concawe
review

Volume 13 • Number 1 • April 2004

Photographs: cover: CEPSA; page 5: Jeffrey R. Cordell, University of Washington; page 6: US Fish and Wildlife Service; page 7: ChevronTexaco; page 23: TOTAL

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Foreword

CONservation of Clean Air and Water in Europe was CONCAWE's original 'raison d'être' and gave the association its name. Water quality issues have been less in focus in recent years, partly as a result of earlier advances, in particular the widespread introduction of biological treatment of waste waters and a general improvement in European water quality. With the promulgation of the Water Framework Directive in 2000 and ongoing work on daughter Directives such as the Groundwater Directive, water quality is once again about to take front stage. CONCAWE is getting ready for the challenges that lie ahead to arrive at fit-for-purpose and cost-effective legislation. In this issue we include a feature on 'whole effluent assessment', a relatively new way of looking at water quality, which aims at assessing the biological and other effects of water discharges on the environment rather than focusing on the more traditional physico-chemical properties of the waters.

Over the past decade, air quality has received much attention in Europe. This has resulted in an array of measures and legislation which, it is generally considered, will lead to a reduction of EU air pollution to the agreed target level by 2010. However, certain questions still need to be answered. Our second article, dedicated to the 'City Delta' project, illustrates the importance of using models that are suited to the problem at hand, particularly in areas as complex as that of air quality modelling.

Road transport has made a major contribution to the reduction of air pollutant emissions, improvements in the quality of fuels providing direct benefits as well as enabling new engine and exhaust control technologies. The results of test programmes recently carried out by CONCAWE on modern vehicles are summarised in our third article. They highlight and compare the potential of fuel quality and of other measures, such as particulate traps for diesel vehicles, to contribute still further to emissions reductions. The transport sector is also in the limelight in the context of greenhouse gas emissions. The Well-to-Wheels study of alternative fuels and powertrains recently completed by a consortium of CONCAWE/EUCAR and the EU Commission's JRC is an important building block to move this debate forward. The main findings are briefly described in our fourth article.

In an industry which deals with flammable, and occasionally explosive products, safety has to be paramount. In the final article we cover various aspects of safety management in the oil industry, which remains a constant challenge in all activities and all types of operation.

Jean Castelein
Secretary-General, CONCAWE

Contents

Increasingly common in the assessment and control of water quality, whole effluent assessment (WEA) includes tests on discharges and on receiving waters. WEA methods complement traditional chemical measures but approach water quality from a different angle, raising new questions regarding their applicability to industrial sites and the acceptability of discharge quality. CONCAWE is active in several industry and regulator groups addressing these issues. The goal is to achieve an environmentally relevant means of assessing water quality for discharges.

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The Integrated Assessment Modelling of air quality in Europe has hitherto been developed on a regional scale. The City Delta project, launched in 2002, is designed to develop relationships between regional and urban air quality. The first phase has now been completed and has demonstrated the inadequacy of the larger scale regional models to describe urban situations, in particular with regard to ozone response to NO_x emission reductions.

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CONCAWE has carried out comprehensive test programmes to evaluate the effects of fuel properties on emissions from new technology engines and vehicles as they approach the market. The results, which will be described in detail in two CONCAWE reports (available shortly), indicate that the penetration of advanced engine and after-treatment technologies, enabled by sulphur-free fuels, will provide large improvements in exhaust emissions from road vehicles. Beyond sulphur reduction, further changes to fuel properties would offer little in terms of improvements in air quality.

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Whole Effluent Assessment (WEA)

A new approach to assessment and control of water quality

Introduction

Refineries handle significant volumes of water, often comparable to the amount of hydrocarbons they process. In common with many industries some of this is discharged as an effluent. Traditionally most effluent discharges have been assessed and controlled using physical and chemical properties such as pH, temperature, chemical oxygen demand and concentrations of specific components such as oil or heavy metals. This type of approach has been successful in reducing the discharge of hazardous substances and has contributed to the substantial improvements in water quality across Europe. It is particularly suited to relatively simple effluents, especially where the discharged substances have known properties, e.g. the likelihood to cause ecotoxicological impact. As the quality of receiving waters in Europe has improved attention has increasingly turned to more subtle effects. Ultimately the aim of improving discharge water quality is to improve the condition of the receiving water, thus minimising risks to both human health and the state of the ecology. Focus has therefore shifted from the physical and chemical characterisation of water quality to its biological quality. Such biological effects measures encompass a broad spectrum from specific toxicity studies on an effluent (either before or after discharge) to monitoring the health of the ecosystem within a receiving water body such as a river or a lake. Such techniques have been used in a limited way in some European countries for many years. They are now starting to enter the mainstream of European regulatory control and are already being used by some companies to assess their own discharges and impacts.

At first glance, the use of such biological effects measures appears a logical step. Tests based upon biological impacts relevant to the ecosystem to be protected appear to make sense. However, finding out what is 'relevant' in this context is not straightforward. Many tests have been developed for use on specific chemicals rather than with a whole ecosystem in mind. Not all of these tests provide an indication of impact upon the 'real' environment. The complex interplay of stresses on the ecosystem makes it very difficult in practice to demonstrate cause and effect relationships. All of this requires a substantial amount of expert judgement to be applied when interpreting data, and a regulatory regime that allows for this flexibility.

In an earlier CONCAWE *Review* article (Vol. 10 No. 2, October 2001) we looked at the state of development of WEA as it was then. This update highlights increased confidence in the application of this methodology.

What is WEA?

The terminology in this area is sometimes confusing as identical terms are used for different things! Whole Effluent Assessment (WEA) refers to a suite of tests used to characterise the quality of an effluent before, during and after discharge. In its broadest sense WEA includes chemical, physical and biological measures, but it is not uncommon to use the term solely to refer to the biological assessments. In this article the biological aspects of WEA will be discussed as these are less familiar to most people, but the reader should remember that classic chemical and physical tests will often complement the biological steps.

The major biological components of WEA cover the three parts of the commonly used acronym PBT—namely Persistence, (potential to) Bioaccumulate, Toxicity. More recently other attributes such as Mutagenicity and Endocrine Effects have also been included in some WEA approaches. Each of these is discussed below.

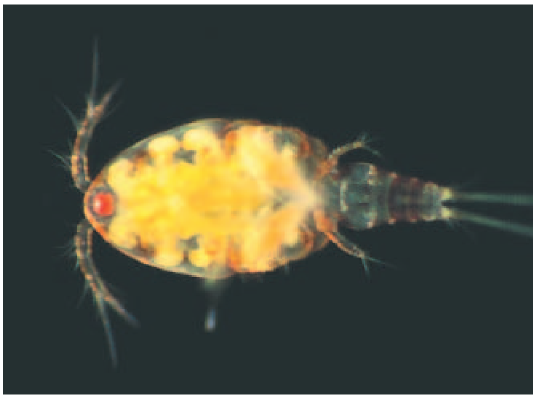
Toxicity

The most commonly used tests in a WEA scheme are those used to assess toxicity. These are probably the best understood tests and many schemes start with some form of toxicity assessment as a first screen. WEA has relied upon methods developed for hazard assessment of single substances. Their use in WEA demands that other factors, including varying composition of effluents with time, interactions within complex mixtures, actual test conditions leading to changes in sample composition and temperature effects be considered. Nevertheless such tests can be used effectively with suitable modifications.

There are two main types of toxicity—acute and chronic toxicity. Acute toxicity is defined as the adverse effects of a sample on an organism or surrogate, exhibited within a short period of exposure. Typically the term 'short' is taken to mean up to 12 hours for a single celled organism and up to one third of the time taken from birth to sexual maturity for invertebrates. This could equate to a period of 2–4 days for higher organisms. Acute toxicity is usually assessed as lethality or immobility (fish and invertebrates) or reduced growth or metabolic function (algae and bacteria). Chronic toxicity is defined as the adverse effects of a sample on an organism or a surrogate, exhibited after a long time period in relation to the lifetime of the organism. Chronic toxicity is usually measured by assessment of sub-lethal effects, e.g. reduced growth rates.

The objective of acute toxicity evaluation is to identify emissions which have immediate toxic effects in the environment and are usually directed towards a point of discharge, although the evaluation can also be carried out on the receiving water. They are generally well understood tests, are relatively cheap and quick to perform and so are the most common form of testing employed. The objective of chronic toxicity tests is to identify discharges which have a detrimental effect over longer time periods. Because of their higher costs and longer timescale they are carried out less frequently. In many cases this will be after an acute toxicity testing regime has already been carried out as part of a stepwise approach to achieving environmental improvements.

A variety of standard test methods are available for both acute and chronic toxicity testing. It is outside the scope of this article to review these in any detail. Commonly



Tisbe—*a typical crustacean used for acute toxicity testing*

used acute tests applicable to WEA include algal growth inhibition, daphnid tests, bivalve embryo larval development, crustacean mobility and fish tests. Chronic toxicity tests use similar species with longer exposure times and non-lethal endpoints. There are a number of limitations and interferences with these tests (as with all analytical methods) and the data require careful interpretation. Assessments can be carried out in a variety of ways—as static, flow through or even as *in-situ* tests. Each method has a specific range of applicability and again expert judgement is required to select the most appropriate, depending on the goal of the testing. Traditionally, effluent toxicity assessments would be carried out using tests across three trophic levels of organism, i.e. bacteria/algae, invertebrates and fish. The use of fish testing is subject to various ethical and cost concerns and its use has been much reduced in recent years. Alternatives such as fish egg development, fish cell lines and the use of solid phase micro-extraction (SPME) techniques have been evaluated. So far no particular technique has emerged as a direct replacement and work continues.

As well as traditional tests using conventional organisms, a variety of methods is being developed to speed up and simplify assessment procedures. Microbiotests are one such approach and examples include Toxkits™, CerioFAST™, and Microtox™ all of which have been used for WEA applications. They may have the advantages of speed and the requirement for less specialised staff to carry out the testing. Nevertheless, their ecological relevance is less obvious and they often do not have

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The use of in vivo *fish testing has been much reduced in recent years for ethical and cost reasons.*

regulatory acceptance. They can be of benefit in internal investigations where their speed can allow a lot of data to be gathered rapidly. Calibration against more conventional test data can help to identify the ecological relevance for a particular site or discharge.

Bioaccumulation

Bioaccumulation of substances is of significant concern as it can lead to the exhibition of toxicity at different levels in the food chain. Typically, substances for which bioaccumulation may be an issue have octanol-water partition coefficients (log K_{ow} values)[1] between 4 and 7, have sufficiently long residence times in contact with the organism to be able to partition to it and are metabolised only slowly (or not at all) by the organism. Many hydrocarbon chemicals have log k_{ow} values in the range where bioaccumulation is possible.

Testing of bioaccumulation potential is usually based upon physico-chemical characteristics of substances and so can only indicate the potential to bioaccumulate. Data generated by such methods can only be used to screen samples for possible impacts. The potential to bioaccumulate is a questionable concept when applied to effluents. It is perhaps more accurate to state that certain components of an effluent, rather than the effluent itself, have the potential to bioaccumulate. A number of surrogate tests have been developed to assess this potential. The most common are High Pressure Liquid Chromatography (HPLC), Solid Phase Micro-extraction (SPME) fibres and the Empore (C18) discs test. Exposure times vary considerably (1 to 20 days) making comparison of data very difficult. At present, the only way to assess actual bioaccumulation with certainty is to measure the component(s) in an organism after a period of exposure. This is time-consuming, requires specialist staff and a dead organism. Establishing the level of component in the organism before exposure can present a challenge to scientific rigour.

[1] *Common measure of fraction which partitions to either the water or oil phase, used here to indicate the partitioning to fat tissues in the body of an organism*

Persistence

Persistence is of regulatory interest because, in principle, the longer an organism is in contact with something, the greater the potential for an adverse effect to occur. This of course presupposes an adverse effect can occur. Persistence can be defined in terms of the resistance of a substance to degradation in the environment by processes such as biodegradation, hydrolysis or photolysis. Persistence is something of a negative determinant—it is not measured directly but interpreted from the continued presence of something. Normally persistence is measured as a degradation half life and values in excess of 50 days are usually taken to mean something is persistent. It is less easy to apply the term persistent to effluents which are often mixtures of components. None of the standard tests for determination of persistence (usually biodegradation tests) have been designed to assess the persistence of mixtures and all have limitations for this purpose.

It is perhaps more relevant in the context of effluents and WEA to talk about the persistence of a property such as toxicity or bioaccumulation potential. This approach can help to identify areas of concern which require further evaluation. The use of assessment schemes combining biodegradation tests with the evaluation of toxicity or potential to bioaccumulate both before and after biodegradation, have proved valuable. Many materials are persistent—this does not automatically mean they are harmful.

Endocrine disruption, mutagenicity and genotoxicity

Endocrine-disrupting chemicals have been described as 'exogenous agents that interfere with the production, release, transport, metabolism, binding and action or elimination of the natural hormones in the body responsible for the maintenance of homeostasis and regulation of the developmental process' (Kavlock *et al.* 1996). This area has attracted substantial regulatory interest, as there is concern that the more traditional methods described above may fail to predict chronic reproductive and development impacts caused by this mode of action. To date no regulatory controls have been imposed. The test methods used are time-consuming, complex, expensive and open to considerable debate as to their environmental relevance. Their use in WEA approaches is unlikely at present, but they are the subject of extensive development work.

Mutagenicity is a term used to describe the ability to cause permanent transmissible changes to the genetic material of cells or organisms. It is used to a limited extent in an effluent regulatory context, although the tests involved are single-substance tests. The applicability of these tests to effluents and their ecological relevance is still unclear. Tests are divided into two main types—bacterial tests such as the Ames assay and eucaryotic tests which use microscopic analysis of genetic material after suitable highlight treatment such as staining.

Genotoxicity is a term used to describe non-transmissible changes in genetic material. It is not explicitly used in a regulatory context. Test methods are similar in nature to those for mutagenicity and include the umuC assay and the Comet assay. The environmental relevance of such tests is unclear and so it is not easy to pinpoint appropriate actions to control this phenomenon.

It is generally true to say that toxicity (both acute, and to a lesser extent chronic) is the only well understood and applied criterion for WEA use so far. The use of persistence and the potential to bioaccumulate in appropriate assessment schemes is becoming more widespread but interpretation of data requires expert judgement. Mutagenicity is applied in a limited regulatory framework but its environmental relevance is not clear in the context of effluents. Other approaches described above do not yet appear ready for widespread deployment and considerable work is still required. Nevertheless, it must be recognised that these approaches are raising a whole set of new questions about discharge and water quality. The risks associated with this and the preventative measures necessary to minimise or eliminate these risks must be evaluated.

Why might WEA matter to a refinery?

Many people in the refinery business will assume their effluents to be much less complex than, for example, a chemical manufacturer's, and so question what WEA means to them. The reality is that refinery effluents have the potential to contain a very complex mixture of organic and inorganic chemicals with varying ecological impacts. As well as the many hydrocarbons and other components of 'oil', refineries also handle and process a wide range of other chemicals from catalysts to corrosion inhibitors, all of which have the potential to be measured in some way in WEA tests. With much work already done to reduce the impact of discharges, it makes sense to target any further efforts towards the discharges or parts of a discharge with the most potential impact on the receiving water. The use of WEA could help to provide this focus. Additionally the use of WEA approaches can help to demonstrate the absence of risk of harm from a discharge.

WEA is increasingly being applied in regulation. The IPPC BREFs for Waste Water, Waste Gas and Economics and Cross Media Issues (in draft) already contain references to WEA methods as a means to assess and demonstrate BAT[2].

Refinery effluents may contain a very complex mixture of organic and inorganic compounds

[2] *Best Available Techniques*

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Several European countries (e.g. Germany, Ireland, UK, Sweden) already use some aspects of WEA in their regulatory regimes and many others are developing such approaches (see Table 1). It is possible that WEA approaches could be used as a tool to support the assessment of Good Ecological Status as required in the Water Framework Directive. OSPAR[3] is studying the use of WEA as a means to reduce or eliminate the presence of Priority Substances from the marine environment. Virtually all refineries are likely to encounter one or more of these regulatory issues.

As the focus moves towards controlling an increasing number of hazardous chemicals, it could prove cost-effective to focus instead on using WEA tools in a risk assessment process to achieve the same goals. Additionally, WEA tools can be used to assess effluent streams within a refinery to identify problematic streams and target them for management at source. This approach can also be beneficial in handling effluent treatment plant problems by identifying which streams are affecting the biology within a treatment plant itself.

Table 1 Some examples of regulatory approaches of WEA *(after Power & Boumfrey, 2003)*

Country	Outline of WEA scheme
EU Generic	IPPC Directive 96/61/EC BAT and related to Environmental Quality Standards. Water Framework Directive good water quality objectives may use a Whole Effluent Toxicity approach.
Belgium	EU approach with sector-specific conditions based on BAT. Demonstration programme being used to develop protocol.
Denmark	Non-statutory approach including biodegradation and bioaccumulation. Source control used to protect receiving water.
Eire	Mandatory Emission Limit Values based on toxic units. Source control primary vehicle with some receiving water monitoring.
England, Scotland and Wales	Small number of consents in place. Direct Toxicity Assessment demonstration programme (industry and regulator initiative) developed protocol for acute toxicity testing. Bioassay use expected to increase where receiving water quality is assessed as poor.
France	EU & routine monitoring. Some site-specific licensing. Used as basis for taxation.
Germany	Regulatory use as hazard reduction under wastewater ordinance and wastewater charges act. Basis of taxation. Primarily source control but also uses daphnids for early warning in large rivers. Some states assess mutagenicity and endocrine effects.
The Netherlands	EU and risk-based approach to account for receiving water conditions. May be used for source control following evaluations.
Norway	Can be applied as regulatory instrument. Emission Limit Values and site specific limits. Source control based upon total emission factors.
Spain	Regional use in permits. Source Emission Limit Values. Hazard based source control. Some taxation of discharges.
Sweden	Surface water protection is main goal. Bioassays used to license some discharges. Source control can include biodegradation and bioaccumulation.
OSPAR	Intersessional Expert Group developing methodology in context of OSPAR Hazardous Substance elimination goals. Currently expected to include assessment of Persistence, Bioaccumulation & Toxicity but details still under development.

[3] *Commission for the Protection of the Marine Environment of the North-East Atlantic (previously 'Oslo and Paris Commission')*

What's happening?

As outlined above, WEA concepts in regulation are being applied to an increasing degree within several countries. CONCAWE's Water Quality Management Group is starting a new Task Force to look at a range of biological effects measures including WEA. One of the aims of this task force is to collect data from operators on the application of WEA assessments at their sites. The intention is to identify the issues and risks involved, and potential benefits coming from their use. A further area of study is to understand the ecological impact of operational changes both in processing and water treatment facilities. Process changes to reduce emissions or optimise performance can have unanticipated effects that WEA techniques can help to identify. This process is already widely used in the chemical industry. As data is gathered this will be developed into a good practice guide to support refineries as the use of this approach increases.

OSPAR is one of the primary legislative drivers for WEA. CONCAWE has a seat on the OSPAR Intersessional Expert Group for WEA and is actively participating in this joint regulator/industry group, bringing expert technical knowledge of the application of WEA methods in the oil industry. Such contributions have significantly influenced the direction of the OSPAR work and have allowed a realistic consideration of a risk assessment approach to be retained within OSPAR's hazard identification framework. CONCAWE is also contributing to an ECETOC task force producing a report on industry experience with WEA. The report includes recommendations for methodologies which can be used to apply WEA methods in practice and these will be discussed at an industry sponsored workshop to be held early in 2004 with OSPAR. These activities will also contribute to the debate on the efficacy of WEA methods and their application in practice to gain environmental improvement. Both of these activities have brought about recognition of the level of expertise available within the industry, thus enabling our views to be taken seriously in the debate. OSPAR is increasingly moving towards assessment of the environment to evaluate the effect of its measures to eliminate harmful discharges. WEA is consistent with this approach and is likely in due course to find a wider role within OSPAR.

In European legislation WEA (in the form of toxicity assessment) is already mentioned in the context of BAT development under IPPC. The concepts also have potential for application within the Water Framework Directive to assess ecological water status. At present this application is regarded as only a possibility but the activity is being tracked. Again the EU Commission is starting to look more at the health of the environment rather than at specific substance controls, and developments are likely to continue.

The use of WEA-type approaches raises new questions about the impact of discharges, emissions and losses from sites. These questions may pose different risks to our operations and to the environment. The new CONCAWE Task Force specifically aims to understand this new area and to identify the optimum way forward.

The City Delta project

Assessing urban air pollutant effects

As part of the Clean Air For Europe (CAFE) programme, the so-called 'City Delta project' commenced in early 2002. The programme, as the name suggests, is designed to develop relationships between regional scale air quality levels and the levels found in cities using state-of-the-art models. These relationships will be incorporated into 'RAINS', the Integrated Assessment Model (IAM), which is being used in the CAFE Programme to examine various emission reduction scenarios as input to policy development. For the first time this will enable the IAM to be used to develop optimum control strategies which simultaneously address both urban and regional scale residual air quality problems in the EU.

The programme is coordinated by the Commission's Joint Research Centre (JRC) in Ispra and guided by a Steering Group of which CONCAWE is a member. Ten modelling teams were involved in the first phase of the programme (City Delta I) which was completed in December 2003 and focused largely on ozone. A smaller number of modelling teams are involved in the second phase which commenced in October 2003, is due to be completed in June 2004, and will focus on fine particulates ($PM_{10}/PM_{2.5}$).

In this brief article we will look at some of the important results that have emerged from the first phase, in particular the relationship between urban scale and regional scale ozone response to NO_x emission reductions.

It has long been recognised that in cities which are characterised by high levels of NO_x emissions, particularly from road transport, incoming ozone levels are reduced over the city due to the reaction of ozone with NO to form NO_2 and molecular oxygen. This is a simple, local scale phenomenon unlike the larger scale, complex photochemical reactions that form ozone downwind of a city. As such it is largely 'invisible' in the larger scale regional modelling which has, to date, underpinned the development of ozone response strategies in Europe.

Given that a major focus for CAFE is population exposure to pollutants of concern (including ozone), the fact that ozone levels drop over cities due to this titration effect is an important phenomenon to capture if the impact is to be reliably represented in the Integrated Assessment Modelling. Perhaps more importantly, the response to emission changes needs to account properly for such a phenomenon to avoid 'regret' policies being developed.

The following series of charts for London, Milan and Paris are reproduced from the modelling assessment toolkit developed by the JRC specifically for City Delta. This has been a key component of the whole City Delta exercise and CONCAWE acknowledges the important contribution that the JRC team has made by developing this tool. It enables a ready assessment/comparison of all the modelling results and provides a powerful means of viewing the impact of the control scenarios examined.

The charts are arranged in pairs; the 'a' figure showing the results of fine scale modelling (5x5 km); the 'b' figure showing the large scale model results (50x50 km). In each case the modelling domain is 300x300 km. The main highways, coastal outlines and country borders are drawn in white. The series of three pairs (London, Milan and Paris) all depict the model responses to a change in NO_x emissions from a '2010 Base Case' (assuming already legislated measures are implemented) to 'Maximum Feasible Reductions' in 2010 (assuming all available further NO_x control measures are applied).

The metric that is plotted here is population weighted AOT30[1] in ppm hours x thousands of people per square kilometre, i.e. a measure of the population exposure to ozone.

[1] *Accumulated exceedances Over Threshold where the threshold is 30 ppb*

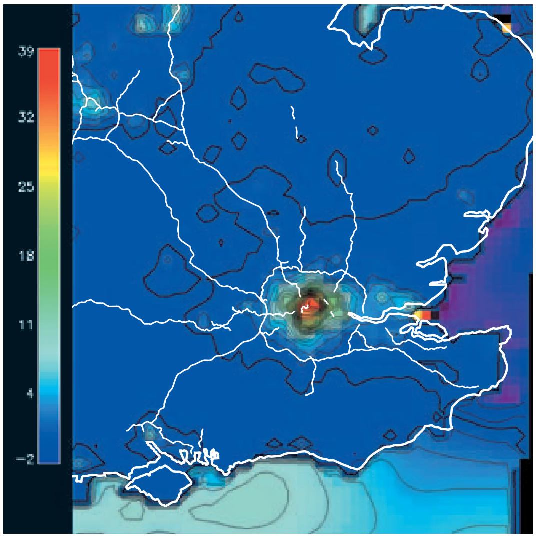


Figure 1a

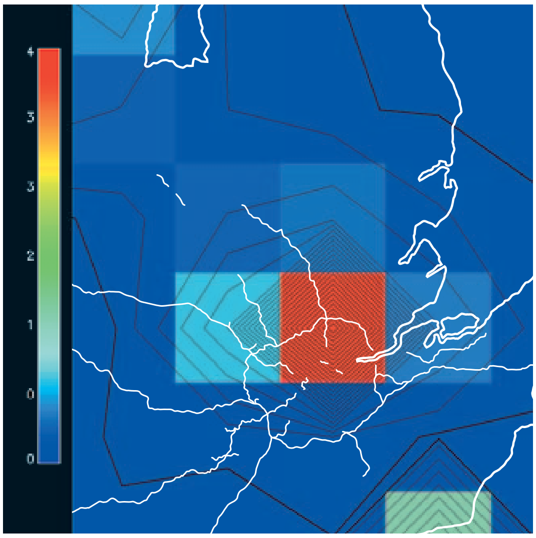


Figure 1b

London Area 2010: Change in AOT30 for NO_x from Base Case to Maximum Feasible Reduction Case at fine scale (Figure 1a) and coarse scale (Figure 1b).

In all three cities the fine scale models show significant increases in the population weighted levels of AOT30 with reduction in NO_x levels beyond the Base Case in 2010. This is to be expected given that the reduction in NO_x removes the NO that titrates the ozone in the city. Hence ozone levels are not reduced as much over the city as in the Base Case, so population exposure to ozone rises.

This has important implications for any cost-benefit assessment based on human population exposure: although further NO_x control (beyond that already legislated) may be beneficial for reducing regional scale ozone, it would increase population exposure to ozone in cities, implying negative human health benefits.

It is important to note that the regional scale modelling results not only miss the significance of this increase in exposure (see Figures 1b, 2b and 3b) but, in the case of Milan and Paris, indicate a reduction rather than an increase in exposure! In other words, it potentially misleads policy makers as to the benefits of such control measures from a human health point of view.

The City Delta project is specifically designed to look at the effects of air pollutants in the urban environment.

Figure 2a

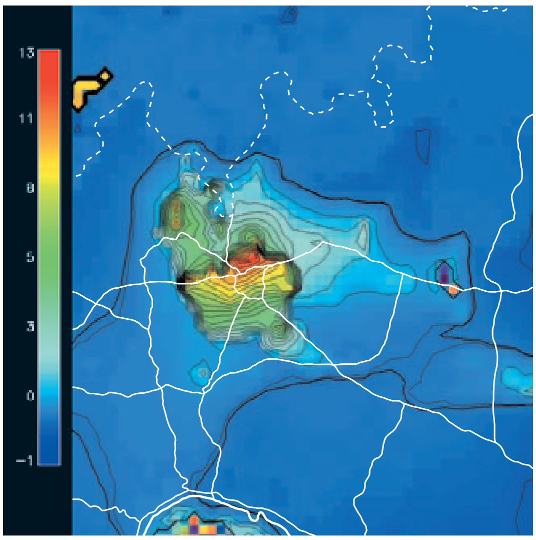
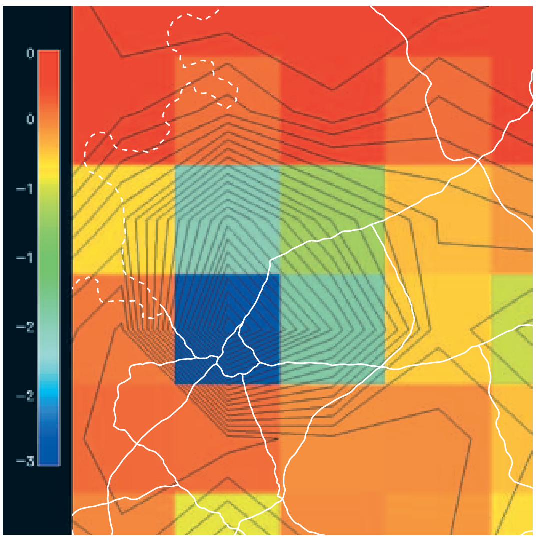


Figure 2b



Milan Area 2010: Change in AOT30 for NO_x from Base Case to Maximum Feasible Reduction Case at fine scale (Figure 2a) and coarse scale (Figure 2b).

The City Delta project

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Paris Area 2010: Change in AOT30 for NO_x from Base Case to Maximum Feasible Reduction Case at fine scale (Figure 3a) and coarse scale (Figure 3b).

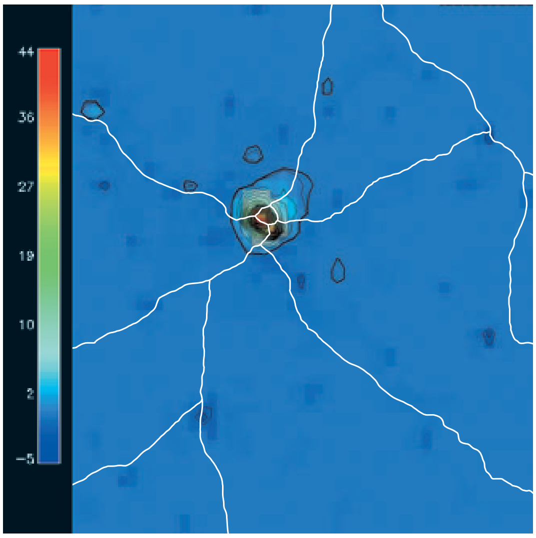


Figure 3a

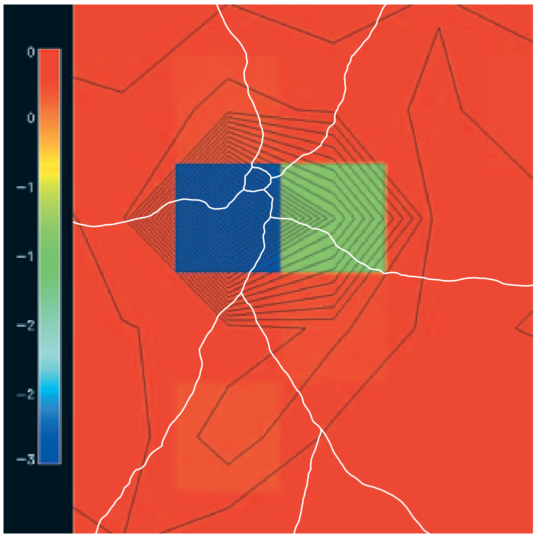


Figure 3b

The information that it generates will constitute a major enhancement to the Integrated Assessment Modelling. CONCAWE welcomes this improvement, which will help to ensure that synergistic solutions are developed for both regional and urban scale problems. In particular, such solutions must take into account potential 'environmental tensions' e.g. between urban and regional ozone abatement strategies. This can only enhance the role that IAM will play in designing robust policies.

Advanced vehicles and fuels

Some recent emissions results

The recent update to the EU Fuels Directive specifies a maximum sulphur content of 50 mg/kg in gasolines and diesel fuels from 2005, with 'appropriately balanced geographic availability' of sulphur-free[1] fuels from the same date, progressing to 100% coverage of sulphur-free fuels by 2009 (this date being subject to a further review for diesel).

Sulphur-free fuels are being introduced to enable advanced engine and exhaust after-treatment technologies to meet increasingly stringent exhaust emissions regulations, with best fuel efficiency and long-term durability. As these new fuels and vehicles are introduced, the potential for further improvements in air quality through changes to fuel properties can be expected to diminish.

Nevertheless, the EU Fuels Directive calls for a further review of other fuel properties to be completed by end 2005. In order to update knowledge on fuel effects on emissions, CONCAWE has continued to evaluate new engine/vehicle technologies as they approach the market. In two recent test programmes, on which full reports will be published soon, emissions from advanced gasoline vehicles and advanced diesel engines and vehicles have been measured using a wide range of fuels. This article gives a summary of the results and implications.

Diesel programme

Two advanced light-duty diesel vehicles and three heavy-duty diesel engines were tested with a wide range of fuels. The main objectives of the programme were to assess:

- The exhaust emissions benefits achieved by advanced diesel engine and exhaust after-treatment technologies in conjunction with low-sulphur fuels,
- The remaining potential for improvements in vehicle emissions through fuel quality.

Only the regulated emissions are described in this article.

Engines/vehicles tested

The two diesel passenger cars selected for testing were chosen as examples of advanced technologies available in the European market in 2002. These included a medium sized DI diesel car with an oxidation catalyst (car A) and a large DI diesel car with an additised particulate filter (car B).

The heavy-duty engines were selected to cover the range of technologies likely to be used to meet the future exhaust emissions standards. A commercial Euro-3 engine without after-treatment provided the base case, compared to prototype Euro-4 (using EGR and CRT) and Euro-5 engines (using SCR/urea but no particulate filter).

Diesel fuels

Fuels tested covered a range of sulphur content and compared conventional fuels with two extreme fuel compositions, Swedish Class 1 and Fischer-Tropsch diesel fuels. Although such fuels cannot be expected to provide a major part of the total diesel fuel volume, even by the year 2020, they provide a means to assess the maximum possible fuel effects.

Test fuels are coded D2 to D8. D2 to D4 were based on a common conventional but sulphur-free fuel with other properties close to average year 2000/05 levels, and designed to study the sulphur effect, from 300 to 50 to 10 ppm. Swedish Class 1 diesel fuel is designated as D5, and Fischer-Tropsch diesel fuel as D8. A second conventional diesel fuel (D6) at the 300 ppm sulphur level, but with higher density and aromatics content, was also tested to provide the other extreme of fuel composition. Finally, fuel D7 was a blend of fuel D4 with 5% RME.

Test methodology

The programme mainly focused on tests over the standard regulated test cycles, namely the NEDC for light-

[1] *With maximum sulphur content of 10 mg/kg*

Advanced vehicles and fuels

Some recent emissions results

duty vehicles and the ESC/ETC for heavy-duty engines. In addition some steady-state tests and 'real-world' drive cycles, defined under the EU's 'ARTEMIS'[2] programme, were included. Only some key examples of the results can be illustrated in this article. Full results will be found in the CONCAWE reports.

For both light-duty and heavy-duty testing, a consistent fuel change, conditioning and testing sequence was followed in order to obtain comparable results for the different fuel/engine combinations. The test programmes were constructed using the principles of statistical experimental design, with each fuel tested three times in each vehicle/engine.

Results and discussion

The diagrams show the average emissions results from the different engines/cars grouped by fuel, versus the relevant Euro emissions limits. Non-overlapping error bars indicate a statistically significant difference between those fuel/engine combinations.

Light-duty diesel vehicles

For CO emissions, both cars performed well within the Euro-4 limit. HC emissions from both cars were very low.

Particulate mass (PM) and NO_x are the more critical emissions from diesel engines. For PM emissions, car A, although certified to Euro-3, produced PM emissions close to the Euro-4 limit. Fuel D6 gave the highest PM emissions in this car. Swedish Class 1 (D5) and FT diesel (D8) gave the lowest PM emissions. The addition of RME to D4 did not significantly affect PM emissions.

The more striking effect was that of the particulate filter, car B producing extremely low PM emissions, below 10% of the Euro-4 limit on all fuels. In this car, the differences between fuels in PM emissions over the NEDC were not significant (Figure 1).

Sulphur had a larger effect on PM emissions under more severe test conditions, in particular the 'ARTEMIS' motorway cycle.

For NO_x emissions, car A almost satisfied the Euro-4 limit, while car B performed within its Euro-3 certification limit. Fuel effects were generally not significant on the NEDC, though directionally fuels D5 and D8 gave lowest NO_x emissions in car B (Figure 2).

NO_x emissions roughly doubled for both cars under the more severe conditions of the 'ARTEMIS' motorway cycle. On this cycle, fuels D5 and D8 gave significant reduction in NO_x emissions in car B, though not in car A.

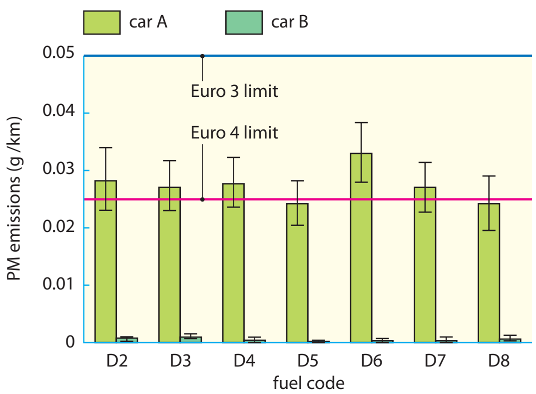
Heavy-duty diesel engines

CO emissions, even for the Euro-3 engine, were well below the Euro-5 limit and fuel effects were small rela-

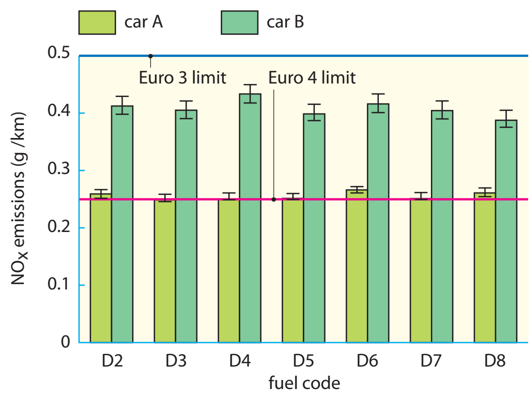
Figure 1 (left)
Car B with a particulate filter produced extremely low PM emissions, less than 10% of the Euro-4 limit.

Figure 2 (right)
Fuel effects on NO_x emissions were small over the NEDC.

PM emissions (NEDC)



NO_x emissions (NEDC)



[2] *Assessment and Reliability of Transport Emission Models and Inventory Systems*

tive to the regulatory limit. The Euro-4 and Euro-5 engines which both include oxidation catalysts gave extremely low CO emissions. HC emissions were around half of the applicable limit for the Euro-3 engine, even lower for the Euro-4 engine and not detectable for the Euro-5 engine. Swedish Class 1 fuel (D5) gave the highest HC emissions in the Euro-3 engine. Other fuel effects on HC emissions were not significant.

For particulate mass (PM), all three engines performed well within their respective PM emissions limits (Figure 3). The Euro-4 engine with particulate filter gave the lowest PM emissions, although PM emissions from the Euro-5 engine were also very low.

In the Euro-3 engine, lower sulphur content reduced PM emissions. Fuels D2 and D6, with comparable sulphur contents but differing in other fuel properties, gave similar emissions. The addition of 5% RME did not change PM emissions. Swedish Class 1 (D5) and Fischer-Tropsch diesel (D8) performed similarly and gave lower PM emissions than the other fuels. In the advanced Euro-4 and Euro-5 engines, the effects versus conventional sulphur-free fuels were very small in absolute terms.

The Euro-4 engine performed well within its NO_x limit on all fuels. NO_x emissions from the Euro-3 and Euro-5 engines were very close to their respective ESC test limits (Figure 4). Considerable progress in control of NO_x emissions from Euro-3 to Euro-5 engines is evident. However, even the Euro-5 NO_x emissions levels are still relatively high compared to the US heavy-duty limits for 2007 and 2010. Further progress can therefore be expected as control of engine-out emissions improves and NO_x after-treatment technology matures.

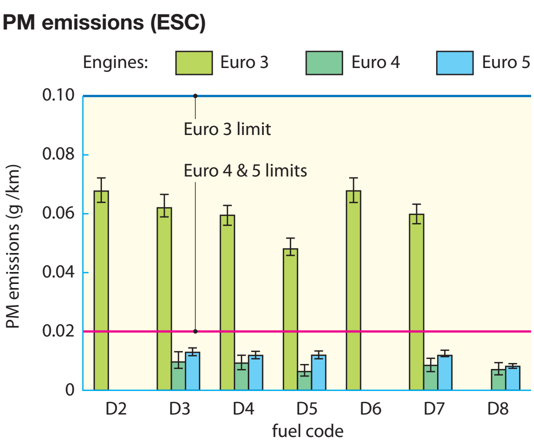
Fuel sulphur content did not directly influence NO_x emissions. Fuel D6 gave the highest NO_x emissions in the Euro-3 engine, although the difference from fuels D2–D4 was small and in-line with previous studies. Effects from addition of 5% RME were small. Larger fuel effects on NO_x emissions were observed with Swedish Class 1 (D5) and Fischer-Tropsch diesel (D8), consistent with the extreme changes in fuel properties.

In the prototype Euro-5 engine, NO_x after-treatment was by SCR/urea. In this system, there was potential to further reduce NO_x emissions with all fuels, if a higher urea injection rate was used.

Diesel programme conclusions

Large improvements in exhaust emissions control are being accomplished through advanced diesel engine technologies and after-treatment systems in combination with low sulphur fuels.

- HC and CO emissions from the advanced diesel engines and vehicles were well below the prescribed emissions limits.
- PM emissions were dramatically reduced in engines/vehicles equipped with diesel particulate filters.



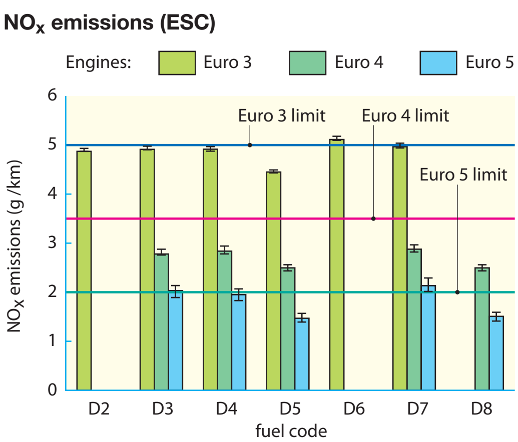


Figure 3 (left)
Substantial improvements can be seen in PM emissions control.

Figure 4 (right)
Clear progress is also evident in the control of NO_x emissions.

Advanced vehicles and fuels

Some recent emissions results

- Clear progress in control of NO_x emissions was demonstrated with the advanced diesel engine technologies. Further improvements can be expected as control of engine-out emissions improves and NO_x after-treatment technology matures, with the availability of sulphur-free fuels.

Gasoline programme

A range of advanced gasoline engine technologies and exhaust after-treatment technologies are being introduced to meet more stringent emissions requirements together with CO_2 reduction. The introduction of sulphur-free fuels is an important step, allowing regenerative devices such as NO_x storage catalysts to be introduced with acceptable durability and best fuel efficiency.

In this programme CONCAWE evaluated the impact of fuel quality on exhaust emissions from advanced gasoline vehicle technologies available in the market in 2002, covering three DI cars and one advanced MPI car. The fuel parameters of interest were evaluated by preparing two independent fuel sets: the first to examine the short-term effect of sulphur content (reported previously, CONCAWE report 5/03); the second to examine the effect of other key fuel properties: aromatics, olefins, volatility and final boiling point (described here).

Test vehicles

Four vehicles were evaluated, selected on the basis of new technologies judged likely to take a significant share of the European car population in the near term. Three examples of DI technologies, one stoichiometric (car A) and two lean-burn (cars C and D), and one advanced MPI system (car B) were tested. Two of these vehicles (A and C) were certified to Euro-3 emissions limits and two (B and D) to Euro-4.

Test fuels

The fuel matrix was designed to evaluate the effects of aromatics, olefins, volatility and final boiling point (FBP) on exhaust emissions. In order to maximise the chance to identify fuel effects, a wide range in the fuel parameters of interest was investigated, covering olefins from 14 to 5% v/v, aromatics from 38 to 26% v/v, E70 from 38 to 22% v/v and FBP from 197 to 176 °C. To reduce the number of emissions tests required, a statistically designed half-factorial matrix of eight fuels was blended, which treated volatility as the combined effects of E70 and E100. The sulphur content of all fuels was kept nominally constant. The key fuel properties are shown in Table 1.

Test methodology

Vehicles were tested according to the current legislated NEDC test procedure and the legislated exhaust emissions—CO, HC, NO_x—were measured. Test order was based on a randomised statistical block design with at least three repeat tests on each fuel/vehicle combination. Multiple regression techniques were used to relate emissions to the four fuel design variables (E70, FBP, aromatics, olefins) described above.

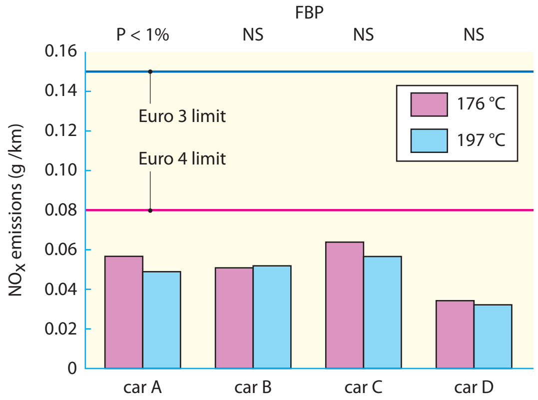
Results and discussion

The results are described below by emission with key illustrative graphs. In these graphs, the data are plotted with common scales for a given emission, with the maximum of the scale set just above the respective Euro-3 emissions limit. Within each graph, there are two bars for each vehicle, showing the mean emissions for the 'low' and 'high' level of the fuel parameter. The

Table 1 Key fuel properties *(The higher levels of each parameter are shaded grey)*

	Units	Fuel code							
		F1	F2	F3	F4	F5	F6	F7	F8
FBP	°C	174	180	174	177	195	202	195	196
E 70 °C	% Vol	19.1	33.4	39.2	20.5	41.2	24.5	22.8	39.0
E 100 °C	% Vol	48.2	61.9	62.9	46.7	62.2	48.0	47.4	62.5
Olefins	% Vol	5.5	3.0	12.7	14.1	4.9	5.3	13.0	14.2
Aromatics	% Vol	25.0	37.8	27.7	39.9	28.6	38.5	24.1	35.9

NO_x emissions (NEDC): effect of FBP



NO_x emissions (NEDC): effect of aromatics

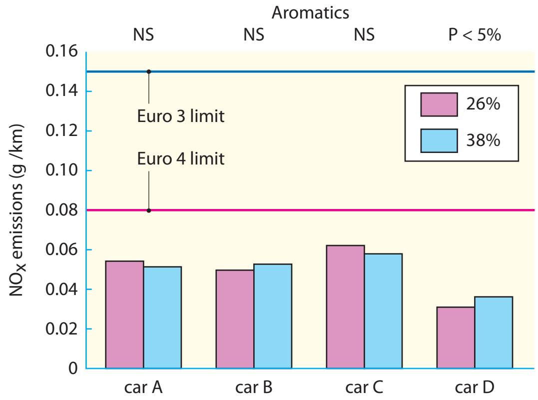


Figure 5 (left)
All four cars performed within the Euro-4 NO_x limit. Lower FBP gave a small increase in NO_x emissions in the DI cars, significant only in car A.

Figure 6 (right)
Aromatics effects on NO_x emissions were small, only car D showing a significant effect.

significance of the effects is denoted by the text above the bars: P < 1% = the probability that an effect could be observed by chance when no real effect exists is less than 1%, i.e. we are 99% confident that the effect is real. Likewise P < 5% = 95% confidence and P < 0.1% = 99.9% confidence. NS = Not significant (< 95%).

NO_x emissions

All four cars met the Euro-4 NO_x emissions limit of 0.08 g/km. Car D gave consistently lower NO_x emissions across all fuels.

Front/mid range volatility (E70) only had a significant effect on car A, the stoichiometric DI; NO_x increasing with higher volatility. Lowering FBP directionally increased NO_x emissions in the three DI cars, although significant only in car A (Figure 5). There was no significant effect of FBP in the MPI car B.

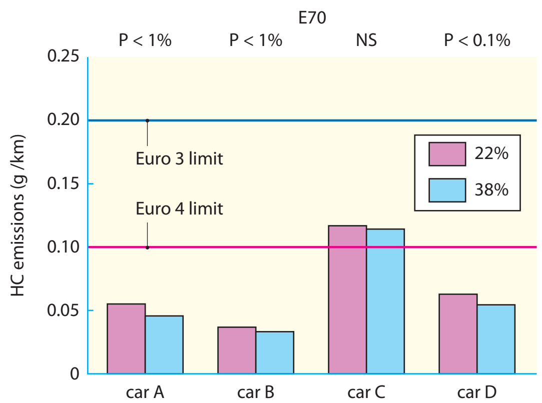
Reducing aromatics showed conflicting trends (Figure 6). The effects were not significant on NO_x emissions in three cars. Car D, a lean DI, showed a small but significant decrease in NO_x emissions with lower aromatics. Reducing olefins yielded no significant effect on NO_x emissions in any car.

HC emissions

HC emissions for three of the four vehicles were well below the Euro-4 limit of 0.1 g/km. Car C operated well below the Euro-3 limit against which it was certified. The other Euro-3 vehicle (car A) had very low HC emissions, in line with the two Euro-4 vehicles. For all four vehicles, the emissions from the ECE phase dominated the NEDC HC emissions.

Decreasing front/mid range volatility (E70 from 38% to 22%) increased HC emissions in all four vehicles, and was

HC emissions (NEDC): effect of E70



HC emissions (NEDC): effect of aromatics

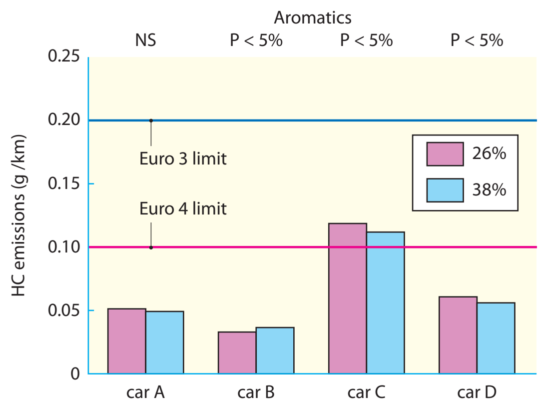


Figure 7 (left)
Three of the four cars performed within the Euro-4 HC limit. Decreasing E70 gave a small increase in HC emissions in all four vehicles.

Figure 8 (right)
Reducing aromatics gave a small increase in HC emissions in the DI cars, whereas the advanced MPI car (B) showed the opposite effect.

Advanced vehicles and fuels

Some recent emissions results

significant in three cases (Figure 7). The overall average increase was 0.006 g/km (10%).

Reducing FBP (from 197 °C to 176 °C) reduced HC emissions in all four cars, and was significant in two cases. The overall average decrease was 0.006 g/km (9%).

Reducing aromatics (from 38% v/v to 26% v/v) increased HC emissions in all three DI cars, and was significant in two cases (Figure 8). The overall average increase in the DI cars was 0.004 g/km (5%). Car B, the advanced MPI car, showed a significant effect in the opposite direction. Reducing olefins had no significant effect on HC emissions in any of the four vehicles.

CO emissions

CO emissions for all four vehicles were well below the Euro-4 limit of 1.0 g/km. Car A gave consistently lower CO emissions across all fuels.

Decreasing front/mid range volatility gave a significant reduction in CO emissions in the lean DI car C and in the advanced MPI vehicle. It had no effect in the other two vehicles. Reducing FBP directionally increased CO emissions in all four vehicles but the effect was significant only in cars B and C.

Changing aromatics content had no effect on CO emissions in any of the cars. Olefin effects on CO emissions were small. Only the advanced MPI vehicle (car B) showed a significant effect, with CO emissions increasing with lower olefins content.

Gasoline programme conclusions

All four gasoline vehicles achieved their respective emissions certification limits, and in most cases measured emissions were lower than the Euro-4 limits.

- A reduction in fuel volatility, representing the combined effects of vapour pressure, E70 (38% v/v to 22% v/v) and E100, had no consistent effect on NO_x emissions, increased HC across all vehicle technologies (10%), but decreased CO emissions in two cars.
- A reduction in FBP from 197 °C to 176 °C increased NO_x emissions in one car but had no significant effect in the others. HC emissions were directionally reduced (9%) and CO emissions directionally increased (20%), with significant effects in both cases in two cars.
- A reduction in aromatics content from 38% v/v to 26% v/v showed conflicting effects, increasing NO_x emissions in two cars, decreasing in the others, but the effects were only significant in one vehicle. Reducing aromatics increased HC emissions in the two lean DI cars but showed the opposite effect in the MPI car.
- A reduction in olefins content from 14% v/v to 5% v/v gave no significant improvement in NO_x, HC or CO emissions in any of the cars.

Summary/outlook

It is clear that very low emissions can be achieved by advanced engine/vehicle technologies operating on sulphur-free fuels, and this will bring substantial improvements in European air quality as the vehicle fleet is replaced. For diesel vehicles, particulate filters have the potential to reduce diesel PM emissions by more than an order of magnitude, and capability for substantial improvements in control of NO_x emissions is also evident. Gasoline vehicles are already achieving very low regulated emissions and the future challenge is to continue to improve fuel efficiency.

The potential for additional air quality benefits from further changes to EU fuel specifications appears to be minimal. It should be borne in mind that any such changes would increase refinery processing, hence CO_2 emissions, and could also limit available fuel volumes. Nevertheless, the EU Fuels Directive review still has some important items to consider, including the end date for 100% market coverage of 10 mg/kg sulphur diesel fuel, gasoline vapour pressure limits with respect to ethanol blending, metallic additives, and non-road diesel fuel requirements.

Joint European Well-to-Wheels study

An analysis of future automotive fuels and powertrains in the European context

The Well-to-Wheels (WTW) study carried out jointly by EUCAR, JRC/IES and CONCAWE was completed at the end of 2003. A full report was prepared and is available on the JRC website at http://ies.jrc.cec.eu.int/Download/eh

The study considered a wide range of primary energy sources, automotive fuels and powertrains. The energy and GHG balance was estimated for close to 500 combinations, thus creating an extensive database for these key elements of the alternative fuels debate. Also included are considerations of the quantities of alternative fuels that could potentially be produced, as well as the associated costs considered from a macro-economic point of view and for Europe as a whole.

This is a field where a lot of development activities are taking place with new, more efficient and/or cheaper routes and processes bound to be developed in the years to come. In order to integrate such developments, the database will need updating at regular intervals and the partners to the study are committed to doing this through a yearly review process.

In this article we briefly revisit the main conclusions of the study in terms of energy and GHG balance, giving particular attention to the issues of potential volumes and optimum use of limited resources.

Energy efficiency and GHG emissions: an inevitable trade-off?

The wide range and diversity of options has been conveniently represented in Figure 1 by plotting the total WTW GHG emissions associated to a pathway (expressed in g CO_2 equivalent per km) against the total energy required (in MJ per 100 km).

Comparison of well-to-wheels GHG emissions and associated energy consumption
(box in lower left hand corner indicates current gasoline vehicle performance)

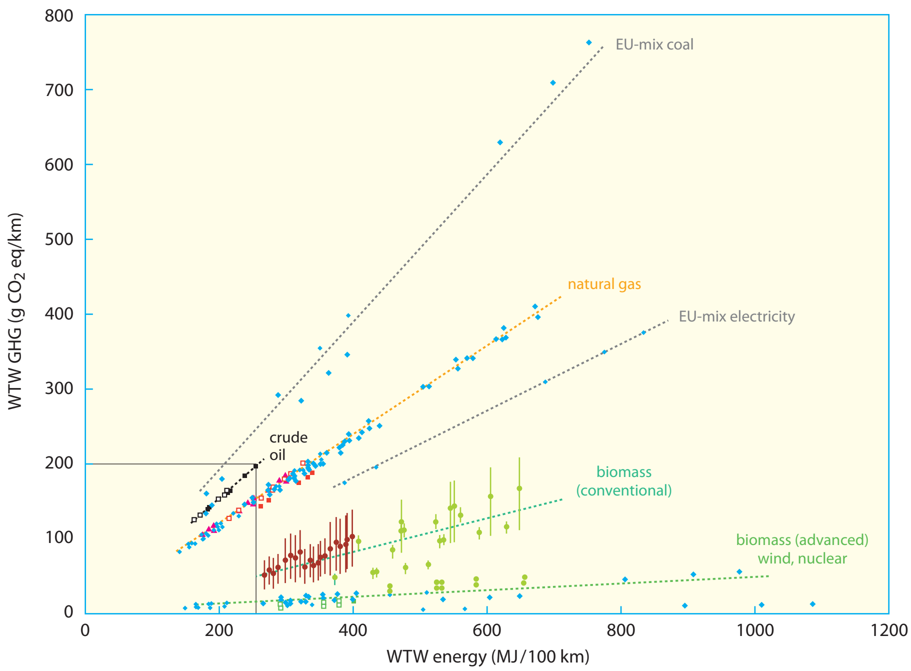


Figure 1
Renewable/low fossil carbon fuel production routes may offer lower GHG emissions, but generally require more energy use.

Joint European Well-to-Wheels study

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The data points cluster on trend lines representing the different primary fuel sources, reflecting a constant GHG emission factor (in g CO_2eq/MJ). For the fossil-based fuels this illustrates the fact that coal, crude oil or natural gas are the primary energy sources used throughout the production pathway of the respective fuels. Thus fuels derived from coal give more GHG emissions for the same energy consumption than equivalent fuels derived from crude oil or natural gas, on account of the lower carbon content of the primary energy source.

Equally noteworthy is the large range of variation along the trend lines—how the fuel is produced and used is just as important as the resource used. The natural gas line illustrates the many ways of using this resource and how different the results can be in terms of energy and GHG emissions. For example, using hydrogen from natural gas reforming in a fuel cell vehicle can be three times more efficient than burning hydrogen in an internal combustion engine when the fuel is prepared by electrolysis and electricity generated from natural gas. The box in the lower left-hand corner of the chart highlights the performance of current gasoline vehicle technology while the points along the crude oil line represent different powertrain technologies, improving in efficiency from the 2002 gasoline conventional port injection engine to a 2010 diesel hybrid. Many of the possible pathways derived from natural gas or coal produce more GHG emissions and consume more energy than today's conventional fuels pathways.

There is more spread when it comes to biomass-based fuels as a range of energy sources is used at different stages of these pathways. Nevertheless, the 'conventional' biofuels (ethanol, FAME) broadly fall on an intermediate line illustrating the fact that their production still involves a significant amount of fossil energy. For these fuels we have shown the large range of variation related to the specific uncertainties over N_2O emissions from agriculture.

The more advanced conversion technologies (e.g. synthetic fuels based on biomass gasification or wind electricity) utilise virtually only renewable energy for the conversion process. As a result GHG emissions are low and the corresponding points lie on an almost horizontal line, very close to the horizontal axis.

Energy efficiency and GHG emissions reduction are both important goals in the quest for alternative energies and fuels. In this plot the 'desirable' area is therefore the bottom left-hand corner. Taking the crude-oil based fuels as a starting point, it is clear that a majority of the alternative fuel routes towards lower GHG emissions correspond to an increase in primary energy use. Only the combination of the most efficient converters (fuel cells) and the most favourable fuel production pathways result in improved energy efficiency. This 'trade-off' between GHG emissions and energy is important because most of the energy resources associated with low GHG emissions have a limited availability. Optimum global GHG emissions reduction therefore implies optimum and efficient use of limited energy resources.

What potential for alternative fuels?

The overarching reasons behind the success of fossil fuels are their high energy density, relatively low cost and, importantly, their very wide availability. Very few, if any, of the alternative candidates can offer a similar package. Energy density is an issue for all gaseous fuels and in particular for hydrogen. Complex production processes, logistics and the like make for generally high costs compared to conventional fuels. But arguably one of the most serious issues facing most alternative fuels, is how much could, or should, be made.

Alternative fuels are pursued for two main reasons, GHG avoidance and diversification of energy supply. Attractive energy sources to produce them are therefore those that are renewable, or at least low-carbon, and 'home-grown'. In the renewable arena, this leaves space only for biomass, wind or direct solar energy. Nuclear energy delivers virtually carbon-free electricity (or high temperature heat) and nuclear fuel is in plentiful supply. It does, however, raise societal and political issues, the discussion of which would go far beyond the scope of this article. Nuclear fusion is likely to be more acceptable but it is still a scientist's dream.

The planet is unlikely to run out of wind any time soon but the number of sites that are suitable for large scale wind farms and also acceptable to the public is clearly limited (in the same way as practically all suitable and acceptable sites for dams have now been exploited). Technology is playing its role, producing ever larger, more efficient, quieter and cheaper turbines. A very wide range of estimates has been proposed for wind energy. What will actually be achieved will depend on a large number of factors, both technological and political.

In spite of spectacular technological advances in, for example, photovoltaic cells, the capture and storage of direct solar energy is still in its infancy and is unlikely to receive serious consideration on a very large scale for several decades.

Wind and most versions of direct solar energy produce electricity which can of course be used directly to meet a portion of the fast-expanding demand. Turning this electricity into say, hydrogen, is an additional step that is unlikely to be justified from an energy efficiency point of view, inasmuch as renewable electricity remains limited.

The amount of biomass that can be produced from a certain area of land is also limited. In addition, energy crops must compete with food crops and other desirable uses of land. Food production is an essential demand and it is difficult to imagine that energy production would ever be given a higher priority. In our attempt to produce a fair estimate of the potential of biomass for energy production, we have therefore adopted a 'constant food' scenario for Europe. The land available for energy crops is then what is currently not in use (set-asides) and what will become available as a result of increasing yields.

We have then considered a number of alternative scenarios in each of which one particular type of fuel would be maximised. The results of these calculations are shown on Figure 2. The cumulative bars show the amount of fuel that could be produced in each scenario, expressed in energy content. This would be achieved by using the surplus land preferentially for e.g. wheat (maximum ethanol), oil seeds (maximum FAME) or wood (maximum synthetic fuels). As most pathways use some fossil fuels, only a portion of that energy is really renewable. Diesel fuel production is more favourable than ethanol, particularly in the form of synthetic diesel (produced from woody biomass). Note also that these figures are expressed on a 'Well-to-Tank' basis, i.e. do not take into account the differences in powertrain efficiency. Reality is likely to be a mixture of these extreme scenarios. In all cases the maximum potential remains modest, say in the order of 1500 PJ/a, compared to a total expected demand for transport fuels of around 14,000 PJ/a.

From a 'Well-to-Wheels' point of view this would translate into CO_2 avoidance as shown in Figure 3, in which hydrogen options have been included. The higher biomass conversion efficiency of the synthesis pathways compared to the 'conventional' FAME and ethanol routes gives a clear advantage to the former. For hydrogen, the conversion efficiency is even higher and can be compounded by the high efficiency of the fuel cell. In the

Potential of biomass for energy production (WTT basis, EU-25)

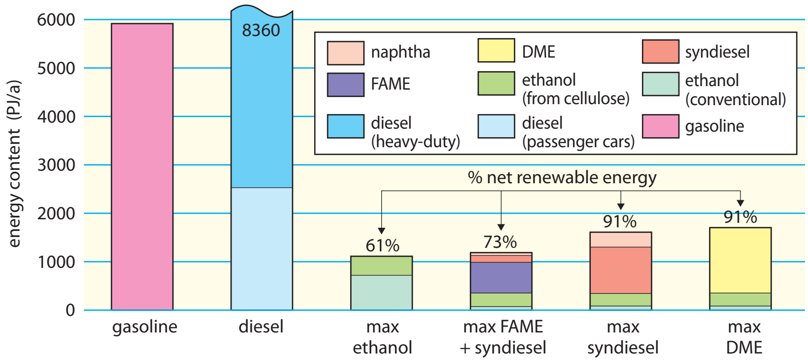
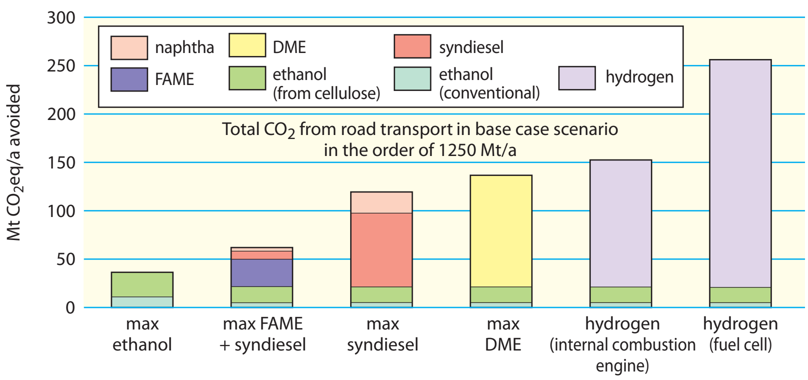


Figure 2
Maximum potential of biomass is around 10% of the European transport fuel demand.

Figure 3
The potential GHG savings depends on the fuel pathway chosen.

Potential CO_2 avoidance (WTW basis, EU-25)



Joint European Well-to-Wheels study

An analysis of future automotive fuels and powertrains in the European context

Potential for CO_2 avoidance through alternative uses of land

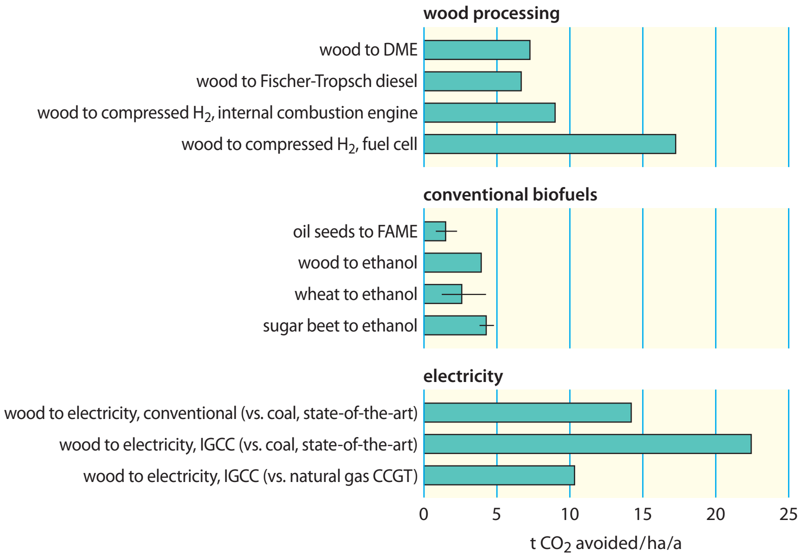


Figure 4

One hectare of land can be used in many different ways, resulting in very different GHG savings.

most favourable 'maximum hydrogen/fuel cell' scenario, the use of biomass could allow a CO_2 avoidance of about 20% of total transport emissions. It should be borne in mind however, that hydrogen involves a complex system of distribution infrastructure and new vehicles, whereas the liquid fuels can be virtually seamlessly integrated into the existing fuel systems. Again reality is likely to be more diverse resulting in a lower figure. The above figures also assume that all surplus biomass is available for road fuels production, which is unlikely to be the case.

Optimising limited renewable resources

It is clear from the foregoing that if renewable sources in general, and biomass in particular, have the potential to play a role in the future fuel mix, they will only be able to cover a fraction of the transport fuels demand. The same renewable energy sources are also eyed by other sectors, in particular electricity—the demand for which is growing at a steady pace. This opens the question of optimisation of their use and in particular of their potential for GHG avoidance.

Using the results of our study, Figure 4 illustrates, with a number of examples, the large range of net GHG that could be avoided through various alternative uses of a hectare of land. This net potential depends of course on the proposed crop and conversion process but also on what is being substituted. For example, displacing coal for electricity production is more effective than substituting gas, even more so when the efficient IGCC (Integrated Gasification and Combined Cycle) process is used. It is clear that the 'conventional' biofuels only have a modest potential in this respect compared to either electricity production or the more sophisticated wood conversion pathways into hydrogen or synthetic fuels. Hydrogen benefits from the expectation of very efficient fuel cells. It must be borne in mind, however, that this is but one aspect of the problem; biofuels and hydrogen are very different propositions in terms of investment, complexity, impact on fuelling infrastructure and vehicles, etc.

All the same, this illustrates the complexity of the issue and the necessity to treat energy questions globally rather than with a narrow focus on transport. Both GHG emissions and security of energy supply are global energy issues rather than specific to the transport sector, and what is favoured for the latter should not be detrimental to the former.

Safety

A constant challenge

Producing and handling petroleum products that are primarily designed to burn is a fundamentally hazardous pursuit. It is no surprise, therefore, that the oil industry has been at the forefront of safety management for many years and in all parts of the world. The industry has long recognised that 'good safety is good business' and safety has become an integral part of running the business, with safety objectives and targets being set at all levels of the organisations. Europe is no exception and safety of operating personnel and assets, but also of the public at large, is the object of ever-increasing attention from both industry and the legislator.

The word 'safety' covers a wide range of issues. The most obvious is the provision of a safe working environment for employees and contractors. This includes monitoring working conditions and practices, and preventing accidents and injuries. Related to this, but focused more on equipment, is 'plant integrity and safeguarding' i.e. a combination of hardware, software and procedures designed to prevent operating accidents. The actual or potential impact of plants on the environment within which they operate is increasingly under scrutiny the world over, as the risk thresholds that governments and the public alike are prepared to tolerate are on a steady downward trend. Finally the safety of the products manufactured by the industry, from the point of view of the customer and of the public at large (e.g. in connection with transportation) is also key to the sustainability of the business.

These various aspects of safety are addressed through a combination of investment in equipment ('hardware' measures) and of integrated safety management systems. These systems ensure coordination of efforts, as well as monitoring performance and degree of attainment of objectives.

In this article, we discuss some of the more recent developments in the field of safety in the European refining industry.

Facility design and operating practices

Refinery facilities have a long life, typically fifteen years at the project stage but often much longer in practice; many plants are still operating after thirty years or more. If a lot of the equipment is renewed during the life of a plant, the basic design concept remains and retrofitting a new safeguarding philosophy can be difficult. Integrating safety into the original design of plants and facilities is therefore essential. Two such aspects that have recently received attention in Europe are described below.

Blast resistant/blast proof constructions

In the wake of some spectacular incidents, most European refiners have, in the past ten years, reassessed the design of on-site buildings and their resistance to shock waves from process explosions. These studies, conducted by qualified consultants, have led the major operators to plan, over several years, either the reinforcement or the rebuilding of the most critical refinery buildings.

This is particularly applicable to control rooms which must not only be able to protect those inside but also remain operational in order to shutdown the plant in a quick and safe fashion in case of incident. There are, however, many other buildings that house equipment critical to normal and shutdown operations and must also be protected (e.g. control and emergency shutdown systems, power supply etc).

A typical blastproof control room

Safety

A constant challenge

Large hydrocarbon storage facilities

Worldwide industry records of the past 40 years show that a number of accidents and fires occurred on large hydrocarbon storage tanks, with a large proportion of these involving crude oil. In the 80s most European refiners participated in the 'Last Fire' project conducted by Resource Protection International, a specialised consulting company (www.resprotint.co.uk). The objectives of this exercise were to establish a database of fires/accidents involving large atmospheric crude oil storage facilities (mainly floating roof tanks), to determine current levels of risk and to develop guidelines for best design and operational practices and make them available throughout the industry. As a further step it was proposed to establish techniques to determine site-specific levels of risk and identify appropriate and cost-effective risk reduction measures.

This exercise was completed in 1995, providing valuable insight into the main types and causes of tank fires and into the most critical aspect of design, inspection, maintenance and operation of large crude oil tanks. A second project (Last Fire Project II), involving the same consultant, is now being started. The main objective is to update the database while some additional issues will also receive attention such as definition of best practices in fire protection and new design and engineering features (e.g. the geodesic roof).

Safety of industrial sites: protecting the neighbourhood

The potential risk that industrial installations impose on their neighbourhood has been a major issue for operators, legislators and the public alike for many years. The Seveso accident in Northern Italy in 1976, involving a major release of dioxins in the environment, acted as a catalyst for the development of European legislation aiming to enhance public protection, improve the transparency of industrial operations and increase the level of control exercised by the competent authorities for delivery of operating permits and monitoring of activities at the sites. The new legislation is embodied into two European Directives on 'Control of Major Accident Hazards' commonly known as the 'Seveso' Directives. The second Directive was finally adopted in 2003 and reinforces the dispositions of the first one particularly in terms of public information. One particular aspect considered in the Directives is the siting of industrial plants and the use of the land immediately surrounding them, known as the 'land-use planning' or LUP issue.

LUP first came on the agenda in Europe during the 90s, resulting in a set of guidelines at European level but no harmonised legislation, EU Member States remaining free to promulgate their own rules and regulations in the matter. Two major accidents reopened this issue: the fire and subsequent explosion at a fireworks storage in Enschede in the Netherlands in May 2000 and the chemical explosion at the AZF plant in Toulouse, France in September 2001. Following these tragic events there were renewed calls for reassessment of current practices and harmonisation of legislation at the European level.

A technical working group was set up by the European Commission in 2003, with the objectives of developing the basis for such future legislation. The main topics under study are the definition of best practices for risk and hazard assessment and the development of a database of accident scenarios for each type of industrial site in order to evaluate the level of risk and recommend minimum safety distances around industrial sites and other measures. The simulation of major events such as explosions, flammable or toxic releases, is essential to the risk evaluation process and requires appropriate models. These models are complex tools that need to be used by experts.

The European oil industry has accumulated much experience in this field and, through CONCAWE, is contributing to this process by sharing information on past incidents, including frequency of similar events, to help establish a consensual list of plausible accident scenarios for its installations. CONCAWE also brings the combined expertise of its member companies in the use of simulation models.

It is hoped that this process based on a scientific and technological approach will lead to the development of realistic proposals providing a high degree of public protection without imposing undue constraints on industry.

Safety management

The introduction of a coherent safety management system is essential to a successful safety policy. Such systems can now be found in all oil companies, either developed in-house or purchased from specialised consulting firms. Increasingly, these systems are integrated into broader enterprise management systems incorporating, amongst others, environment and quality.

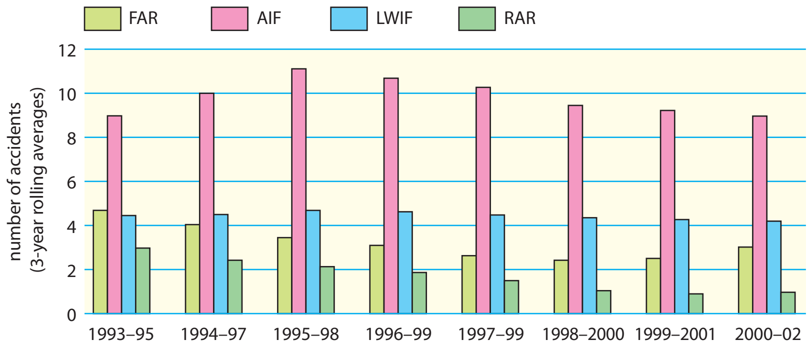
Incident prevention and monitoring: the cornerstone of safety management

How people relate to safety in general bears a strong relation to their day-to-day behaviour and, in particular, to the way they perform their professional duties. Increasing 'on-the-job' safety awareness is therefore essential to building a safety-conscious organisation. This is particularly important in an industry that deals with flammable and occasionally explosive products, and the oil industry has been putting these principles into practice for many years.

Monitoring performance is an important part of prevention. Virtually every oil company in Europe keeps statistical records of work-related incidents and injuries. At the pan-European level, CONCAWE has been collecting data from its member companies since 1993, providing a view of the industry's performance for the whole region as well as a benchmark for individual operators. The yearly report, including data for 2002, will be published shortly. Figure 1 illustrates the steady improvement of the industry performance in terms of total recordable injuries since the mid 90s. The lost work time injury rate has marginally improved. The seemingly increasing trend in the all injuries rate in the mid 90s is believed to be mainly due to gradually better and more complete reporting as more attention turned to this indicator. Fatalities, after a long period of steady decrease, have disappointingly increased again in recent years. In spite of the successful reduction of the road accident rates, the share of road accidents in the total number of injuries and, more particularly, the fatalities remain a cause for concern.

These results are put in perspective when compared to other related industrial sectors and to the general performance in the European work scene. In terms of lost work time injuries, the downstream oil industry is streets ahead of other branches, only surpassed by the impressive record of the upstream oil industry. The oil industry's fatality rate is also much lower than the European average.

Safety performance in the European downstream oil industry



FAR: Fatal Accident Rate (per 100 million hours worked)
AIF: All Injuries Frequency (per million hours worked)
LWIF: Lost Workday Injuries Frequency (per million hours worked)
RAR: Road Accident Rate (per million hours worked)

Figure 1
The industry's AIF and RAR have improved steadily since the mid-90s. LWIF has improved marginally.

Learning from experience: information exchange and 'lessons learned' management

The past 10 to 15 years saw the realisation that much was to be gained in improving the flow of information related to safety. This is particularly relevant to the identification and the dissemination of the 'lessons learned' from incidents and near-misses to avoid reoccurrence of past accidents and disasters. Nowadays, 'lessons-learned management' takes advantage of companies' intranet to broadcast relevant messages and documentation throughout the different business sectors of a company. The exchange of such information between otherwise competing companies is also well established and CONCAWE, through its Safety Management Group in which all member companies can participate, contributes to this process.

	CONCAWE 2002	OGP 2002 Europe	OGP 2002 World	CEFIC 2001	EU all branches 1999
FAR	3.3	NA	3.9[1]	NA	8.0[2]
AIF	8.5	7.0	3.6	NA	NA
LWIF	3.9	2.0	1.1	10.5	19.9[2]

OGP: International Association of Oil & Gas Producers
CEFIC: Conseil Européen de l'Industrie Chimique/European Chemical Industry Council
[1] *Own staff and contractors only*
[2] *Estimated from statistical data compiled by the European Commission (EUROSTAT)*

Safety

A constant challenge

More traditional media such as booklets or pamphlets still have their place. In this respect the 'Process Safety Booklet Series' issued by BP is particularly interesting. Following the example of the US industry, the European refiners are also engaged in the process of setting up a common database on this issue.

Mutual assistance and equipment sharing

Mutual assistance arrangements, in case of major fire or other safety- or environment-related incidents, have been in place for many years at the local level—separate sites in the same industrial area sharing, for example, fire-fighting facilities or consumable stocks (e.g. foam). This has proven to be workable, beneficial as well as efficient. As fire-fighting equipment becomes more sophisticated and expensive to purchase and maintain, the European refiners have been considering the possibility of sharing heavy equipment at the scale of a region or in some cases a country. This of course must be integrated with fast and reliable transportation arrangements and requires extensive discussions with local and permitting authorities. At this point fire pre-plan studies and cost/benefit analyses are being carried out to demonstrate the feasibility of such projects, with a view to organising full scale trials.

Product safety: the REACH legislation

Ensuring the safe transportation and use of its products is central to the long-term sustainability of the industry and a key element is to disseminate the relevant information. CONCAWE have compiled a series of product dossiers summarising the physical and chemical properties and toxicological, health, safety and environmental information for petroleum substances. These dossiers are available for free download from the CONCAWE website.

The existing European chemicals legislation that affects petroleum substances includes, among others, the Dangerous Substances Directive, the Dangerous Preparations Directive and the Existing Substances Regulation (Additional information on the above legislation may be found on the European Chemicals Bureau website: http://ecb.jrc.it/). For many years, CONCAWE has provided recommendations for the health and environmental classification (and labelling) of petroleum substances in accordance with existing legislation. These recommendations are published as CONCAWE reports and updated as new information becomes available or the legislation is amended.

Recently the EU Commission issued a draft proposal for a far-reaching new piece of legislation for the **R**egistration, **E**valuation and **A**uthorisation of **CH**emicals (known as 'REACH'). If adopted into law, REACH will radically change the responsibilities of industry and the authorities for the control of chemicals in the years ahead. In particular, the responsibility for undertaking the health and environmental risk assessment on substances will shift from the authorities to industry. Recognising the challenges that lie ahead to perform risk assessments on petroleum substances, which have a complex and variable composition and for which risk assessment methodologies need to be developed, CONCAWE has undertaken a voluntary initiative to conduct risk assessments of petroleum substances. The current programme of risk assessments started in 2002 and will continue for most of this decade.

Conclusions

Safety in all its aspects is nowadays fully integrated into the management of the European oil business. Much has been achieved and the European downstream oil industry can be proud of its safety record. All the same, much remains to be done. Open sharing of information within organisations and between companies is essential if hazardous situations and incidents are not to be repeated. All human activities include an element of risk. Pooling of resources and experience at industry level for a common and consistent approach to problems is likely to pay dividends in the form of better and more cost-effective solutions.

Cooperation at the European level is well-established. Cooperation and information exchange between regions of the world is less developed and this may be an opportunity for the future.

Abbreviations and terms used in this CONCAWE *Review*

AIF	All Injuries Frequency
AOT	Accumulated exceedances Over Threshold
ARTEMIS	Assessment and Reliability of Transport Emission Models and Inventory Systems
BAT	Best Available Techniques
BREF	BAT Reference document: Full title: 'Reference Document on Best Available Techniques for …' (A series of documents produced by the European Integration Pollution Prevention and Control Bureau (EIPPCB) to assist in the selection of BATs for each activity area listed in Annex 1 of Directive 96/61/EC)
CAFE	Clean Air For Europe
CCGT	Combined Cycle Gas Turbine
CEFIC	Conseil Européen de l'Industrie Chimique/ European Chemical Industry Council.
CRT	Continuously Regenerative Trap
DI	Direct Injection
DME	Di-methyl ether
E100	% v/v gasoline evaporated at 100 °C
E70	% v/v gasoline evaporated at 70 °C
ECE	Urban driving part of the NEDC
ECETOC	European Centre for Ecotoxicology and Toxicology of Chemicals
EGR	Exhaust Gas Recirculation
ESC	European Steady-state Cycle
ETC	European Transient Cycle
EUCAR	EUropean Council for Automotive Research and development
FAME	Fatty Acid Methyl Ester
FAR	Fatal Accident Rate
FBP	Final Boiling Point
GHG	Greenhouse gas
HPLC	High Pressure Liquid Chromatography
IAM	Integrated Assessment Model
IES	Institute for Environment and Sustainability (one of the institutes that constitute the Commission's Joint Research Centre)
IGCC	Integrated Gasification Combined Cycle
IPPC	Integrated Pollution Prevention and Control (EU Council Directive 96/61/EC of 24 September 1996 concerning integrated pollution prevention and control)
JRC	The EU Commission's Joint Research Centre
LUP	Land Use Planning
LWIF	Lost Workday Injury Frequency
MPI	Multi-Point Injection
NEDC	New European Drive Cycle
OGP	International Association of Oil & Gas Producers
OSPAR	Commission for the Protection of the Marine Environment of the North-East Atlantic (previously 'Oslo and Paris Commission')
PJ/a	PetaJoule per annum (PJ = 10^{15} Joules)
PBT	Persistence, (potential to) Bioaccumulate, Toxicity
RAINS	Regional Air Pollution Information and Simulation model. (A tool developed by the International Institute for Applied Systems Analysis (IIASA) for analysing alternative strategies to reduce acidification, eutrophication and ground-level ozone in Europe)
RAR	Road Accident Rate
REACH	Registration, Evaluation and Authorisation of Chemicals (Proposal for a new EU regulatory framework for chemicals adopted by the EU Commission in October 2003)
RME	Rapeseed Methyl Ester
SCR	Selective Catalytic Reduction
SPME	Solid Phase Micro-Extraction
WEA	Whole Effluent Assessment

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CONCAWE publications

Reports published by CONCAWE from 2003 to date

1/03	Performance of European cross-country oil pipelines—statistical summary of reported spillages—2001
2/03	European downstream oil industry safety performance—statistical summary of reported incidents—2001
3/03	European oil industry guideline for risk-based assessment of contaminated sites (revised)
4/03	The IPPC directive, refinery BREF, and European refineries—a guidance manual
5/03	Fuel effects on emissions from modern gasoline vehicles: Part 1—sulphur effects
6/03	A guide for reduction and disposal of waste from oil refineries and marketing installations
1/04	Chronic toxicity studies on white oils
2/04	Fuel effects on emissions from modern gasoline vehicles: Part 2—aromatics, olefins and volatility effects
3/04*	Hot and cold weather driveability performance of advanced European gasoline vehicles
4/04	Trends in oil discharged with aqueous effluents from oil refineries in Europe—2000 survey
5/04*	Occupational health auditing
6/04*	European downstream oil industry safety performance—statistical summary of reported incidents—2002

* Available shortly

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Printed on chlorine-free paper made from
recycled waste, sawmill residues, forest thinnings
and fibre from sustainable forests.