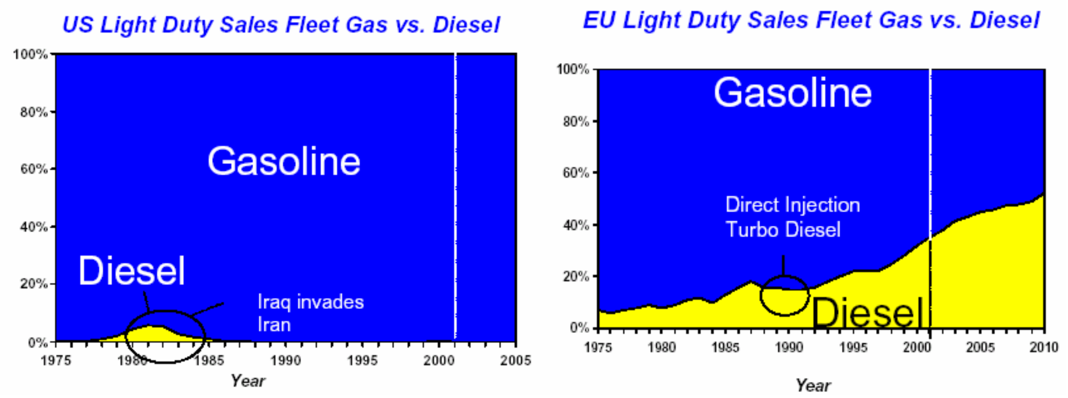
Source: Martec, 2002

In Europe, average engine displacement climbed from ~1.5L in 1975 to ~1.8L in 2000 even as tax increases were used to support the floor on retail pump prices.
As regards the USA, the drop in engine displacement in the 1970s was mainly due to the increase of smaller-sized vehicles from Japan as a result of the oil shock. In the 10-year period from 1980-1990, the decade in which CAFE had the most impact on manufacturers' product offering, average engine displacement fell only moderately.

2.5.5 Diesel sales

Diesel demand in Europe has increased dramatically with the advent of direct injection turbo diesels that give consumers fuel economy + performance comparable with gasoline alternatives. The rising diesel share supports the EU industry's voluntary CO_2 reduction targets.

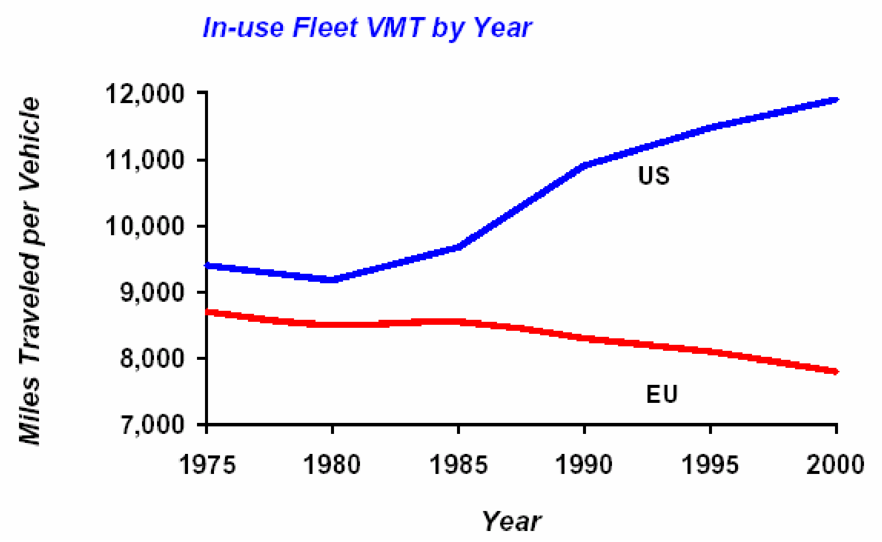
Figure 2.39: Light-duty diesel vehicle vs. gasoline vehicle sales in the USA and the EU



Source: Martec, 2002

2.5.6 Vehicle miles travelled

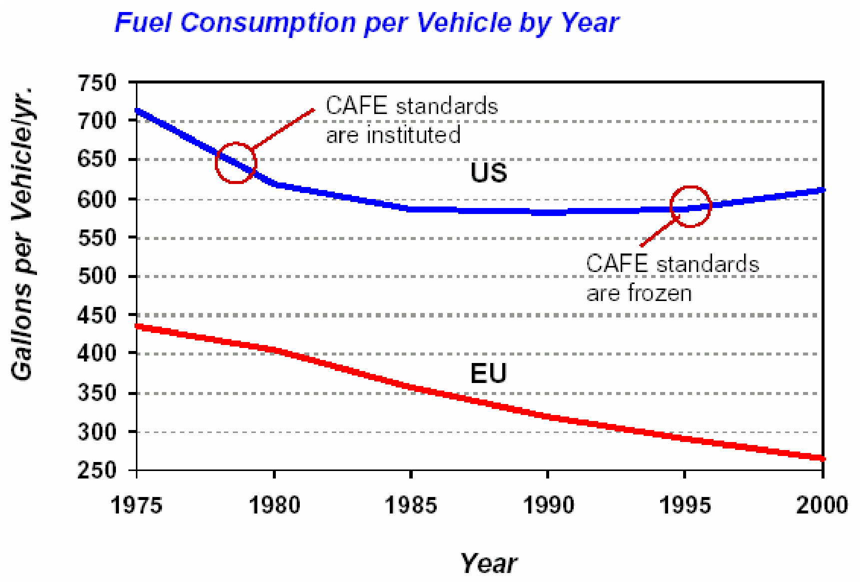
Figure 2.40: In-use fleet vehicle miles travelled by year in USA vs. EU



Source: Martec, 2002

After declining modestly between 1975 and 1980 (post embargo), US miles travelled per light–duty vehicle per year have increased steadily at +1.3% for US light vehicle fleet. European VMT has declined at about a -0.44% rate over the same period as EU governments have increased taxes to maintain high vehicle operating costs.

Figure 2.41: Fuel consumption per vehicle by year in USA vs. EU



Source: Martec, 2002

US consumption per vehicle posted its largest decline during the 1975-1980 period (Shah of Iran falls) as CAFE was being phased in.

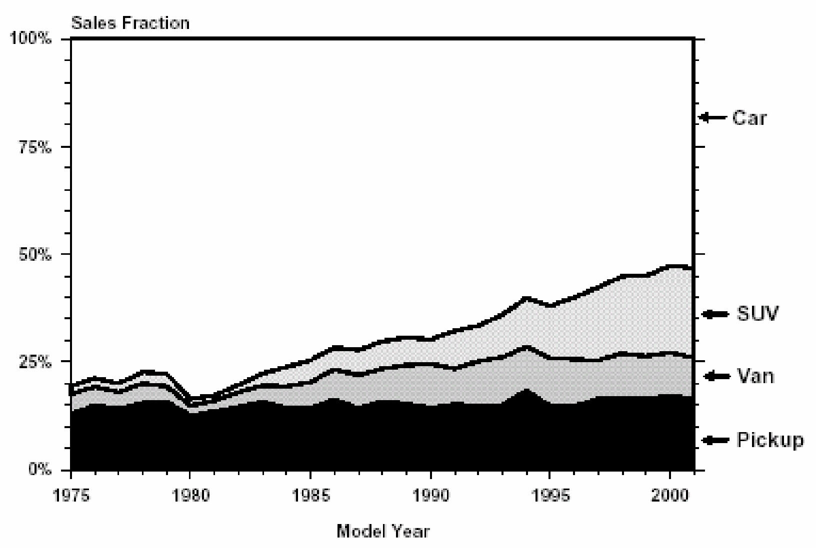
- Gains in US fuel use per vehicle stagnated from 1985 to 1995.
- Fuel use per vehicle has been climbing since 1995, reflecting consumer demand for light trucks and increased VMT/vehicle.
- CAFE has reduced relative vehicle operating costs, encouraging consumers to burn more fuel (recognizing CAFE freeze since 1995).

In Europe, the fuel taxation policy has resulted in a steady decline in fuel use per vehicle:

- High operating costs have successfully encouraged consumers to purchase desired vehicles/technology and to adapt use patterns consistent with the stated policy objectives.
- The policy also meets the EU's objectives for CO_2 emissions by controlling fuel consumption.

2.5.7 Car technology penetrations in the USA

Figure 2.42: Sales fractions by vehicle type in the USA

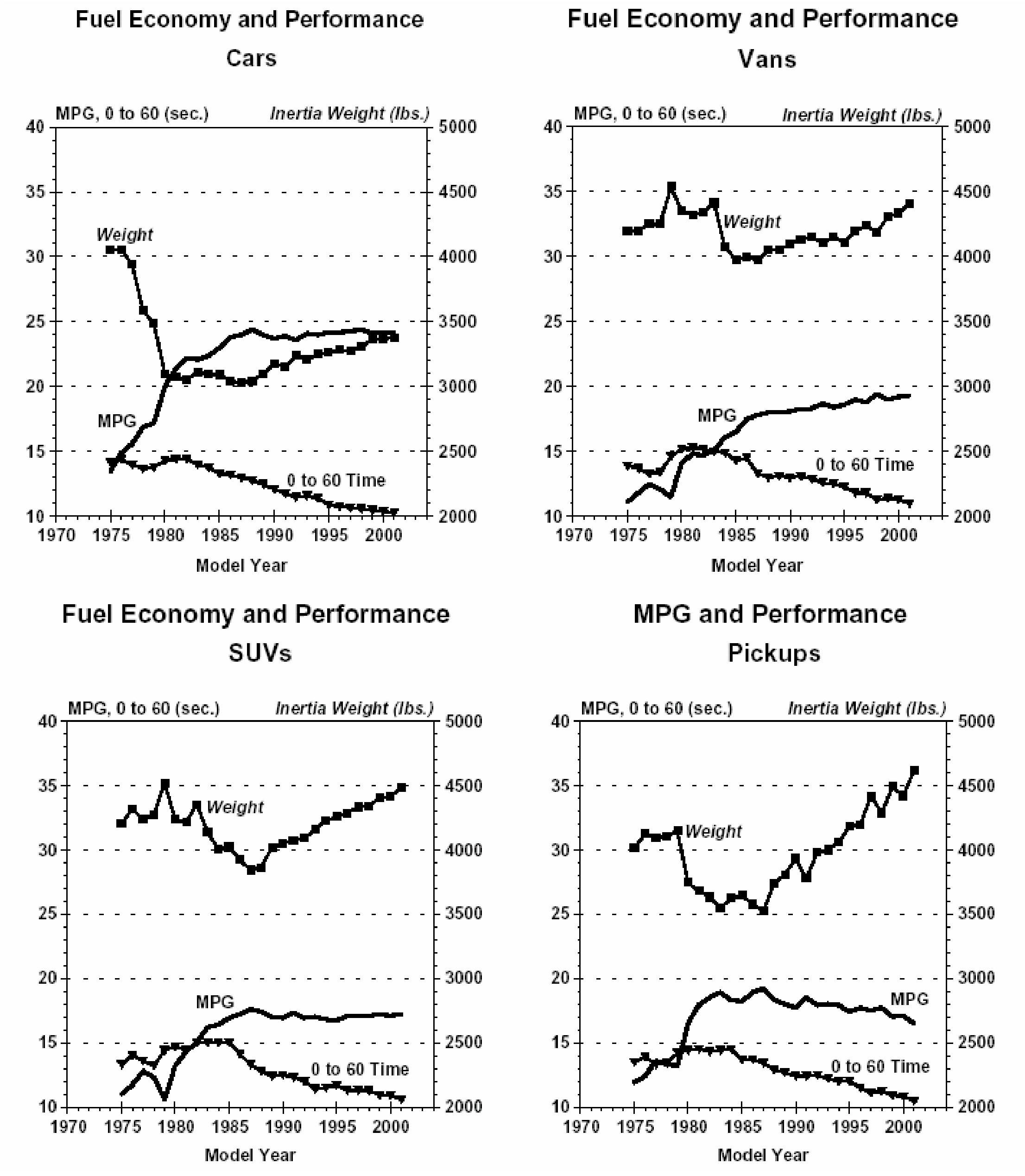


Source: EPA, 2001

It is clear that the sales share of SUVs has been rising steadily. Moreover, from 1980 there is a definite increase in vehicle mass, even per vehicle category.

More efficient technologies - such as engines with more valves and more sophisticated fuel injection systems, and transmissions with lock-up torque converters and extra gears - continue to penetrate the new light vehicle fleet. The trend has clearly been to apply these new technologies to accommodate increases in average new vehicle weight, power and performance while maintaining a constant level of fuel economy. This is reflected by heavier average vehicle weight (up 22% since 1981), rising average horsepower (up 84% since 1981), and lower 0 to 60 mile-per-hour acceleration time (27% faster since 1981).

Figure 2.43: Trends in fuel economy and performance of different vehicle types



Source: EPA, 2001

2.5.8 References

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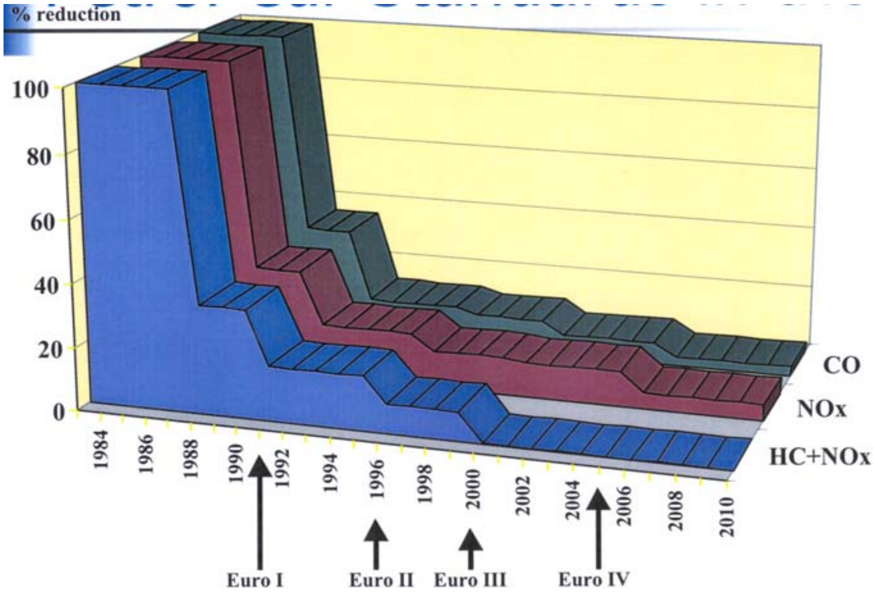
2.6 Trends in emissions

2.6.1 Legislation

Emission factors are related to the emission regulations vehicles must comply with.

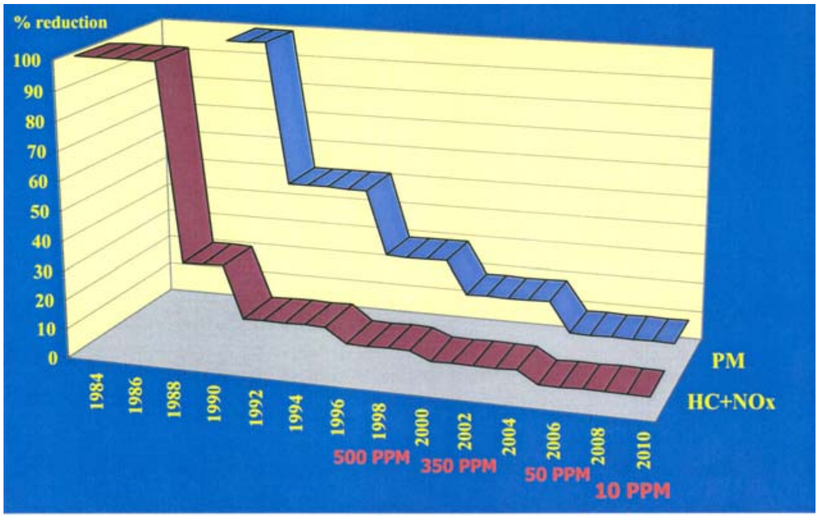
In the past decades regulations have seriously reduced emissions (and will continue to do so). The following figures demonstrate this for gasoline and diesel cars within European legislation.

Figure 2.44: Gasoline car standards in the EU



Source: Walsh, 2002

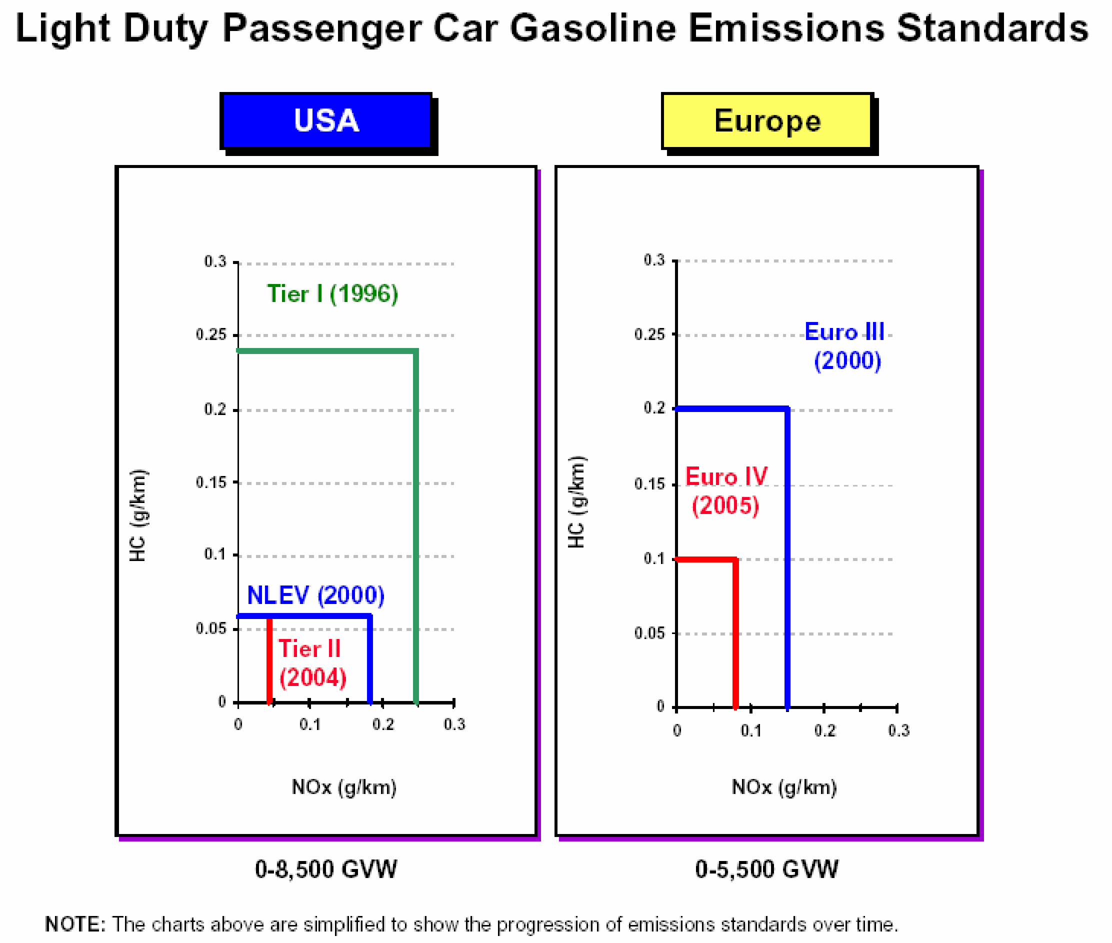
Figure 2.45: Diesel car standards in the EU



Source: Walsh, 2002

Although test cycles in the USA and Europe are different, the following figures give an idea of the comparison of emission standards for NO_x vs. HC for gasoline vehicles and for NO_x vs. PM for diesel vehicles. Generally it can be said that emission regulations are stricter for the USA than for Europe. The emphasis in Europe, however, has been more on a reduction of CO_2 and fuel consumption.

Figure 2.46: Light-duty passenger car gasoline emission standards (HC vs. NO_x)

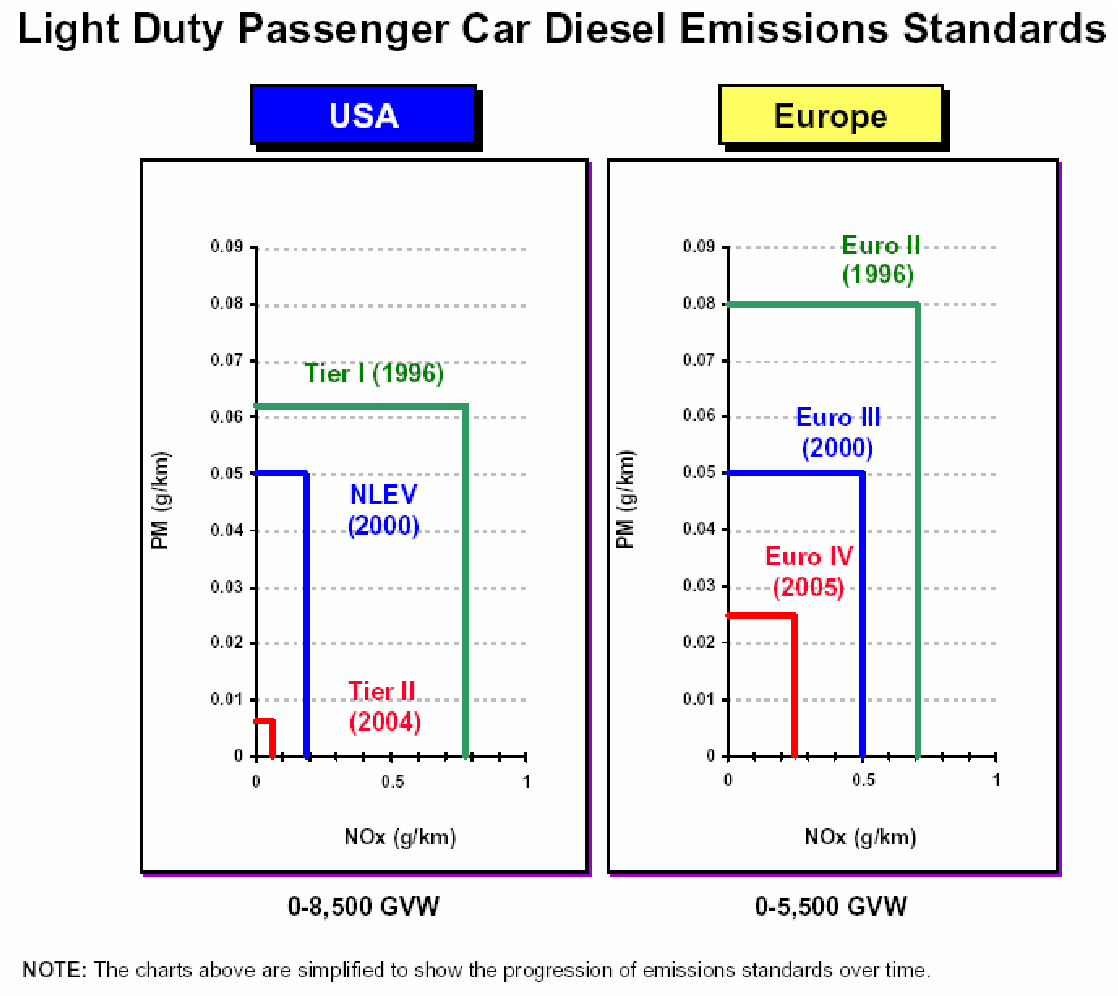


Light Duty Passenger Car Gasoline Emissions Standards

NOTE: The charts above are simplified to show the progression of emissions standards over time.

Source: Martec, 2002

Figure 2.47: Light-duty passenger car diesel emission standards (HC vs. NO$_x$)



NOTE: The charts above are simplified to show the progression of emissions standards over time.

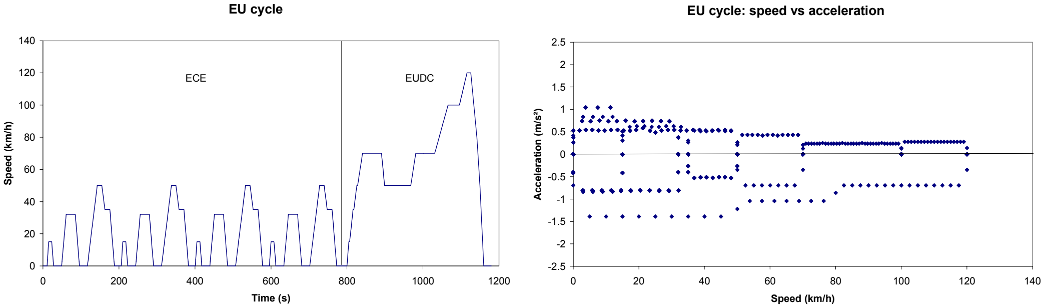
Source: Martec, 2002

2.6.2 Comparison between emissions in regulated test cycles vs real driving

Emission certification tests are a means of comparing the emissions of vehicles and checking if they stay within certain limits. Standard test cycles are used depending on the type of vehicle. For heavy duty vehicles, the engine is usually tested separately on and engine test bench. Light-duty vehicles are mostly tested on a chassis dynamometer according to a predefined test cycle. This test cycle should create repeatable emission measurement conditions and at the same time simulate real driving conditions.
In Europe the ECE15 + EUDC test cycle is used for light-duty vehicles.

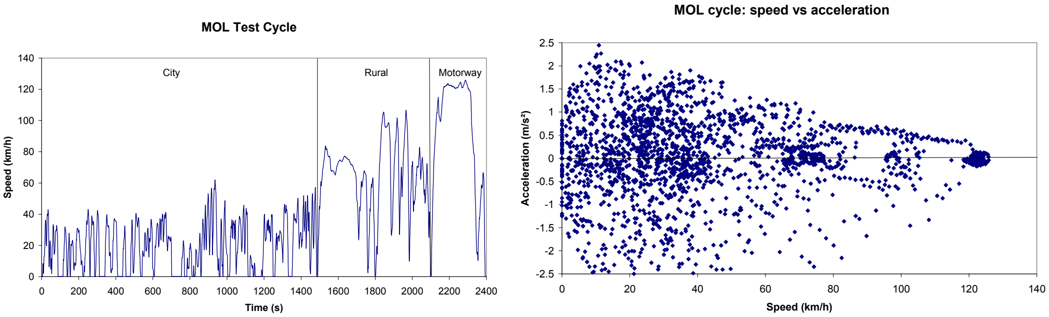
The cycle is often criticised because of its very smooth acceleration profile. The engine reaches a very small area of its operating range and, to fulfil the emission test, engine manufacturers only have to focus on these zones. The following figures show the difference between the EU cycle and a test cycle based on real-world driving. It is immediately clear that, although the base vehicle (which was recorded in real driving) was certainly not very powerful, the accelerations in the real-traffic-based cycle are much higher than in the EU cycle, especially in city traffic.

Figure 2.48: ECE15 – EUDC cycle



Source: Pelkmans, 2002

Figure 2.49: Real-world-traffic based test cycle (‘Mol cycle’)



Source: Pelkmans, 2002

Within the EC funded project ‘DECADE’, three typical vehicles were tested to compare the emission results in various circumstances [Pelkmans, 2002].

The following tables show the difference in fuel consumption and emissions between the EU test cycle and a real-world based test cycle (Mol cycle).

Table 2.6-1: Chassis dynamometer measurements on diesel delivery van, Citroen Jumper 2.5D (Euro 2 certified, simulated weight: 1800 kg)

CITROEN JUMPER		**EU cycle**		**MOL cycle**		
		ECE	**EUDC**	**City**	**Rural**	**Motorway**
Speed	**km/h**	18.4	61.8	19.4	62.0	92.2
RPA	**m/s²**	0.17	0.10	0.40	0.25	0.13
Fuel consumption	**l/100km**	12.4	9.4	13.5	10.4	13.4
CO_2	**g/km**	323	247	353	272	350
CO	**g/km**	0.007	0.009	0.007	0.011	0.030
NO_x	**g/km**	1.17	0.80	1.27	0.80	1.34
THC	**g/km**	0.012	0.010	0.020	0.018	0.015
PM	**g/km**	0.10	0.14	0.24	0.27	0.20

Source: Pelkmans, 2002

Table 2.6-2: Chassis dynamometer measurements on diesel family car, Skoda Octavia 1.9 TDi (Euro 3 certified, simulated weight: 1350 kg)

SKODA OCTAVIA 1.9 TDi		**EU cycle**		**MOL cycle**		
		ECE	**EUDC**	**City**	**Rural**	**Motorway**
Speed	**km/h**	18.8	61.9	19.4	62.8	92.6
RPA	**m/s²**	0.16	0.10	0.38	0.25	0.14
Fuel consumption	**l/100km**	6.6	4.9	8.1	5.6	6.5
CO_2	**g/km**	173	129	211	147	170
CO	**g/km**	0.012	0.008	0.049	0.012	0.013
NO_x	**g/km**	0.62	0.42	1.02	0.92	0.99
THC	**g/km**	0.027	0.010	0.021	0.008	0.006
PM	**g/km**	0.06	0.08	0.08	0.08	0.18

Source: Pelkmans, 2002

Table 2.6-3: Chassis dynamometer measurements on small gasoline car, VW Polo 1.4 (Euro 4 certified, simulated weight: 1050 kg)

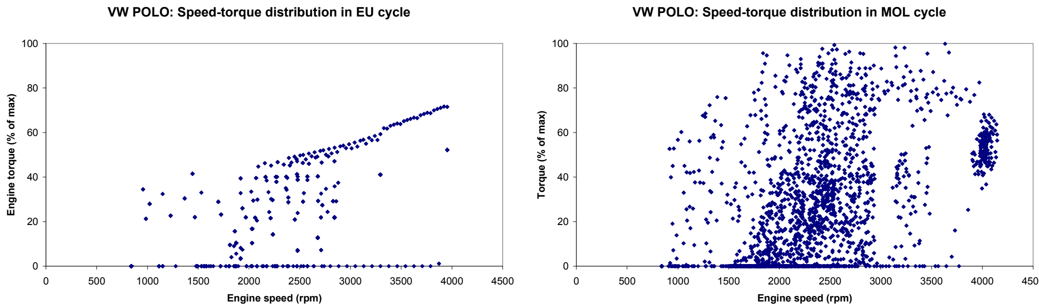
VW POLO 1.4		**EU cycle**		**MOL cycle**		
		ECE	**EUDC**	**City**	**Rural**	**Motorway**
Speed	**km/h**	18.5	61.8	19.2	62.6	93.7
RPA	**m/s²**	0.16	0.10	0.40	0.26	0.14
Fuel consumption	**l/100km**	8.5	6.1	10.6	6.9	7.6
CO_2	**g/km**	202	143	250	163	179
CO	**g/km**	0.003	0.039	0.071	0.479	0.579
NO_x	**g/km**	0.025	0.007	0.350	0.123	0.050
THC	**g/km**	0.004	0.002	0.005	0.008	0.010

Source: Pelkmans, 2002

It is remarkable that the differences are quite moderate for the Euro 2 certified diesel van (only PM has a significant increase in the real-world based cycle), while for the Euro 3 and the Euro 4 certified vehicles the difference tends to rise, particularly for NO_x and CO.

Most of the difference has to do with the specific speed-torque distribution in the test cycle. This is illustrated in the following figures.

Figure 2.50: Speed-torque distribution in EU cycle vs MOL cycle



Source: Pelkmans, 2002

The results show that the emission levels measured during the official EU cycle can be very different from the emissions produced in real traffic. The EU cycle seems too smooth to be realistic and vehicle manufacturers only have to focus on limited engine operating zones to obtain low emissions on this cycle. In practice, real-world emissions can be substantially higher. It turned out that a new vehicle, which already complies with the future EURO 4 limits, may reach 10 times higher emissions for CO and NO_x in real traffic.

One should therefore be careful when using the official emission and fuel consumption figures from the EU cycle.

2.6.3 Emission factors – the MEET project

The COST 319 action "Estimation of pollutant emissions from transport" involved co-operation between some one hundred European researchers between 1993 and 1998. These were the objectives of the MEET-project (*Methodologies for Estimating Air Pollutant Emissions from Transport)*:

- To provide a set of data and models, allowing various users of the project to calculate the pollutant emissions and the fuel or energy consumption of the various transport modes at strategic level.
- To provide a comprehensive method of calculation using the set of data and models.
- To make sure that this comprehensive method corresponds to the requirements of the potential users in terms of accuracy, simplicity and input data availability.

The results are described in Joumard, 1999.
(http://www.inrets.fr/infos/cost319/C319finalreport.pdf).

Numerous emission models have been developed to assess emissions from transportation as a function of explanatory variables. Emission modelling focuses mainly on hot emissions, but specific methodologies can be proposed to take into account cold-start emissions, evaporative emissions, and the influence of road gradient or load factor. Most of these elements are found in the COPERT II methodology [Ahlvik *et al.*, 1997] and the German-Swiss model [Hassel *et al.*, 1994; Keller *et al.*, 1995].

2.6.4 Application of emission factors to the UK situation

The application of these various emission factors to a country's situation depends on the traffic distribution (fleet composition, annual mileage, mileage distribution and representative speeds).

The following tables show an overview of the UK emission factors:

Table 2.6-4: Fuel consumption factors (g fuel/km) in the UK, Factors based on 1998 speed-emission functions, averaged over distribution of engine sizes/vehicle weights in UK fleet

FUEL (g/km)

		Urban	**Rural single carriage way**	**Rural dual carriage way**	**Motorway**
GASOLINE CARS	Pre-ECE	79.5	61.7	62.2	77.1
	ECE 15.00	68.3	50.8	49.4	62.8
	ECE 15.01	68.3	50.8	49.4	62.8
	ECE 15.02	63.0	49.7	50.0	64.9
	ECE 15.03	63.0	49.7	50.0	64.9
	ECE 15.04	55.9	44.4	47.0	58.2
	Euro I	62.9	48.9	47.4	74.9
	Euro II	62.9	48.9	47.4	74.9
DIESEL CARS	Pre-Euro I	61.6	45.7	41.4	64.0
	Euro I	46.7	35.0	29.2	37.2
	Euro II	46.7	35.0	29.2	37.2

Source: NAEI, 1999

Table 2.6-5: HC Emission factors for cars in the UK (in g/km). Factors based on 2002 speed-emission functions, with typical UK representative speeds

HC (g/km)

		Urban	**Rural**	**Motorway**
GASOLINE CARS	Pre-Euro I	1,473	0,922	0,789
	Euro I	0,082	0,066	0,159
	Euro II	0,065	0,046	0,047
	Euro III	0,045	0,032	0,033
	Euro IV	0,034	0,024	0,025
DIESEL CARS	Pre-Euro I	0,147	0,087	0,061
	Euro I	0,075	0,046	0,039
	Euro II	0,061	0,030	0,025
	Euro III	0,043	0,021	0,017
	Euro IV	0,039	0,020	0,016

Source: AEI, 2002

Table 2.6-6: NO_x Emission factors for cars in the UK (in g/km). Factors based on 2002 speed-emission functions, with typical UK representative speeds

NO_x (g/km)

		Urban	Rural	Motorway
GASOLINE CARS	ECE 15.04	1,635	2,206	3,159
	Euro I	0,249	0,365	0,660
	Euro II	0,227	0,243	0,368
	Euro III	0,136	0,146	0,221
	Euro IV	0,073	0,078	0,118
DIESEL CARS	Pre-Euro I	0,616	0,566	0,714
	Euro I	0,523	0,460	0,686
	Euro II	0,540	0,499	0,807
	Euro III	0,540	0,499	0,807
	Euro IV	0,270	0,250	0,403

Source: NAEI, 2002

Table 2.6-7: CO Emission factors for cars in the UK (in g/km). Factors based on 2002 speed-emission functions, with typical UK representative speeds

CO (g/km)

		Urban	Rural	Motorway
GASOLINE CARS	Pre-Euro I	9,837	6,255	7,537
	Euro I	1,406	1,401	4,142
	Euro II	0,983	0,726	0,607
	Euro III	0,885	0,654	0,546
	Euro IV	0,590	0,436	0,364
DIESEL CARS	Pre-Euro I	0,665	0,453	0,421
	Euro I	0,282	0,152	0,205
	Euro II	0,240	0,073	0,073
	Euro III	0,144	0,044	0,044
	Euro IV	0,144	0,044	0,044

Source: NAEI, 2002

Table 2.6-8: PM_{10} Emission factors for cars in the UK (in g/km). Factors based on 2002 speed-emission functions, with typical UK representative speeds

PM_{10} (g/km)		**Urban**	**Rural**	**Motorway**
GASOLINE CARS	Pre-Euro I	0,0235	0,0149	0,0180
	Euro I	0,0029	0,0040	0,0088
	Euro II	0,0007	0,0013	0,0053
	Euro III	0,0007	0,0013	0,0053
	Euro IV	0,0007	0,0013	0,0053
DIESEL CARS	Pre-Euro I	0,171	0,148	0,188
	Euro I	0,064	0,055	0,086
	Euro II	0,057	0,041	0,063
	Euro III	0,040	0,028	0,044
	Euro IV	0,020	0,014	0,022

Source: NAEI, 2002

2.6.5 Degradation of pollution controls

In the case of conventional spark-ignition and diesel vehicles, the emission behaviour generally deteriorates within a service interval. The emission level can, however, be restored to approximately that of a new vehicle by adjustment and maintenance or by the correction of defects, whatever the mileage. Because of this, no deterioration of the emission figures as a function of vehicle mileage is quoted in the case of conventional spark-ignition and diesel vehicles. The generally poorer maintenance condition of older vehicles does have the effect of increasing emissions but this is ignored.

Closed-loop catalyst vehicles

In the case of catalyst vehicles, however, an unavoidable deterioration in the degree of conversion by the catalyst (due to thermal ageing and contamination) leads to an increase in emission with increasing mileage. Defects, setting errors and lack of maintenance are superimposed, in practical operation, on the physically determined reduction in the degree of conversion. In contrast to conventional spark-ignition vehicles, however, the new condition emission level cannot be restored at higher mileage even after faults have been corrected, unless a replacement catalyst is fitted.

European and American legislation demands evidence that the emission standards will not be exceeded up to a mileage of 80,000 km. The manufacturer has the possibility of demonstrating observance of this regulation, as part of the type testing, by an exactly defined 80,000 km endurance test in which emission measurements are carried out at intervals of 10,000 km. The so-called deterioration factor is determined by using regression analysis. This is defined as the quotient of the emission at 80,000 km and that in the new condition. The deterioration factors determined in this way on individual vehicles in type approval tests are not, however, suitable for estimating the deterioration of the emissions of the closed loop catalyst cars. This is because the type testing procedure does not reflect, or does not representatively reflect, for example, the driving behaviour, state of maintenance and cold starting procedures.

In order to achieve this objective, one possibility is to determine the statistical relationship between emission and mileage by using regression analysis on the basis of a sufficiently large vehicle population. In Europe such an investigation was conducted in the German / Swiss Emission Factor Programme. It was deduced that a regression analysis on the basis of the US-Test-75 realistically reflects the influence of vehicle mileage on emission behaviour.

A further analysis has been conducted using the larger international data set available to the MEET project. Because it was necessary to include as many data as possible, for vehicles in a wide range of mileage classes, results from legislative test cycles (EC Urban and EUDC) were used. For real-world cycles, data for vehicles in some mileage classes are very few. The analysis confirmed a systematic degradation of emissions with increasing mileage for CO, HC and NO_x, but CO_2 emissions (and therefore fuel consumption) remained stable.

Three phases of the degradation process were identified:

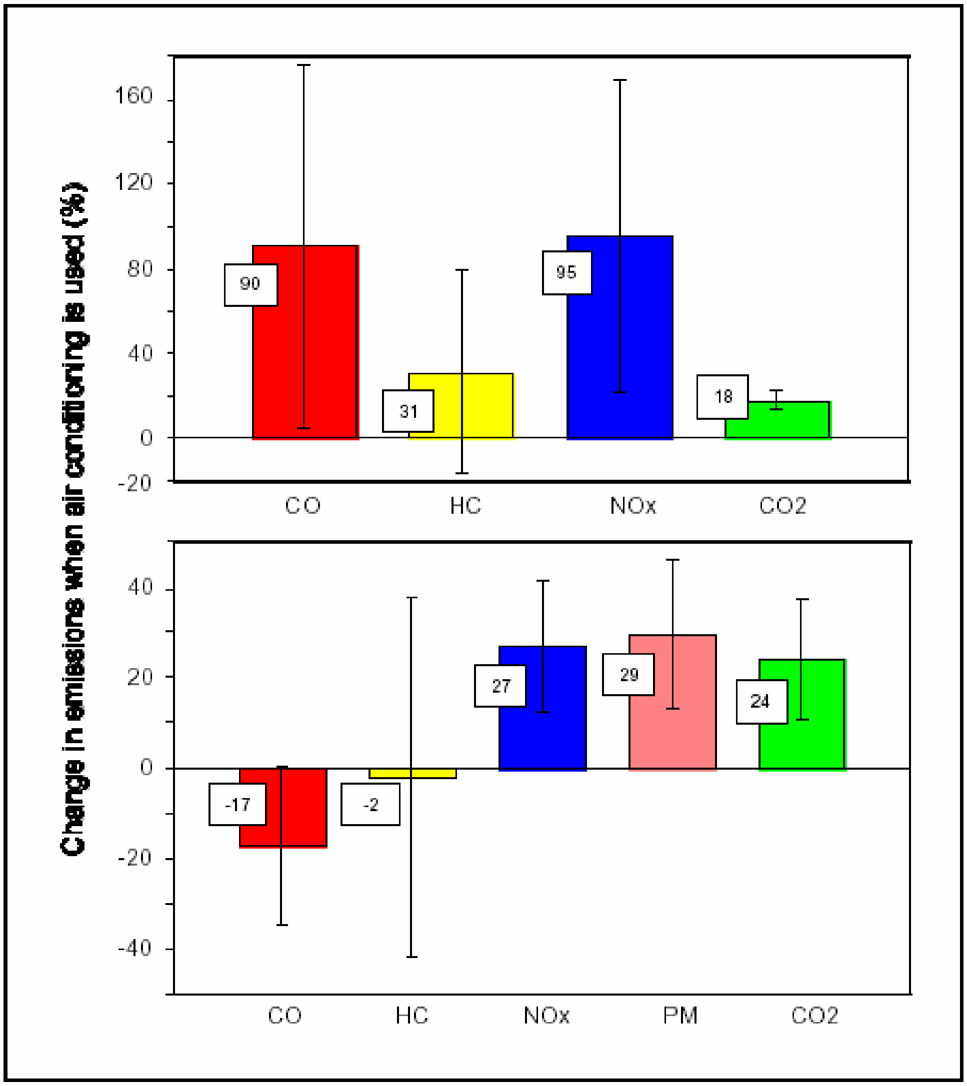
- *The running-in phase (0 - 10,000 km)*: Even relatively new vehicles show an emission deterioration, but emission levels during this period remain low.
- *The middle phase (10,000 - 100,000 km)*: Degradation continues during this phase, at about the same rate, and emissions eventually reach quite high levels.
- *The final phase (> 100,000 km):* Emissions of very high mileage vehicles seem to stabilise.

This may be because of the need to repair or replace the emission control system on high mileage vehicles, though it should be noted that there are very few data for this phase, and the finding is uncertain.

2.6.6 Air conditioning

There is an increasing tendency for passenger cars to be equipped with air conditioning systems. When the air conditioning is in use, it imposes an increased load on the engine, with consequential effects on fuel consumption and emissions. Tests have been conducted by ADEME and UTAC to compare emissions and fuel consumption on a range of diesel and three-way catalyst cars. The two sets of tests were carried out somewhat differently, but because of the relatively small sample of cars and the variability of the results, no systematic differences were apparent: they have therefore been considered together. Figure 2.51 shows the surplus of emissions caused by air conditioning, the average variation in emissions and the 95% confidence intervals for the two types of vehicle over the range of regulated pollutants.

Figure 2.51: Effects of air conditioning on emissions from gasoline (top) and diesel cars



Source: Hickman, 1999

For the gasoline cars, all emissions increase on average, though there is considerable uncertainty except for CO_2, where there is a statistically significant increase of almost 20%. The diesels showed significant increases for NO_x, PM and CO_2, of 20 to 30%, but decreases (not statistically significant) for CO and HC. Thus, it is clear that the use of air conditioning increases fuel consumption (indicated by the CO_2 results), while effects on other emissions depend on the combustion efficiency of the engine under the higher load and may, in some cases, decrease. There remain too many uncertainties to be able to propose quantitative factors to correct for the use of air conditioning systems: the data relate only to a single legislative cycle (the European test cycle), and they are from a small number of tests. Similarly, the operational data needed to evaluate this effect are not available: the frequency and level of use of air conditioning systems is not known.

2.6.7 Cold start emissions

During cold start and during the time the engine is heating up, excess emissions are produced compared to hot engine conditions. These excess emissions create some kind of penalty (expressed in grams), which is to be counted for every engine start.

Excess start emissions are an important part in an emission inventory model for two principal reasons. Firstly, the average trip length of passenger cars in Europe is about 5 to 8 km [Laurikko *et al.*, 1995; André *et al.*, 1999], whereas urban trips are even shorter (2 to 4 km). Consequently, a high proportion of mileage is driven under cold start conditions.
Secondly, the engine temperature affects the emission rate, and the ratio of cold start emissions to hot start emissions has been shown to vary between around 1 and 16 according to the vehicle technology, the pollutant, and other parameters [Joumard *et al.*, 1995b].

The reference value for the excess emission in MEET was defined to be the amount produced at an average speed of 20 km/h with a start temperature of 20°C, and over a trip long enough for the engine to reach its fully warmed-up condition.
Functions were derived by which the reference value could be corrected for the *actual start temperature* and *average speed* and also for the *distance travelled* (some trips are shorter than the distance needed fully to warm up the engine, and on those trips, the total excess emission is not produced).

Table 2.6-9: Reference excess cold-start emission at 20°C and 20 km/h

Technology	**Pollutant (g)**				
	CO_2	**CO**	**HC**	**NO_x**	**Fuel Cons.**
Gasoline cars without catalyst	144	63.5	8.2	-0.3	84
Diesel cars without catalyst	183	2.2	0.8	0.06	63
Gasoline cars with catalyst	132	28.7	4.6	1.8	60
Diesel cars with catalyst	153	0.7	0.6	0.03	55

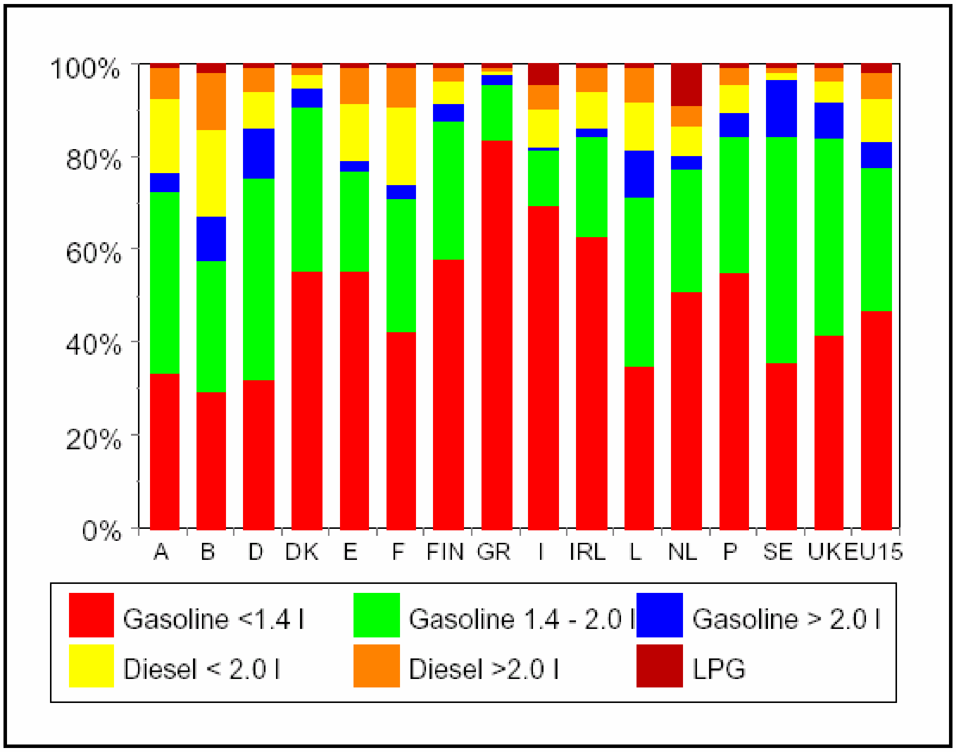
Source: Hickman, 1999

In some cases, assessing start-related excess emissions for a single trip is sufficient, but it is more often required to calculate excess emissions for the whole traffic characterised by a number of general parameters such as vehicle flow, average speed and environmental conditions (time of day, week, year, temperature). The formulae initially applied to a single trip must be extended to the whole traffic using available statistical data relating to characteristic traffic parameters [Hickman, 1999].

2.6.8 Passenger car fleet distribution

Figure 2.52 shows the 1995 passenger car fleet broken down by fuel type and engine capacity, for each EU 15 Member State. It is clear that the great majority of cars have gasoline engines smaller than 2.0 l. Diesel cars were around 15% on average in 1995, while LPG vehicles have a significant presence only in Italy and the Netherlands.

Figure 2.52: Passenger car fleet distribution (1995 data) for EU 15.



Source: Hickman, 1999

The distribution of the vehicles within the various emission categories is closely related to their age (since the various emission standards were introduced on a fixed time scale in most

Member States). The average age of passenger cars is between seven and eight years, but there are again variations from country to country: the oldest cars are in Finland where the average age is about 11 years, while the youngest fleet is in Luxembourg, with an average age of about four years [Hickman, 1999].

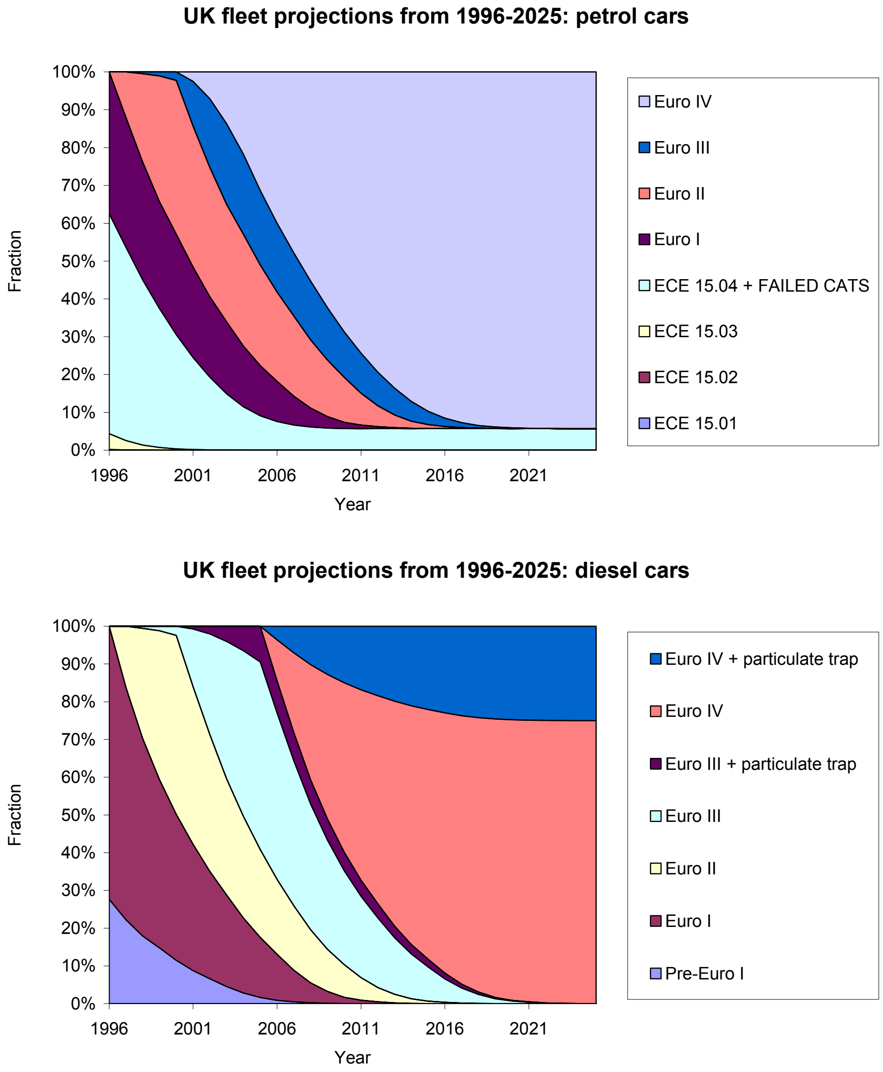
Table 2.6-10: Fleet composition of passenger cars in the EU15

Fuel	Size	Emission class	1990	1995	2000	2005	2010	2015
Gasoline	< 1,4 l	Pre ECE	1021070	86255	17607	1286	0	0
		ECE 15-00/01	6475731	2512760	643928	142382	0	0
		ECE 15-02	8223269	3408434	1213514	243321	43135	0
		ECE 15-03	16358551	10786820	4315452	1327218	289594	33918
		ECE 15-04	28129882	25727216	18008216	9087375	3026898	590933
		Improved conventional	2622375	2775255	1445294	78331	392	0
		Open loop	1163049	1283641	741714	54718	10126	7546
		EURO 1	2046401	29757551	27797214	18670060	7945842	2591545
		EURO 2	0	0	30129786	28534721	20022398	8364965
		EURO 3	0	0	0	26547831	24903256	16910963
		EURO 4	0	0	0	6843364	41505927	74614254
	1,4 - 2,0 l	Pre ECE	299931	23281	3997	185	0	0
		ECE 15-00/01	2505609	803620	201438	38319	0	0
		ECE 15-02	5085304	1321898	396362	83725	11049	0
		ECE 15-03	11108954	6488579	1481161	439587	94230	4886
		ECE 15-04	16671074	14900369	8504923	3137095	1014124	199003
		Improved conventional	881557	975838	515072	15741	64	0
		Open loop	1105784	1176860	572818	37405	1791	1086
		EURO 1	4632960	24711765	21663290	11389737	2777916	757541
		EURO 2	0	0	21824563	20404085	12466365	2985261
		EURO 3	0	0	0	19017002	17548321	9823400
		EURO 4	0	0	0	4850665	29097586	52224126
	> 2,0 l	Pre ECE	38541	3083	619	33	0	0
		ECE 15-00/01	336379	104849	29232	5703	0	0
		ECE 15-02	869685	179605	54579	12400	1658	0
		ECE 15-03	1984944	1122457	196033	63742	13936	873
		ECE 15-04	2524515	2235188	1130907	395188	143548	28795
		EURO 1	1686907	5513757	4520158	2026585	366907	101126
		EURO 2	0	0	4084022	3799462	2198947	394415
		EURO 3	0	0	0	3565536	3270165	1705738
		EURO 4	0	0	0	908011	5418393	9710936
Diesel	< 2,0 l	Uncontrolled	7246304	4504625	1463252	354876	50317	5092
		EURO 1	4356769	10400150	9749753	5511770	1826876	418300
		EURO 2	0	0	5063975	4811714	3311837	1054474
		EURO 3	0	0	0	5425605	5005611	3023927
		EURO 4	0	0	0	1389559	8323444	14830483
	> 2,0 l	Uncontrolled	4536862	2813680	937427	235964	33546	3396
		EURO 1	2732163	6456915	6060376	3452626	1175107	278194
		EURO 2	0	0	3145670	2989941	2061771	676292
		EURO 3	0	0	0	3374939	3115316	1888370
		EURO 4	0	0	0	86493	5185689	9244458
LPG	All	Uncontrolled	1053661	681970	343189	99895	9086	274
		EURO 1	537735	1112665	1118167	822338	413449	111011
		EURO 2	0	0	523962	508012	421499	247703
		EURO 3	0	0	0	580073	553674	437546
		EURO 4	0	0	0	150596	915251	1638171
2-stroke	All	Uncontrolled	5300	6218	7088	7908	8665	9349

Source: Hickman, 1999

The UK National Atmospheric Emissions Inventory (NAEI) also calculated fleet projections for passenger cars in the UK (divided into emission legislation categories) up to 2025. The following figures illustrate the results.

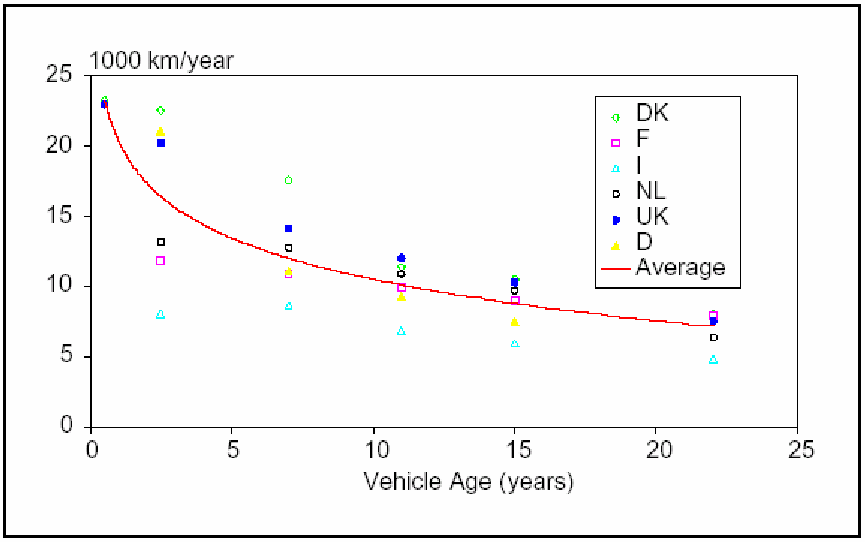
Figure 2.53: Fractions of emissions categories within diesel and gasoline cars in the UK (projections up to 2025)



Source: NAEI, 2002

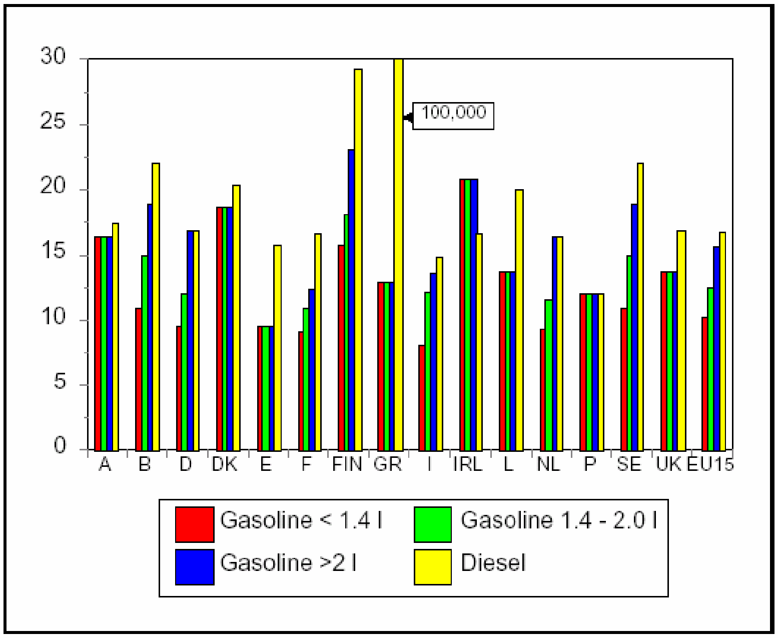
Many of the vehicle attributes (size, age, fuel etc.) are related to the way they are used, and this is reflected in their typical annual mileage. For passenger cars, there is a general tendency for newer cars, cars with larger engines and diesel cars to be driven greater annual distances. Figure 2.54 shows the relationship with age for six Member States, and Figure 2.55 shows the relationship with engine size and fuel for the EU15.

Figure 2.54: Annual mileage as a function of passenger car age (1990 data)



Source: Hickman, 1999

*Figure 2.55: Relation between engine type/size and the annual mileage (*1000) of passenger cars in EU 15 (1995 data)*



Source: Hickman, 1999

To obtain typical emission figures, the number of vehicles should be combined with the annual mileage of each vehicle type, the average mileage distribution between urban, rural and highway traffic and representative speeds in each of these traffic types. The following table shows typical values for the EU15.

Table 2.6-11: Annual mileage, mileage distribution and representative speeds for passenger cars in the EU15 (Reference year 1995)

Fuel	Size	Emission class	Annual Mileage (km)	Mileage distrib. (%)			Repres. Vehicle speed (km/h)		
				Urban	Rural	HWay	Urban	Rural	HWay
Gasoline	< 1,4 l	Pre ECE	7495	44	42	14	21	59	91
		ECE 15-00/01	6977	43	42	15	22	59	94
		ECE 15-02	7060	42	43	15	24	65	98
		ECE 15-03	8501	41	43	16	26	71	103
		ECE 15-04	9543	38	46	16	25	70	103
		Improved conventional	8709	36	38	26	34	71	105
		Open loop	9011	37	39	24	36	74	105
		EURO 1	11810	37	44	19	28	71	103
		EURO 2	11810	37	44	19	28	71	103
		EURO 3	11810	37	44	19	28	71	103
		EURO 4	11810	37	44	19	28	71	103
	1,4 - 2,0 l	Pre ECE	7005	36	47	17	22	61	95
		ECE 15-00/01	9328	31	48	21	24	60	99
		ECE 15-02	10058	31	47	22	26	65	105
		ECE 15-03	10030	35	44	21	29	70	112
		ECE 15-04	11747	37	45	18	27	70	109
		Improved conventional	10848	37	38	25	36	74	123
		Open loop	10787	36	39	25	35	72	120
		EURO 1	13934	37	42	21	31	72	115
		EURO 2	13934	37	42	21	31	72	115
		EURO 3	13934	37	42	21	31	72	115
		EURO 4	13934	37	42	21	31	72	115
	> 2,0 l	Pre ECE	8319	34	47	19	23	61	97
		ECE 15-00/01	12550	29	49	22	25	57	104
		ECE 15-02	12473	31	48	21	27	63	109
		ECE 15-03	12366	36	43	21	31	70	117
		ECE 15-04	13727	36	44	20	28	68	113
		EURO 1	17401	37	40	23	33	73	120
		EURO 2	17401	37	40	23	33	73	120
		EURO 3	17401	37	40	23	33	73	120
		EURO 4	17401	37	40	23	33	73	120
Diesel	< 2,0 l	Uncontrolled	14214	38	44	18	27	69	109
		EURO 1	17619	39	43	18	29	69	112
		EURO 2	17619	39	43	18	29	69	112
		EURO 3	17619	39	43	18	29	69	112
		EURO 4	17619	39	43	18	29	69	112
	> 2,0 l	Uncontrolled	14873	36	43	21	27	70	112
		EURO 1	18259	38	42	20	28	69	113
		EURO 2	18259	38	42	20	28	69	113
		EURO 3	18259	38	42	20	28	69	113
		EURO 4	18259	38	42	20	28	69	113
LPG	All	Uncontrolled	20046	44	37	19	21	64	104
		EURO 1	20696	41	38	21	22	63	104
		EURO 2	20696	41	38	21	22	63	104
		EURO 3	20696	41	38	21	22	63	104
		EURO 4	20696	41	38	21	22	63	104
2-stroke	All	Uncontrolled	5150	30	60	10	30	80	100

Source: Hickman, 1999

2.6.9 Penetration of new technologies and alternative fuels: scenarios

Table 2.6-12: Estimated percentage market share for new technology vehicles during the years 2010 and 2020.

Vehicle type	**% market share**			
	Low case		High case	
	2010	2020	2010	2020
EV	0.5	5	1	10
HEV	1	10	2	20
FCV	0	5	0	10

Source: Hickman, 1999

In 2001 the European Commission proposed a set of measures to promote the use of alternative fuels and in particular biofuels. According to the EC, concerning the alternative fuels, an "optimistic development scenario" at this stage might look like the following (not excluding other possibilities such as DME):

Table 2.6-13: Optimistic development scenario for alternative fuels

	% market share			
Year	Biofuels	Natural gas	Hydrogen	**Total**
2005	2			**2**
2010	6	2		**8**
2015	(7)	5	2	**14**
2020	(8)	10	5	**(23)**

Source: EC, 2001

2.6.10 References

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3 EMISSION REGULATIONS FOR LIGHT-DUTY VEHICLES – A COMPARISON OF THE USA AND EUROPE

By Staffan Hultén (MERIT) & Luc Pelkmans (VITO)

We can identify at least three types of emissions from cars:
Regulated emissions are

- Carbon monoxide (CO).
- Nitrogen oxides (NO_x), composed of nitric oxide (NO) and nitrogen dioxide (NO_2). Other oxides of nitrogen which may be present in exhaust gases, such as N_2O, are not regulated.
- Hydrocarbons (HC), regulated either as total hydrocarbon emissions (THC) or as non-methane hydrocarbons (NMHC).
- For diesel vehicles Diesel particulate matter (PM) are also measured also.

Not regulated emissions are toxic air contaminants (TACs) with substances including benzene, formaldehyde and 1,3 butadiene. Butadiene has been found to cause cancer of the heart, lung, breast, ovaries, stomach, liver, pancreas, thyroid and testes. Benzene is a known human carcinogen that has been found to cause leukaemia and cancers of the lymphatic system. Formaldehyde has been found to cause nasal cancer in animal studies.

Carbon dioxide (CO_2) is regulated in international agreements such as the Kyoto Protocol. Vehicles contribute a minority of the carbon dioxide in the atmosphere, but in California that is a significant 40%. Most CO_2 around the world comes from factories and refineries. The US federal Environmental Protection Agency does not consider CO_2 a regulated exhaust emission. CO_2 is expelled by all living things and is not poisonous. In fact, green plants need it to survive, and the planet needs a certain amount to remain warm enough to inhabit.

In Europe an agreement was signed in July 1998 between the European Commission and the European car industry represented by the European Automobile Manufacturers Association (ACEA) on the reduction of CO_2 emissions from cars.

3.1 A Brief History of Emissions Standards

In Europe the regulation of the reduction of car emissions was established with the application of the directive 70/220/EEC in 1970. A succession of directives has brought the emission standards in 1996/1997 to a level that is 90% lower than the first years of the 1970s[9]. The scope of reductions in the standards diminished gradually, however, and it became necessary to give greater attention to the interactions between the vehicles and the fuels.

In the USA “The Clean Air Act ” of 1963 and its later amendments established standards for automobiles. These amendments became effective in 1980, 1984 and 1994, and according to Truett and Hu (1997) the costs for respecting these standards resulted in increased costs for developing diesel engines and the refining of fuels, reducing the economic advantage of the diesel engine.

The most important steps were:

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[9] Service de la Commission Européenne, *Auto Oil II Programme*, Octobre 2000 p14

- Crankcase controls (US 1970 CAA; 70/220/EEC).
- Oxidation catalysts (US-77, 88/76/EEC).
- Three-way catalysts (US Tier 0; 91/441/EEC).
- Advanced engine modifications, electronic control, fast light-off catalysts (US Tier 1; 94/12/EC).
- Even more advanced engine modifications and after-treatment controls (US Tier 2; 98/69/EC).

Each step in emissions controls has required fuel improvements:

- Lead phase-out for catalysts.
- Increased octane for optimised performance.
- Reduced sulphur for efficient after-treatment performance.

If we compare the two regulations, the American regulation makes no difference between the standards for diesel oil and for gasoline, while the European standards created a difference from the start between gasoline and diesel. In addition, the American regulation was much more severe than other regulations in the world, and in particular in comparison with European standards during the 1980s.

Consequently it seems as if the restraining regulation in the USA has impeded the development of diesel. In comparison, the European legislation, much less demanding due to the powerful lobby of transportation firms, allowed the development of diesel engines in Europe and gave incentives to European car manufacturers to develop a cleaner diesel engine compared with the diesel engines of the 1970s and 1980s.

Current Japanese standards are considered less stringent than current US or EU standards (planned reductions will narrow the gap). Countries previously with minimal or no emission standards are catching up - e.g. China plans to be same as the EU in 2010. While most countries follow the EU or USA, some are developing unique requirements:

- Korea is proposing its own drive cycle/standards
- India has adopted a modified EU cycle to accommodate low-power vehicles

Very few countries are adopting/allowing Japanese requirements and even Japan is rumoured to be considering 98/69/EC.

Greater trend toward EU standards vs American: In the Asia-Pacific region, Taiwan stands out as one of the few countries that require US-based emission standards. Countries such as Australia and Hong Kong, which currently allow either US or EU based compliance, are moving to EU-only. More than 50% of vehicles registered worldwide today are sold in countries following ECE emission protocols. That percentage will grow significantly in the next five years and beyond. Registrations in “new” markets grow faster than they do in developed markets. More countries are following ECE requirements.

3.2 How Emissions Are Regulated: Tailpipe Emission Standards

"Tailpipe" emission standards specify the maximum amount of pollutants allowed in exhaust gases discharged from a diesel engine. The tailpipe emission standards were initiated in California in 1959 to control CO and HC emissions from gasoline engines. Today, emissions from internal combustion engines are regulated in tens of countries throughout the world.

Emissions are measured over an engine or vehicle test cycle which is an important part of every emission standard. Regulatory test procedures are necessary to verify and ensure compliance with the various standards. These test cycles are supposed to create repeatable emission measurement conditions and, at the same time, simulate a real driving condition of a given application. Analytical methods that are used to measure particular emissions are also regulated by the standard.

Regulatory authorities in different countries have not been unanimous in adopting emission test procedures and many types of cycles are in use. Since exhaust emissions depend on engine speed and load conditions, specific engine emissions measured on different test cycles may not be comparable even if they are expressed or recalculated into the same units of measure. This should be borne in mind whenever emission standards from different countries are compared.
Tailpipe emission standards are usually implemented by government ministries responsible for the protection of the environment, such as the EPA (Environmental Protection Agency) in the USA. The duty to comply with these standards is on the equipment (engine) manufacturer. Typically all equipment has to be emission-certified before it is released to the market.

The regulated gasoline emissions include:

- **Nitrogen oxides** (NO_x), composed of nitric oxide (NO) and nitrogen dioxide (NO_2). Other oxides of nitrogen which may be present in exhaust gases, such as N_2O, are not regulated.
- **Hydrocarbons** (HC), regulated either as total hydrocarbon emissions (THC) or as non-methane hydrocarbons (NMHC). One combined limit for HC + NO_x is sometimes used instead of two separate limits.
- **Carbon monoxide** (CO).
- For diesel vehicles **Diesel particulate matter** (PM) are also measured using gravimetric methods. Sometimes diesel smoke opacity is measured by optical methods and also regulated.

3.3 Emission Standards: European Union Cars and Light Trucks

This chapter presents firstly the European Union emission standards for cars and light trucks and, secondly discusses the European Union agreements with the car industry concerning the reduction of carbon dioxide emissions.

3.3.1 EU emission standards

European emission regulations for new light-duty vehicles (cars and light commercial vehicles) were originally specified in the European Directive 70/220/EEC. Amendments to that regulation include the Euro 1/2 standards, covered under Directive 93/59/EC, and the most recent Euro 3/4 limits (2000/2005), covered by Directive 98/69/EC. The 2000/2005 standards were accompanied by an introduction of more stringent fuel quality rules that require minimum diesel cetane number of 51 (year 2000), maximum diesel sulphur content of 350 ppm in 2000 and 50 ppm in 2005, and maximum gasoline (gasoline) sulphur content of 150 ppm in 2000 and 50 ppm in 2005.

The emission test cycle for these regulations is the ECE15 + EUDC procedure. Effective in year 2000, that test procedure is modified to eliminate the 40s engine warm-up period before the beginning of emission sampling. All emission limits are expressed in g/km. The EU light-duty vehicle standards are different for diesel and gasoline vehicles. Diesels have lower CO standards but are allowed higher NO$_x$. Gasoline vehicles are exempted from PM standards. The standards for new cars are summarised in Table 3.3-1, the standards for light trucks in Table 3.3-2.

Table 3.3-1: EU emission standards for passenger cars, g/km

	Year	CO	HC	HC+NO$_x$	NO$_x$	PM
DIESEL						
Euro 1	1992	2.72	-	0.97	-	0.14
Euro 2 - IDI	1996	1.0	-	0.7	-	0.08
Euro 2 - DI	1999	1.0	-	0.9	-	0.10
Euro 3	2000.01	0.64	-	0.56	0.50	0.05
Euro 4	2005.01	0.50	-	0.30	0.25	0.025
GASOLINE						
Euro 3	2000.01	2.30	0.20	-	0.15	-
Euro 4	2005.01	1.0	0.10	-	0.08	-

Table 3.3-2: EU emission standards for light commercial vehicles, g/km

Class		Year	CO	HC	HC+NO$_x$	NO$_x$	PM
DIESEL							
N1: <1305 kg	Euro 1	1994.10	2.72	-	0.97	-	0.14
	Euro 2	1998.01	1.0	-	0.60	-	0.10
	Euro 3	2000.01	0.64	-	0.56	0.50	0.05
	Euro 4	2005.01	0.50	-	0.30	0.25	0.025
N2: 1305-1760 kg	Euro 1	1994.10	5.17	-	1.40	-	0.19
	Euro 2	1998.01	1.2	-	1.1	-	0.15
	Euro 3	2002.01	0.80	-	0.72	0.65	0.07
	Euro 4	2006.01	0.63	-	0.39	0.33	0.04
N3: >1760 kg	Euro 1	1994.10	6.90	-	1.70	-	0.25
	Euro 2	1998.01	1.35	-	1.3	-	0.20
	Euro 3	2002.01	0.95	-	0.86	0.78	0.10
	Euro 4	2006.01	0.74	-	0.46	0.39	0.06
GASOLINE							
N1: <1305 kg	Euro 1	1994.10	2.72	-	0.97	-	-
	Euro 2	1998.01	2.2	-	0.50	-	-
	Euro 3	2000.01	2.3	0.20	-	0.15	-
	Euro 4	2005.01	1.0	0.1	-	0.08	-
N2: 1305-1760 kg	Euro 1	1994.10	5.17	-	1.40	-	-
	Euro 2	1998.01	4.0	-	0.65	-	-
	Euro 3	2002.01	4.17	0.25	-	0.18	-
	Euro 4	2006.01	1.81	0.13	-	0.10	-
N3: >1760 kg	Euro 1	1994.10	6.90	-	1.70	-	-
	Euro 2	1998.01	5.0	-	0.80	-	-
	Euro 3	2002.01	5.22	0.29	-	0.21	-
	Euro 4	2006.01	2.27	0.16	-	0.11	-

Note: For Euro 1/2 the weight classes were N1 (<1250 kg), N2 (1250-1700 kg), N3 (>1700 kg).

Useful vehicle life for the purpose of emission regulations is 80,000 km through the Euro 3 stage, and 100,000 km beginning at the Euro 4 stage (2005).

The 2000/2005 regulations include several additional provisions, such as:

- EU Member States may introduce tax incentives for early introduction of 2005 compliant vehicles.
- Requirement for on-board emission diagnostics systems (OBD) phased-in between 2000 and 2005.
- Requirement for low-temperature emission test (7°C) for gasoline vehicles effective 2002.

Source: www.dieselnet.com (Revision 00/12)

3.3.2 The Swedish Motor Vehicle Emission Requirements

Sweden has applied requirements on exhaust-emission control systems since the mid-1970s and the requirements have been tightened gradually. The current regulatory system on motor vehicle emissions is based on several principles, including manufacturer product responsibility, emission control system durability requirements, in-use conformity testing and regular vehicle inspections. As a result of these measures, the level of total emission from road traffic has decreased and will continue to go down over coming years.

3.3.2.1 Swedish vehicle emission legislation

The Swedish regulations governing vehicle emissions currently apply to cars, light commercial vehicles, small buses and heavy-duty trucks and buses. Vehicles that run on gasoline (light vehicles only) and diesel and gas (all vehicles) fuels have to comply. The regulations are based on the provisions stipulated in the *Act on Motor Vehicle Emission Control and Motor Fuels* (2001:1080) and the *Motor Vehicle Emission Control Ordinance* (2001:1085). The Swedish Parliament and the Government, respectively, decide on these statutes. The legislation is founded on the manufacturer's product responsibility, a requirement on the durability of the emission-control system and regulations covering the follow-up of these requirements in the form of durability checks and vehicle inspections.

Since Sweden joined the European Union, the requirements have been based on community vehicle emission directives (see Table 3.3-3). In Sweden, a national system for the environmental classification of new vehicles has been applied since 1992.

Table 3.3-3: Current EC motor vehicle emission directives

First directive	Current version	Title	Area
70/220/EEC	91/441/EEC and later amendments	Measures against air pollution by emissions from motor vehicles	Passenger cars, light commercial vehicles and small buses with gasoline, diesel and gas engines
88/77/EEC	1999/96/EC and later amendments	Measures to be taken against the emission of gaseous and particulate pollutants from compression ignition engines for use in vehicles, and the emission of gaseous pollutants from positive ignition engines fuelled with natural gas or liquefied petroleum gas for use in vehicles	Diesel and gas engines for heavy duty vehicles and buses
72/306/EEC	72/306/EEC and later amendments	Measures to be taken against the emission of pollutants from diesel engines for use in vehicles.	Diesel smoke.
97/24/EC	97/24/EC and later amendments	Directive on certain components and characteristics of two or three-wheel motor vehicles. See Chapter 5: Measures to be taken against air pollution caused by two or three-wheel motor vehicles	Mopeds. Motorcycles and motor tri cycles.

Note: All European Union motor vehicle directives are available on-line at the Eur-lex website at: http://europa.eu.int/eur-lex/en/lif/reg/en_register_133010.html

3.3.2.2 Product responsibility

Product responsibility obliges the manufacturer to ensure that the vehicle or engine fulfils the emission performance requirements stipulated under the Vehicle Emissions Ordinance. This is to be verified in the form of an EC type-approval or an environmental classification.

3.3.2.3 Durability requirements

If the emission-control requirements are to have the desired effect, the emission control system has to work and emissions must be low throughout a vehicle's whole life-cycle and not just when it is new. This must be taken into consideration early, starting with the design of the emission-control system. The emission regulations therefore stipulate limit values that may not be exceeded after a certain number of kilometres have been clocked up in "normal traffic" - the durability requirement. For passenger cars, this distance is 80,000 km but this will be increased to 100,000 km from 2005. The manufacturer must state the car's expected deterioration when accepting responsibility for meeting these requirements.

3.3.2.4 Vehicle inspection

The purpose of compulsory vehicle inspection is primarily to ensure that the vehicle owner has carried out the necessary maintenance in order for the emission control system to function properly. A periodic inspection includes all sorts of inspections and tests, not only for emissions. Along with the basic durability requirements, maintenance is of central importance if the requirements are to have the intended effect. The emission tests carried out as part of today's vehicle inspection includes visual inspection of the emission control system in order to check that the required - approved - equipment is fitted to the vehicle. Measurement of emissions: for gasoline engine vehicles, carbon monoxide and hydrocarbons at idle and high idle speed as well as the air/fuel-ratio (lambda value) and, for diesel vehicles, smoke opacity at free acceleration.

3.3.2.5 The manufacturer's undertaking

A warranty for emission-related deficiencies must be issued to the customer for every new vehicle offered for sale in Sweden. This means that the manufacturer must rectify any deficiency in the emission-control system of any vehicles he has sold, or intends to sell, discovered at periodic vehicle inspections by the authorities - the manufacturer's undertaking. For passenger cars, this undertaking applies for the first five years or up to a maximum of 80,000 km.

3.4 The ACEA agreement on reducing carbon dioxide emissions

In the agreement in July 1998 between the European Commission and the European car industry represented by the European Automobile Manufacturers Association (ACEA), the ACEA committed itself to:

a) Achieving an average carbon dioxide emission level of 140g/km by 2008 for all its new cars sold in the EU, as measured according to the EU's test procedure.
b) Bringing to the market individual car models with carbon dioxide emission levels of 120g/km or less by 2000.
c) Reaching an indicative target (not a commitment according to the ACEA) of 165-170g/km in 2003.
d) Reviewing the potential for additional improvements with a view to moving the new car fleet average to 120g/km by 2012. This review will be undertaken in 2003. [P. Kågeson, 2000].

The results so far are quite good according to the Joint Report of the European Automobile Manufacturers Association and the Commission Services of June 25, 2002. The average (gasoline and diesel) specific carbon dioxide emission fell from 169g/km in 2000 to 164g/km in 2001. The average carbon dioxide emission was 172g/km for gasoline cars in 2001 (from 177g/km in 2000) and diesels went to 153g/km in 2001 (from 157g/km in 2000).

This reduction occurred in spite of the fact that the average car mass increased 0.8%, engine capacity 1.0% and power 4.2%. More than 2.8 million ACEA cars with carbon dioxide emission levels of 140g/km or less were sold in 2001. The average reduction from 1995 in carbon dioxide emission is 1.9% a year. To meet the goal of 140g/km in 2008, the car industry must achieve an average reduction of 2.1% in the period 2002-2008.

3.5 Emission Standards: USA Cars and Light-Duty Trucks

3.5.1 Federal Standards

Two sets of standards, Tier 1 and Tier 2, have been defined for light-duty vehicles in the Clean Air Act Amendments (CAAA) of 1990. The Tier 1 regulations were published as a final rule on June 5 1991, and fully implemented in 1997. The Tier 2 standards were adopted on December 21 1999, to be phased-in from 2004.

3.5.2 Tier 1 Standards

Tier 1 light-duty standards apply to all new light-duty vehicles (LDV) such as passenger cars, light-duty trucks, sport utility vehicles (SUV), mini-vans and pick-up trucks. The LDV category includes all vehicles of less than 8500 lb gross vehicle weight rating, or GVW (i.e. vehicle weight plus rated cargo capacity). LDVs are further divided into the following sub-categories: passenger cars, light light-duty trucks (LLDT) below 6000 lbs GVW; and heavy light-duty trucks (HLDT) above 6000 lbs GVWR.

The Tier 1 standards were phased in progressively between 1994 and 1997 and apply to a full vehicle useful life of 100,000 miles (effective 1996). The regulation also defines an intermediate standard to be met over a 50,000-mile period. The difference between diesel and gasoline car standards is a more relaxed NOx limit for diesels, which applies to vehicles through 2003 model year.

Car and light truck emissions are measured over the Federal Test Procedure (FTP 75) test and expressed in g/mile. In addition to the FTP 75 test, a Supplemental Federal Test Procedure (SFTP) will be phased in between 2000 and 2004. The SFTP includes additional test cycles to measure emissions during aggressive highway driving (US06 cycle), and also to measure urban driving emissions while the vehicle's air conditioning system is operating (SC03 cycle). The exact phase-in schedules, as well as the US06 and SC03 standards, are available from the EPA web site.

Table 3.5-1: EPA Tier 1 emission standards for cars and light-duty trucks, FTP 75, g/mi

Category	50,000 miles/5 years						100,000 miles/10 years[1]					
	THC	NMHC	CO	NOx D	NOx G	PM	THC	NMHC	CO	NOx D	NOx G	PM
Passenger cars	0.41	0.25	3.4	1.0	0.4	0.08	-	0.31	4.2	1.25	0.6	0.10
LLDT, LVW <3,750 lbs	-	0.25	3.4	1.0	0.4	0.08	0.80	0.31	4.2	1.25	0.6	0.10
LLDT, LVW >3,750 lbs	-	0.32	4.4	-	0.7	0.08	0.80	0.40	5.5	0.97	0.97	0.10
HLDT, ALVW <5,750 lbs	0.32	-	4.4	-	0.7	-	0.80	0.46	6.4	0.98	0.98	0.10
HLDT, ALVW >5,750 lbs	0.39	-	5.0	-	1.1	-	0.80	0.56	7.3	1.53	1.53	0.12

[1] Useful life 120,000 miles/11 years for all HLDT standards and for THC standards for LDT

Abbreviations:

D: diesel
G: Gasoline
LVW: loaded vehicle weight (curb weight + 300 lbs)
ALVW: adjusted LVW (the numerical average of the curb weight and the GVWR)
LLDT: light light-duty truck (below 6,000 lbs GVWR)
HLDT: heavy light-duty truck (above 6,000 lbs GVWR)

3.5.3 National LEV Program

On December 16 1997, EPA finalised the regulations for the National Low Emission Vehicle (NLEV) programme (*63 FR 926, January 7, 1998*). The NLEV is a voluntary programme that came into effect through an agreement by the north-eastern states and the auto manufacturers. It provides more stringent emission standards for the transitional period before the Tier 2 standards are introduced.

Starting in the north-eastern states in model year 1999 and nationally in model year 2001, new cars and light light-duty trucks have to meet tailpipe standards that are more stringent than EPA can legally mandate prior to model year 2004. However, after the NLEV programme was agreed upon, these standards are enforceable in the same manner as any other federal new motor vehicle programme.

The National LEV program harmonises the federal and California motor vehicle standards and provides emission reductions that are basically equivalent to the California Low Emission Vehicle programme. The programme is phased in through schedules that require car manufacturers to certify a percentage of their vehicle fleets to increasingly cleaner standards (TLEV, LEV, ULEV). The National LEV program extends only to lighter vehicles and does not include the Heavy LDT (HLDT, GVW>6,000 lbs) vehicle category.

3.5.4 Tier 2 Standards

The Tier 2 standards bring significant emission reductions relative to the Tier 1 regulation. In addition to more stringent numerical emission limits, the regulation introduces a number of important changes that make the standard more stringent for larger vehicles. Under the Tier 2 standard, the same emission standards apply to all vehicle weight categories - i.e. cars, minivans, light duty trucks, and SUVs have the same emission limit. Since light-duty emission standards are expressed in grams of pollutants per mile, large engines (such as those used in light trucks or SUVs) will have to utilise more advanced emission control technologies than smaller engines in order to meet the standard.

In Tier 2, the applicability of light-duty emission standards has been extended to cover some of the heavier vehicle categories. The Tier 1 standards applied to vehicles up to 8500 lbs GVW. The Tier 2 standard applies to all vehicles that were covered by Tier 1 and, additionally, to “medium-duty passenger vehicles” (MDPV). The MDPV is a new class of vehicles that are rated between 8,500 and 10,000 GVW and are used for personal transportation. This category includes primarily larger SUVs and passenger vans. Engines in commercial vehicles above 8500 lbs GVW, such as cargo vans or light trucks, will continue to certify to heavy-duty engine emission standards.

The same emission limits apply to all engines regardless of the fuel they use. That is, vehicles fuelled by gasoline, diesel, or alternative fuels all must meet the same standards.

The Tier 2 tailpipe standards are structured into eight certification levels of different stringency, called “certification bins”, and an average fleet standard for NO_x emissions. Vehicle manufacturers will have a choice to certify particular vehicles to any of the

eight bins. At the same time, the average NO_x emissions of the entire vehicle fleet sold by each manufacturer will have to meet the average NO_x standard of 0.07 g/mi.
Additional temporary certification bins (bin 9, 10, and an MDPV bin) of more relaxed emission limits will be available in the transition period. These bins will expire after the 2008 model year.

The Tier 2 standards will be phased-in between 2004 and 2009. For new passenger cars and light LDTs, Tier 2 standards will be phased in from 2004, with the standards to be fully phased in by 2007. For heavy LDTs and MDPVs, the Tier 2 standards will be phased in from 2008, with full compliance in 2009. During the phase-in period from 2004-2007, all passenger cars and light LDTs not certified to the primary Tier 2 standards will have to meet an interim average standard of 0.30 g/mi NO_x, equivalent to the current NLEV standards for LDVs. During the period 2004-2008, heavy LDTs and MDPVs not certified to the final Tier 2 standards will phase in to an interim programme with an average standard of 0.20 g/mi NO_x, with those not covered by the phase-in meeting a per-vehicle standard (i.e. an emissions "cap") of 0.60 g/mi NO_x (for HLDTs) and 0.90 g/mi NO_x (for MDPVs).
The emission standards for all pollutants (certification bins) are shown in the following table. The vehicle "full useful life" period has been extended to 120,000 miles. The EPA bins cover California LEV II emission categories, to make certification to the federal and California standards easier for vehicle manufacturers.

Table 3.5-2: Tier 2 Emission Standards, FTP 75, g/mi

	50,000 miles					**120,000 miles**				
	NMOG	**CO**	**NO_x**	**PM**	**HCHO**	**NMOG**	**CO**	**NO_x***	**PM**	**HCHO**
Temporary Bins										
MDPV[c]						0.280	7.3	0.9	0.12	0.032
10[a,b,d,f]	0.125 (0.160)	3.4 (4.4)	0.4	-	0.015 (0.018)	0.156 (0.230)	4.2 (6.4)	0.6	0.08	0.018 (0.027)
9[a,b,e]	0.075 (0.140)	3.4	0.2	-	0.015	0.090 (0.180)	4.2	0.3	0.06	0.018
Permanent Bins										
8[b]	0.100 (0.125)	3.4	0.14	-	0.015	0.125 (0.156)	4.2	0.20	0.02	0.018
7	0.075	3.4	0.11	-	0.015	0.090	4.2	0.15	0.02	0.018
6	0.075	3.4	0.08	-	0.015	0.090	4.2	0.10	0.01	0.018
5	0.075	3.4	0.05	-	0.015	0.090	4.2	0.07	0.01	0.018
4	-	-	-	-	-	0.070	2.1	0.04	0.01	0.011
3	-	-	-	-	-	0.055	2.1	0.03	0.01	0.011
2	-	-	-	-	-	0.010	2.1	0.02	0.01	0.004
1	-	-	-	-	-	0.000	0.0	0.00	0.00	0.000

* average manufacturer fleet NO_x standard is 0.07 g/mi

a. Bin deleted at end of 2006 model year (2008 for HLDTs)
b. The higher temporary NMOG, CO and HCHO values apply only to HLDTs and expire after 2008
c. An additional temporary bin restricted to MDPVs, expires after model year 2008
d. Optional temporary NMOG standard of 0.195 g/mi (50,000) and 0.280 g/mi (120,000) applies for qualifying LDT4s and MDPVs only

e. Optional temporary NMOG standard of 0.100 g/mi (50,000) and 0.130 g/mi (120,000) applies for qualifying LDT2s only
f. 50,000-mile standard optional for diesels certified to bin 10

The Tier 2 regulation brings new requirements for fuel quality. Cleaner fuels will be required by advanced emission after-treatment devices (e.g. catalysts) that are needed to meet the regulations.

Sulphur Levels in Gasoline -- The programme requires that most refiners and importers meet a corporate average gasoline sulphur standard of 120 ppm and a cap of 300 ppm beginning in 2004. By 2006 the average standard will be reduced to 30 ppm with an 80 ppm sulphur cap. Temporary, less stringent standards will apply to some small refiners through to 2007. In addition, temporary, less stringent standards will apply to a limited geographical area in the western USA for the 2004-2006 period.

Diesel Fuel Quality - In May 1999 the EPA published an Advanced Notice of Proposed Rulemaking (ANPRM) on the quality of diesel fuel, soliciting comments on what sulphur levels are needed and when. Proposed rulemaking on diesel fuel sulphur was expected in early 2000.

3.6 California Emission Standards

Because California's Air Resources Board was established before the US Environmental Protection Agency was formed under the Clean Air Act of 1970, California is unique in its ability to impose air quality standards independent of federal regulation. The state air board already sets strict standards for tailpipe emissions of smog-causing pollutants such as nitrogen oxides. Current Tier 1/LEV California emission standards extend through to the year 2003. More stringent LEV II regulations will be in place with effect from 2004.

3.6.1 Low Emission Vehicle (LEV) Standards

Current Californian emission standards are expressed through the following emission categories:

- Tier 1
- Transitional Low Emission Vehicles (TLEV)
- Low Emission Vehicles (LEV)
- Ultra Low Emission Vehicles (ULEV)
- Super Ultra Low Emission Vehicles (SULEV)
- Zero Emission Vehicles (ZEV)

Car manufacturers are required to produce a percentage of vehicles certified to increasingly more stringent emission categories. The phase-in schedules are fairly complex and are generally based on vehicle fleet emission averages. The exact schedules can be found on the EPA web. After 2003, Tier 1 and TLEV standards will be eliminated as available emission categories.

The same standards for gaseous pollutants apply to diesel and gasoline fuelled vehicles. PM standards apply to diesel vehicles only. Emissions are measured over the FTP 75 test and are expressed in g/mile. The additional SFTP procedure will be phased in in California between 2001 and 2005.

Table 3.6-1: California emission standards for light-duty vehicles, FTP 75, g/mi

Category	50,000 miles/5 years					100,000 miles/10 years				
	NMOG[a]	CO	NO_x	PM	HCHO	NMOG[a]	CO	NO_x	PM	HCHO
Passenger cars										
Tier 1	0.25	3.4	0.4	0.08	-	0.31	4.2	0.6	-	-
TLEV	0.125	3.4	0.4	-	0.015	0.156	4.2	0.6	0.08	0.018
LEV	0.075	3.4	0.2	-	0.015	0.090	4.2	0.3	0.08	0.018
ULEV	0.040	1.7	0.2	-	0.008	0.055	2.1	0.3	0.04	0.011
LDT1, LVW <3,750 lbs										
Tier 1	0.25	3.4	0.4	0.08	-	0.31	4.2	0.6	-	-
TLEV	0.125	3.4	0.4	-	0.015	0.156	4.2	0.6	0.08	0.018
LEV	0.075	3.4	0.2	-	0.015	0.090	4.2	0.3	0.08	0.018
ULEV	0.040	1.7	0.2	-	0.008	0.055	2.1	0.3	0.04	0.011
LDT2, LVW >3,750 lbs										
Tier 1	0.32	4.4	0.7	0.08	-	0.40	5.5	0.97	-	-
TLEV	0.160	4.4	0.7	-	0.018	0.200	5.5	0.9	0.10	0.023
LEV	0.100	4.4	0.4	-	0.018	0.130	5.5	0.5	0.10	0.023
ULEV	0.050	2.2	0.4	-	0.009	0.070	2.8	0.5	0.05	0.013

a – NMHC for all Tier 1 standards

Abbreviations:
LVW - loaded vehicle weight (curb weight + 300 lbs)
LDT – light-duty truck
NMOG – non-methane organic gases
HCHO – formaldehyde

3.6.2 Low Emission Vehicle II (LEV II) Standards

On November 5 1998 the ARB adopted the LEV II emission standards that will extend from the year 2004 until 2010.
Under the LEV II regulation, the light-duty truck and medium-duty vehicle categories of below 8,500 lbs gross weight are reclassified and will have to meet passenger car requirements, as shown in Table 8. As a result, most pick-up trucks and sport utility vehicles will be required to meet passenger car emission standards. The reclassification will be phased in by the year 2007. Medium-duty vehicles above 8,500 lbs gross weight (old MDV4 and MDV5) will still certify to the medium-duty vehicle standard.

Under the LEV II standard, NO_x and PM standards for all emission categories are significantly tightened. The same standards apply to both gasoline and diesel vehicles (under revisions adopted on November 15 2001, gasoline vehicles are no longer exempted from the PM standard). Light-duty LEVs and ULEVs will certify to a 0.05 g/mi NO_x standard, to be phased-in starting with the 2004 model year. A full useful life PM standard of 0.010 g/mi is introduced for light-duty diesel vehicles and trucks less than 8,500 lbs gross weight certifying to LEV, ULEV, and SULEV standards. The TLEV emission category has been eliminated in the final regulatory text. It is believed, therefore, that emission certification of light-duty diesel vehicles in California will be possible only if advanced emission control technologies, such as particulate traps and NO_x catalysts, are developed.

Table 3.6-2: California LEV II emission standards, passenger cars and LDVs < 8500 lbs, g/mi

Category	50,000 miles/5 years					120,000 miles/11 years				
	NMOG	CO	NOx	PM	HCHO	NMOG	CO	NOx	PM	HCHO
LEV	0.075	3.4	0.05	-	0.015	0.090	4.2	0.07	0.01	0.018
ULEV	0.040	1.7	0.05	-	0.008	0.055	2.1	0.07	0.01	0.011
SULEV	-	-	-	-	-	0.010	1.0	0.02	0.01	0.004

Source: www.dieselnet.com

3.6.3 Zero Emission Vehicles - ZEV

ZEVs (zero emission vehicles) are a key element of California's plan for reducing air pollution caused by automobiles. ARB is committed to the successful introduction of ZEVs and is taking steps to ensure the market is ready.

1990: In 1990 ARB adopted the Low-Emission Vehicle and Clean Fuels regulations. These regulations included a requirement that the seven largest auto manufacturers produce the following percentages of ZEVs. The Low-Emission Vehicle (LEV) Regulations were adopted by the CARB in 1990. The original LEV Regulations required the introduction of ZEVs in 1998 as 2% of all vehicles produced for sale in California, and increased the percentage of ZEVs from 2% to 10% in 2003.

1996: After several CARB reviews and manufacturer introduction of prototype and pre-production test fleet ZEVs, the CARB granted a reprieve to the auto-makers in March 1996. The ZEV program was modified to encourage a market-based introduction of ZEVs in California in the near-term and to promote advances in electric vehicle battery technology. This reprieve required the automakers to meet the same emission reduction requirements that would have resulted from the introduction of the ZEVs in 1998, and it required, under a formal Memorandum of Agreement (MOA), that large auto-makers produce, promote, and market and sell through their retail dealership network a significant and specified number of ZEVs. The 10% ZEVs for 2003 and beyond remains in place.

3.6.3.1 Memoranda of Agreement (MOA)

In order to establish a programme that allows vehicle introductions to be voluntary, but requires continued investment in battery and vehicle development, demonstration, and commercialisation, the ARB entered into a separate memorandum of agreement (MOA) with each of the seven largest auto manufacturers - Chrysler, Ford, General Motors, Honda, Mazda, Nissan and Toyota. Each MOA represents a co-operative agreement between the auto manufacturer and the ARB and commits both parties to tasks designed to ensure the successful launch and long-term success of the ZEV programme.

3.6.3.2 Principle Elements of the MOA

The seven largest auto makers agreed to: Offset the emission benefits lost due to the elimination of the ZEV requirements in model years 1998 to 2002 by opting-in to the National Low-Emission Vehicle programme beginning in 2001, three years earlier than could be required under federal law; continue investing in ZEV and battery research and development and to place up to 3,750 advanced battery-powered ZEVs in 1998, 1999 and 2000; participate in a market-based ZEV launch by offering ZEVs to consumers in accordance with market demand; provide annual and biennial reporting requirements.

The ARB has committed to: facilitate the purchase of ZEVs in state fleets; work with other state agencies, local governments and private industry to address various infrastructure issues; continue to work with emergency response officials to create a comprehensive emergency response training program; and support reasonable incentive programs.

3.6.3.3 Enforcement

The ARB will conduct biennial reviews of the ZEV programme. The most recent biennial review took place on July 30 1998. A manufacturer that fails to comply with the requirements of the MOA will be subject to fines and could be subject to the reinstatement of the ZEV requirements prior to 2003.

Benefits of the MOA:
1. Market-based ZEV launch which is consistent with manufacturers' product introduction plans and estimates of market acceptance - production commitments already made for four models.
2. Continued progress and investment in critical technology.
3. Cooperative effort on implementation issues.
4. Reporting requirements to keep the process "honest".
5. Strong enforcement features.
6. No loss in emission benefits.
7. Percentage production requirement retained for 2003 and beyond.
8. Increased assurance of long-term success of ZEV programme.

In November 1998, CARB again weakened the ZEV Regulations, which were a part of a larger body of new regulations for passenger cars, light-duty trucks, sport utility vehicles (SUVs) and medium-duty trucks (MDTs). Environmental groups tried to influence members of CARB to keep the original content of the ZEV Regulations intact, to prevent the use of gasoline for achieving credits toward the ZEV requirements, and to prevent the use of diesel to qualify as a low-emission fuel for SUVs and MDTs. The CARB voted to allow up to 60% of the 10% ZEV requirement to be met by vehicles that could achieve partial ZEV credits. These Partial ZEV Credit vehicles included gasoline powered "Super Ultra Low-Emission (SULEV)" warranted to 150,000 miles, hybrid-electric vehicles (HEVs) meeting the SULEV standard and fuel cell vehicles. Several automakers have built and certified for sale SULEVs that meet the requirement to achieve partial ZEV credits. New HEVs are being represented as the answer to the range limitation and inconvenience of the battery-powered ZEVs. In addition, several automakers are using the results of their MOA experience to campaign against the remaining 40% ZEV requirement for 2003.

3.6.4 Greenhouse gas emission reduction in California

California lawmakers are looking at limiting greenhouse gas emissions. The following two texts are extracts from articles in newspapers.

"This would be tantamount to a driving tax. The only way to get less CO_2 (carbon dioxide) released into the atmosphere is to combust less fuel," said Eron Shosteck, a spokesman for the Alliance of Automobile Manufacturers. To many Californians, that would mean driving a sub-compact instead of an SUV, he said. "I don't think a lot of soccer moms in Marin County would appreciate that." Nearly half, 47%, of passenger vehicles sold in the nation's most-populous state are SUVs, mini-vans or light trucks.

> *The proposed law would require the state's Air Resources Board to adopt, by 2005, regulations that would achieve "the maximum feasible reduction" in emissions of greenhouse gases, including carbon dioxide, emitted by cars and light-duty trucks, the category that includes sport utility vehicles.*
>
> *The bill was introduced by Fran Pavley, a state assembly member representing Woodland Hills, a suburb north of Los Angeles. It was passed by the Assembly and will be heard by the state Senate's appropriations committee on April 29.*
>
> *If the bill becomes law, the regulations would not take effect until at least Jan. 1, 2006.*
>
> *"Because CO_2 has not been considered a major pollutant, it has been the purview of the federal government," said Jerry Martin, a spokesman for the state's air board. "But the (Bush) Administration has not endorsed the Kyoto agreement so there are no regulations that specify CO_2 levels."*
>
> *"It is silly that Californians would pay the price for a global problem," one auto company representative said. "The bill is too broad and too vague." The bill's sponsors, however, say global warming presents unique risks for the state including potential reductions in water supplies and a projected doubling of catastrophic wildfires.*

(Story by Deena Beasley, REUTERS NEWS SERVICE)

> *California Governor Gray Davis plans to sign a bill into law today that environmentalists say will reduce global warming and that the auto industry says is a camouflaged attempt to regulate fuel economy, something only the federal government legally can do.*
>
> *The auto industry is expected to sue to stop enforcement of the law, citing the fuel-economy argument. Automakers already have temporarily halted full enforcement of California's zero-emissions, electric-car mandate by convincing a federal judge that parts of it amount to back-door fuel-economy regulation.*
>
> *The new law directs the California Air Resources Board (CARB) to come up with rules by the end of 2005 that "achieve the maximum feasible reduction of greenhouse gases" beginning in 2009. The main greenhouse gas is carbon dioxide, and the only way to reduce emissions of it is to burn less fuel.*
>
> *"By and large, it's true" that increasing fuel economy is the way to decrease carbon dioxide, acknowledges Jon Coifman, spokesman for the Natural Resources Defense Council. "But our argument is that by whatever means they choose to meet the standard, it's a tailpipe standard, and California absolutely has the right to regulate it."*

> *Environmental groups say cutting fuel consumption should be easy using "off-the-shelf" parts and technologies that don't require expensive, lengthy development. Among them: overhead-camshaft engines instead of old-tech, push-rod designs; low-rolling-resistance tires; and continuously variable transmissions (CVTs). But real-world experience is more complex. Ford Motor, for instance, uses sophisticated, overhead-camshaft V-8 engines in its big sport-utility vehicles and pickups. But those typically get worse, not better, fuel economy than General Motors' push-rod V-8s. Current CVTs aren't made for more-popular and less-fuel-efficient trucks. Truck CVTs would make the biggest difference the most quickly. When CVTs are tuned for best fuel economy, tests show, consumers don't like how they drive. When tuned to satisfy consumers, they do little for fuel economy.*

(By James R. Healey, *USA TODAY*)

3.7 CAFE and Fuel consumption

The long-term development of fuel consumption of US automobiles presents a dismal picture (see chapter 2). The decline in fuel efficiency is linked to the increasing sales of SUVs, vans and pick-up trucks. These cars consume much more fuel than standard passenger cars. SUVs consume more fuel because they are both heavier and less aerodynamic than the average passenger car.

In response to the oil crises of the 1970s, the US Congress faced intense domestic pressure to reduce the nation's dependence on oil. In response to these pressures, Congress created the CAFE standards, which, beginning in the 1978 model year, set the average fuel economy standard for all cars produced at 18 miles per gallon. Since 1990 the requirement for passenger cars has been 27.6 mpg and 20.7 mpg for a light truck. If a manufacturer's vehicles fall below this standard, it faces a penalty of $5.00 for every tenth of a mile per gallon that its vehicles fall short, multiplied by the number of vehicles the manufacturer sold in the United States.[10] While it is debatable if this is the best policy to pursue in order to reduce national fuel consumption[11], it has motivated American car manufacturers to produce more fuel-efficient vehicles.

The EU viewed CAFE as blatantly discriminatory move against European automobile exports. Nearly all vehicles turned out by Jaguar, BMW, Volvo, Saab, Mercedes Benz, Rolls-Royce and Porsche are high-end products with relatively low mileage per gallon. Unlike their US and Japanese competitors, these auto-makers had few smaller, more fuel-efficient vehicles to bring up their corporate average fuel economy. In 1991, although the European manufacturers' cars accounted for only 4% of US sales, they paid 100% of CAFE penalties.[12] In 1983 Jaguar missed the CAFE standard by seven miles per gallon and was required to pay a penalty of $350 for each car it sold.[13] Between 1985 and 1989 Jaguar paid CAFE penalties totalling $27 million, BMW paid $32

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[10] David Vogel, Barrier or Benefits Regulation in International Trade (Washington DC: Brookings Institute Press, 1997) pp. 38

[11] David Vogel, "Social Regulations as Trade Barriers", *The Brookings Review*, Winter 1998, pp. 33.

[12] J. Friffiths, "Fuel economy rule may hit Jaguar", *The Financial Times*, February 28, 1983, pp. 1.

[13] David Vogel, supra note 33, pp. 34.

million, and Mercedes-Benz paid $85 million.[14] As a result of these fines, the EU requested the convening of a dispute settlement panel to determine if CAFE, and two other automobile taxes were GATT-compliant.[15] (by Dedric Mortelmans, University of Washington)

CAFE regulation forces SUV manufacturers to produce lighter compact vehicles because even in the CAFE regulation for light trucks the manufacturers must produce a mix of vehicles that meet the standard. The CAFE (Corporate Average Fuel Economy) standard for automobiles is 27.5 mpg in 2002 and 20.7 mpg for light trucks. The purpose of these relaxed fuel economy requirements for light trucks is to benefit small businesses that use trucks in their business. In the late 1990s, however, most SUVs (84%) and pick-up trucks (74%) were being used mainly for personal transportation. (Davis and Truett, 2000).

Changes in the CAFE standards are also discussed in Washington. The Federal Government has rejected a proposed 50% boost in fuel efficiency for gas-guzzling cars and SUVs. In a press release from the Alliance of Automobile Manufacturers of February 15 2002, the car industry urged the Senate to avoid passing energy legislation that would effectively eliminate SUVs, mini-vans and pick-up trucks. The industry suggested that the fuel economy standards should consider “technological feasibility, cost, safety, emissions controls, consumer choice and effects on American jobs. Automakers oppose legislative increases in fuel economy standards.” (http://www.autoalliance.org/pressreleases/pr021502.htm)

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[14] Roger 1. Crain, "EC Not Quite Unified Yet..." *Global Trade and Transportation*, April 1993,pp.10.

[15] "US Auto Fuel-Efficiency Taxes to be Examined by GATT Panel", *News and Views from the GATT*, June 3,1993,pp.4. and "US Blocks EC Bid for GATT Dispute Panel on Car Tax", *Reuters European Business Report*, March 24,1993,pp.1.

Table 3.7-1 : Fuel economy standards for passenger cars and light-duty trucks, model years 1978 through 2002 (in mpg)

		Light Trucks (1)		
Model Year	Passenger Cars	Two-wheel Drive	Four-wheel Drive	Combined (2), (3)
1978	18.0(4)	...	...	...
1979	19.0(4)	17.2	15.8	...
1980	20.0(4)	16.0	14.0	...(5)
1981	22.0	16.7(6)	15.0	...(5)
1982	24.0	18.0	16.0	17.5
1983	26.0	19.5	17.5	19.0
1984	27.0	20.3	18.5	20.0
1985	27.5(4)	19.7(7)	18.9(7)	19.5(7)
1986	26.0(8)	20.5	19.5	20.0
1987	26.0(9)	21.0	19.5	20.5
1988	26.0(9)	21.0	19.5	20.5
1989	26.5(10)	21.5	19.0	20.5
1990	27.5(4)	20.5	19.0	20.0
1991	27.5(4)	20.7	19.1	20.2
1992	27.5(4)	...	...	20.2
1993	27.5(4)	...	...	20.4
1994	27.5(4)	...	...	20.5
1995	27.5(4)	...	...	20.6
1996	27.5(4)	...	...	20.7
1997	27.5(4)	...	...	20.7
1998	27.5(4)	...	...	20.7
1999	27.5(4)	...	...	20.7
2000	27.5(4)	...	...	20.7
2001	27.5(4)	...	...	20.7
2002	27.5(4)	...	...	20.7

1. Standards for MY 1979 light trucks were established for vehicles with a gross vehicle weight rating (GVWR) of 6,000 pounds or less. Standards for MY 1980 and beyond are for light trucks with a GVWR of 8,500 pounds or less.
2. For MY 1979, light truck manufacturers could comply separately with standards for four-wheel drive, general utility vehicles and all other light trucks, or combine their trucks into a single fleet and comply with the standard of 17.2 mpg.
3. For MYs 1982-1991, manufacturers could comply with the two-wheel and four-wheel drive standards or could combine all light trucks and comply with the combined standard.
4. Established by Congress in Title V of the Motor Vehicle Information and Cost Savings Act.
5. A manufacturer whose light truck fleet was powered exclusively by basic engines which were not also used in passenger cars could meet standards of 14 mpg and 14.5 mpg in MYs 1980 and 1981, respectively.
6. Revised in June 1979 from 18.0 mpg.
7. Revised in October 1984 from 21.6 mpg for two-wheel drive, 19.0 mpg for four-wheel drive, and 21.0 mpg for combined.
8. Revised in October 1985 from 27.5 mpg.
9. Revised in October 1986 from 27.5 mpg.
10. Revised in September 1988 from 27.5 mpg.

3.8 Specific country initiatives

3.8.1 Introduction

Apart from the legislation on overall levels (such as found in the USA or EU), countries can also take specific measures to introduce certain technologies or fuels.
The most successful has been the introduction of ethanol vehicles in Brazil. This will be discussed later.

Other measures had less impact than the Brazilian experience, but nevertheless had some success. Some examples include:

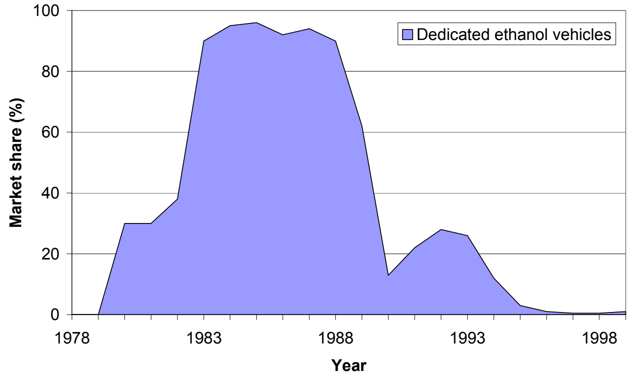
- Natural gas in Italy.
- LPG in the Netherlands.
- Gasohol in the USA.
- Biodiesel in Austria, Germany and France.
- Electric vehicles in California.

3.8.2 Ethanol in Brazil

As a reaction to the oil crisis in 1973, the Brazilian Government created the Brazilian National Alcohol Program (PROALCOOL) in 1975 to regulate the ethanol market and encourage the production and use of fuel ethanol from Brazilian sugar cane.
To start the programme, the government made the use of alcohol vehicles mandatory in its official fleet. To attract new consumers and manufacturers, tax incentives were created. The price for alcohol were set as a fixed percentage of regular gasoline, so that the fuel bill for alcohol would be less than that of a gasoline-powered car for similar use.
The first alcohol vehicles were manufactured in 1979. As the main technical problems were solved, sales of these vehicles boomed. Market penetration averaged 92% between 1983 and 1988. Alcohol production (anhydrous and hydrated) rose from 0.5 million m^2/yr in the late 70’s to 15 million m^2/yr in 1987. Gasoline dropped sharply until 1990, when alcohol sales (on an energy basis) were equivalent to gasoline sales. By 1990 more than five million alcohol-fuelled vehicles were in circulation and represented an estimated 50% of the fleet.
An ethanol shortage in 1989 reduced the confidence of customers, with a steep reduction of market penetration to an average of 30% until 1993. In 1994 market penetration dropped to 12% and from there on sales dwindled to less than 1%.
Sales of hydrated ethanol in Brazil peaked in 1992 at 10 million m^3, declining to 5.1 million m^3 in 2000. Sales of hydrated alcohol have continued to fall, since 200,000 to 300,000 alcohol vehicles are scrapped each year and only 10,000 new ones were sold in the year 2000. In 2001, there were still 3.7 million older ethanol vehicles in circulation and the distribution network is still in place.

The reduction in hydrated ethanol has in part been compensated for by increasing demand for anhydrous alcohol, which can be blended up to a proportion of 24% with gasoline. Until 1997, the rapidly increasing new fleet of gasoline vehicles and a policy of increasing the percentage of alcohol in the blend with gasoline, increased total alcohol consumption until 1997, but it then declined 20% to less than 12 million m³ in 2000 [Buarque de Holanda & Dougals Poole, 2001].

Figure 3.1: Market share (of total vehicle sales) of dedicated ethanol vehicles in Brazil



Source: Buarque de Holanda & Dougals Poole, 2001

PROALCOOL was never formally terminated, but from 1998 subsidies were gradually extinguished and alcohol prices were set to fluctuate with the market.

3.9 References

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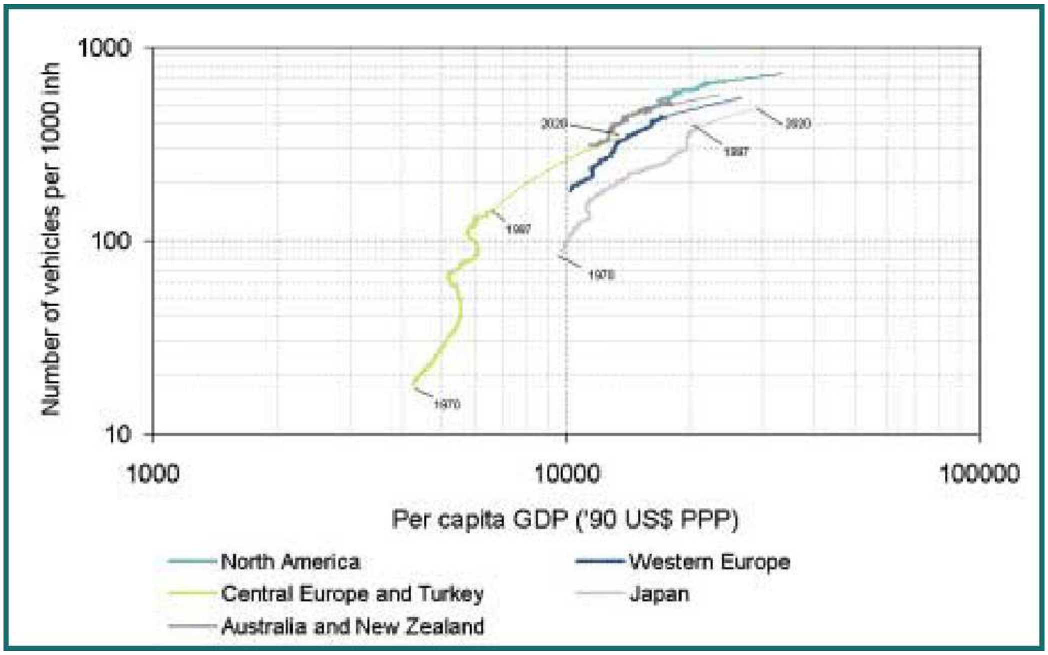
4 DRIVING FACTORS AFFECTING THE DECISIONS ON THE PURCHASING, SUBSTITUTING AND SCRAPPING OF CARS

by Panayotis Christidis, IPTS

4.1 Introduction

The decision to buy, substitute or scrap a passenger car is a choice made by each individual on the basis of various financial, socio-economic and technological parameters. Car ownership is an important element of modern society and its level often reflects a country’s average income and underlying consumption patterns. Although the degree may vary depending on local conditions, there is an evident correlation between car ownership and per capita income that has been consistent in the past and is expected to remain so in the future (Figure 4.1). The relevant literature generally suggests that aggregate car ownership levels increase with income until they reach a saturation level, when the income elasticity of car ownership falls to zero [Greenspan and Cohen (1996), Dargay and Gately (1999), Schafer and Victor (2000), Medlock and Soligo (2002)]. Saturation levels for Western Europe and North America are estimated to range between 600 and 700 passenger cars per 1000 inhabitants. Such levels would mean that the majority of holders of driving licences who can afford to own a car actually own one (or more).

Figure 4.1: Vehicle ownership and per capita GDP: past trends and projections



Source: Landwehr and Marie-Lilliu (2002)

4.2 Car purchase

At an individual level, the decision to buy a car depends on household income and utility, and can be compared with the purchasing behaviour demonstrated for typical durable goods. In general terms, the majority of households buy at least one passenger car if their finances permit it, and replace older cars for newer ones - if they can afford it - in order to increase performance, reduce maintenance costs, or just enjoy the feeling of buying a new car. The household's income is the main determinant for the purchasing decision and the chances of buying a car increase when income increases. On the other hand, the price of the car, as well as the cost of using and maintaining it, act as inhibiting factors. An example of how these three variables, i.e. household income, fixed costs and variable costs, influence car ownership is given in Table 4.2-1. Country-specific parameters also affect the extent of the impact of each variable. Differences in urbanisation or the quality of public transport may explain different behaviour in different countries. People living in metropolitan areas with good public transport services do not need a car as much as people living in rural areas.

Table 4.2-1: Income, variable cost and fixed cost elasticity of car ownership

	Norway	Denmark	Holland
Income	+0.33	+0.41	+0.15
Variable costs	-1.33	-0.78	-0.41
Fixed costs	-2.65	-1.29	-0.80

Source: Bjorner (1999)

Demographics and lifestyles also play an important role. Households that own a second or third car are becoming frequent. The increased participation of women in the workforce over the last 30 years (and the additional income they bring to the household) has largely contributed to the increase in car ownership. In addition, the fact that a larger proportion of the younger generation holds a driving licence, a phenomenon even more evident for women, suggests that a larger number of potential car buyers exists today than did 10 or 20 years ago. As surveys from France and the UK show, the gaps between generations, which have been important in the past, have been smoothed out for households whose head was born since the 1940s, implying that the diffusion of car ownership over generations is nearing completion [Dargay, Madre et al. (2000)].

Figure 4.2: Households with regular use of car, UK

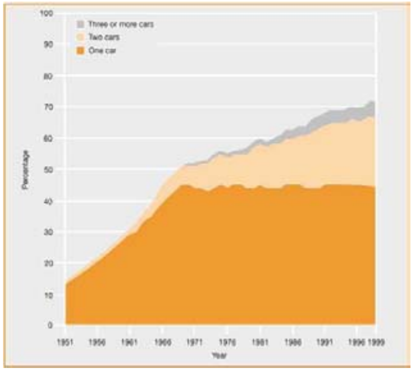
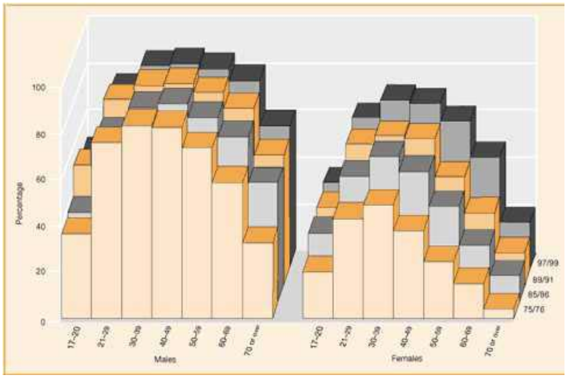


Figure 4.3: Driving licence holders statistics, UK



Source: DETR (2001)

New car purchases at an aggregate level correspond to the sum of the effect of the change in car ownership levels plus the substitution of cars that are removed from the car park (scrapped or exported as used cars). This implies that the overall car ownership level of a country is determined by the average income, the extent to which car ownership levels are saturated, and country-specific parameters related to urbanisation and transport patterns. A number of cars are also removed each year, being too old or too expensive to maintain. New car registrations represent the cars bought by individuals who did not own a car before (because they did not need or want one, or because they could not afford one, or because they were too young to have a driving licence), and the cars bought in order to replace a car that was scrapped.

The type of car purchased depends on numerous variables, not all of them quantifiable. Purchase and use costs are certainly important parameters, and probably provide a reliable indicator of market segmentation: high-price cars are bought by high-income households, low-income households are more sensitive to price differences, etc. There are, however, numerous non-economic factors that influence the type of car the individual consumer buys. Such factors may include the prestige associated with a certain brand or car size, fashion or lifestyle trends, advertising and marketing, and technological progress itself. The combination of the above factors in the last decade has resulted in a highly fragmented car market with strongly connected segments.

The share of the small and lower-medium segments has increased, probably as a result of the gradual fall of car prices compared with lower and medium income levels (Table 4.2-2). The fact that more young drivers and women buy cars, combined with the increasing number of second and third cars in one household, is probably the main reason. But issues such as congestion, the lack of parking space in urban areas or the increasing environmental concerns of consumers could also be drivers in the trend toward smaller cars. The introduction of modern small cars such as Smart or Mercedes A1 can be seen as either a trend-setter or, from the opposite point of view, as the reaction of auto manufacturers to the trends in society. Consumer tastes have also changed concerning body type. Saloons dominated the market in 1995, but newer car designs are rapidly increasing their share in consumer preferences. The trend towards more Sport Utility Vehicles (SUVs) that was impressive in the USA over the last decade seems to be taking off in Europe too. The share of another special category, 4x4 passenger cars, has doubled in the last 10 years, reaching 5% of sales in 2001 [ACEA (2002)].

Table 4.2-2: New cars in EU 15 by segments and bodies

Years	Passenger cars in EU-15: breakdown by segments							Passenger cars in EU-15: breakdown by bodies							
	Total Market	Small	Lower-Medium	Upper-Medium	Executive	Others	Unknown	Total Market	Saloons	Estates	Coupes	Convertibles	Mono-spaces	Others	Unknown
2001	14,418,763	32.8	33.8	15.9	12.6	4.9	0.1	14,418,763	66.2	12.1	1.9	1.9	2.3	15.6	0.1
2000	14,312,085	32.7	34.2	15.7	12.7	4.6	0.1	14,312,085	67.5	12.6	2.2	1.5	2.3	13.8	0.1
1999	14,635,183	31.3	33.9	17.8	12.5	4.5	0.1	14,635,183	71.5	14.4	2.2	1.4	5.8	4.6	0.1
1998	13,933,908	31.1	33.2	18.9	12.9	3.8	0.1	13,933,908	73.4	14.4	2.0	1.5	4.6	3.9	0.1
1997	13,007,766	32.6	31.6	19.3	13.2	3.2	0.1	13,007,766	75.8	13.0	1.9	1.7	4.0	3.5	0.1
1996	12,403,108	32.3	32.3	18.8	13.6	2.9	0.2	12,403,108	79.3	11.1	2.1	1.4	2.5	3.5	0.2
1995	11,631,823	32.9	31.4	18.7	14.0	2.9	0.1	11,631,823	80.6	10.6	2.2	1.3	1.7	3.5	0.1
1994	11,568,008	31.9	31.6	20.0	13.1	2.7	0.7								
1993*	11,126,839	31.1	28.0	32.5	12.7	3.0	0.7								
1992*	13,150,203	31.6	30.7	21.7	12.5	2.7	0.8								
1991*	13,137,494	32.2	27.9	22.9	13.2	2.6	1.2								
1990*	13,165,421	30.4	27.7	22.9	13.0	2.4	2.7								

source: ACEA (2002)

Consumers demonstrate a strong tendency towards cars of higher performance (Table 4.2-3). Aided by the relative drop in car and fuel prices compared with average income which is accompanied by (and, to a large extent, driven by) improvements in car technology and fuel efficiency, the average power of new cars has risen dramatically during the last decade. Another important factor for this trend is the fact that a large share of new car sales is in fact a replacement of the car that the individual owned before. Consumers tend to upgrade cars; they often sell or scrap their old car in order to buy a larger, faster or more expensive one. This results in an increased cost for the consumer that cannot be explained in strict economic terms. The utility of a car with improved performance, probably better than that actually needed, cannot be measured, since it depends on each consumer's perceived needs and choices.

The type of engine and/or fuel used seems to be a secondary decision. Since only two real alternatives exist today, i.e. gasoline and diesel fuelled internal combustion engines, the individual's choice depends largely on price, performance and use costs. As diesel technology has made great improvements in the last 10 years in terms of performance, fuel efficiency and environmental impacts, the share of diesel fuelled sales has risen from less than 14% in 1990 to more than 35% in 2001. Except for some limitations for diesel cars in urban areas (e.g. in Greece), and the still limited supply of a full range of diesel models (e.g. Japanese cars or smaller models), there doesn't seem to be any other differentiating factor between gasoline and diesel cars of comparable performance, apart from cost. The same cannot be easily said, however, about emerging technologies such as electric cars, fuel cells or car fuelled by natural gas or bio-fuels. Whereas gasoline and diesel are established fuels, and the internal combustion engine is a proven technology, the emerging alternatives still lag in terms of maturity, infrastructure and fuel availability, safety and public perception, and are not yet considered as alternatives by consumers. Whether they will eventually become such, when their cost falls to competitive levels, remains an open question.

Table 4.2-3: Average engine power of new cars

Average Power (KW)	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001
AUSTRIA	62	64	64	63	63	63	65	66	69	71	73	76
BELGIUM	57	58	60	61	62	62	64	64	66	66	68	73
DENMARK	63	66	66	67	66	67	69	71	72	73	74	77
FINLAND												
FRANCE	54	54	54	56	55	55	56	60	61	63	65	71
GERMANY	67	66	67	68	69	69	71	73	76	78	81	83
GREECE												
IRELAND	51	53	54	58	58	58	58	58	62	62	63	68
ITALY	52	54	54	54	57	59	61	58	59	62	63	65
LUXEMBOURG	65	58	69	71	73	74	75	77	80	81	83	87
NETHERLANDS	58	60	61	62	63	64	65	67	67	68	70	76
PORTUGAL	47	49	50	51	50	52	54	57	59	60	62	64
SPAIN	58	61	63	61	58	58	60	61	63	65	67	69
SWEDEN	80	83	86	88	90	91	90	89	89	91	92	101
UNITED KINGDOM	63	63	64	64	65	67	69	71	73	74	74	78
EUROPEAN UNION (15)						63	65	66	68	70	71	75
ICELAND												
NORWAY										75	77	82
SWITZERLAND	80	83	84	84	85	87	87	89	91	93	95	99
EFTA						87	87	89	91	89	90	95
WEST. EUROPE	60	61	61	62	63	64	65	67	68	70	71	75

source: ACEA (2002)

Table 4.2-4: New passenger car registrations in Western Europe, Jan-Oct 2002

		Country	JAN	FEB	MAR	APR	MAY	JUN	JUL	AUG	SEP	OCT	YTD
		PC-Passenger Cars											
EU (15)	EC (12)	B	55.872	52.611	52.851	51.858	40.912	37.632	34.850	26.145	31.678	37.702	422.111
		DK	7.075	8.132	10.240	10.030	11.889	11.204	9.190	8.858	8.752	8.770	94.140
		F	192.089	173.064	198.302	207.891	186.265	200.835	199.321	121.781	153.069	188.209	1.820.826
		D	243.400	233.281	321.840	304.326	282.632	308.450	282.560	244.287	266.005	281.059	2.767.840
		GR	27.021	21.403	23.348	29.365	23.403	23.003	29.109	19.310	21.154	21.065	238.181
		IRL	31.075	24.173	18.814	15.482	18.456	11.724	12.468	8.742	6.348	5.075	152.357
		I	248.300	197.200	205.500	191.300	209.100	180.300	202.400	101.300	165.200	190.600	1.891.200
		L	3.368	4.713	5.278	5.276	4.068	3.779	3.782	2.191	2.798	3.565	38.818
		NL	70.838	42.523	47.046	40.361	44.728	46.953	39.907	36.261	40.908	43.173	452.698
		P	18.960	19.831	23.476	18.892	25.968	24.030	25.450	13.566	13.737	15.353	199.263
		E	95.946	105.271	127.211	112.851	127.698	125.734	152.945	79.416	80.812	111.783	1.119.667
		UK	205.476	93.515	423.727	208.976	208.669	207.330	195.637	87.245	432.661	184.145	2.247.381
		EC (12)	**1.199.420**	**975.717**	**1.457.633**	**1.196.608**	**1.183.788**	**1.180.974**	**1.187.619**	**749.102**	**1.223.122**	**1.090.499**	**11.444.482**
		A	23.291	20.398	29.666	30.320	26.295	25.904	26.260	18.813	21.402	24.388	246.737
		SF	12.132	8.446	9.519	11.066	12.709	10.866	10.287	10.221	8.985	9.719	103.950
		S	16.293	18.848	22.936	24.311	24.617	22.861	17.410	18.618	22.101	23.249	211.244
		Efta (3)	**51.716**	**47.692**	**62.121**	**65.697**	**63.621**	**59.631**	**53.957**	**47.652**	**52.488**	**57.356**	**561.931**
	total	EU (15)	**1.251.136**	**1.023.409**	**1.519.754**	**1.262.305**	**1.247.409**	**1.240.605**	**1.241.576**	**796.754**	**1.275.610**	**1.147.855**	**12.006.413**
EFTA (3)		IS	423	418	410	530	906	1.081	725	567	474	0	5.534
		N	7.386	7.024	7.068	8.833	7.912	7.324	8.724	7.273	6.985	8.089	76.618
		CH	22.001	21.754	28.087	29.947	29.668	29.396	26.686	19.803	21.348	22.827	251.517
	total	Efta (3)	**29.810**	**29.196**	**35.565**	**39.310**	**38.486**	**37.801**	**36.135**	**27.643**	**28.807**	**30.916**	**333.669**
total		*Total*	*1.280.946*	*1.052.605*	*1.555.319*	*1.301.615*	*1.285.895*	*1.278.406*	*1.277.711*	*824.397*	*1.304.417*	*1.178.771*	*12.340.082*

Source: Association Auxiliaire de l'Automobile

Table 4.2-5: Passenger car sales by region

Year	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000
Western Europe	13233	13500	13497	11450	11934	12021	13083	13138	14038	15049	14742
NAFTA	10532	9466	9449	9653	10154	9424	9390	9333	9357	10023	N/a
Japan	5103	4868	4454	4200	4210	4444	4669	4492	4093	4154	4260
Asia (excl Japan)	1994	2086	2355	2853	2972	3267	3533	3599	2468	3333	1063
Eastern Europe	1995	1697	1731	1654	1560	1533	1729	1906	1820	1900	N/a
Other Markets	1730	1775	1989	2344	2617	2970	3088	3423	3012	2706	N/a
Total	**34587**	**33392**	**33475**	**32154**	**33447**	**33659**	**35492**	**35891**	**34788**	**37165**	**N/a**

Source: Economist Intelligence Unit

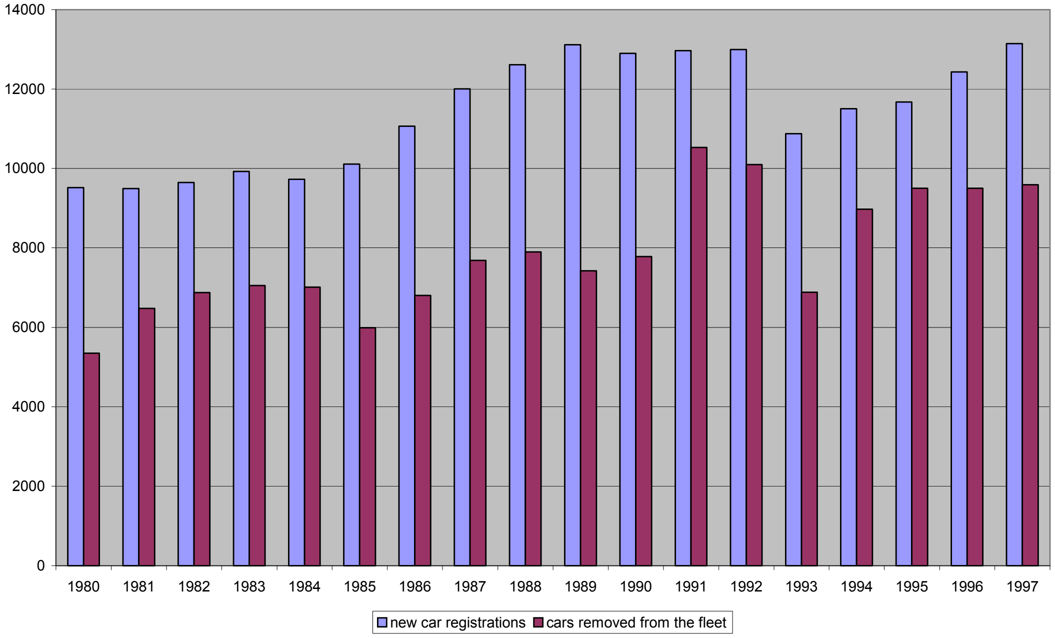
4.3 Car scrapping

Car scrapping refers to the case of a car being removed from circulation. This can be the consequence of one or more of the following:

- The car is not usable any more (e.g. because of mechanical problems or as a result of an accident).
- The car is too expensive to use or maintain: other options such as buying another car or owning no car at all are more attractive for the owner, and no other buyer can be found.
- The car is sold in another country as a used car: this case has more to do with statistics rather than with actual scrapping, but it also implies that the perceived value of the used car in the country of origin is lower than in the destination.
- Specific regulations or measures prohibit the use of a specific type or age-group of cars, or stimulate the early retirement of older vehicles.

In all of the above cases, the underlying variables are the cost of use and the remaining value of the car. A micro-economic approach modelling the decision to buy or scrap a car was used in Adda and Cooper (1997) in order to estimate the impacts of car-scrapping subsidies in France. Individuals are assumed to have a certain utility from buying or scrapping a car, and a change of the relative costs through government intervention greatly affects the overall car market, accelerating the speed of replacement when scrapping subsidies are given. The models used by Alberini, Harrington et al. (1998) simulate the owner's decision to keep, repair or scrap their old vehicles. This decision depends critically on the owner's perceived value of the vehicle that, in turn, depends on the mileage and condition of the car, and declines systematically with its age. Greenspan and Cohen (1996) divide scrapping into two types, engineering scrapping and cyclical scrapping. Engineering scrapping results mainly from age-dependent physical wear and tear, while cyclical scrapping is a result of business cycles. The non-engineering component of scrapping also depends on the price of gasoline, the price of new vehicles and on the cost of repairs. An increase in their price delays the purchase of new vehicles and the scrapping decision, while a reduction in the cost of repairs encourages increased repair of vehicles and less scrapping. The price of new vehicles relative to repair costs is considered as significant in explaining total scrapping.

Figure 4.4: New car registrations versus scrapped cars, EU-15



source: IPTS

Table 4.3-1: Vehicle scrapping and recycling in the UK

		1997	1998	1999	2000
Number of End of Life Vehicles				(est.)	
	Cars	1700000	1600000	1600000	1832431
	Vans	200000	200000	200000	184706
	Total	1900000	1800000	1800000	2017137
Average weight of vehicle (kg)		1025	1030	1030	1030
Weight of vehicles for disposal		1947500	1854000	1854000	2078000
Re-use and recovery percentage		76%	74%	77%	80%

Source: SMMT

Table 4.3-2: Estimates of number of vehicles scrapped

Country	Sector	TRENDS/RT deregistered vehicles	Müller 1994 scrapped vehicles	percentage	
B	Buses	2094	496	24%	
B	Heavy Duty Vehicles	13856	51	0%	
B	Light Duty Vehicles	19228	16859	88%	
B	Motorcycles	18636	6571	35%	
B	Passenger Cars	405394	274546	68%	
D	Buses	9835	3795	39%	
D	Heavy Duty Vehicles	96689	57988	60%	
D	Light Duty Vehicles	117313	70304	60%	
D	Motorcycles	280921	76160	27%	
D	Passenger Cars	1968036	2147133	109%	*)
DK	Buses	983	377	38%	
DK	Heavy Duty Vehicles	14188	9484	67%	
DK	Light Duty Vehicles	18320	12268	67%	
DK	Motorcycles	10517	1230	12%	
DK	Passenger Cars	128405	88932	69%	
E	Buses	2633	1768	67%	
E	Heavy Duty Vehicles	13049	8255	63%	
E	Light Duty Vehicles	66840	42391	63%	
E	Motorcycles	139942	14596	10%	
E	Passenger Cars	593879	341224	57%	
F	Buses	7718	3483	45%	
F	Heavy Duty Vehicles	51883	45771	88%	
F	Light Duty Vehicles	265745	235034	88%	
F	Motorcycles	194856	85736	44%	
F	Passenger Cars	1568162	1607248	102%	*)
GR	Buses	487	243	50%	
GR	Heavy Duty Vehicles	826	780	94%	
GR	Light Duty Vehicles	3303	3121	95%	
GR	Motorcycles	4714	1161	25%	
GR	Passenger Cars	17784	21564	121%	*)
I	Buses	382	3249	852%	**)
I	Heavy Duty Vehicles	5849	29382	502%	**)
I	Light Duty Vehicles	4026	48762	1211%	**)
I	Motorcycles	3439	110107	3202%	**)
I	Passenger Cars	63696	956722	1502%	**)
IRL	Buses	4636	45	1%	***)
IRL	Heavy Duty Vehicles	41851	7349	18%	***)
IRL	Light Duty Vehicles	69315	5064	7%	***)
IRL	Motorcycles	295574	3113	1%	***)
IRL	Passenger Cars	1328675	52108	4%	***)
L	Buses	83	21	25%	
L	Heavy Duty Vehicles	1752	1	0%	
L	Light Duty Vehicles	465	127	27%	
L	Motorcycles	1063	238	22%	
L	Passenger Cars	18341	12937	71%	
NL	Buses	1828	421	23%	
NL	Heavy Duty Vehicles	63800	22340	35%	
NL	Light Duty Vehicles	539	22340	4144%	****)
NL	Motorcycles	39833	6570	16%	
NL	Passenger Cars	505493	386195	76%	
P	Buses	287	155	54%	
P	Heavy Duty Vehicles	1500	10117	674%	*****)
P	Light Duty Vehicles	1668	11226	673%	*****)
P	Motorcycles	16865	138	1%	*****)
P	Passenger Cars	31349	11296	36%	
UK	Buses	9864	4674	47%	
UK	Heavy Duty Vehicles	48965	61093	125%	*)
UK	Light Duty Vehicles	195824	244369	125%	*)
UK	Motorcycles	67649	104135	154%	*)
UK	Passenger Cars	1620850	1419677	88%	

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*) Impossible figure.

**) Deregistrated vehicles for Italy from TRENDS/RT possible too low by factor of 10-40.

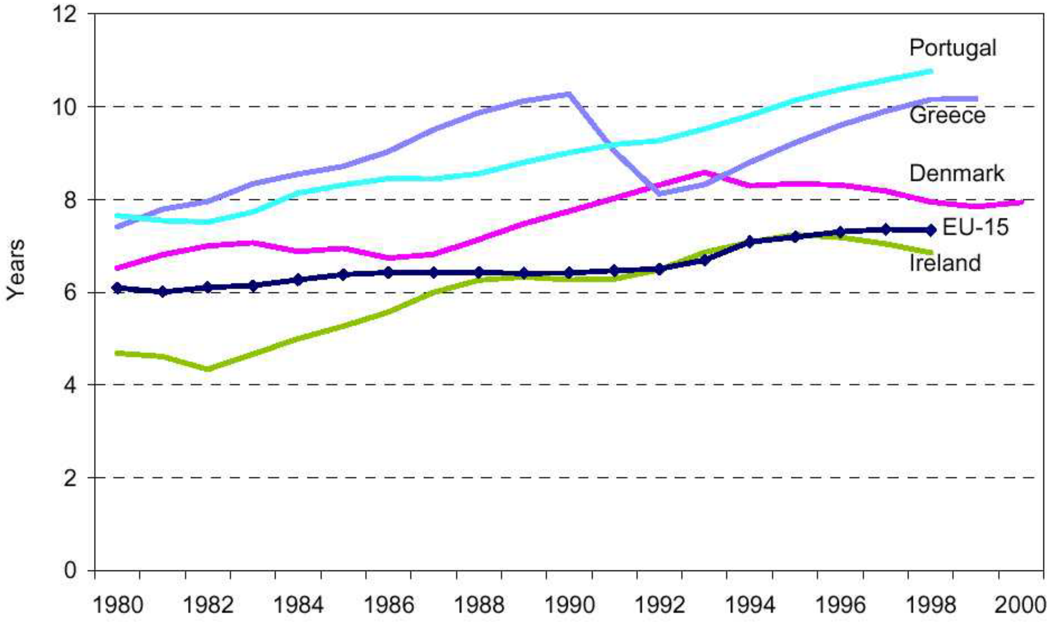
***) Figures for Ireland from TRENDS/RT too high with regard to population.

****) Deregistrated LDV from Holland from TRENDS/RT too low by approx. a factor of 100.

*****) Deregistrated HDV+LDV from Portugal too low, MC too high by a factor of approx. 10

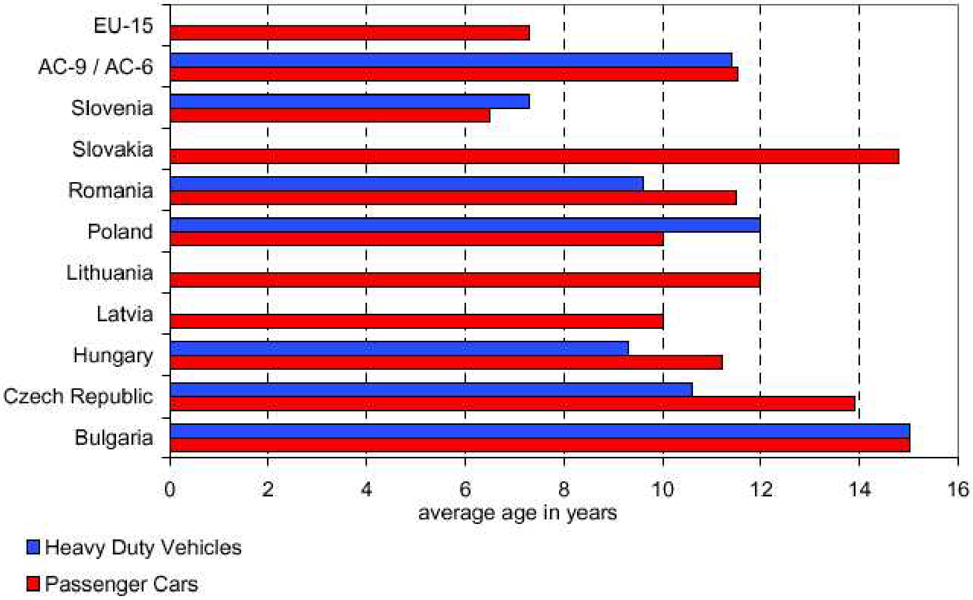
Source: LAT (2002)

Figure 4.5: Average age of passenger cars, EU



source: EEA, Eurostat

Figure 4.6: Average age of passenger cars and heavy-duty vehicles, accession countries (AC)



Source: EEA

4.4 Used cars

An intermediate phase between the purchase of a new car and its eventual scrapping is the sale of the car as a used car. The same principles apply in this case for the buyer and seller of a used car. The buyer may be a first-time buyer (usually young), or somebody replacing an even older car, who can not afford (or does not consider it worth the cost) to buy a new car of similar characteristics. The fact that the various segments of the car market are strongly connected also means that some buyers prefer to buy a larger second-hand car than a smaller new car. From the seller's point of view, in the majority of cases the sale of a car is related to the purchase of a newer and/or larger car.

Statistics at an EU level show that the used car market is very active, and in most cases larger than that for new cars (Table 4.4-1). In the UK and the Netherlands in particular, the figures suggest that the average car should be expected to change owner at least four times before it is finally removed from circulation. Data from the UK shows that although older cars form the larger part of the used-car market, a significant number are less than two years old.

The factors that influence the dynamics of the used-car market are to a large extent cyclical. New-car prices, parallel imports, interest rates, insurance costs, emission-related taxes, warranty regulations, as well as the EU guarantees legislation and the ELV recycling legislation affect the price and the attractiveness of used cars. In addition, the behaviour of company cars and rental fleets influences the supply of second-hand cars, while the distribution structure of both new and used cars influences the market's operation. Demographics still play a role, with car driver profiles and buying behaviour largely affected by age and income.

Table 4.4-1: Used car sales in various EU countries

	Used car sales (m)	Used car sales per 1000 population	Used/new car sales ratio
UK	7.5	126	3.3
Germany	7.4	91	2.0
France	4.7	80	2.4
Italy	2.2	38	0.9
Netherlands	1.7	110	3.2
Spain	1.4	35	1.2
Belgium	0.7	63	1.4
Portugal	0.5	49	1.9
Denmark	0.4	67	2.2
Sweden	0.3	30	1.1
Norway	0.3	77	2.4

Source: UKCC (2000)

Table 4.4-2: Passenger car registrations in France ('000s)

Year	1985	1990	1995	2000	2001
New cars	1766	2309	1931	2134	2255
Used cars	4803	4759	4129	5082	5396

Source: METLTM

Table 4.4-3: First time passenger car registrations in Ireland

Year	**1997**	**1998**	**1999**	**2000**	**2001**
New cars	125818	138538	170322	225269	160908
Used cars	41554	39565	36878	24003	15237

Source: CSO

Table 4.4-4: Car sales in the USA

Year	**1990**	**1995**	**1997**	**1998**	**1999**	**2000**
New cars (000s)	13890	14730	15130	15600	16960	17410
Used cars (000s)	37530	41758	41240	40840	40740	41620
Av. price new (US$)	16350	19819	20214	20276	20534	21850
Av. price used (US$)	5830	7776	8164	8213	8674	8715

Source: CNW

Table 4.4-5: Breakdown of the volume of used car sales by age of car, UK, 1998

Age of used cars (years)	**%**
0-2	13.2
3-5	22.3
6-8	19.5
9 and over	45.1
Total	100.0
Volume (m)	7.5

Source: UKCC (2000)

4.5 References

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5 UNDERLYING FACTORS OF DIESELIFICATION AND INCREASE OF SUVs

5.1 The Introduction of Diesel Engines in Cars

by Robin Cowan, Staffan Hultén and Nassef Hmimda, MERIT

The oil crisis of 1973 pushed the diesel to become an alternative to the gasoline engine. With a substantially lower consumption of fuel per kilometre and a lower price per litre, the diesel built a reputation of being an economic alternative to gasoline. But beside this image of economic advantage the diesel also acquired a reputation of being more polluting (exhausts of black smoke, of NO_x, of particles), more noisy and less performant (acceleration and speed) than the gasoline engine.

Nearly 30 years later the diesel has become a real competing technology, at least in western Europe, with more than half the sales in the year 2001 in many countries (France, Belgium, and Spain). In this paper we will elaborate the factors that explain the progressive “ dieselification ” of the global automobile market.

5.1.1 Diesel sales in Europe

Figure 5.1: Registration of diesel cars in western Europe

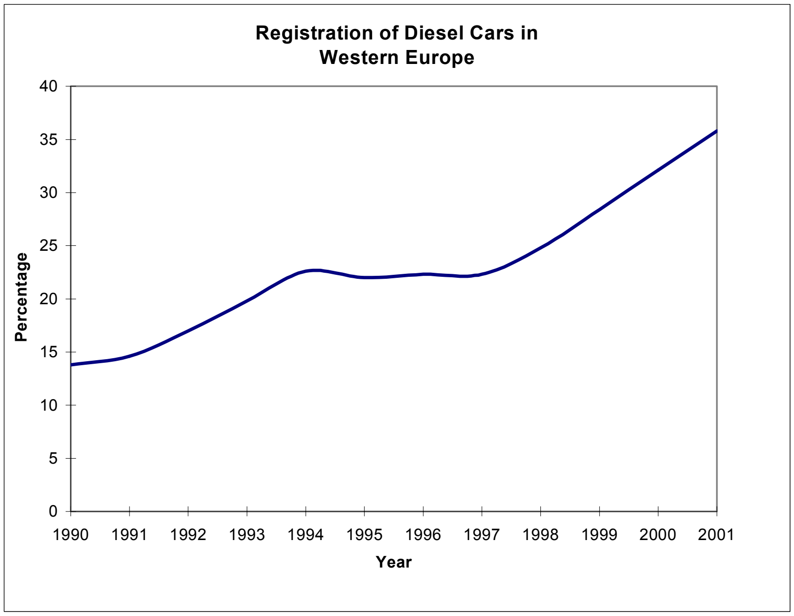

Table 5.1-1: Sales of diesel cars in western Europe 1990-2001

Diesel (%)	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001
Austria	25,7	22,1	26,2	31,6	39,9	42,8	49,4	53,3	54,5	57,4	61,9	65,4
Belgium	32,7	30,8	31,8	36,9	42,4	46,8	45,7	49,8	52,2	54,3	56,3	62,6
Denmark	4,1	2,6	2,4	2,2	2,7	2,9	2,9	3	4,7	9,4	13,2	17,9
Finland	5,2	4,9	5	7,8	5,6	6,7	13,5	14,6	15,3	15,7		
France	33	38,4	39	45,5	47,6	46,5	39,2	41,8	40,2	44,1	49	56,2
Germany	9,8	11,8	14,8	14,6	16,6	14,5	15	14,9	17,6	22,4	30,3	34,5
Greece									1,1	0,7	0,7	0,7
Ireland	13,6	15,5	14,2	15,6	16,7	15,9	13,3	11,3	12,8	10,9	10,1	12,9
Italy	7,3	5,7	7,6	8,4	9,1	9,9	16,5	17,5	22,5	29,4	33,6	36
Luxembourg	21,3	16,7	25,1	27,6	28,1	28,5	32,4	35,2	38,8	42	50,4	58,2
Netherlands	10,9	11	11,6	11	12	13,9	15,3	17,1	20,3	22,8	22,5	22,9
Portugal	4,9	7	7,8	11,3	11,6	10,7	12,6	16,9	18,8	20,9	24,2	27
Spain	14,6	12,8	16,6	23,2	27,5	33,6	37,5	42,2	47,8	50,6	53,1	52,5
Sweden	0,6	0,9	0,8	3,1	3,2	2,7	5,2	7,6	11	7,2	6,3	5,6
United Kingdom	6,4	8,7	12,5	19	21,7	20,2	17,8	16,1	15,3	13,8	14,1	17,8
European Union					23,1	22,6	22,9	22,8	25,3	29	32,8	36,4
Iceland									15,1	16,4	17,1	13,3
Norway	2,6	6,4	10,8	14,5	9,7	6	7,2	6,2	6,7	8,2	9	13,3
Switzerland	3	2,7	3,1	3,5	4,7	4,2	4,7	5,1	5,9	6,8	9,3	13,3
EFTA					5,9	4,7	5,5	5,4	6,4	7,4	9,5	13,3
West. Europe	13,8	14,6	17	19,8	22,6	22	22,3	22,3	24,8	28,4	32,1	35,8

Source : AAA (Association Auxiliaire de l'Automobile)

We will try and explain this growing presence of diesel cars with the help of four key factors: Costs, Innovation/ Performance, Regulation and Image of diesel cars.

5.1.2 The Costs of Diesel Cars

The relative price of diesel oil is one of the cost factors that explains the growing popularity of diesel cars. The price of diesel oil at the gasoline station has always been lower than gasoline in most western European countries. Despite rapid increases in the taxation of diesel oil, it still remains cheaper than gasoline.

However, as we can see in

Table 5.1-2, diesel oil is slightly more expensive than non-lead gasoline in the UK. Nevertheless, diesel cars have captured nearly 20% of the British market.

Table 5.1-2: Price of super gasoline without lead and diesel oil at the gasoline station in France, Germany and the UK (c€/l)

France	**1990**	**1995**	**2001**
Super without lead 98	79	86	105
% tax	71%	80%	72%
Diesel oil	54	59	78
% tax	61%	72%	62%
Relative price Super/Diesel	1,46	1,46	1,35

Germany	1994	1995	2001
Super without lead 95	81,2	82,28	102,84
% tax	76%	76%	71%
Diesel oil	59,28	59,41	82,51
% tax	68%	68%	63%
Relative price Super/Diesel	1,37	1,38	1,25

Great-Britain	1994	1995	2001
Super without lead 95	66,73	64,67	121,88
% tax	70%	74%	76%
Diesel oil	66,76	65,06	125,41
% tax	69%	73%	74%
Relative price Super/Diesel	1,00	0,99	0,97

Source: *Bulletin Pétrolier*

This observation allows us to modify the proposition by Greene (1996)[16] that he developed to explain the evolution of the market share of diesel cars in the USA. For Greene, "the rise and fall of diesel cars can be traced primarily to the price differential between gasoline and diesel fuel ". The British case shows that it is not only the relative price of diesel oil that explains the market share of diesel cars; and in all countries the relative price of diesel fuel has been rising while the market share of diesel cars has also been rising.

We can identify other factors that impinge on the relative costs of using a diesel car. For example in

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[16] Greene, David L., *Transportation & Energy*, Eno Transportation Foundation, Inc., 1996.

Table 5.1-3 we have figures showing the fuel consumption (litres per 100 kilometres) for diesel cars and gasoline cars of the same makes and similar performance – size, speed and acceleration.

Table 5.1-3: Fuel consumption of diesel and gasoline models of same engine size

	Mercedes Benz 190 (Model 1985)			**VW Jetta (Model 1990)**		
Fuel	**Diesel**	**Gasoline**	**Difference**	**Diesel**	**Gasoline**	**Difference**
L/100 Km (Urban)	7,8	12,4	4,6	6,4	9,4	3
L/100 Km (Non-urban)	7,1	10,7	3,6	5,5	7,4	1,9
L/100 Km (Mixed)	7,6	11,2	3,6	5,9	8,7	2,8
	VW Golf (Model 2002)			**Peugeot 206 (Model 1997)**		
Fuel	**Diesel**	**Gasoline**	**Difference**	**Diesel**	**Gasoline**	**Difference**
L/100 Km (Urban)	6,9	10,2	3,3	6,6	10,7	4,1
L/100 Km (Non-urban)	5,2	8,1	2,9	4,1	6,1	2
L/100 Km (Mixed)	6,2	9,4	3,2	5	7,7	2,7
	Audi A4 2.4 Pack +			**Mercedes Class S S320 BA5**		
Fuel	**Diesel**	**Gasoline**	**Difference**	**Diesel**	**Gasoline**	**Difference**
L/100 Km (Urban)	12,5	14	1,5	11,4	17,3	5,9
L/100 Km (Non-urban)	6,3	6,8	0,5	6	8,2	2,2
L/100 Km (Mixed)	8,6	9,4	0,8	8	11,5	3,5

Fuel	**Energy savings**	
	Difference	**(%)**
L/100 Km (Urban)	3,73	30%
L/100 Km (Non-urban)	2,18	28%
L/100 Km (Mixed)	2,77	29%

The sample of selected cars gives an average of nearly 30% in fuel savings for the diesel engine. This comparison is of the same magnitude as can be found in the press[17] or by the Diesel Technology Forum[18]. These economies in fuel consumption added to a lower price for the fuel represent strong incentives to buy cars with diesel engines.

But, the fuel economy of diesel cars with engines of the same engine size as a gasoline car is counterbalanced by two factors. First, the diesel car has lower performance in speed and acceleration. Second, the diesel car is more expensive.

If we take performance a diesel car still gives less kW for a given engine size than does a gasoline car. To compensate for this, a bigger engine needs to be fitted to the diesel car. In recent years car manufacturers have developed more powerful diesel cars such as the Volkswagen 1.9 TDI with 110 kW for an engine of 1.9 litres. The comparable gasoline engine is 1.8 litres with turbo.

The reason why a diesel car is more expensive than a gasoline car can be found in the fact that the engine is much heavier and more expensive because of a much higher compression ratio. Another reason is that diesel cars were marketed later (the first diesel engine car, the Mercedes-Benz 260 D, was produced in 1936 and sold roughly 2000 units before World War II) and are sold in smaller quantities than gasoline cars. As we can see in Table 4, diesel cars are more expensive than gasoline cars. The price differences seem to have persisted over the last 20 years. The Volkswagen 1.9 TDI with

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[17] " Fuel economy generally is more than 30% better than that of gasoline engines " American Metal Market, *US Diesel use falling further behind Europe*, June 25, 2001

[18] " Light-duty diesels, such as automobiles, use 30-60% less fuel than similarly sized gasoline engines, depending on the type of vehicle and driving conditions " Diesel Technology Forum, *Engineering Clean Air : The Continuous Improvement of Diesel Engine Emission Performance*, March 2001

110 kW costs €24,200 and the Volkswagen 1.8 GTI costs €21,900 in Germany in 2002. Mercedes-Benz often charge the same price for a diesel car with the same performance as a gasoline car despite the fact that the diesel car has a bigger engine. In 2002 the Mercedes-Benz E-Class 240 gasoline car with 178 bhp costs 28,040 GBP in Great Britain and Mercedes-Benz E-Class 270 CDI diesel car with 177 bhp costs 27,435 GBP. In Germany the diesel car is €700 more expensive than the gasoline car.

Table 5.1-4: Price of cars with diesel engines and gasoline engines

Year	Model	Price of gasoline car	Price of diesel car	Difference in price (%)
1980	VW Rabbit 4-door Hatchback	5 890	6 415	8,9%
1980	Audi 5000 Sedan	10 600	11 400	7,5%
1981	Isuzu I-Mark	6 069	7 194	18,5%
1981	Peugeot 505	10 990	11 990	9,1%
1982	VW Jetta 4-door Sedan	8 595	9 240	7,5%
1982	Volvo 4-door Sedan	10 885	13 180	13,9%
2002	Audi A4	35 770	37 860	5,5%
2002	Mercedes 320	71 400	66 600	-7,2%
2002	Peugeot 206 (2.0 l)	16 800	18 050	6,9%

5.1.3 Innovation / Performance of Diesel Cars

The present performance of diesel cars is making us forget the characteristics of diesel cars from 1970. Take, for example, the Volvo S60 D5 2.4 diesel that accelerates from 0-100 km/h in 9.5 seconds, has a top speed of 209 km/h, and a fuel consummation of 6.5l/100 km. Another example is the Audi A8 3.3L that entered the record books in 2001 when it reached a speed of 240.9 km/h over five kilometres. These results are the outcome of continuous technical improvements and the introduction of new technologies.

Technologies such as “Electronic Fuel Injection, high pressure fuel injection, and turbocharging” have not only made possible high top speeds and much improved accelerations, they have also permitted the quasi-definitive solving of the problem of starting a diesel car and reducing substantially the emission of carbon gases as well as the polluting emissions.

These technologies, combined with techniques to treat exhaust gases, permit reductions that are even more important. As a consequence of the introduction of catalytic converters and particle filters on diesel cars, the emissions of noxious gases have been cut by three since 1993.[19] The reduction of the emissions from diesel engines can be taken even further in the years to come. According to laboratory tests, diesel engines can cut their emissions of NOx by 70%[20].

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[19] Dossier du CFFA, *Des progrès pour l'environnement : L'automobile citoyenne*, Comité des Constructeurs Français d'automobile

[20] New Technology Reduces Noxious Emissions, Foundry Management & Technology, Jun2001, Vol. 129 Issue 6, p21

5.1.4 Regulation

In Europe the regulation of the reduction of car emissions was established with the application of the directive 70/220/EEC in 1970. A succession of directives has brought the emission standards in 1996/1997 to a level that is 90% lower than that of the first years of the 1970s[21]. The scope of reductions in the standards diminished gradually, however, and it became necessary to pay greater attention to the interactions between the vehicles and the fuels and to other types of political solutions. These political solutions could be to improve the direction of road traffic, look for other energy sources, and the promotion of public transport. In this way, in October 1992, the European Commission organised a conference whose principal conclusion was that future emission standards should be based on a more comprehensive and integrated approach.[22]

In the USA "The Clean Air Act " of 1963 with its later amendments established standards for automobiles. These amendments became effective in 1980, 1984 and 1994, and, according to Truett and Hu (1997), the costs of respecting these standards resulted in increased costs for developing diesel engines and the refining of fuels, reducing the economic advantage of the diesel engine. In this manner it is estimated that to reach the level of the 1982 standard, the cost of refining diesel oil increased abruptly by five cents a gallon to eliminate the sulphates.[23]

In comparing the two regulations it is shown that the American regulation makes no difference between the standards for diesel oil and for gasoline, while the European standards created a difference from the start that was to become important in allowing the European car industry to improve the diesel engine (Figure 5.2). In addition, the American regulation was much more severe than other regulations in the world, and in particular in comparison with European standards during the 1980s (Figure 5.3). This difference in the regulatory systems must have made it easier for European car manufacturers to prepare themselves for changing standards and to produce a more ecological diesel car in the 1990s.

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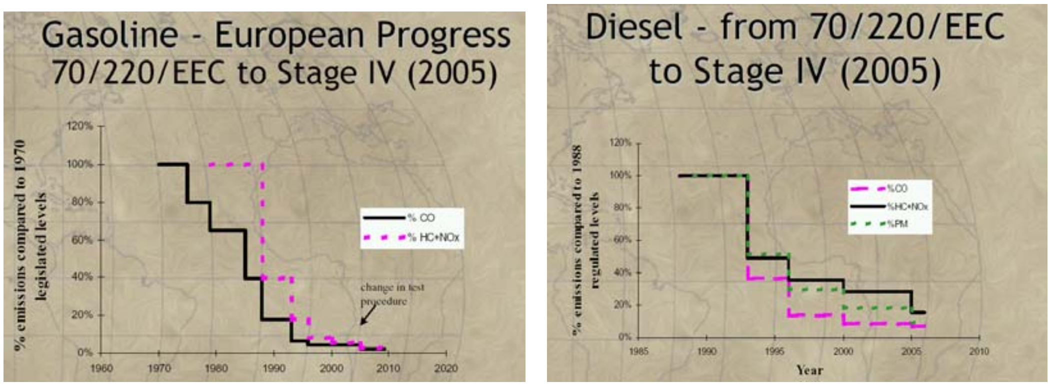
[21] Service de la Commission Européenne, *Auto Oil II Programme*, Octobre 2000 p14

[22] Op. cit

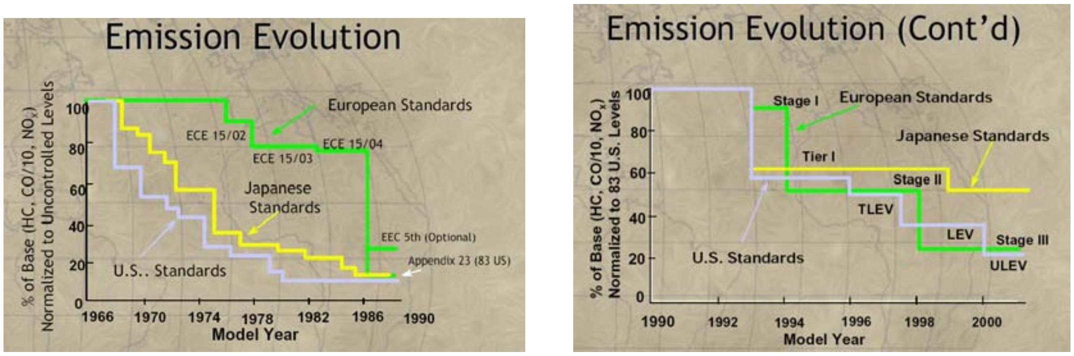
[23] Truett, L.F. and Hu, P.S, *Past, Current And Potential Future Diesel Engine Penetration In The United States, Vehicle Classes 1 and 2 : A Literature Review, Cursory Data Collection, and Brief Opinion Survey*, October 1, 1997, Oak Ridge National Laboratory, p 13

Figure 5.2: Evolution of emission standards for diesel and gasoline engines in Europe



[Homeister, 2001]

Figure 5.3: Comparison of US, European and Japanese emission standards



[Homeister, 2001]

It seems therefore that American political choices put the development of diesel cars at a disadvantage during the 1980s. This feature of American policy is further strengthened by the fact that the USA is one of the few countries that levies a higher tax on diesel oil than on gasoline.

Table 5.1-5 : Taxation of gasoline and diesel oil in some OECD countries

Motor Fuel Tax Rates for selected Countries as of February 1, 1997 (cents per gallon)

Country	Gasoline tax rate	Diesel tax rate
Belgium	**279**	**156**
France	**290**	**177**
Germany	**265**	**160**
Italy	**281**	**196**
Netherlands	**285**	**163**
United Kingdom	**271**	**266**
Japan	**182**	**110**
United States[a]	**37**	**43**

Source: Federal Highway Administration, *Monthly Motor Fuel Reported by States*, November 1996, FHWA-PL-97-005

[a] Includes the weighted average of states taxes plus the Federal tax.

Consequently it seems as if the restraining regulation in the USA has impeded the development of diesel. In comparison, the European legislation, much less demanding due to the powerful lobby of transportation firms, allowed the development of diesel engines in Europe, and gave incentives to the European car manufacturers to develop a cleaner diesel engine compared with the diesel engines of the 1970s and 1980s.

5.1.5 Image of Diesel

Thanks to its performance – speed, acceleration, and power – and progress in terms of reducing polluting emissions, the diesel car has lost its image of being polluting, slow and noisy. Mike Fry, in a recent edition of the professional press, affirms that ”even now, the word many motorists immediately associate with ‘diesel’ is ‘dirty’. However, in very few years, ‘desirable’ could be what springs to mind instead ”[24]. This may happen in Brazil where the diesel car was forbidden after the oil crisis of 1973.[25]

This is far from the case in the USA, however. “ In The United States, diesels suffers undeservingly from poor image brought on by public experience with poor-quality engines –dirty, smelly and noisy – sold in cars two decades ago. ”[26] This image is confirmed by a public opinion poll taken on the week-end of July 4, 1997. Of the 1,000 people questioned, 75% answered “NO ” to the question: “For your next new vehicle purchase, would you consider buying a diesel engine version that got 40% better fuel economy and cost $1,500 additional ?” Their answers were based on the following perceptions of the diesel car:

• Noise	21%
• Fuel availability	15%
• Smell/ odour	12%
• Don’t know enough about it	11%
• Vehicle price	09%
• Pollution, Smoke, Environment	09%
• Maintenance	09%

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[24] Mike Fry, *Dirty to desirable*, Automotive Engineer, February 2002 p72-74

[25] Kutney Pedro, Desire For Diesels, Automotive News International, September 2001. p42-43

[26] American Metal Market, *US Diesel use falling further behind Europe*, June 25, 2001

- All other reasons 16%[27]

This image seems to lose its force, however. For example, "General Motors Corp, Ford Motor Co and the Chrysler Group of Daimler-Chrysler AG would like to use diesel engines in their hybrid electric vehicles (HEVs) because of what they would add to the fuel economy benefits of the advanced propulsion systems "[28]. The association of diesel with a technology considered to be ecological show the evolution of the image of diesel towards a clean fuel. In addition, diesel is more and more proposed as a means of reducing greenhouse gases, because diesel engines emit less HC, CO et CO_2 than do gasoline cars. Diesels must be allowed if CO_2 reductions are a vehicle fleet priority. "[29]
In a report from the US department of Energy, James J. Eberhardt affirms that:

> *"Dieselisation" is a real and viable strategy for reducing transportation energy use with the concomitant reduction in carbon dioxide emissions. Progress in diesel emission controls, together with ultra low sulphur fuel will enable these devices to work effectively, and will make "clean" diesel technology commercially viable in the near future. In addition, diesel engine emission control devices suitably modified will work as well with the gasoline direct injection engine which has similar NOx and PM emission problems as the diesel since both are lean burn engines. As clean diesel and gasoline direct injection engines operating on low sulphur fuels replace the port fuel injected gasoline engines in automobiles and other light-duty vehicles the result will be cleaner air, since the emissions control technologies being developed for lean burn engines is more effective than the conventional catalytic converter. In retrospect, therefore, the efforts to promote dieselisation ultimately will lead to cleaner air.* [30]

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5.2 Study on SUV in the USA

by Staffan Hultén, MERIT

5.2.1 Introduction

What do we mean by the concept of sport utility vehicle? Davis and Truett (2000) write: "Generally speaking, SUVs are being described as being large, sturdy, high-priced, appropriate for hauling/towing, safe (to the SUV occupants) and 'trendy'." An SUV is not the same as a 4WD car. Many SUVs are in fact 2WD. In many ways the SUV belongs to the bigger group of utility vehicles – SUV, vans, mini-vans and pick-up trucks – that is rapidly winning market share in the USA. In 2001 these cars had captured 52% of the US automobile market.

Sales of 4WD cars and light trucks are also picking up in Europe. In 2001 they represented 4.5% of car sales in the European Union, up from 2.4% in 1994. The highest market shares for 4WDs are found in Sweden with 7.3%, Luxembourg 6.7%, Austria 6.6% and the UK with 6.5%. In Iceland more than 40% of the new cars are 4WD, in Switzerland 19.1% and in Norway 11.6% (AAA, Association Auxiliaire de l'Automobile). A particular breed of SUV is the Norwegian SUV with only two front seats that benefits from lower taxation – in downtown Oslo it is called "börstraktor" which, in English, translates to "stockbroker tractor".

SUVs ride higher than passenger cars and they are built using two different designs. The first US-built SUVs used light-truck platforms which gave them poor riding characteristics. Newer models, in particular Japanese and European SUVs, are built on passenger platforms. Toyota's Lexus 300 uses a Camry sedan platform. Honda's Acura MDX uses the mini-van platform from the Odessey. Best-selling American SUVs continue to use pick-up platforms –for example, the Ford Explorer and the Chevrolet Blazer (D. Welch, Business Week, 27-11-2000).

Today an SUV is no longer just an SUV. SUVs are moving into maturity, discovering what they are, to whom they appeal and why. Thus, the segment is individualising its vehicles to appeal to a broader range of incomes and interests (Automotive Industries, October 2001).

The sport utility vehicle is available in engine sizes ranging from 1.6 to 6.5 litres, curb weights from about 2,700 pounds to over 5,500 pounds and prices ranging from less than $14,000 to more than $65,000. SUVs are often, in the USA, categorised as small, medium and large according to the size of the engine. A small SUV has an engine of less than three litres, a medium an engine of three to five litres and a large an engine of more than five litres. Some models have different engine sizes and can therefore belong to more than one category. SUVs are currently categorised as light trucks and they therefore have to meet the federal fuel economy and emission standards for light trucks. These standards are less stringent than those for cars.

5.2.2 How did the SUV market appear?

In the mid to late 1980s there appeared a more authentic American trend than the European import of aerodynamic cars. It emerged in the exploding market for what the industry called sport utility vehicles, which included pick-up trucks, vans, jeeps, and other automotive hybrids. These vehicles were not new – they had been around for decades, but mainly as specialty vehicles tailored to the needs of small markets for work or sport transport (D. Gartman, 1994).

The first step in the transformation of the pick-up happened as far back as the 1950s. "Auto-makers became alert to the growing mellowness of the farmer and began dressing up and styling the farmer's pick-up truck, which originally began as a lowly mechanised workhorse. By 1956 farmers in large numbers were being sold pick-up trucks with whitewall tyres, quilted plastic upholstery… and colours such as flame red, golden-red yellow, and meadowmist green."[31]

The Jeep was also around in the 1950s, but its sales growth was much slower than that of the pick-up truck. One type of pick-up was a car with truck-like features – for example, the Chevrolet El Camino. These cars never sold more than 50,000 annually in the 1950s and early 1960s. A few early vans based on car chassis that were re-engineered onto a truck chassis appeared in the 1960s. These vans looked car-like and total annual sales never surpassed 200,000 vans.

The British car manufacturer Range Rover produced the first luxury full-time 4WD in 1970. Targeted towards wealthy customers, annual sales of this car have never surpassed 50,000 (http://www.4wdonline.com).

In Porac *et al.* (2001) there is a suggestion that one important reason for the creation of the SUV market was the conceptual revolution that the mini-van created in the 1980s.

One possible explanation is that the conceptual instability triggered by the mini-van helped redefine the conceptual market position of sport utility vehicles as well.

Journalistic accounts of the development of the modern mini-van suggest that consumer research in the 1970s pointed to widespread consumer sentiment in favour of small people-mover vans. General Motors and Ford designers had begun to work on such vehicles, and in both cases the models were scuttled by top management due to high costs and low-volume projections. Marketing experts at both companies concluded that the wide diversity of consumers expressing interest in a small van was a sign that no single population segment wanted the vehicle in sufficient numbers to make its production profitable.

For a couple of years two designs competed: car-like and truck-like conceptual systems. It was Chrysler that made the breakthrough, creating the market with a mini-van with low height, and car-like handling capabilities which combined to make it attractive for women who needed to transport children conveniently and safely.

It is widely acknowledged that mini-vans gained most of their sales from traditional family sedan buyers. As the artefacts in the category (the mini-van) converged on the car-like conceptual system in terms of attributes, many potential buyers chose instead to purchase the more truck-like sport utility vehicles, although citing many of the purchase rationales that mini-van buyers have used (e.g. command of the road, visibility, versatility, etc.). One possible reason for this phenomenon is that as mini-van models converged on a car-like set of attributes, they left a conceptual and behavioural gap for downsized, truck-like two-box vehicles, which sport utility vehicles fit well. For many automobile buyers, mini-vans have an inherent problem: it is hard to be "cool" driving a mini-van.

The late 1980s and 1990s have also seen a dramatic surge in the level of car-like luxury, comfort, and styling applied to pick-up trucks and closely related vehicles in the US market, and an equally dramatic shift in the sales distribution between cars and trucks. More and more, consumers are making trucks their vehicle of choice for urban

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[31] Vance Packard, New Frontiers for Recruiting Customers, chapter 16 in The Hidden Persuaders

commuting and are equipping them with features and options historically found only in cars (Porac et al, 2001).
Luxury trucks have become a standard offering by all major truck producers, and new competitors are emerging annually.

5.2.3 Growth of the SUV market in the USA

The period 1980-2002 is actually marked by a redefinition of the American car. SUVs, mini-vans, vans and pick-ups had a market share of 20% in 1980 and nearly half of the market in 1999. Predictions in 2000 were that annual sales of SUVs would be more than three million annually in 2000-2010. In reality they reached nearly 3.8 million in 2001 (Automotive News, 16-09-2002), and Americans bought 600,000 more SUVs, mini-vans, vans and pick-ups than they did passenger cars in 2001. These vehicles now account for almost 52% of the vehicles sold in the USA (*Automotive News,* 29-08-2002).
Sales of SUVs started to climb in the early 1980s from 243,000 sold vehicles in 1980 to more than 500,000 in 1984, nearly one million in 1990 (7% of the market) to more than three million (19% of the market) in 1999. In 1999 the mix of SUVs on the road, as measured by registration data, was about 8.7% (Davis and Truett, 2000).
Small SUVs sold very well in the period 1983-87 when they reached 600,000 sold vehicles per year. In 1988, reports from the Consumers Union indicated that small SUVs were less safe than other vehicles. At that date sales dropped and the annual sales of small SUVs fluctuated around 200,000 to 300,000 in the 1990s.
In 2000 SUVs became the most popular vehicle for males, when it overcame the pick-up trucks. From January to October 2001, the SUV market accounted for 25% compared with 21% for pick-ups. Perhaps more interesting is that SUVs also became the choice of women in 2001. They then surpassed the mid-sized car. SUVs went from 13.5% of the female market in 1996 to 23.9% in January to October in 2001, while at the same time the mid-sized car fell from 26.1% to 23.2%. SUVs seem to have won customers among women from all car categories in the period 1996-2001, except luxury cars (Polk, January 6th 2002).

5.2.4 Factors that explain the success of the SUV

The steady growth of SUV can be explained by a number of mutually reinforcing factors – car manufacturers benefit from higher margins than on passenger cars, consumers find many SUV features appealing, and US politicians have been slow to react to safety concerns and fuel consumption increases because SUVs are often US-made.

5.2.4.1 Incentives for manufacturers

A car manufacturer earns $10,000 on a luxury SUV – for example, the Ford Expedition and the Cadillac Escalade. This is a much higher margin than on a standard car. For many years the SUVs sold without discounts. This changed in 1996 when Ford offered a discount lease deal on the Explorer (*US News and World Report*, 21-10-1996). Later, competitors started to offer similar incentives.

Other costs also increased. Total advertising on SUVs was $502.5 million in 1995 when 1.75 million SUVs were sold. In 1996 advertising expenditure increased to $762.1 and sales to 2.14 million SUVs (J. Halliday, *Advertising Age*, 29-09-1997).

For many decades, the USA has been the undisputed producer and market for all sorts of light trucks. In 2001, world production of light trucks was 16,181,000 vehicles. The USA was the biggest producer with 6,570,400 light trucks, while the total production in Europe was 2,678,000 and Japan produced 1,660,000. As a comparison it can be noted that Europe produced 17,423,000 cars, the USA 4,879,100 cars, and Japan 8,117,600 cars (http//:www.oica.net).

5.2.4.2 More car producers enter the SUV market

The growing success of SUVs meant that more manufacturers entered the market and that they offered more models. The number of models went from 10 in 1981-82 to 30 in 1990 and more than 40 in 1999. In the beginning of the 1990s there were 27 SUVs on offer on the US market, and this had grown to 34 models in 1997 (J. Halliday, *Advertising Age*, 29-09-1997). Twenty-four new models were predicted for the following five years in 1997 but many more models arrived. In 2000, car manufacturers offered 162 car models and 91 truck models, in 2001 they offered 153 car models and 96 truck models. For 2002, the following passenger car models are planned to be dropped: Honda Prelude, Cadillac Eldorado, Lincoln Continental, Chevrolet Camaro, Pontiac Firebird and Oldsmobile’s entire line-up (USA Today.com 06-07-2001).

The SUV market has also been expanding towards more passenger car-like models and more and more expensive models. Ford has added bigger and bigger SUVs and Chevrolet has done the same. Luxury SUVs have also appeared with vehicles from Cadillac, BMW and Mercedes.

Volvo is the latest car manufacturer that has added an SUV to its model programme. The Volvo SUV is called XC90 and promises to be a safe SUV that will prevent roll-overs, one of the key disadvantages with SUVs. The Volvo will also be equipped with reinforced roof parts (*Automotive Industries*, June, 2002).

So-called cross-over vehicles, such as the Toyota Highlander, Acuras MX, and Volvo XC, make it hard to pinpoint sales trends. These cars sit tall, like trucks, and have some light-duty, off-pavement capability, but they ride and handle more like cars than truck-based SUVs, such as the Ford Explorer. A million or more of these cars were probably sold in 2001.

5.2.4.3 Image of SUVs

Despite high fuel prices, negative publicity, roll-over worries and recalls, US consumers are more likely than ever to make SUVs their next car. “They just keep buying the suckers,” says George Peterson, head of consultant AutoPacific (J. R. Healey, *USA Today*, 2001-04-25).

In a study by AutoPacific, a forecast firm in Los Angeles, 44% of respondents will consider an SUV as their next vehicle purchase. Nearly 65% of buyers under the age of 30 will consider an SUV. (*Automotive Industries*, October 2001) Interestingly, these figures are lower than in a similar survey in 1999 when 73% of buyers under the age of 30 indicated that they were considering an SUV for the next purchase and 48% of all respondents stated that they were considering an SUV as their next vehicle purchase (Davis and Truett, 2000). By comparison we can note that in 1995 18.7% defected from

SUVs to non-SUVs, and that defections rose to 21.7% in 1996 and to 24% in the first half of 1997, according to CNW Marketing/Research sample survey (J. Halliday, *Advertising Age*, 29-09-1997).

In 1999 the average SUV owner was male (63.7%), married (76.4%), aged 45 years and in a household with an income of $94,400 (Davis and Truett, 2000).

There are many different interpretations of why Americans buy SUVs in increasing numbers. Both people who like SUVs and people who dislike them express strong opinions on why SUVs are selling in increasing numbers.

For the baby boomers, the fact that the SUV is different from their childhood car has been suggested. Many characteristics of the car present a feeling of security – four-wheel drive, higher chassis, bigger than other cars, heavier than other cars. Factors that SUV owners find to be the least important attributes of a car are fuel economy and price (Davis and Truett, 2000).

According to a Polk Automotive Intelligence Sport Utility Vehicle usage study (Polk website, August 28, 2002) owners of SUV mentioned the following aspects:

- 79.3% indicated that they “sometimes” or “frequently” used their SUV for driving during harsh weather.
- 27.3% indicated that their main reason for feeling satisfied with their SUV was because it was “ideal for their active lifestyle”.
- 50% of the owners indicated that they used their SUV to haul tools, appliances or other bulky items to their home.
- 40% used their SUV to access homes or locations on steep hills or driveways.
- 40% of the owners said that SUVs were also used to transport children to various activities.
- 24% indicated that they used their SUV to carry bikes, kayaks, canoes or skis or used it to tow boats, snow mobiles or other motorised items requiring the use of trailer.
- 24% of SUV owners expressed that they “felt very safe”, which was a key issue in their SUV purchase.
- 15% used their SUV to go “off-roading”.

The sheer size of the bigger SUVs is often listed as an attraction for buyers. In Godek (1997) it is claimed that the American regulation of fuel consumption (CAFE) forced consumers to buy heavier cars that weren’t penalised by the legislation. “Given that under CAFE large cars are penalised, small cars are subsidised, and light trucks are largely unregulated, there are obvious reasons to expect CAFE to stimulate the demand for both small cars and light trucks. Size and safety considerations, however, would make light trucks rather than small cars the better substitute for large cars.” This is the case because CAFE represents a mandated decrease in safety. Godek (1997) argues that because “vehicle weight is considered to be an important determinant of fatality and injury risk” one way that drivers as consumers can react to mandated decreases in car safety is to buy more and heavier light trucks.

A French interpretation of why SUVs sell so well is found in *Le Temps* (a Swiss daily newspaper). The French anthropologist Clotaire Rapaille suggests that the Americans look for cars that carry a message. Aerodynamically designed cars carried no messages. According to his theory, the choice to buy an SUV is dictated by the reptile brain that dictates all our most primitive instincts. This means that in the case of an accident “it’s better that he loses his life, than me”. He continues to say the Americans are always on the path of war, they are always ready to fight. The Europeans, the Germans, the

Italians, and the French, have another notion of survival: the speed. It is the idea of the feline (Henry Ploüidy, *Le Temps*).

5.2.5 Factors that could present a problem for continued SUV market growth

SUVs are often criticised for being polluting, gas-guzzling, dangerous for drivers of other cars and pedestrians, and for inciting drivers to drive dangerously.

5.2.5.1 Safety and accidents

The majority of traffic fatalities in the USA can be attributed to accidents involving passenger cars and light trucks, dubbed "mismatch" collisions. SUVs raise many safety issues. The much publicised Firestone case involving the Ford Explorer and Firestone tyres highlighted the propensity of SUVs to roll over more easily than did passenger cars. Ford and Firestone were criticised because the Ford Explorer had an unusually high number of accidents following tread separations of Firestone tyres. When the problems with the tyres became apparent Ford decided that the firm would provide free replacements for all Firestone ATX and Wilderness AT tyres on Ford vehicles – a total of 6.5 million tyres.

The much higher risks associated with roll-overs in SUVs compared with those of passenger cars were first discussed in the 1980s when reports said that small SUVs were more dangerous and had more roll-overs than passenger cars. The roll-over problem is still around although SUVs built on passenger platforms and really big SUVs have fewer roll-overs than average-sized SUVs built on pick-up platforms. In 2001, 1,729 passengers in SUVs were killed in single vehicle roll-over accidents, 2,163 passengers in pickup trucks, 553 passengers in vans and 3,948 passengers in passenger cars. These figures show that SUVs and other light trucks are over-represented in this kind of fatal accident as they represent approximately 10% of the US vehicle park and passenger cars represent much more than 50%.

SUVs also present much greater dangers for pedestrians. One in every four pedestrian accidents from 1995 to 99 involving a large van resulted in a pedestrian death. By contrast, only one of every 20 pedestrian accidents involving a car resulted in a pedestrian death. For large SUVs, one in seven accidents involving a SUV and a pedestrian resulted in a pedestrian fatality. Light trucks and large vans kill more pedestrians than cars if there is an accident, because they are higher and have another type of frontal geometry. Therefore the pedestrians are impacted at different, often higher, parts of the body – for example, the head (Leffler and Gabler).

Table 5.2-1: Deaths per million passenger vehicles 1-3 years old, 2000 (USA)

Size[a]	Cars (including minivans)	Pick-ups (2WD)	Pick-ups (4WD)	SUVs (2WD)	SUVs (4WD)
Very small	190	n/a	n/a	n/a	n/a
Small	154	155	n/a	n/a	142
Medium	121	16173	160	208	126
Large	96	140	146	118	106
Very large	109	124	126	n/a	106

[a] It should be noted that the definitions of "size" are not the same for the different types of vehicles in these categories. Size is defined in terms of wheelbase and length for cars and in terms of weight for pick-ups and SUVs. The designations into size categories are approximate and, for SUVs, are not precisely as defined in Table 1. "N/a" indicates that there are too few vehicles in a category to give reliable data.
Source: Insurance Institute for Highway Safety, "Fatality Facts," http://www.highwaysafety.org/safety_facts/fatality_facts/passveh.htm.

Table 5.2-2: Deaths per million registered vehicles from single vehicle crashes, 2000 (USA)

All Cars (including minivans)	54
All 2WD pickups	90
All 4WD Pickups	99
All 2WD SUVs	116
All 4WD SUVs	76

Source: Insurance Institute for Highway Safety, "Fatality Facts," http://www.highwaysafety.org/safety_facts/fatality_facts/passveh.htm.

5.2.5.2 Fuel consumption

Truck sales were up 9.2% when car sales were down 13.5% at GM in June 2001, despite higher gasoline prices. Ford dropped 15.5% in car sales but truck sales were flat. Toyota's truck sales were up 36.3% in the same period. (USA Today.com 06-07-2001)
The long-term development of fuel consumption of US automobiles presents a dismal picture (see table below). The decline in fuel efficiency is linked to the increasing sales of SUVs, vans and pick-up trucks. These cars consume much more fuel than do standard passenger cars. SUVs consume more fuel because they are both heavier and less aerodynamic than the average passenger car.

Table 5.2-3: US national average miles per gallon of new vehicles 1980-2000

Year	Mpg
1980	19.1
1985	21
1990	22.3
1995	21.2
2000	20.5

Source: *Newsweek*, July 2, 2001

CAFE regulation will force SUV manufacturers also to produce lighter compact vehicles because, even in the CAFE regulation, the manufacturers must produce a mix of vehicles that meet the standard. The CAFE (Corporate Average Fuel Economy) standard for automobiles is 27.5 mpg in 2002 and 20.7 mpg for light trucks (see 3.7: CAFE and Fuel consumption). The purpose of these relaxed fuel economy requirements for light trucks is to benefit small businesses that use trucks in their business. In the late 1990s, however, most SUVs (84%) and pick-up trucks (74%) were being used mainly for personal transportation (Davis and Truett, 2000).

The CAFE standards are also in line for change. In a press release from the Alliance of Automobile Manufacturers on February 15 2002, the car industry urged the Senate to avoid passing energy legislation that would effectively eliminate SUVs, mini-vans and pick-up trucks. The industry suggested that fuel economy standards should consider "technological feasibility, cost, safety, emission controls, consumer choice and effects on American jobs. Automakers oppose legislative increases in fuel economy standards."
Source: http://www.autoalliance.org/pressreleases/pr021502.htm

Table 5.2-4: Light truck fleet characteristics for Mys 1999 and 2000

	TOTAL FLEET		Two-wheel Drive		Four-wheel Drive	
CHARACTERISTICS	1999	2000	1999	2000	1999	2000
Fleet Average Fuel Economy, mpg	20.9	21.2	22.2	22.7	19.1	19.5
Fleet Average Equivalent Test Weight, lbs.	4530	4510	4356	4349	4747	4728
Fleet Average Engine Displacement, cu. in.	251	244	239	231	267	263
Fleet Average Horsepower/ Weight ratio, HP/100 lbs.	4.24	4.31	4.29	4.20	4.17	4.24
% of Fleet	100	100	55.5	57.5	44.5	42.5
% of Fleet from Foreign-based Manufacturers	15.6	19.6	11.8	18.0	20.2	21.9
Segmentation by Type, %						
Passenger Van	17.1	17.8	29.9	30.1	1.2	1.3
Cargo Van	3.5	2.8	6.2	4.7	0.2	0.2
Small Pickup	3.2	4.2	5.8	7.4	0.0	0.0
Large Pickup						
Two-Wheel Drive	17.9	17.9	32.3	31.2	0.0	0.0
Four-Wheel Drive	13.7	13.9	0.0	0.0	30.9	32.7
Special Purpose						
Two-Wheel Drive	14.3	15.3	25.8	26.7	0.0	0.0
Four-Wheel Drive	30.2	28.0	0.0	0.0	67.8	65.8

Source: Automotive Fuel Economy Program, **ANNUAL UPDATE CALENDAR YEAR 2000**

5.2.6 Emissions

Related to the problem of fuel consumption is the relatively higher air pollution that SUVs produce compared with passenger cars. According to EPA air pollution comparisons, most passenger cars produce from 7.9 to 12.9 pounds of smog-forming pollution per 15,000 miles (this gives them a score of 6-7 on a scale from 0-10 where 10 represents no pollution). The majority of the SUVs produce 20.8 to 25.0 pounds of smog-forming pollution per 15,000 miles (a score of four). A few passenger cars get scores as bad as four, but in the SUV class dozens of vehicles get a zero (63.8-121.1 pounds of smog-forming pollution per 15,000 miles). These include for example, the GMC C1500 Yukon 2WD, the Chevrolet C1500 Suburban, the Toyota Sequoia 2WD and 4WD, the Cadillac Escalade 2WD, the Mercedes Benz ML55 AMG, the Chevrolet K1500 Avalanche 4WD and the Lexus LX 470. The biggest cars from Ford and Lincoln get a score of one. SUVs that pollute this much use more than 13 litres of gasoline to travel 100 kilometres on a highway and more than 16 litres in the city. The worst performers consume more than 18 litres of gasoline to travel 100 kilometres on a highway and more than 23 litres in a city.

Again there is softer legislation that protects SUVs. The table below gives some comparisons between passenger cars and SUVs for federal exhaust emission certification standards for five years or 50,000 miles.

Table 5.2-5: Comparison of emissions between passenger cars and SUVs

Vehicle type	Examples	NMHC	CO	NOx
LDV	Passenger car	0.25	3.4	0.4
LDT1	Small 2-Door/4-Door SUV	0.25	3.4	0.4
LDT2	Sport 2-Door SUV	0.32	4.4	0.7
LDT3	Mid-Size 4-Door SUV	0.32	4.4	0.7
LDT4	Full-Size 4-Door SUV	0.39	5.0	1.1

Source: Manufacturers of Emission Controls Association, Clean Air Facts

5.3 References

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6 ANNEX: DETAILED DATA AND FIGURES

6.1 Annex to Chapter 1

6.1.1 Consumption of vehicle fuels in the USA

Table 6.1-1: Estimated consumption of vehicle fuels in the USA, 1993-2002 (Thousand Gasoline-Equivalent Gallons)

Fuel	1993	1994	1995	1996	1997
Alternative fuels					
LPG	264,655	248,467	232,701	239,158	238,356
CNG	21,603	24,160	35,162	46,923	65,192
LNG	1,901	2,345	2,759	3,247	3,714
M85	1,593	2,340	2,023	1,775	1,554
M100	3,166	3,190	2,150	347	347
E85	48	80	190	694	1,280
E95	80	140	995	2,699	1,136
Electricity	288	430	663	773	1,010
Subtotal[a]	**293,334**	**281,152**	**276,643**	**295,616**	**312,589**
Oxygenates					
MTBE	2,069,200	2,018,800	2,691,200	2,749,700	3,104,200
Ethanol in Gasohol[a]	760,000	845,900	910,700	660,200	830,700
Biodiesel	na	na	na	na	na
Total Alternative and Replacement Fuels	**3,122,534**	**3,145,852**	**3,878,543**	**3,705,516**	**4,247,489**
Traditional fuels					
Gasoline[d]	111,323,000	113,144,000	115,943,000	117,783,000	119,336,000
Diesel	24,296,630	27,293,370	28,555,040	30,101,430	31,949,270
Total Fuel Consumption[a e]	**135,912,964**	**140,718,522**	**144,774,683**	**148,180,046**	**151,597,859**

Fuel	1998	1999	2000	2001	2002
Alternative fuels					
LPG	241,386	242,750	247,062	*251,353*	*255,515*
CNG	72,412	89,476	98,351	*111,797*	*113,554*
LNG	5,343	6,820	7,121	*8,786*	*10,504*
M85	1,212	1,073	585	*440*	*330*
M100	449	447	437	*406*	*0*
E85	1,727	3,802	7,074	*8,736*	*10,075*
E95	59	58	13	*0*	*0*
Electricity	1,202	1,384	2,670	*3,903*	*4,460*
Subtotal[a]	**323,790**	**345,810**	**363,313**	***385,421***	***394,438***
Oxygenates					
MTBE	2,903,400	3,331,000	3,087,900	*2,890,400*	*2,531,000*
Ethanol in Gasohol[a]	889,500	939,800	1,106,300	1,117,500	*1,118,900*
Biodiesel	na	na	6,816	25,431	na
Total Alternative and Replacement Fuels	**4,116,690**	**4,616,610**	**4,564,329**	**4,418,752**	**4,044,338**
Traditional fuels					
Gasoline[d]	122,849,000	125,111,000	125,720,000	*127,916,000*	130,735,000
Diesel	33,665,360	35,796,800	36,979,200	*38,843,150*	39,314,960
Total Fuel Consumption[a,e]	**156,838,150**	**161,253,610**	**163,062,513**	***167,144,571***	***170,444,398***

Source: EIA (2002): "Alternatives to Traditional Transportation Fuels 2000"

[a] 1999 and 2000 estimates have been revised.

[b] The remaining portion of 85-% methanol and both ethanol fuels is gasoline. Consumption data include the gasoline portion of the fuel.

[c] Includes a very small amount of other ethers, primarily Tertiary Amyl Methyl Ether (TAME) and Ethyl Tertiary Butyl Ether (ETBE).

[d] Gasoline consumption includes ethanol in gasohol and MTBE.

[e] Total fuel consumption is the sum of alternative fuel, gasoline, and diesel consumption. Oxygenate consumption is included in gasoline consumption.

6.1.2 Description of LPG conversion systems

Overview of the main LPG conversion systems in 2002 in Belgium (www.LPG.be).

AG AUTOGAS

The Dutch AG Systems have been developing LPG systems for over 20 years. AG have established significant links with a number of OE vehicle manufacturers including Renault, Citroen and VW.

They have three main systems:

- **DGC -** Digital Gas Carburetion uses a single-point gas venturi mixer that is very finely controlled.
- **DGI -** Digital Gas Injection uses a multi-point gas injector system for maximum power and efficiency.
- **SGi -** Sequential Gas Injection promises to be an excellent system with virtually no power loss due to its advanced electronics which map the data for each individual injector. SGi is being supplied to Peugeot and Citroen for factory fit options.

PRINS AUTOGAS

The Dutch company Prins develops, produces and markets LPG and CNG conversion systems for cars, trucks, buses and stationary engines.

Prins have two primary LPG conversion systems: AFS and YPS

- **AFS system** - A closed loop system without adjustment. This system is controlled by digital, programmable electronics. The self-learning capability enables the program to adapt continuously to changing engine conditions. A reference system controls the LPG based on flow management in the inlet channel - this combined with the advanced electronics make the AFS one of the best venturi systems
- **YPS system** - YPS is a multi-point gas injection system which is fully integrated with the vehicle's engine management system. The gasoline system determines how much fuel the engine system needs when running on LPG and the YPS computer converts fuel demand into the correct quantity of LPG. YPS is self-learning and leaves the OBD2 (on-board diagnostics) system fully intact.

KOLTEC-NECAM (EGI, GSI)

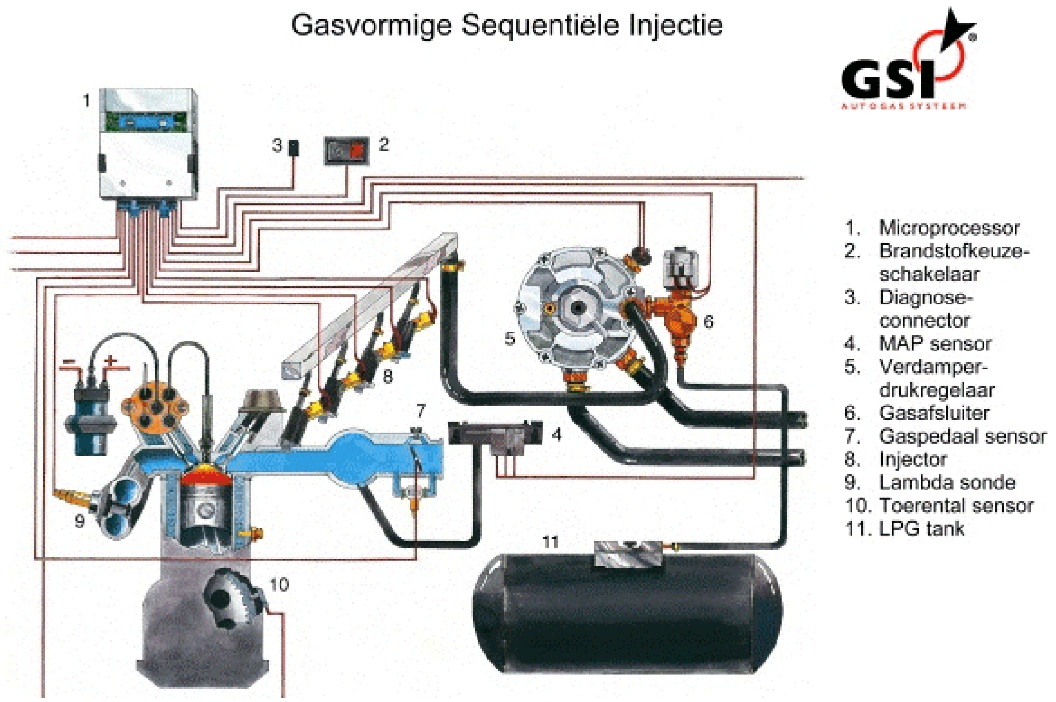
In the late 1970s the former company of Koltec BV introduced their LPG conversion systems in the Netherlands. In 1994 they joined with Necam BV, one of the main competitors in the Netherlands.

These are the main systems they currently offer:

- **EGI -** Electronic Gaseous Injection means a reliable technique in which the risk of backfire and loss of power are history. This kind of system is also called "Third Generation". The main difference with the second-generation systems is that the gaseous LPG is now injected much closer to the inlet valves through individual injectors. The main components of the EGI system: LPG tank (cylindrical or ring tank), Vaporiser, Distributor, Injectors, ECM. The over-pressure of approximately 4 bars in the LPG tank leads the liquid LPG to the vaporiser where it becomes gaseous and the pressure drops to where it reaches a slight overpressure compared with the inlet manifold pressure. Specially developed sensors keep a constant eye on pressure changes and engine torque so that good driveability remains guaranteed. Through the distributor the right amounts of gas are transported to the injectors at exactly the right time.

- **GSI -** The development of Gaseous Sequential Injection is the most important step towards further decrease of emissions and improved driveability. Within current and future European regulations on EOBD (European On-Board Diagnostics) this system is an important breakthrough. The main difference with the EGI system is that each GSI injector is controlled individually, which results in optimum timing of injection. In this set-up no distributor is needed. This GSI system is suited for LPG, CNG and in future for Hydrogen. Furthermore the complexity of after market conversion has decreased significantly by using a new type of ECU which can be mounted directly on the engine or elsewhere in the engine compartment.

Figure 6.1: GSI (Gaseous sequential injection) system of Koltec-Necam



Source: www.LPG.be

[TARTARINI]()

Tartarini of Italy have 50 years' experience with LPG systems and their Tec systems have the capability of being installed in many hundreds of vehicle models.

The Tec99 model is suitable for most fuel injected vehicles and can be tuned using a laptop computer. This generic system can produce very good power and emissions results.

Other manufacturers of conversion systems:

DELTEC (DELTEC2000)
LANDI-RENZO (IGSystem, LCS2)
VIALLE (LPI)
LANDI (LIS)
BRC (Flying, Sequent)
LOVATO (Logic)
BIGAS (SGIS)

6.1.3 Worldwide natural gas vehicles and tank stations

Table 6.1-2: Latest international NGV statistics

Country	Vehicles Converted	Refuelling Stations	VRA*	Last Updated
Argentina	721,830	969		Nov 01
Italy	380,000	369		Nov 01
Pakistan	265,000	310		Jun 01
Brazil	232,973	284		May 02
USA	102,430**	1,250		Jan 01
India	84,150	116		Mar 02
Venezuela	40,962	170		Jan 02
Egypt	37,642	60		May 02
China	36,000	70		Jan 01
Ukraine	35,000	87		Dec 01
Russia	31,000	208	2	Dec 01
Canada	20,505	222	2,845	Aug 01
New Zealand	12,000	100	1	Aug 00
Japan	12,539	181	606	Jun 02
Germany	10,000	146	450	Jan 01
Colombia	9,126	32		Nov 01
Bolivia	6,000	17	46	Nov 01
Belarus	5,500	24		Dec 01
Bangladesh	5,000	9		Jul 02
France	4,550	105	100	Oct 00
Trinidad & Tobago	4,000	12		Nov 01
Malaysia	3,700	18		Oct 00
Indonesia	3,000	12		Aug 00
Chile	3,000	11		Nov 01
Australia	2,104	127	55	Aug 01
Sweden	1,550	25		Mar 00
Iran	1,000	3		Mar 02
Great Britain	835	18	46	Aug 00
Moldova	800	3		Dec 01
South Korea	746	28		Dec 01
Holland	574	27	384	Aug 00
Switzerland	520	26	29	Apr 02
Thailand	468	5		Jun 02
Netherlands	300	15		May 02
Spain	300	6	12	Aug 00

Belgium	300	5	60	Aug 00
Mexico	300	2	13	Nov 01
Portugal	238			May 02
Turkey	189	3		Aug 00
Austria	182	6	25	Nov 01
Ireland	81	2	6	Sep 00
Cuba	45	1		Feb 01
Finland	34	5	4	Aug 00
Czech	30	11		Aug 00
Nigeria	28	2		Aug 00
Luxembourg	25	5		Aug 00
Iceland	21	1		May 02
Poland	20	4	13	Aug 00
Norway	18	3		Aug 00
Taiwan	6	1		Nov 00
Denmark	5	1	3	Aug 00
Korea	4	1		Aug 00
Algeria		1		Aug 00
Hungary			14	Aug 00
South Africa			4	Aug 00
TOTALS	**2,074,310**	**5,119**	**4,718**	

Source: http://statistics.iangv.org/

*VRA = Vehicle Refuelling Appliance
**Projected 2001 figures for the USA as of January 2001, were 111,769 NGVs (109,730 CNG, 2,039 LNG). See Energy Information Administration for more information.

6.1.4 World ethanol production

Table 6.1-3: World ethanol production

	World Ethanol Production (1000hl)				
Country	**2001**	**2000**	**1999**	**1998**	**1997**
France	8 000	8 120	7 540	7 788	7 671
Germany	2 950	2 850	3 400	3 640	3 750
Italy	1 900	2 056	2 009	2 251	2 297
Spain	2 250	1 450	1 250	1 400	1 360
UK	4 300	4 350	4 100	4 220	4 100
Other EU	2 221	1 871	1 853	1 876	2 020
EU	**21 621**	**20 697**	**20 152**	**21 175**	**21 198**
Czech Republic	900	900	900	1 050	1 090
Hungary	510	553	481	494	531
Poland	1 580	1 600	1 700	2 080	2 400
Russia	11 700	11 500	12 800	12 000	11 800
Ukraine	2 200	1 960	1 740	1 560	2 470
Other Europe	3 023	3 032	2 952	3 045	3 587
Europe	**41 534**	**40 242**	**40 725**	**41 404**	**43 076**
Argentina	1 530	1 710	1 735	1 766	1 610
Brazil	119 000	114 000	129 821	141 221	154 934
Canada	2 380	2 380	2 000	1 500	1 500
Cuba	850	840	800	795	1 100
Ecuador	627	375	321	313	263
Guatemala	600	600	450	450	500
Mexico	701	671	562	531	532
USA	75 800	70 500	66 050	64 500	58 860
Other Americas	4 180	4 042	3 867	3 828	3 770
Americas	**205 668**	**195 118**	**205 606**	**214 904**	**223 069**
China	30 900	29 700	28 600	28 000	26 900
India	17 800	17 200	16 900	16 881	16 470
Indonesia	1 650	1 600	1 500	1 650	1 740
Japan	1 360	1 100	1 040	1 020	1 040
Saudi-Arabia	3 900	4 100	3 900	3 700	3 900
Thailand	1 500	1 000	3 200	2 650	3 750
Other Asia	2 485	2 613	2 653	2 820	2 763
Asia	**59 595**	**57 313**	**57 793**	**56 721**	**56 563**
Australia	1 540	1 200	1 000	900	850
New Zealand	174	195	176	190	178
Other Oceania	80	80	80	80	80
Oceania	**1 794**	**1 475**	**1 256**	**1 170**	**1 108**
Malawi	120	120	122	119	154
South African CU	3 852	3 800	3 900	4 100	4 300
Zimbabwe	293	257	263	221	252
Other Africa	1 059	1 036	1 048	991	1 089
Africa	**5 324**	**5 213**	**5 333**	**5 431**	**5 795**
World	**313 915**	**299 361**	**310 713**	**319 630**	**329 611**

Source: Berg 2001, http://www.distill.com/world_ethanol_production.htm

6.2 Annex to Chapter 2

6.2.1 Data on sales and production

Table 6.2-1: Passenger cars - new registrations 1990-2001 in Western Europe

New Registrations in WESTERN EUROPE
By Country

		Country	1990	1991	1992	1993	1994	1995	1996	1997	1998	1999	2000	2001
EU (15)	EC (12)	B	473.506	462.125	466.194	375.409	387.348	358.868	397.359	396.240	452.129	489.621	515.204	488.683
		DK	80.654	83.685	83.679	82.013	139.680	135.773	142.430	152.084	162.508	143.727	112.690	96.173
		F	2.309.130	2.031.274	2.105.700	1.721.222	1.972.919	1.930.504	2.132.091	1.713.030	1.943.553	2.148.423	2.133.884	2.254.732
		D	3.349.788	4.158.674	3.929.558	3.194.204	3.209.224	3.314.057	3.496.320	3.528.179	3.735.987	3.802.176	3.378.343	3.341.718
		GR	115.480	167.737	199.094	147.789	109.544	125.023	139.821	159.867	180.145	261.711	290.222	280.214
		IRL	82.584	68.440	68.415	64.161	80.402	86.959	115.199	136.662	145.702	174.242	230.795	164.730
		I	2.307.055	2.249.990	2.372.347	1.695.428	1.671.766	1.731.747	1.732.198	2.403.744	2.378.516	2.338.464	2.423.084	2.426.443
		L	38.422	43.065	37.248	29.674	29.082	28.029	29.980	31.418	35.928	40.476	41.896	42.833
		NL	502.627	490.755	491.970	391.904	434.004	447.942	471.989	478.290	542.978	611.487	597.625	530.232
		P	210.924	228.554	276.972	242.671	232.916	201.471	217.910	213.636	248.398	272.883	257.836	255.215
		E	988.170	886.983	982.044	743.901	909.682	834.369	910.928	1.016.383	1.192.530	1.406.246	1.381.256	1.425.573
		UK	2.008.934	1.592.326	1.593.600	1.778.426	1.910.933	1.945.366	2.025.450	2.170.725	2.247.403	2.197.615	2.221.670	2.458.769
		EC (12)	**12.467.274**	**12.463.608**	**12.606.821**	**10.466.802**	**11.087.500**	**11.140.108**	**11.811.675**	**12.400.258**	**13.265.777**	**13.887.071**	**13.584.505**	**13.765.315**
		A	288.618	303.723	320.034	285.157	273.663	279.610	307.645	275.001	295.865	314.182	309.427	293.528
		SF	139.095	92.483	68.547	55.836	67.201	79.890	95.830	104.507	125.751	136.324	134.646	109.487
		S	229.941	188.308	154.173	124.434	156.375	169.756	183.820	225.263	253.430	295.249	290.529	246.581
		Efta (3)	**657.654**	**584.514**	**542.754**	**465.427**	**497.239**	**529.256**	**587.295**	**604.771**	**675.046**	**745.755**	**734.602**	**649.596**
	total	**EU (15)**	**13.124.928**	**13.048.122**	**13.149.575**	**10.932.229**	**11.584.739**	**11.669.364**	**12.398.970**	**13.005.029**	**13.940.823**	**14.632.826**	**14.319.107**	**14.414.911**

Source: http://www.acea.be/ACEA/auto_data.html

Table 6.2-2: New retail automobile sales in the USA, 1970–2000

Calendar year	Domestic[a] (thousands)	Import[b] (thousands)	Total (thousands)	Percentage imports	Percentage transplants[c] on model year basis	Percentage imports and transplants	Percentage diesel
1970	7.119	1.285	8.404	15,3%	[d]	[d]	[d]
1975	7.053	1.571	8.624	18,2%	[d]	[d]	0,31%
1980	6.581	2.398	8.979	26,7%	2,1%	28,8%	4,31%
1981	6.209	2.327	8.536	27,3%	1,8%	29,1%	6,10%
1982	5.759	2.223	7.982	27,9%	1,4%	29,3%	4,44%
1983	6.795	2.387	9.182	26,0%	1,3%	27,3%	2,09%
1984	7.952	2.439	10.391	23,5%	2,0%	25,5%	1,45%
1985	8.205	2.838	11.043	25,7%	2,2%	27,9%	0,82%
1986	8.215	3.238	11.453	28,3%	2,8%	31,1%	0,37%
1987	7.081	3.197	10.278	31,1%	5,2%	36,3%	0,16%
1988	7.526	3.099	10.626	29,2%	5,8%	35,0%	0,02%
1989	7.073	2.825	9.898	28,5%	7,3%	35,8%	0,13%
1990	6.897	2.404	9.301	25,8%	11,2%	37,0%	0,08%
1991	6.137	2.038	8.175	24,9%	13,7%	38,6%	0,10%
1992	6.277	1.937	8.213	23,6%	14,1%	37,7%	0,06%
1993	6.742	1.776	8.518	20,9%	14,9%	35,8%	0,03%
1994	7.255	1.735	8.990	19,3%	16,5%	35,8%	0,04%
1995	7.129	1.506	8.635	17,4%	18,9%	36,3%	0,04%
1996	7.255	1.271	8.526	14,9%	22,3%	37,2%	0,10%
1997	6.917	1.355	8.272	16,4%	23,7%	40,1%	0,09%
1998	6.762	1.380	8.142	16,9%	25,1%	42,0%	0,13%
1999	6.979	1.719	8.698	19,8%	24,6%	44,4%	0,16%
2000	6.831	2.016	8.847	22,8%	24,4%	47,2%	0,26%
	Average annual percentage change						
1970–2000	-0,1%	1,5%	0,2%				
1990-2000	-0,1%	-1,7%	-0,5%				

[a] North American built.

[b] Does not include import tourist deliveries.

[c] A transplant is an automobile which was built in the USA by a foreign firm. Also included are joint ventures which are built in the USA.

[d] Data are not available

Source: Transportation Energy Data Book: Edition 21

- Domestic and import data - 1970–97: American Automobile Manufacturers Association, *Motor Vehicle Facts and Figures 1998*, Detroit, MI, 1998, p. 15, and annual. 1997 data from *Economic Indicators, 4th Quarter 1997.*
- 1998-2000: Ward's Communication, *Ward's Automotive Yearbook*, Detroit, MI, 2000, p. 15.
- Diesel data - Ward's Communications, *Ward's Automotive Yearbook*, Detroit, MI, 2001, p. 59, and annual.
- Transplant data - Oak Ridge National Laboratory, Light Vehicle MPG and Market Shares Data System, Oak Ridge, TN, 1996. (Additional resources: www.aama.com, www.wardsauto.com)

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Table 6.2-3: Japanese Car Sales

	Cars	Trucks	Buses	Total	Three-Wheelers
1950	...	...	...	31,507	...
1955	20,055	40,498	3,977	64,530	87,735
1956	31,743	70,020	5,388	107,151	103,572
1957	44,431	110,363	6,269	161,063	114,518
1958	49,236	115,646	6,196	171,078	103,339
1959	73,050	158,607	6,473	238,130	151,958
1960	145,227	255,693	7,260	408,180	260,143
1961	229,057	504,703	9,159	742,919	217,441
1962	259,269	662,781	10,941	932,991	143,364
1963	371,076	826,421	13,021	1,210,518	114,070
1964	493,536	985,453	15,214	1,494,203	74,475
1965	586,287	1,073,832	14,843	1,674,962	42,851
1966	740,259	1,302,416	17,467	2,060,142	30,498
1967	1,131,337	1,561,943	21,491	2,714,771	21,465
1968	1,569,312	1,715,328	24,195	3,308,835	14,269
1969	2,036,677	1,772,058	26,704	3,835,439	9,656
1970	2,379,137	1,693,502	27,828	4,100,467	6,431
1971	2,402,757	1,596,536	21,824	4,021,117	4,508
1972	2,627,087	1,717,731	21,757	4,366,575	2,006
1973	2,953,026	1,970,281	25,771	4,949,078	610
1974	2,286,795	1,540,254	22,690	3,849,739	6
1975	2,737,641	1,551,454	19,836	4,308,931	...
1976	2,449,429	1,631,363	23,259	4,104,051	...
1977	2,500,095	1,671,238	22,916	4,194,249	...
1978	2,856,710	1,800,376	24,777	4,681,863	...
1979	3,036,873	2,092,894	23,985	5,153,752	...
1980	2,854,176	2,137,947	23,387	5,015,510	...
1981	2,866,695	2,237,404	22,897	5,126,996	...
1982	3,038,272	2,201,366	21,793	5,261,431	...
1983	3,135,611	2,226,396	20,310	5,382,317	...
1984	3,095,554	2,320,938	20,267	5,436,759	...
1985	3,104,083	2,431,178	21,573	5,556,834	...
1986	3,146,023	2,540,174	21,617	5,707,814	...
1987	3,274,800	2,721,581	22,018	6,018,399	...
1988	3,717,359	2,980,103	23,542	6,721,004	...
1989	4,403,749	2,829,394	23,530	7,256,673	...
1990	5,102,659	2,649,909	24,925	7,777,493	...
1991	4,868,233	2,632,730	23,796	7,524,759	...
1992	4,454,012	2,483,484	21,577	6,959,073	...
1993	4,199,451	2,248,803	19,025	6,467,279	...
1994	4,210,168	2,298,685	17,843	6,526,696	...
1995	4,443,905	2,403,825	17,303	6,865,033	...
1996	4,668,728	2,391,790	17,227	7,077,745	...
1997	4,492,006	2,217,257	15,763	6,725,026	...

1998	4,093,148	1,772,136	14,141	5,879,425	...
1999	4,154,084	1,692,654	14,478	5,861,216	...
2000	4,259,872	1,686,599	16,571	5,963,042	...
2001	4,289,683	1,600,858	15,932	5,606,473	...

Note: New registration statistics in our publication include sales figures of mini vehicles which are not registered

Source: Japan Automobile Dealers Association, Inc.
Japan Mini Vehicles Association, Inc.

Table 6.2-4: EU car production.

EU Production	1990	1991	1992	1993	1994	1995
Austria	0	0	0	0	0	0
Belgium	1.160.412	1.050.647	1.075.547	1.086.298	1.202.031	1.168.354
Denmark	0	0	0	0	0	0
Finland	0	0	0	0	0	0
France	3.294.815	3.187.634	3.329.490	2.836.280	3.175.213	3.050.929
Germany	4.660.657	4.676.666	4.863.721	3.753.341	4.093.800	4.362.038
United Kingdom	1.295.611	1.236.900	1.291.880	1.375.524	1.466.823	1.523.084
Greece	0	0	0	0	0	0
Ireland	0	0	0	0	0	0
Italy	1.874.672	1.632.904	1.476.627	1.117.053	1.340.878	1.422.359
Luxembourg	0	0	0	0	0	0
Netherlands	121.300	84.709	94.019	80.246	92.044	100.434
Portugal	0	0	0	0	0	0
Spain	1.679.301	1.733.752	1.790.615	1.505.949	1.821.696	1.958.789
Sweden	335.853	269.431	293.499	279.002	352.951	387.659
Total	14.422.621	13.872.643	14.215.398	12.033.693	13.545.436	13.973.646

EU Production	1996	1997	1998	1999	2000
Austria	0	0	0	0	90.289
Belgium	1.144.106	1.004.970	951.196	917.514	929.977
Denmark	0	0	0	0	0
Finland	0	0	0	0	11.000
France	3.147.622	3.350.846	3.800.000	4.156.573	2.877.619
Germany	4.539.400	4.678.022	5.348.115	5.309.241	4.694.889
United Kingdom	1.686.134	1.697.966	1.748.305	1.786.624	1.630.597
Greece	0	0	0	0	0
Ireland	0	0	0	0	0
Italy	1.317.995	1.562.865	1.378.105	1.410.317	1.375.716
Luxembourg	0	0	0	0	0
Netherlands	145.206	197.225	242.989	265.000	216.984
Portugal	0	0	0	0	161.496
Spain	1.934.716	1.997.700	2.216.386	2.208.685	2.318.515
Sweden	367.799	375.705	368.305	385.044	288.146
Total	14.282.978	14.865.299	16.053.401	16.438.998	14.595.228

Source: Economist Intelligence Unit (EIU).
From: Auto Industry Statistics (2001): "European Vehicle Production Since 1990", data from Economist Intelligence Unit (EIU), http://www.autoindustry.co.uk/statistics/production/europe.html

Table 6.2-5: United States car production

	1960	1965	1970	1975	1980	1985	1990	1991
Production								
Passenger cars	6,703	9,335	6,550	6,717	6,376	8,185	6,077	5,439
Commercial vehicles[a]	1,202	1,785	1,734	2,270	1,634	3,468	3,706	3,372
Total	7,905	11,120	8,284	8,987	8,010	11,653	9,783	8,811
Factory (wholesale) sales								
Passenger cars	6,675	9,306	6,547	6,713	6,400	8,002	6,050	5,407
Commercial vehicles[a]	1,194	1,752	1,692	2,272	1,667	3,464	3,725	3,388
Total	7,869	11,057	8,239	8,985	8,067	11,467	9,775	8,795

	1992	1993	1994	1995	1996	1997	1998
Production							
Passenger cars	5,664	5,981	6,614	6,351	6,083	5,927	5,554
Commercial vehicles[a]	4,038	4,917	5,649	5,635	5,749	6,192	6,448
Total	9,702	10,898	12,263	11,985	11,833	12,119	12,003
Factory (wholesale) sales							
Passenger cars	5,685	5,962	6,549	6,310	6,140	6,070	5,677
Commercial vehicles[a]	4,062	4,895	5,640	5,713	5,776	6,153	6,435
Total	9,747	10,857	12,189	12,023	11,916	12,223	12,112

[a] Includes trucks under 10,000 pounds gross vehicle weight rating (gvwr), such as compact and conventional pickups, sport utility vehicles, minivans, and vans, and trucks and buses over 10,000 pounds gvwr.

NOTES: Factory sales can be greater than production total because of sales from previous year's inventory. Numbers may not add to totals due to rounding.

SOURCE: Ward's, Motor Vehicle Facts & Figures 1999 (Southfield, MI: 1999), p. 3.

Table 6.2-6: Japanese car production

	Cars	Trucks	Buses	Total	Three-Wheelers
1950	1,594	26,501	3,502	31,597	35,498
1951	3,611	30,817	4,062	38,490	43,802
1952	4,837	29,960	4,169	38,966	62,224
1953	8,789	36,147	4,842	49,778	97,484
1954	14,472	49,582	5,749	69,803	98,081
1955	20,268	43,857	4,807	68,932	87,904
1956	32,056	72,958	6,052	111,066	105,409
1957	47,121	126,820	8,036	181,977	114,937
1958	50,643	130,066	7,594	188,303	98,877
1959	78,598	177,485	6,731	262,814	158,042
1960	165,094	308,020	8,437	481,551	278,032
1961	249,508	553,390	10,981	813,879	224,595
1962	268,784	710,716	11,206	990,706	114,167
1963	407,830	862,781	12,920	1,283,531	117,190
1964	579,660	1,109,142	13,673	1,702,475	80,048
1965	696,176	1,160,090	19,348	1,875,614	42,944
1966	877,656	1,387,858	20,885	2,286,399	33,364
1967	1,375,755	1,743,368	27,363	3,146,486	26,453
1968	2,055,821	1,991,407	38,598	4,085,826	21,794
1969	2,611,499	2,021,591	41,842	4,674,932	17,082
1970	3,178,708	2,063,883	46,566	5,289,157	14,061
1971	3,717,858	2,058,320	34,596	5,810,774	11,929
1972	4,022,289	2,238,340	33,809	6,294,438	3,202
1973	4,470,550	2,570,916	41,291	7,082,757	2,904
1974	3,931,842	2,574,179	45,819	6,551,840	1,020
1975	4,567,854	2,337,632	36,105	6,941,591	...
1976	5,027,792	2,771,516	42,139	7,841,447	...
1977	5,431,045	3,034,981	48,496	8,514,522	...
1978	5,975,968	3,237,066	56,119	9,269,153	...
1979	6,175,771	3,397,214	62,561	9,635,546	...
1980	7,038,108	3,913,188	91,588	11,042,884	...
1981	6,974,131	4,102,996	102,835	11,179,962	...
1982	6,881,586	3,783,218	66,990	10,731,794	...
1983	7,151,888	3,903,823	55,948	11,111,659	...
1984	7,073,173	4,319,538	72,209	11,464,920	...
1985	7,646,816	4,544,688	79,591	12,271,095	...
1986	7,809,809	4,407,666	42,342	12,259,817	...
1987	7,891,087	4,308,100	49,987	12,249,174	...
1988	8,198,400	4,443,994	57,413	12,699,807	...
1989	9,052,406	3,931,255	42,074	13,025,735	...
1990	9,947,972	3,498,639	40,185	13,486,796	...
1991	9,753,069	3,447,914	44,449	13,245,432	...
1992	9,378,694	3,068,585	52,005	12,499,284	...
1993	8,493,943	2,685,528	48,074	11,227,545	...
1994	7,802,037	2,702,970	49,112	10,554,119	...
1995	7,610,533	2,537,737	47,266	10,195,536	...
1996	7,863,763	2,428,897	53,126	10,345,786	...
1997	8,491,440	2,421,413	62,234	10,975,087	...
1998	8,055,763	1,937,076	56,953	10,049,792	...
1999	8,100,169	1,746,912	48,395	9,895,476	...
2000	8,363,485	1,726,818	54,544	10,144,847	...
2001	8,117,563	1,601,536	58,092	9,777,191	...

Source: Japan Automobile Manufacturers Association, Inc.

6.2.2 Data on car prices

Table 6.2-7: Maximum difference in car prices in EU 15

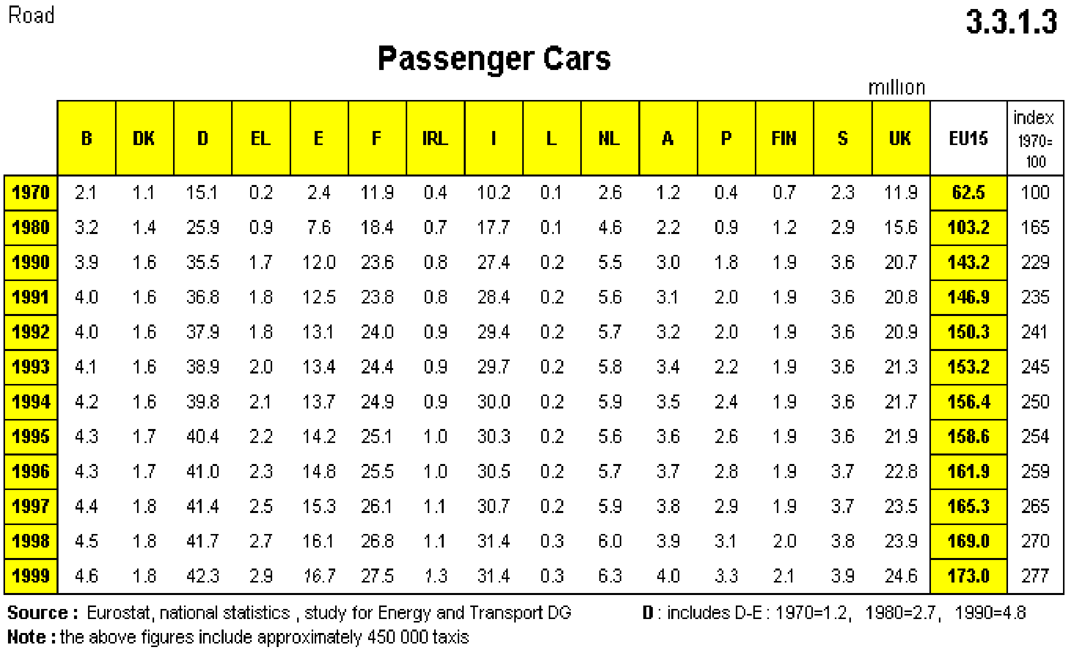
Small segments A and B	1/5/2002	1/11/2001	1/5/2001	1/11/2000
Opel Corsa	18.1 %	36.9 %	37.4 %	24.6 %
Ford Fiesta	n.a.	16.4 %	16.5 %	20.5 %
Renault Clio	19.5 %	26.4 %	31.3 %	23.0 %
Peugeot 106	24.4 %	20.3 %	23.5 %	11.4 %
VW Polo	22.6 %	14.7 %	28.0 %	29.1 %

Medium segment C	1/5/2002	1/11/2001	1/5/2001	1/11/2000
VW Golf	30.5 %	34.5 %	33.1 %	32.9 %
Opel Astra	21.4 %	32.2 %	51.6 %	27.6 %
Ford Focus	24.4 %	21.0 %	18.6 %	18.1 %
Renault Mégane	26.5 %	22.9 %	25.8 %	18.5 %
Peugeot 307	27.2 %	29.6 %	24.2 %	18.9 %

Large segments D, E and F	1/5/2002	1/11/2001	1/5/2001	1/11/2000
BMW 318i	11.2 %	11.6 %	13.4 %	13.9 %
Audi A4	11.9 %	13.5 %	13.7 %	21.0 %
Ford Mondeo	21.5 %	20.5 %	22.2 %	29.9 %
Opel Vectra	28.0 %	41.0 %	48.5 %	25.2 %
VW Passat	27.3 %	23.1 %	22.3 %	22.1 %

Source: "Car prices in the European Union: still substantial price differences, especially in the mass market segments", EU Press release, 22 July 2002, http://www.europa.eu.int/rapid/start/cgi/guesten.ksh?p_action.gettxt=gt&doc=IP/02/1109|0|RAPID&lg=EN

Table 6.2-8: Price index for new passenger cars in the EU15



Road

3.3.1.3

Passenger Cars

million

	B	DK	D	EL	E	F	IRL	I	L	NL	A	P	FIN	S	UK	EU15	index 1970= 100
1970	2.1	1.1	15.1	0.2	2.4	11.9	0.4	10.2	0.1	2.6	1.2	0.4	0.7	2.3	11.9	**62.5**	100
1980	3.2	1.4	25.9	0.9	7.6	18.4	0.7	17.7	0.1	4.6	2.2	0.9	1.2	2.9	15.6	**103.2**	165
1990	3.9	1.6	35.5	1.7	12.0	23.6	0.8	27.4	0.2	5.5	3.0	1.8	1.9	3.6	20.7	**143.2**	229
1991	4.0	1.6	36.8	1.8	12.5	23.8	0.8	28.4	0.2	5.6	3.1	2.0	1.9	3.6	20.8	**146.9**	235
1992	4.0	1.6	37.9	1.8	13.1	24.0	0.9	29.4	0.2	5.7	3.2	2.0	1.9	3.6	20.9	**150.3**	241
1993	4.1	1.6	38.9	2.0	13.4	24.4	0.9	29.7	0.2	5.8	3.4	2.2	1.9	3.6	21.3	**153.2**	245
1994	4.2	1.6	39.8	2.1	13.7	24.9	0.9	30.0	0.2	5.9	3.5	2.4	1.9	3.6	21.7	**156.4**	250
1995	4.3	1.7	40.4	2.2	14.2	25.1	1.0	30.3	0.2	5.6	3.6	2.6	1.9	3.6	21.9	**158.6**	254
1996	4.3	1.7	41.0	2.3	14.8	25.5	1.0	30.5	0.2	5.7	3.7	2.8	1.9	3.7	22.8	**161.9**	259
1997	4.4	1.8	41.4	2.5	15.3	26.1	1.1	30.7	0.2	5.9	3.8	2.9	1.9	3.7	23.5	**165.3**	265
1998	4.5	1.8	41.7	2.7	16.1	26.8	1.1	31.4	0.3	6.0	3.9	3.1	2.0	3.8	23.9	**169.0**	270
1999	4.6	1.8	42.3	2.9	*16.7*	27.5	*1.3*	31.4	0.3	6.3	4.0	3.3	2.1	3.9	24.6	**173.0**	277

Source : Eurostat, national statistics , study for Energy and Transport DG

D : includes D-E : 1970=1.2, 1980=2.7, 1990=4.8

Note : the above figures include approximately 450 000 taxis

http://www.europa.eu.int/comm/competition/car_sector/price_diffs/2002_05.pdf
Source: "European Union Energy and Transport in Figures", European Commission, Directorate-General for Energy and Transport, May 2002,
http://www.europa.eu.int/comm/energy_transport/etif/transport_means_road/cars.html

Table 6.2-9: Average price of new passenger cars evolution in the USA

	Domestic[a]		Import		Total	
Year	Current dollars	Constant 1998 dollars[b]	Current dollars	Constant 1998 dollars[b]	Current dollars	Constant 1998 dollars[b]
1970	3.708	15.568	2.648	11.118	3.542	14.872
1975	5.084	15.400	4.384	13.280	4.950	14.994
1980	7.609	15.055	7.482	14.803	7.574	14.985
1981	8.912	15.976	8.896	15.947	8.910	15.972
1982	9.865	16.662	9.957	16.818	9.890	16.727
1983	10.516	17.208	10.868	17.784	10.606	17.356
1984	11.079	17.390	12.336	19.362	11.375	17.854
1985	11.589	17.563	12.853	19.479	11.838	17.941
1986	12.319	18.317	13.670	20.326	12.652	18.812
1987	12.922	18.536	14.470	20.757	13.386	19.202
1988	13.418	18.493	15.221	20.978	13.932	19.201
1989	13.936	18.327	15.510	20.397	14.371	18.899
1990	14.489	18.076	16.640	20.760	15.042	18.766
1991	15.192	18.182	16.327	19.540	15.475	18.521
1992	15.644	18.175	18.593	21.601	16.336	18.979
1993	15.976	18.029	20.261	22.864	16.871	19.039
1994	16.930	18.619	21.989	24.183	17.903	19.689
1995	16.864	18.035	23.202	24.813	17.959	19.206
1996	17.468	18.152	26.205	27.231	18.777	19.512
1997	17.838	18.116	28.193	28.633	19.551	19.856
1998	18.579	18.579	31.986	31.986	20.849	20.849
1999	18.725	18.323	30.350	29.699	21.022	20.571

[Transportation Energy Data Book, 21]
Source: U.S. Department of Commerce, Bureau of Economic Analysis, “National Income and Product Accounts”, underlying detail estimates for Motor Vehicle Output, Washington, DC, 2000.
(Additional resources: www.stat-usa.gov)

Table 6.2-10: Average price of passenger cars in Japan, compared with North America

US $	**1987**	**1988**	**1989**	**1990**	**1991**	**1992**	**1993**	**1994**	**1995**	**1996**	**1997**	**1998**	**1999**
North American	9.280	9.914	10.594	10.942	10.223	10.883	11.320	11.981	12.974	13.659	14.224	13.659	14.662
Japan	9.509	10.064	10.522	10.868	10.335	11.106	11.761	11.742	13.535	15.137	14.862	13.924	14.140
Other Countries	11.515	13.625	14.339	14.518	13.304	13.301	14.517	17.595	18.827	21.413	22.862	23.030	21.838
Total all Countries	**10.101**	**11.201**	**11.818**	**12.109**	**11.288**	**11.763**	**12.533**	**13.773**	**15.112**	**16.736**	**17.316**	**16.871**	**16.880**

Source: Statistics Canada Catalogue Number 63-007-XPB.
Industry Canada (2001): “Average prices of passenger cars”, http://strategis.ic.gc.ca/SSG/am01358e.html

6.2.3 Data on user costs

Table 6.2-11: Automobile ownership and operation costs

Model year	Variable cost	Fixed cost	Total cost	Total cost per mile
1985	1.245	2.967	4.213	42,13
1986	991	3.505	4.496	44,96
1987	1.055	3.729	4.785	47,85
1988	1.113	4.267	5.380	53,80
1989	1.062	4.072	5.134	51,34
1990	1.071	4.151	5.222	52,22
1991	1.199	4.139	5.337	53,37
1992	1.080	4.354	5.434	54,34
1993	1.072	4.133	5.206	52,06
1994	1.034	4.209	5.243	52,43
1995	1.093	4.252	5.345	53,45
1996	1.073	4.389	5.461	54,61
1997	1.121	4.388	5.509	55,09
1998	1.104	4.499	5.603	56,03
1999	1.070	4.730	5.800	58,00
2000	1.219	4.376	5.595	55,95
Average annual percentage change				
1985–2000	-0,1%	2,6%	1,9%	1,9%

Source: American Automobile Association, Your Driving Costs, 2000 Edition, Heathrow, FL, and annual. (Additional resources: www.aaa.com, www.runzheimer.com)
From: Transportation Energy Data Book: Edition 21. OAK RIDGE NATIONAL LABORATORY.

The costs per mile in this table are based on 10.000 miles per year.

Table 6.2-12: Costs of ownership and operation distribution

Model Year	Variable Cost (1998 $/year)			Fixed Cost (1998 $/year)				Total cost
	Gas and Oil	Maintenance	Tires	Insurance	Registration Fees and Taxes	Capital Depreciation	Finance Charges	
1985	934	186	99	762	174	1,104	864	4,123
1999	549	323	167	951	221	2,652	811	5,674

Source: S. Davis, ORNL, *Transportation Energy Databook Edition 19*, Tables 5.11 and 5.12, and Transportation Energy Databook Edition 20 - Draft, April 2000, Tables 5.12 and 5.13. Original source data, American Automobile Association, Your Driving Costs, 1999 Edition and annual.
From: http://www.ott.doe.gov/facts/archives/fotw129supp.shtml

Table 6.2-13: Comparative study between diesel and gasoline automobiles

SEGMENT	MAKE	MODEL	COST PER MILE	CO2 EMISSIONS (g/km)	MPG	New VED
Supermini	**Citroen**	**Saxo 1.4 SX 3dr**	**27,9**	**160**	**43,5**	**£120**
	Citroen	**Saxo 1.5D SX 3dr**	**26,4**	**139**	**53,3**	**£110**
Lower Medium	**Opel**	**Astra 1.8i 16V CD 5dr**	**40,1**	**185**	**36,2**	**£140**
	Opel	**Astra 2.0Di CD 5dr**	**36,9**	**153**	**49,6**	**£130**
Upper Medium	**Peugeot**	**406 2.0 LX**	**42,6**	**203**	**33,9**	**£155**
	Peugeot	**406 2.0 HDi 90 LX**	**37,3**	**154**	**50,5**	**£130**
	Peugeot	**406 2.0 HDi 110 LX**	**38,9**	**150**	**51,3**	**£110**
Executive	**Mercedes-Benz**	**E 320 Elegance**	**79,3**	**246**	**27,4**	**£155**
	Mercedes-Benz	**E 320 CDI Elegance**	**68,4**	**207**	**36,2**	**£160**
Dual purpose	**Land Rover**	**Discovery V8i ES 7 seat**	**94,3**	**397**	**17**	**£155**
	Land Rover	**Discovery TD5 ES 7 seat**	**79,4**	**248**	**30,1**	**£160**
Multi-purpose vehicle	**Ford**	**Galaxy 2.3i 16v Ghia**	**53,6**	**242**	**28**	**£155**
	Ford	**Galaxy 1.9 Tdi (110PS) Ghia**	**51,2**	**178**	**42,8**	**£150**

Source: Data from August 2000 edition of "What Car?" Magazine.
From: http://www.smmt.co.uk/downloads/Dieselfactsandfigures.ppt

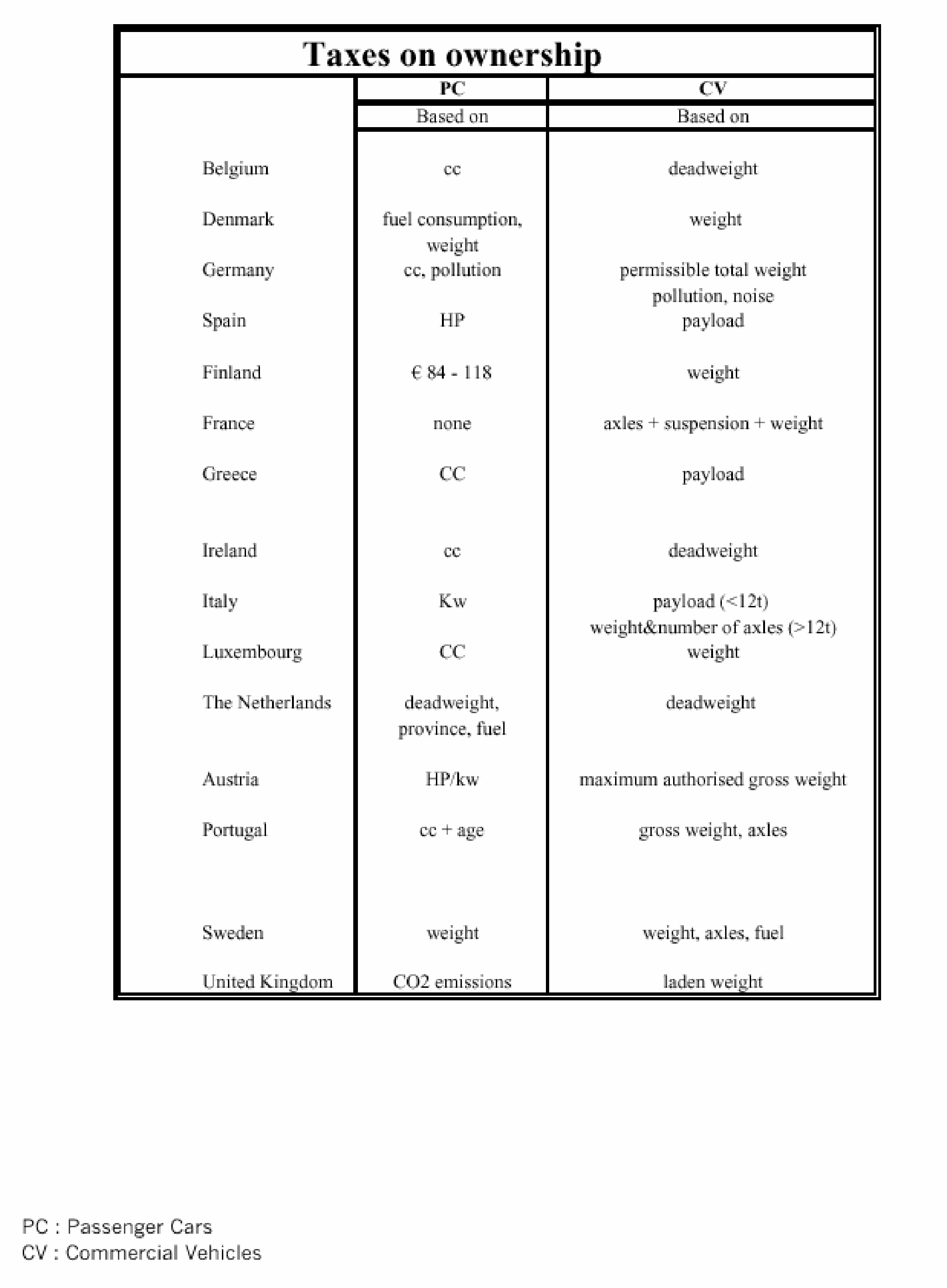
Cost per mile (pence) calculated over three years / 36,000 miles.
The cost per mile includes depreciation, maintenance, road tax, funding and fuel, but in this analysis insurance in not included.
MPG is official combined fuel consumption.

Table 6.2-14: Motor vehicle taxation (on acquisition) in the European Union – Summary table

Taxes on acquisition				
		Sales / Registration tax		
	VAT (%)	Passenger cars	Commercial Vehicles	Registration charge
Belgium	21	Based on cc + age e.g. 1.8 litres: € 124	none	€ 62
Denmark	25	105% up to DKK 57400 180% on the remainder	95% of value exceeding DKK 13800 (below 2t) 30% of value exceeding DKK 34100 (2-4t)	DKK 1180
Germany	16	none	none	€ 25.60
Spain	16	< 1.6 litres: 7% > 1.6 litres: 12%	none	€ 15.80
Finland	22	(100% - € 824) - € 774	none	
France	19.6	none	none	€ 16 – 30 & parafiscal charge
Greece	18	New car: 7–88%	New vehicle: 6-26%	none
Ireland	21	< 1.4 litres: 22.5% 1.4 – 2 litres: 25% > 2 litres: 30%	LCV 13.3 % Others € 51 – 127	none
Italy	20	IPT	IPT	€ 151 – 453
Luxembourg	15	none	none	€ 28.90
The Netherlands	19	Gasoline car : 45.2% - € 1540 Diesel car : 45.2% + € 328	none	€ 32 – 42
Austria	20	Based on fuel consumption (MVEG), max 16%	none	€ 147 – 163
Portugal	20	Based on cc e.g. 1.6 litres: € 5032	none	€ 85
Sweden	25	None	none	None
United Kingdom	17.5	None	none	£ 25

Source: http://www.acea.be/ACEA/20020506PublicationsTaxguideIntro.pdf

Table 6.2-15: Taxes on ownership



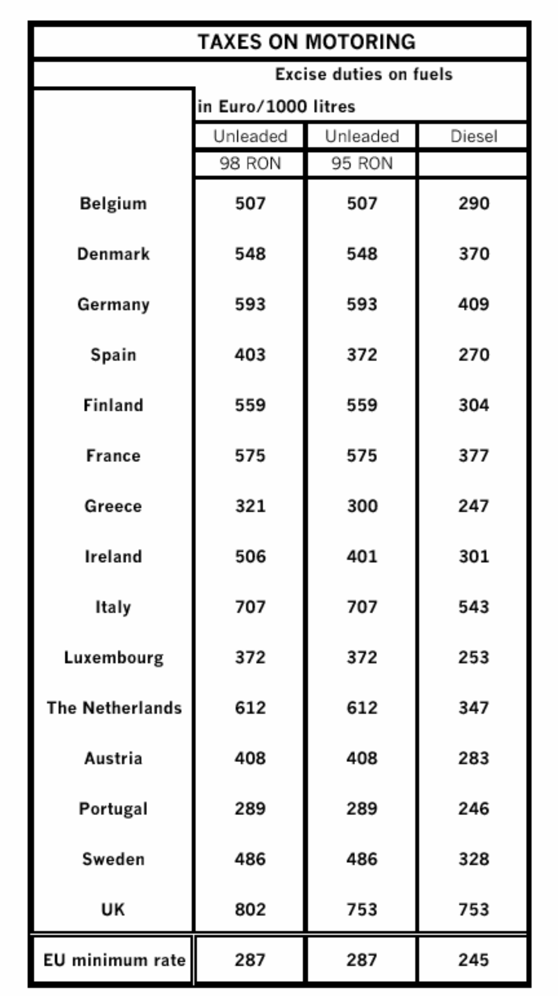
Taxes on ownership

	PC	CV
	Based on	Based on
Belgium	cc	deadweight
Denmark	fuel consumption, weight	weight
Germany	cc, pollution	permissible total weight pollution, noise
Spain	HP	payload
Finland	€ 84 - 118	weight
France	none	axles + suspension + weight
Greece	CC	payload
Ireland	cc	deadweight
Italy	Kw	payload (<12t) weight&number of axles (>12t)
Luxembourg	CC	weight
The Netherlands	deadweight, province, fuel	deadweight
Austria	HP/kw	maximum authorised gross weight
Portugal	cc + age	gross weight, axles
Sweden	weight	weight, axles, fuel
United Kingdom	CO2 emissions	laden weight

PC : Passenger Cars
CV : Commercial Vehicles

Source: http://www.acea.be/ACEA/20020506PublicationsTaxguideIntro.pdf

Table 6.2-16: Taxes on motoring



TAXES ON MOTORING

	Excise duties on fuels in Euro/1000 litres		
	Unleaded 98 RON	Unleaded 95 RON	Diesel
Belgium	507	507	290
Denmark	548	548	370
Germany	593	593	409
Spain	403	372	270
Finland	559	559	304
France	575	575	377
Greece	321	300	247
Ireland	506	401	301
Italy	707	707	543
Luxembourg	372	372	253
The Netherlands	612	612	347
Austria	408	408	283
Portugal	289	289	246
Sweden	486	486	328
UK	802	753	753
EU minimum rate	287	287	245

Source: http://www.acea.be/ACEA/20020506PublicationsTaxguideIntro.pdf

Table 6.2-17: Fiscal Income from motor vehicles in Europe (Belgium, Germany, Spain)

Motor vehicle tax revenue	**Belgium € bn, 2000**	**Germany € bn, 2000**	**Spain € bn, 2000**
1. Purchase or transfer			
1.1 VAT on vehicles, servicing/repair parts, tyres	2.590	23.470	3.532
1.2 Fuels & Lubricants (VAT + excise duties)	4.727	37.940	11.842
1.3 Sales & registration taxes	0.322		1.022
2. Annual ownership taxes	1.059	7.000	1.503
3. Driving license fees	0.006		0.052
4. Insurance tax	0.358	3.070	0.407
5. Tolls			
6. Customs duties	0.093	0.770	
7. Other taxes	0.221	0.260	0.266
TOTAL	**9.476**	**72.510**	**22.157**

Source: http://www.acea.be/ACEA/20020506PublicationsTaxguideIntro.pdf

6.2.4 Data on vehicle lifetime and scrapping rates

Table 6.2-18: Automobile survival and scrappage rates

Vehicle Age (years)	1970 model year		1980 model year		1990 model year	
	Survival rate	Scrappage rate	Survival Rate	Scrappage rate	Survival rate	Scrappage rate
4	99,0	3,9	100,0	3,2	100,0	1,6
5	94,1	5,0	96,3	4,2	100,0	2,1
6	88,4	6,1	91,3	5,1	99,4	2,6
7	82,0	7,2	85,7	6,1	96,3	3,2
8	75,2	8,3	79,7	7,1	92,7	3,7
9	68,1	9,5	73,3	8,1	88,7	4,3
10	60,9	10,6	66,6	9,0	84,4	4,9
11	53,8	11,7	60,0	10,0	79,8	5,5
12	46,9	12,8	53,3	11,0	75,0	6,1
13	40,3	14,0	46,9	12,0	70,0	6,7
14	34,2	15,1	40,8	13,0	64,9	7,3
15	28,7	16,2	35,1	14,0	59,7	7,9
16	23,7	17,4	29,8	15,0	54,6	8,6
17	19,3	18,5	25,0	16,1	49,5	9,3
18	15,5	19,6	20,8	17,1	44,6	9,9
19	12,3	20,8	17,0	18,1	39,9	10,6
20	9,6	21,9	13,8	19,1	35,4	11,3
21	7,4	23,0	11,0	20,1	31,1	12,0
22	5,6	24,2	8,7	21,2	27,2	12,7
23	4,2	25,3	6,7	22,2	23,5	13,5
24	3,1	26,4	5,2	23,2	20,2	14,2
25	2,2	27,5	3,9	24,2	17,1	15,0
26	1,6	28,6	2,9	25,3	14,5	15,7
27	1,1	29,7	2,2	26,3	12,1	16,5
28	0,8	30,8	1,6	27,3	10,0	17,2
29	0,5	31,9	1,1	28,4	8,2	18,0
30	0,4	33,0	0,8	29,4	6,6	18,8
Median lifetime	11,5		12,5		16,1	

Source: Schmoyer, Richard L., unpublished study on scrappage rates, Oak Ridge National Laboratory, Oak Ridge, TN, 2001.
From: Transportation Energy Data Book: Edition 21. OAK RIDGE NATIONAL LABORATORY.

Table 6.2-19: Car components age

Component	1970	1980	1990	2000
Exhaust	3	5	7	10
Drive Belt	3	5	7	10
Damper	7	8	10	12
Clutch	6	8	12	15
Water pump	7	8	12	15

[Autopolis, November 2000]
Source: ICDP sponsor, quoted in Research Paper 6/98 (op. Cit.)

6.2.5 Technical characteristics of vehicle categories

In order to identify the level of emission control, the years of introduction of the various amendments to EU legislation may be linked with the model years of vehicles within the fleet. Table 6.2-20 therefore also indicates the model years appropriate for each vehicle category. This association should be regarded only as indicative as there have been some slight differences in procedures in different Member States. Some of the classes refer to future vehicle types - either standard vehicles that will be introduced after future proposed changes in emission control legislation or vehicles using new fuels and engine technologies. These future types are indicated by italics.

One of the most important of the criteria used to define the vehicle categories in Table 6.2-20 is the 'control level'. This is defined as the emission control standard to which the vehicle was type approved. But another way of classifying vehicles would be according to the technology of their engines and emission control systems.
For gasoline-engined passenger cars, for example, such a classification might be 'uncontrolled', 'open loop catalyst', and 'closed loop catalyst'. There is, though, a reasonably close correspondence between the two alternative classification systems: the limit values set by legislation usually dictate the types of technologies needed to meet them, even though the technologies themselves are not legally specified. In this section, the history of emission standards in the EU is briefly examined with reference to their effects on vehicle technology and rates of emission.

The first emission standard adopted in the EU set limit values for carbon monoxide and hydrocarbon emissions from gasoline-engined vehicles (Directive 70/220/EEC). At this stage, the legislation was principally intended to prevent individual national requirements from creating barriers to trade: Member States were not obliged to adopt the standards, but could not set standards that were more stringent. The Directive itself was based on regulations developed by the United Nations Economic Commission for Europe (ECE Regulation 15).
No special emission control equipment was needed to meet the early standards and the limit values were easily achievable.

Successive amendments to the Directive were introduced with a number of purposes:

- Directive 74/290 reduced the emission limits.
- Directive 77/102 added a limit value for oxides of nitrogen.
- Directive 78/665 again reduced the emission limits.
- Directive 83/351 further reduced the emission limits, gave a combined limit for oxides of nitrogen and hydrocarbons and made them also applicable to diesel cars. Changes were also made to the methods of sampling and analysis used in the test procedure.

Under this series of standards, the emission limits were specified as grams of pollutant per test, and varied depending on the weight of the vehicle. The test cycle was a low-speed, urban driving simulation (approximately 4 km at an average speed of 19 km/h). In approximate terms, the emission limits of Directive 83/351/EEC were around a half of those originally required by 70/220/EEC, but it was still possible for them to be achieved by cars without any special emission control systems.

The first five stages of EU legislation were adopted from ECE Regulations, and for that reason vehicles are frequently referred to in those terms rather than by the equivalent EC Directives. Equivalences are as follows:

Directive 70/220/EEC: ECE Regulation 15.00
Directive 74/290/EEC: ECE Regulation 15.01
Directive 77/102/EEC: ECE Regulation 15.02
Directive 78/665/EEC: ECE Regulation 15.03
Directive 83/351/EEC: ECE Regulation 15.04

Table 6.2-20: Vehicle categories for passenger cars

Category	Engine / fuel	Size	Model year	Control level
Passenger car	gasoline	<1.4 l	until 1971	Pre-regulation
			1972 - 1977	70/220 & 74/290/EEC
			1978 - 1980	77/102/EEC
			1981 - 1984	78/665/EEC
			1985 - 1992	83/351/EEC
			1986 - 1991	Improved Conventional
			1986 - 1991	Open loop catalyst
			1991 - 1996	91/441/EEC (EURO I)
			1996 - 2001	94/12/EEC (EURO II)
			2001 - 2005	*EURO III*
			2005 -	*EURO IV*
		1.4-2.0 l	until 1971	Pre-regulation
			1972 - 1977	70/220 & 74/290/EEC
			1978 - 1980	77/102/EEC
			1981 - 1984	78/665/EEC
			1985 - 1992	83/351/EEC
			1986 - 1991	Improved Conventional
			1986 - 1991	Open loop catalyst
			1991 - 1996	91/441/EEC (EURO I)
			1996 - 2001	94/12/EEC (EURO II)
			2001 - 2005	*EURO III*
			2005 -	*EURO IV*
		>2.0	until 1971	Pre-regulation
			1972 - 1977	70/220 & 74/290/EEC
			1978 - 1980	77/102/EEC
			1981 - 1984	78/665/EEC
			1985 - 1992	83/351/EEC
			1986 - 1991	Improved Conventional
			1986 - 1991	Open loop catalyst
			1991 - 1996	91/441/EEC (EURO I)
			1996 - 2001	94/12/EEC (EURO II)
			2001 - 2005	*EURO III*
			2005 -	*EURO IV*
Passenger car	diesel	< 2.0 l	until 1986	Uncontrolled
			1986 - 1996	88/436 & 91/441/EEC (EURO I)
			1996 - 2001	94/12/EEC (EURO II)
			2001 - 2005	*EURO III*
			2005 -	*EURO IV*
		> 2.0 l	until 1986	Uncontrolled
			1986 - 1996	88/436 & 91/441/EEC (EURO I)
			1996 - 2001	94/12/EEC (EURO II)
			2001 - 2005	*EURO III*
			2005 -	*EURO IV*
Passenger car	LPG	All	until 1986	Conventional
			1986 - 1996	88/436 & 91/441/EEC (EURO I)
			1996 - 2001	94/12/EEC (EURO II)
			2001 - 2005	*EURO III*
			2005 -	*EURO IV*
	CNG	*All*		
	Alcohols	*All*		
	Bio diesel	*All*		
	Electric	*All*		
	Hybrid	*All*		
	2 stroke	*All*		*Uncontrolled*
				Future categories

Source: Hickman, 1999

6.2.5.1 Hot emission factors

The following tables show an overview of the speed-dependent emission factors.

Table 6.2-21: Gasoline passenger cars, CO emissions

Vehicle class	Cylinder capacity	Speed range	CO emission factor (g/km)	R^2
PRE ECE	All categories	10-100	$281V^{-0.630}$	0.924
	All categories	100-130	$0.112V + 4.32$	-
ECE 15-00/01	All categories	10-50	$313V^{-0.760}$	0.898
	All categories	50-130	$27.22 - 0.406V + 0.0032V^2$	0.158
ECE 15-02	All categories	10-60	$300V^{-0.797}$	0.747
	All categories	60-130	$26.260 - 0.440V + 0.0026V^2$	0.102
ECE 15-03	All categories	10-20	$161.36 - 45.62 \ln(V)$	0.790
	All categories	20-130	$37.92 - 0.680V + 0.00377V^2$	0.247
ECE 15-04	All categories	10-60	$260.788V^{-0.910}$	0.825
	All categories	60-130	$14.653 - 0.220V + 0.001163V^2$	0.613
Improved conventional	CC < 1.4 l	10-130	$14.577 - 0.294V + 0.002478V^2$	0.781
	1.4 l < CC < 2.0 l	10-130	$8.273 - 0.151V + 0.000957V^2$	0.767
Open loop	CC < 1.4 l	10-130	$17.882 - 0.377V + 0.002825V^2$	0.656
	1.4 l < CC < 2.0 l	10-130	$9.446 - 0.230V + 0.002029V^2$	0.719
EURO I	CC < 1.4 l	10-130	$9.846 - 0.2867V + 0.0022V^2$	0.133
	1.4 l < CC < 2.0 l	10-130	$9.617 - 0.245V + 0.001729V^2$	0.145
	CC > 2.0 l	10-130	$12.826 - 0.2955V + 0.00177V^2$	0.109

Source: Hickman, 1999

Table 6.2-22: Gasoline passenger cars: VOC emission factors

Vehicle class	Cylinder capacity	Speed range	VOC emission factor (g/km)	R^2
PRE ECE	All categories	10-100	$30.34V^{-0.693}$	0.980
	All categories	100-130	1.247	-
ECE 15-00/01	All categories	10-50	$24.99V^{-0.704}$	0.901
	All categories	50-130	$4.85V^{-0.318}$	0.095
ECE 15-02/03	All categories	10-60	$25.75V^{-0.714}$	0.895
	All categories	60-130	$1.95 - 0.019V + 0.00009V^2$	0.198
ECE 15-04	All categories	10-60	$19.079V^{-0.693}$	0.838
	All categories	60-130	$2.608 - 0.037V + 0.000179V^2$	0.341
Improved conventional	CC < 1.4 l	10-130	$2.189 - 0.034V + 0.000201V^2$	0.766
	1.4 l < CC < 2.0 l	10-130	$1.999 - 0.034V + 0.000214V^2$	0.447
Open loop	CC < 1.4 l	10-130	$2.185 - 0.0423V + 0.000256V^2$	0.636
	1.4 l < CC < 2.0 l	10-130	$0.808 - 0.016V + 0.000099V^2$	0.49
EURO I	CC < 1.4 l	10-130	$0.628 - 0.01377V + 8.52E{-}05V^2$	0.207
	1.4 l < CC < 2.0 l	10-130	$0.4494 - 0.00888V + 5.21E{-}05V^2$	0.197
	CC > 2.0 l	10-130	$0.5086 - 0.00723V + 3.3E{-}05V^2$	0.043

Source: Hickman, 1999

Table 6.2-23: Gasoline passenger cars: NO_x emission factors

Vehicle class	**Cylinder capacity**	**Speed range**	**NO_x emission factor (g/km)**	**R^2**
PRE ECE ECE 15-00/01	CC < 1.4 l	10-130	$1.173 + 0.0225V - 0.00014V^2$	0.916
	1.4 l < CC < 2.0 l	10-130	$1.360 + 0.0217V - 0.00004V^2$	0.960
	CC > 2.0 l	10-130	$1.5 + 0.03V + 0.0001V^2$	0.972
ECE 15-02	CC < 1.4 l	10-130	$1.479 - 0.0037V + 0.00018V^2$	0.711
	1.4 l < CC < 2.0 l	10-130	$1.663 - 0.0038V + 0.00020V^2$	0.839
	CC > 2.0 l	10-130	$1.87 - 0.0039V + 0.00022V^2$	-
ECE 15-03	CC < 1.4 l	10-130	$1.616 - 0.0084V + 0.00025V^2$	0.844
	1.4 l < CC < 2.0 l	10-130	$1.29\ e^{0.0099V}$	0.798
	CC > 2.0 l	10-130	$2.784 - 0.0112V + 0.000294V^2$	0.577
ECE 15-04	CC < 1.4 l	10-130	$1.432 + 0.003V + 0.000097V^2$	0.669
	1.4 l < CC < 2.0 l	10-130	$1.484 + 0.013V + 0.000074V^2$	0.722
	CC > 2.0 l	10-130	$2.427 - 0.014V + 0.000266V^2$	0.803
Improved conventional	CC < 1.4 l	10-130	$-0.926 + 0.719 \ln(V)$	0.883
	1.4 l < CC < 2.0 l	10-130	$1.387 + 0.0014V + 0.000247V^2$	0.876
Open loop	CC < 1.4 l	10-130	$-0.921 + 0.616 \ln(V)$	0.791
	1.4 l < CC < 2.0 l	10-130	$-0.761 + 0.515 \ln(V)$	0.495
EURO I	CC < 1.4 l	10-130	$0.5595 - 0.01047V + 1.08E\text{-}04V^2$	0.122
	1.4 l < CC < 2.0 l	10-130	$0.526 - 0.0085V + 8.54E\text{-}05V^2$	0.077
	CC > 2.0 l	10-130	$0.666 - 0.009V + 7.55E\text{-}05V^2$	0.014

Source: Hickman, 1999

Table 6.2-24: Gasoline passenger cars: CO_2 emission factors

Vehicle class	**Cylinder capacity**	**Speed range**	**CO_2 emission factor (g/km)**	**R^2**
PRE ECE	CC < 1.4 l	10-130	$768 + 3.13V - 199\ln(V)$	-
	1.4 l < CC < 2.0 l	10-130	$1005 + 4.15V - 263\ln(V)$	-
	CC > 2.0 l	10-130	$1498 + 8.21V - 0.0133V^2 - 421\ln(V)$	-
ECE 15-00/01	CC < 1.4 l	10-130	$173 - 2.52V + 0.0182V^2 + 1930/V$	-
	1.4 l < CC < 2.0 l	10-130	$1065 + 4.00V - 284 \ln(V)$	-
	CC > 2.0 l	10-130	$835 + 3.71V + 2297/V - 229\ln(V)$	-
ECE 15-02	CC < 1.4 l	10-130	$345 + 0.0106V^2 + 1275/V - 68.6\ln(V)$	-
	1.4 l < CC < 2.0 l	10-130	$835 + 3.93V + 986/V - 231\ln(V)$	-
	CC > 2.0 l	10-130	$879 + 4.32V + 2298/V - 244\ln(V)$	-
ECE 15-03	CC < 1.4 l	10-130	$664 + 2.09V + 0.00449V^2 - 167\ln(V)$	-
	1.4 l < CC < 2.0 l	10-130	$1074 + 5.49V - 0.00461V^2 - 305\ln(V)$	-
	CC > 2.0 l	10-130	$957 + 4.51V + 1832/V - 264\ln(V)$	-
ECE 15-04	CC < 1.4 l	10-130	$614 + 2.56V - 157\ln(V)$	-
	1.4 l < CC < 2.0 l	10-130	$264 + 0.0103V^2 + 2049/V - 49.8\ln(V)$	-
	CC > 2.0 l	10-130	$1173 + 4.83V - 315\ln(V)$	-
Improved conventional	CC < 1.4 l	10-130	$226 - 3.91V + 0.0368V^2$	-
	1.4 l < CC < 2.0 l	10-130	$333 - 6.11V + 0.0518V^2$	-
Open loop	CC < 1.4 l	10-130	$238 - 3.67V + 0.0319V^2$	-
	1.4 l < CC < 2.0 l	10-130	$331 - 5.88V + 0.0499V^2$	-
EURO I	CC < 1.4 l	5-130	$157 - 2.07V + 0.0172V^2 + 1835/V$	-
	1.4 l < CC < 2.0 l	5-130	$231 - 3.62V + 0.0263V^2 + 2526/V$	-
	CC > 2.0 l	5-130	$294 - 5.50V + 0.0393V^2 + 3513/V$	-

Source: Hickman, 1999

Table 6.2-25: Uncontrolled diesel vehicles (< 2.5 ton)

Pollutants	Cylinder capacity	Speed range	Emission factor (g/km)	R^2
CO	All categories	10-130	$5.413V^{-0.574}$	0.745
NO_x	CC < 2.0l	10-130	$0.918 - 0.014V + 0.000101V^2$	0.949
	CC > 2.0l	10-130	$1.331 - 0.018V + 0.000133V^2$	0.927
VOC	All categories	10-130	$4.61V^{-0.937}$	0.794
PM	All categories	10-130	$0.45 - 0.0086V + 0.000058V^2$	0.439
CO_2	All categories	10-130	$374 - 6.58V + 0.0442V^2 - 30.3/V$	-

Source: Hickman, 1999

Table 6.2-26: Euro 1 diesel vehicles (< 2.5 ton)

Pollutants	Cylinder capacity	Speed range	Emission factor (g/km)	R^2
CO	All categories	10-120	$1.4497 - 0.03385V + 2.1E\text{-}04V^2$	0.550
NO_x	All categories	10-120	$1.4335 - 0.026V + 1.785E\text{-}04V^2$	0.262
VOC	All categories	10-130	$0.1978 - 0.003925V + 2.24E\text{-}05V^2$	0.342
PM	All categories	10-130	$0.1804 - 0.004415V + 3.33E\text{-}05V^2$	0.294
CO_2	All categories	10-130	$286 - 4.07V + 0.0271V^2$	-

Source: Hickman, 1999

Table 6.2-27: Conventional LPG (< 2.5 ton)

Pollutants	Cylinder capacity	Speed range	Emission factor (g/km)	R^2
CO	All categories	10-130	$12.523 - 0.418V + 0.0039V^2$	0.893
NO_x	All categories	10-130	$0.77V^{0.285}$	0.598
VOC	All categories	10-130	$26.3V^{-0.865}$	0.967
CO_2	All categories	10-130	$283 - 4.15V + 0.0291V^2$	-

Source: Hickman, 1999

Table 6.2-28: Euro 1 LPG (< 2.5ton)

Pollutants	Cylinder capacity	Speed range	Emission factor (g/km)	R^2
CO	All categories	10-130	$0.00110V^2 - 0.1165V + 4.2098$	n/a
NO_x	All categories	10-130	$0.00004V^2 - 0.0063V + 0.5278$	n/a
VOC	All categories	10-130	$0.00010V^2 - 0.0166V + 0.7431$	n/a
CO_2	All categories	10-130	$0.0208V^2 - 2.70V + 228$	n/a

Source: Hickman, 1999

6.2.6 Effect of alternative fuels (MEET project)

Alternative fuels were discussed in Chapter 1. This chapter will show some figures used in the MEET approach [Hickman, 1999].

Table 6.2-29: Effects of alternative fuels on the regulated emissions.

Alternative over conventional fuels	Vehicle type	CO	HC	NO_x	PM
NG over gasoline	TWC LDV	Decrease (0.4 - 0.5)	Increase (1.5 – 2.0)	Decrease (0.4 – 0.6)	n/a
NG over diesel	HDV (1)	Decrease (0.1 – 1.0)	Increase (0.2 – 6.0)	Decrease (0.1 – 1.0)	Decrease (0.05 – 0.2)
Methanol over gasoline	TWC LDV	No change (0.7 – 0.9) (2)	Decrease (0.7 – 0.8) (2)	Decrease (0.8 – 1.0) (2)	n/a
Ethanol over gasoline	TWC LDV	No change (0.4 – 1.4) (2)	Increase (1.0 – 1.3) (2)	Decrease (0.4 – 1.0) (2)	n/a
Methanol over diesel	HDV	No change (0.8 – 3.0) (2)	No change (0.6 – 3.0) (2)	Decrease (0.2 – 0.4)	Decrease (0.2 – 0.6)
Ethanol over diesel	HDV	Increase (1.1 – 1.3) (2)	No change (0.7 – 1.5) (2)	Decrease (0.87 – 0.9)	Decrease (0.2 – 0.6)
DME over diesel	HDV	n/a	n/a	Decrease (0.2 – 0.5)	Decrease (0.05 – 0.3)
Biodiesel over diesel	HDV	Decrease (0.75 – 0.8)	Decrease (0.2 – 0.8)	Increase (1.1 – 1.2)	No change (0.6 – 1.2)

(1) Range reflects operating principle (lean burn or stoichiometric)
(2) A much larger scatter is indicated by the U.S. data

Source: Hickman, 1999

The range of scale factors in parentheses is indicated as a ratio of the emissions with the alternative fuel over the emissions with the conventional fuel.

Table 6.2-30: Emission correction factors for various CNG fuelled vehicle categories.

	CNG vs. Gasoline car with TWC min	 average	 max
CO	0.19	0.38	0.59
HC	1.18	1.81	2.37
NO_x	0.12	0.37	0.49
NMHC	(1)	0.13	(1)
Methane	(1)	9.45	(1)
Benzene	(1)	0.003	(1)
Butadiene	(1)	0.000	(1)
Formaldehyde	(1)	0.88	(1)
Acetaldehyde	(1)	0.34	(1)

Source: Hickman, 1999

Table 6.2-31: Emission correction factors for methanol fuelled vehicles

	Methanol vs. gasoline (passenger car)		
	min	average	max
CO	0.14	0.91	2.47
HC	0.09	0.67	2.25
NMHC	0.04	0.6	2.00
NO_x	0.21	1.14	3.14
CO_2	0.84	0.92	2.47

Source: Hickman, 1999

Table 6.2-32: Emission correction factors for various ethanol fuelled vehicle categories

	Ethanol (E85/RFG) vs. gasoline (passenger car)		
	min	average	max
CO	0.44	1.43	3.67
HC	0.51	1.30	3.15
NMHC	0.30	1.02	2.67
NO_x	0.39	1.03	3.00
CO_2	0.90	0.94	0.98

Source: Hickman, 1999

Table 6.2-33: Emission correction factors for various DME fuelled vehicle categories

	DME vs diesel (Light duty vehicle)			DME vs diesel (test engine)			DME vs diesel (Heavy duty vehicle)		
	min	average	max	min	average	max	min	average	max
CO	(1)	0.22	(1)	(1)	1.42	(1)	0.25	0.32	0.40
HC	(1)	0.22	(1)	(1)	1.00	(1)	n/a	n/a	n/a
NO_x	(1)	0.21	(1)	(1)	0.10	(1)	0.40	0.42	0.44
PM	(1)	0.00	(1)	(1)	0.05	(1)	n/a	n/a	n/a

Source: Hickman, 1999

6.2.7 Effect of new technologies (MEET project)

New technologies, such as electric, hybrid and fuel cells vehicles, were discussed in Chapter 1. This chapter will focus on the MEET approach [Hickman, 1999].

Table 6.2-34: Vehicle emission factors from new technology vehicles in g/km., with the spread of data for the HEV.

	HEV	FCEV	EURO 1 gasoline car < 1.4 l	
Speed range	20 - 100 km/h	20 - 100 km/h	20 - 50 km/h	50 - 100 km/h
CO_2	112 ± 31	113	175	120
CO	0.17 ± 0.12	0.00	3.00	1.00
NO_x	0.02 ± 0.01	0.00	0.30	0.40
HC	0.01 ± 0.01	0.00	0.25	0.10

Source: Hickman, 1999

Full energy cycle emission factors

New technology vehicles generally have very low exhaust emissions. To make an honest comparison with other technologies and fuels, however, the full energy cycle should be considered. The following table shows some results, mentioned in the MEET report.

Table 6.2-35: Full energy cycle emission factors for new technology vehicles: average factor and spread of data in g/km.

	Electric vehicles		**Hybrid electric vehicles**	**Fuel cell electric vehicles**	
Speed range	20 – 50 km/h	50 – 100 km/h	20 – 100 km/h	20 – 50 km/h	50 – 100 km/h
CO_2	122 ± 55	94 ± 39	126 ± 34	150 ± 17	140 ± 10
CO	0.02 ± 0.01	0.02 ± 0.01	0.17 ± 0.12	0.04 ± 0.02	0.03 ± 0.01
NO_x	0.31 ± 0.14	0.24 ± 0.10	0.09 ± 0.03	0.16 ± 0.07	0.12 ± 0.04
HC	0.29 ± 0.13	0.05 ± 0.02	0.13 ± 0.04	0.25 ± 0.11	0.18 ± 0.07
SO_2	0.71 ± 0.32	0.55 ± 0.23	0.36 ± 0.09	0.03 ± 0.01	0.02 ± 0.01
PM	0.04 ± 0.02	0.21 ± 0.09	0.00 ± 0.00	0.01 ± 0.00	0.01 ± 0.00

Source: Joumard, 1999

For electric vehicles, the average electricity generating mix has a significant effect on the full energy cycle emissions. The following table shows the emission factors for the electricity generating mix by country in 1997.

Table 6.2-36: Emission factors for the average electricity generating mix by country (1997 data)

Country	**Emission factor (g/GJ)**						
	CO_2	**CO**	**NO_x**	**NMHC**	**SO_2**	**CH_4**	**PM**
Austria	62900	14,5	92,7	16	74,2	80,3	6,9
Belgium	94300	16,7	289,4	12,2	533,5	240,3	27,2
Denmark	257300	43	811,6	24,7	912,9	902,7	62,7
Finland	155100	38,6	307,3	15,6	198	310,9	23,4
France	17600	3,2	61	3,2	183,9	36,1	7,9
Germany	189700	27,3	306,3	9,4	931,5	465,1	56,2
Greece	296400	38,7	393,6	38,9	979,2	604	62,4
Ireland	212900	33,8	672	44,6	1639,5	466,7	74,3
Italy	162500	33,4	551,7	105,3	977,2	111,8	41,1
Luxembourg	101900	16,2	90,1	16,9	71,1	27,3	3,7
Netherlands	175700	31,6	281,8	32	185,2	392,5	19
Norway	1700	0,6	2,8	0,2	3,7	6	0,2
Portugal	170400	34	507,1	53,7	1260,7	359	59,4
Spain	126800	19,4	414,2	16	1235,8	306,8	57,8
Sweden	20600	6	42,2	6,6	34,7	22,2	3,1
Switzerland	6600	2,5	12,9	1,4	21,5	0,7	1,1
United Kingdom	167800	27,4	631,8	20,2	1445,8	458,9	69,9
European Average	127400	21,3	325,9	22,6	744,9	282,6	39,1

Source: Hickman, 1999