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Foreword

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Earlier this year, CONCAWE became aware of a discussion around the status of gasoline under the REACH legislation. This discussion could have led to a momentous change that would have made gasoline a 'preparation' rather than a 'substance', putting in jeopardy all the work done so far by the industry to prepare for the implementation of REACH. In April, CONCAWE had the opportunity to review the issue in detail with the European Chemicals Agency (ECHA) in order to reach a common understanding. This meeting produced a satisfactory outcome for our industry, which represents a real mark of recognition by the authorities of the quality of CONCAWE's work on petroleum products over the past 30 years, in support of European legislation on dangerous substances.

Such results can only serve to strengthen our vocation and objective, i.e. to work in a spirit of continuity, rigour and transparency to gather and generate objective information as input for the legislator and stakeholders when developing future legislative texts. Living up to this objective also requires a large degree of forward thinking and judgment to anticipate which subjects will be of relevance tomorrow.

We hear a great deal about advanced combustion engines (HCCI, CAI, etc.) and the contributions these can potentially make to reducing vehicle emissions. In order to remain abreast of developments, to understand how fuel properties can influence the performance of these new engine technologies and which changes in fuel properties, if any, these technologies would require, CONCAWE has undertaken its own study, the results of which will be published in a future issue of the *Review*. Before initiating this study, we carried out a comprehensive review of the extensive literature which exists on the subject, to better understand the state of development of these new concepts and their potential implications for future fuels. The conclusions of this literature study are presented in this *Review*.

CO_2 emissions from refineries are the subject of much scrutiny within the context of both the Emissions Trading Directive and the Fuels Quality Directive. The Emissions Trading Directive seeks to decrease CO_2 emissions by 21% between 2005 and 2020 while, at the same time, changes in both product quality and demand could cause these emissions to increase by 40%. Another article in this *Review* analyses the emission trends and the mitigation options available to EU refiners. Through such studies, we can demonstrate to the EU legislators the incompatibilities between several 'environmental' legislations.

The IPPC Directive is a crucial piece of legislation for EU refiners, as most emission limits are determined by the way it is interpreted and applied. Ten years after its entry into force, significant gaps remain in its implementation by member states, with the result that the EU Commission is now proposing a revised directive which imposes an EU-wide command and control system. The proposed revision of this Directive is a major cause for concern, as it makes the application of the BAT (Best Available Techniques) concept very rigid without due consideration for local circumstances, turning guidance values for emission levels into hard limit values. Two of the articles in this *Review* describe and explain the work CONCAWE is undertaking to demonstrate how a scientific, rational and objective methodology could help to achieve the health and environmental objectives in a far more cost-effective way. The first illustrates once again the fact that EU-wide BAT more than doubles the cost of complying with environmental objectives, as compared to locally adjusted measures. The second demonstrates that the cost-benefit methodology of the EU Commission is partly flawed and needs to be revisited.

Environmental objectives set by EU and national legislators are not for CONCAWE to question. The way these objectives are to be attained must, however, be the subject of broad and open debates in which CONCAWE has an essential role to play.

We still have work to do!

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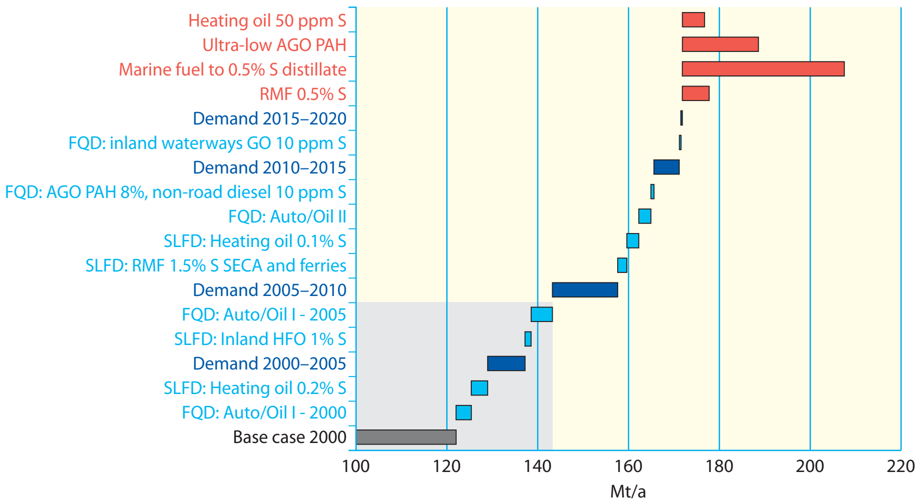
The current focus on climate issues and, more specifically, greenhouse gas (GHG) emissions is generating much debate regarding emission sources and reduction options. Oil refineries are amongst the so-called 'energy-intensive' industries that do emit large quantities of GHGs, the vast majority of which is carbon dioxide, CO_2. In this article we review the current situation in EU refineries with regard to energy consumption and CO_2 emissions, their evolution in the past few years and the factors that will affect them in the future. We also consider the mitigating options available to the refiners.

Turning crude oil into marketable products requires energy to physically separate molecules and chemically modify them to obtain the desired yield structure and product quality. As demand has gradually shifted towards lighter and cleaner products, refineries have become more complex and, in the process, have gradually required more energy use. Today's EU refineries consume the equivalent of 6.5 to 7% of the energy content of their feedstocks. The majority is internally generated, although there can also be imports of electricity and natural gas. Burning fuels to generate energy is currently responsible for about 90% of EU refinery CO_2 emissions on average. The other 10% is 'chemical' CO_2 generated by decarbonisation of hydrocarbon molecules to produce the hydrogen required for desulphurising and saturating various streams (note that this proportion varies a great deal depending on the refinery configuration). This 'chemical' portion is steadily growing as more conversion of residues to light product is required and as treating requirements are becoming more stringent.

As part of CONCAWE's refinery modelling activities we have endeavoured to forecast the future refinery emission trends in the EU, taking into account the foreseen changes in demand and in product quality. For the latter we have taken into account all currently agreed legislation (some provisions of which will only come into force in future years) and also considered a few 'step out' cases to represent possible additional legislation based on current debates. We have chosen to represent the reduction of the polyaromatics (PAH) content of diesel fuel to very low levels, reduction of heating oil sulphur to 50 ppm and either a complete switch of marine fuels to distillates or desulphurisation of residual marine fuel to 0.5%. It should be stressed that these extreme changes in product quality are intended only to emphasise the impact on CO_2 emissions from refineries and do not represent the oil industry preferred end point. Although

Figure 1 Expected evolution of CO_2 emissions from EU refineries



CO_2 emissions from European refineries are on an upward trend. (The grey shaded area indicates past evolution.)

all these changes including emission mitigation measures will also have a large impact on refinery costs and investment requirements, we have deliberately left this out of the scope of this article to focus on CO_2 emissions.

Figure 1 shows the expected evolution of CO_2 emissions from European[1] refineries between 2000 and 2020, split into 5-year periods. All main legislative changes are shown while the impact of demand changes is highlighted separately. From the 2020 reference, the step-out cases (shown in red) for potential legislation have been added.

Clearly CO_2 emissions are on an upward trend. By 2005 Auto/Oil road fuels specifications had largely been implemented but there are other changes to come including migration of non-road diesel to road diesel specifications, sulphur reductions in heating oil and the implementation of the new marine fuels legislation. The steadily increasing imbalance between gasoline and diesel and the slow erosion of residual fuel markets create a need for more conversion, mostly of the hydrocracking type, which leads to increased hydrogen requirements and consequently to higher CO_2 emissions.

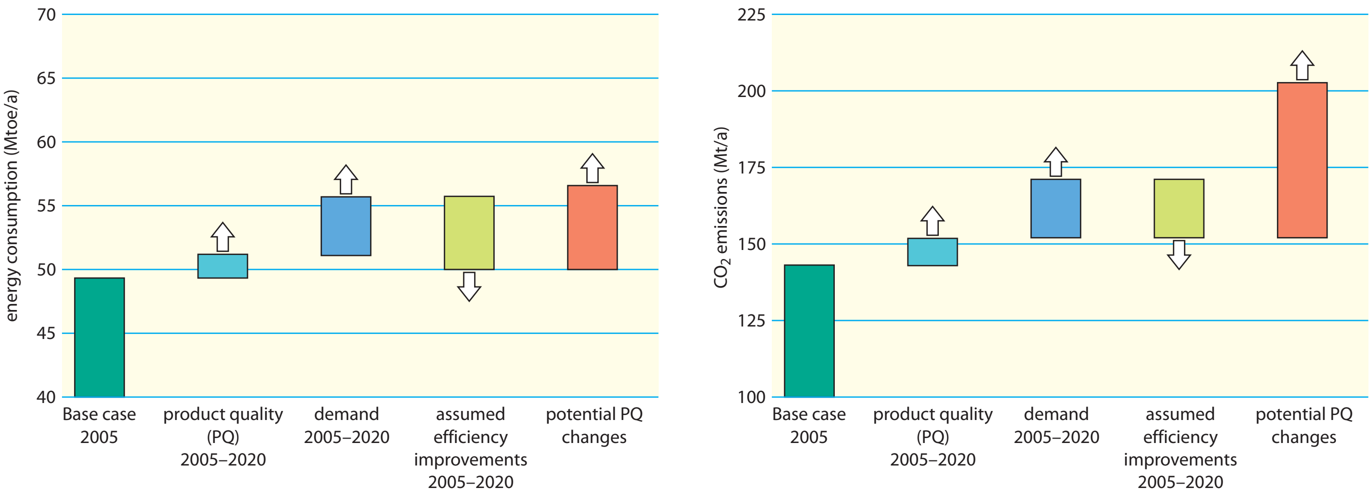
It should be noted that, although the difference between the 0.5% S residual and distillate marine fuels appears large, large-scale production of residual fuel of this quality is unlikely to occur as conversion of residues for the ever-expanding distillate market is bound to be much more profitable[3].

Faced with this reality on the one hand and with the increasing cost of carbon on the other hand, the EU refiners are considering their options to mitigate these trends.

Energy efficiency

Increasing energy efficiency i.e. using less energy to deliver the same service is undoubtedly a non-regret option, where economically justified, as it is the only one that offers both energy and GHG emission savings. This is not a new pursuit in an industry where fuel represents a considerable part of the operating costs. Between 1990 and 2005, EU refiners have increased the efficiency of their operations by an estimated 13%. This is partly the result of sustained focus on energy saving in every-day operation and of cost-effective investments, for instance in improved heat integration or energy efficient pumps and compressors. The 'low-hanging fruits' have long been picked and improvements in recent years have already involved complex and expensive schemes. As a matter of fact a significant part of the efficiency improve-

Figure 2 Impact of energy efficiency improvements on energy consumption and CO_2 emissions from EU refineries[2]



[1] *Includes EU-27 plus Norway and Switzerland.*

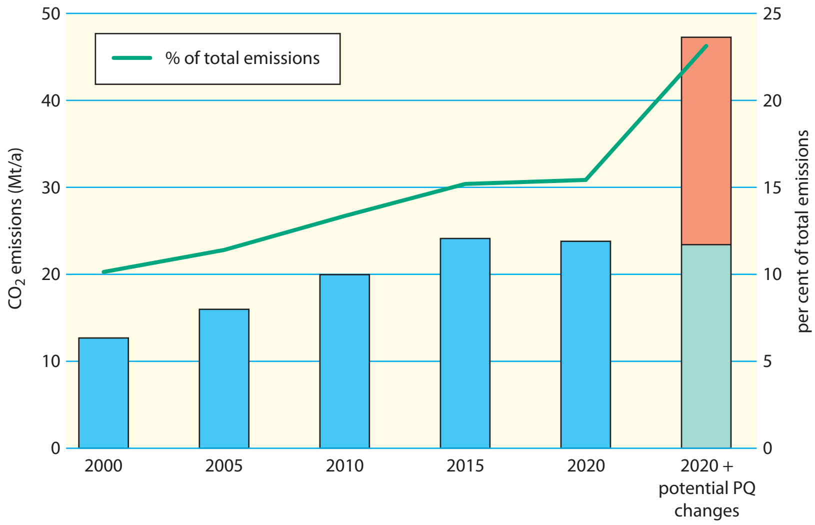
[2] *'Potential PQ changes' (Figures 2 and 4) represents the sum of the step-out cases shown in Figure 1 excluding 'Residual Marine Fuel 0.5% S'.*

[3] *See CONCAWE report 2/06,* Techno-economic analysis of the impact of the reduction of sulphur content of residual marine fuels in Europe.

CO_2 emissions from EU refineries

History, trends and mitigating options

Figure 3 'Chemical' CO_2 from hydrogen production in EU refineries



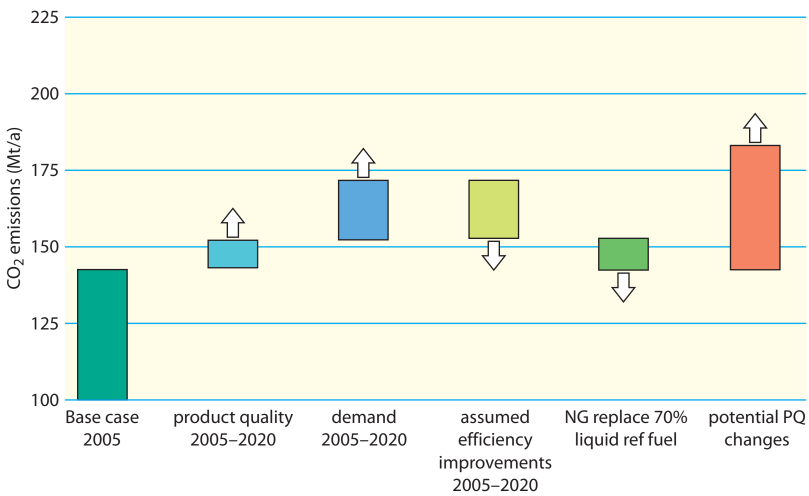
Above: hydrogen-related emissions are set to roughly double between 2000 and 2020 to reach 15% of total emissions.

ments has been achieved by installing highly efficient combined heat and power plants (CHP) in replacement of simple steam boilers and imported electricity. Further opportunities still exist but are increasingly difficult to achieve and less cost-effective.

Energy management is a site-specific issue and it is difficult to take an overall view of what might be achievable. Starting from the historical figure above we have assumed a general 0.5% improvement per year, with a 20% better energy performance for new plants compared to existing ones at any given time. It has to be emphasised that this is not a forecast based on hard technical data but rather a challenging scenario. Figure 2 illustrates the impact of such efficiency improvements in terms of energy consumption and CO_2 emissions.

The higher efficiency can, to a large extent, compensate for the increased energy requirement. The situation is less favourable for CO_2 emissions. This is due in part to small fuel pool changes, as future processing schemes tend to produce relatively less fuel gas, which is then compensated by additional liquid fuel, but mostly to additional emissions that are incurred when more 'chemical' CO_2 is produced. This is illustrated in Figure 3, which shows that hydrogen-related emissions are set to roughly double between 2000 and 2020 to reach 15% of total refinery emissions. The potential product quality-related legislation envisaged would be particularly hydrogen intensive and imply a large further increase.

Figure 4 Impact of liquid fuel substitution by natural gas on CO_2 emissions from EU refineries[2]



Fuel substitution

The majority of fuels burned in refineries are self-generated in the form of light gases (C1-C2) and, in refineries that operate a Fluid Catalytic Cracker (FCC), the coke that is formed on the circulating catalyst as part of the process. Mostly as a result of emission control legislation and specific local environmental pressure, a number of EU refineries have already replaced heavy fuel oil with imported natural gas (currently 5–10% of refinery energy). The balance (about 25% on average) has traditionally been provided by liquid fuel, mostly low value residues that the refineries are equipped to handle. Typically, refineries are very effective at efficiently burning low value fuels that would otherwise need to be upgraded or would displace other fuels on the market.

Replacing more liquid fuel by natural gas is of course a way to reduce direct CO_2 emissions from a refinery site. Figure 4 shows the additional impact of substituting 70% of the liquid fuel burned in our 2020 reference case with natural gas (100% substitution would not be realistically achievable as a number of refineries do not have access to a gas supply today and are unlikely to have it in the future).

The combination of challenging efficiency improvements and a switch to natural gas can only be expected to stabilise emissions, as long as no further product quality legislation is introduced.

The net effect of the substitution is to replace crude oil with natural gas. From the point of view of global CO_2 emissions, this only represents a true reduction if this effectively causes additional natural gas to be produced and used. In reality this may, at least partially, not be the case as the increased natural gas demand in Europe may cause users in other regions to switch to cheaper and more carbon-intensive fuels. Note that, in our modelling, we have assumed that the heavy fuel not used as refinery fuel would be converted (i.e. that the refinery output would remain constant). In reality this may not be the case in all refineries, particularly in the simplest that would seek to sell the extra fuel. It would then also displace other fuels in the market.

Using lighter crude oil

It is often suggested that processing lighter crude oil would be a way to reduce refinery emissions. It is undoubtedly correct that heavier crudes require more processing energy to achieve the same product yield pattern, because they contain more residual material that needs to be converted and also generally require more sulphur to be removed. Crudes are expected to become heavier worldwide, and the average crude diet in Europe is expected to follow this trend albeit at a fairly slow rate compared to other regions of the world. This is because a number of light crude producing provinces are within easy reach of Europe where, as a result of prolonged availability of North Sea crudes, a large number of refineries have been optimised for light crude processing.

In our modelling we recognise this reality but also use a heavy Middle East crude as incremental feed. In order to illustrate the impact of a lighter crude diet we have, in a sensitivity case, made the assumption that all heavy Middle East crude over and above what was in use in 2000 would be replaced by a light North Sea type crude (Brent). This represents a major shift of some 70 Mt/a (nearly 1.5 Mbbl/d) from heavy to light crude, which is roughly 10% of the total crude intake. The results are shown in Table 1.

The energy consumption of the refineries is reduced by 3% whereas the reduction of refinery CO_2 emissions reaches 6% for two reasons:

1. With a lighter crude, less conversion and less desulphurisation are required resulting in a lower requirement for hydrogen and a lower 'carbon loss', i.e. lower CO_2 emissions from decarbonisation of hydrocarbons.
2. The refinery fuel diet has a somewhat lower emission factor in the case of the lighter crude, with more fuel gas and less FCC coke.

Table 1 Impact of crude diet on CO_2 emissions from EU refineries

Case	2020		Difference	
	Reference	*Light marginal crude*		
Crude diet (mt/a)				
Total	715	711	-4	-0.6%
Light North Sea			70	
Heavy Middle East			-74	
% light crude	45%	55%	10%	
Average %S	1.12%	0.91%	-0.22%	
Fuel consumption (Mtoe)	50.0	48.6	-1.5	-3.0%
CO_2 emissions (Mt/a)				
Total from refineries	153	144	-9	-6.0%
'Chemical' CO_2 from hydrogen production	24	20	-3	-14.0%
Total inc. burning of fuel products	2149	2138	-11	-0.5%

CO_2 emissions from EU refineries

History, trends and mitigating options

When including the CO_2 emissions from burning the fuel products, the difference between the two cases increases somewhat from 9 to 11 Mt/a reflecting marginal differences in carbon/hydrogen content of the products. The overall 11 Mt/a reduction represents only 0.5% of the total emissions.

The above calculation considers only refining and does not make any assumptions with regard to the GHG footprint associated with production and transport of crude oil. There is no correlation between crude quality and extraction and/or transport energy, and the difference could go either way depending on the actual crude origins being considered.

These impacts may seem significant to some but there are other crucial points to consider:

- Whether Europe would be able to attract such a large additional amount of light crude can be a matter of conjecture but, in any case, crude oil consumption is largely a 'zero sum game' when considered worldwide. Should Europe be successful in securing more low sulphur crude, other world regions would have to process the heavier grades and emit correspondingly more CO_2. This would effectively cancel any benefit and potentially lead to marginally higher CO_2 emissions due to additional global transport of crudes.
- Over the years, refineries have become gradually more complex in order to be able to process increasingly heavier crudes, thereby transforming low value residues into high value distillates. With decreasing resources of light crudes, it is important that refineries worldwide invest in that sort of complexity. Processing light crude is in fact a kind of 'poor man's option' that can avoid investment in a more sophisticated facility. The savings in capital expenditure result in the need for more expensive crudes, thereby impacting on refinery profitability. Focusing on low sulphur crude processing capability would make refineries in the region less flexible, less able to take opportunities of cheap crudes, and more dependent on a declining and ever popular resource of light crudes.

Since crude oil composition is a given on a global basis, the major determinant of energy usage and CO_2 emissions in the global refining sector is the product pattern required in terms of both quality and quantity, which determines the required level of residue conversion, the type of conversion unit and the amount of post-treating of intermediate products.

Burning biomass in refineries

Production of heat and power, particularly when these can be combined (CHP), is the most effective way of using biomass from the point of view of GHG emissions avoidance. Refineries are indeed major users of both steam and power and offer good opportunities for CHP.

As mentioned above, only about 25% of refinery fuel on average is available for substitution, with fairly wide variations depending on the processing scheme. Biomass would be essentially solid fuel such as wood pellets or dried agricultural/forestry residues. This could realistically only be envisaged for steam boilers but not for process heaters. Reliability of energy supply is an essential safety feature and any such boiler would have to be fully backed up. Many refineries have recently installed high efficiency gas-fired combined cycle gas turbines; introducing biomass on a large scale would make such investment at least partially redundant. In addition refineries are not normally located near sources of large amounts of biomass (such as forests) and consequently fairly long distance transport would likely be involved.

Although some refineries with a particular set of favourable circumstances may find good justification for such biomass burning, it is unlikely to become a major feature in the refining sector as a whole. What biomass is available is likely to be more attractive as co-firing fuel in coal power stations or local CHP plants serving small industrial communities.

Carbon capture and storage (CCS): the Holy Grail?

CCS is a technology under development that is attracting a lot of attention as possibly the only acceptable way to continue to use fossil carbon resources in the next decades. Thus far development has focused on large single point emitters such as (coal fired) power stations where economies of scale can be realised. A number of demonstration projects are being considered with a view to developing full-size plants by 2020 at the earliest. The legislative framework still needs clarification, particularly with regard to long-term liabilities .

Although figures remain a matter of debate, CCS will inevitably be costly, not least because it requires additional energy (possibly as much as 30–40% compared to a conventional plant) for capturing, separating, possibly treating CO_2, then transporting it and safely storing it for the long term. Capture is significantly cheaper and less energy intensive when concentrated CO_2 streams are available. For this reason power generation involving oxy-combustion or gasification followed by hydrogen production are being contemplated for such applications. These schemes can produce highly concentrated CO_2 streams that are much easier to capture. Although there are trade-offs in terms of cost and energy consumption (e.g. to produce pure oxygen) many believe these schemes will result in an overall GHG reduction advantage. In refineries, only some 10–12% of CO_2 is currently emitted in concentrated form (from hydrogen production), and oxy-combustion is uncharted territory. In addition many refineries have multiple stacks making it difficult to gather all flue gases at a single point.

The other key success factor for a CCS project is the availability of a suitable geological storage structure within reasonable distance. In all cases, a CO_2 transport infrastructure will be required. Such infrastructures are only likely to develop around large emitters.

Some refineries may develop CCS projects based on a combination of local favourable circumstances. In the next 15 years this will be the exception rather than the rule. In the longer term, the viability of wider use of CCS in refineries remains to be demonstrated.

Conclusions

Effectively reducing refinery CO_2 emissions is a tough challenge. Energy consumption and CO_2 emissions in EU refineries are on an upward trend as a result of changes in demand and the need to meet ever more stringent product quality requirements. Mitigating measures such as efficiency improvements and refinery fuel substitution can at best be expected to stabilise emissions at/near their current level. Additional product quality legislation would put further upward pressure on emissions.

Although seemingly effective for individual refineries, replacing liquid refinery fuel with natural gas or processing lighter crude oils are unlikely to result in global emission reductions as they would largely result in reverse substitution elsewhere.

Although some refineries may find a justification for projects involving biomass burning, this is generally not well suited to a refinery environment. Likewise a few CCS projects may be developed in refineries in the next 5–15 years but large-scale use is unlikely before 2020 and beyond.

Cost-benefit analysis for air quality policies

An update and an IPPC Directive case study

An article published in CONCAWE *Review* Vol. 15, No. 2, described the methodology for assigning a monetary value to the effects of air pollution on human health. In the present article we briefly reintroduce some important concepts, discuss updates of actual monetary values based on recent scientific work and consider other aspects of cost-benefit analysis (CBA) methodology in general. We also discuss, as a case study, the CBA prepared for the EU Commission as the basis for the IPPC Directive revision.

The metric: VPF or VOLY?

The two metrics used to monetise impacts on human health are the Value of a Prevented Fatality (VPF, also called Value of a Statistical Life VSL) and the Value of One Life Year (VOLY). While the VPF concept is very useful in a context where we consider *observable* deaths (e.g. traffic accidents), the VOLY metric is much more appropriate when looking at chronic effects of air pollution, where we consider changes in *life expectancy*. In our opinion it is the only relevant metric for chronic mortality caused by air pollution (especially particulate matter, PM).

Mean or median?

In the context of European policy development the actual monetary value used for VOLY is obtained by using survey techniques. A representative value is derived from a range or distribution of survey responses. There are two possible options: using the mean (arithmetic average) or the median (the mid-point in the range of answers). As these response ranges (distributions) are not at all Gaussian, but highly skewed, the value of the mean is extremely sensitive to a few large outliers. We therefore agree with those experts who advocate the use of the median as a much more robust representative value for the VOLY.

There is another consideration when determining an appropriate VOLY for environmental policy decisions. The median is in effect a voting system where the answer of each individual participating in the survey is counted as a 'yes' or 'no' vote because it is either above or below a reference value (i.e. the median). Using the median, one could say that every 'vote' is given the same weight. By contrast, using the mean takes the strength of the vote into account: an individual A whose answer is higher than that of individual B carries more weight in the determination of the results. Choosing the median is thus closer in spirit to a typical yes/no vote in democratic elections and this approach would thus best reflect the average public's 'willingness to pay' for improvements in health standards. It is sometimes argued that the strength of a vote should be taken into account for issues which clearly involve a matter of degree, and that the mean should therefore be used. However, in our view this argumentation is not convincing in this context, where the influence of a few high outliers on the VOLY valuation is disproportionate.

An update of VOLY values

As discussed in the Autumn 2006 article, the CAFE[1] CBA uses results obtained from the NewExt study. NewExt uses survey results obtained in Italy, France and the UK. For VOLY the NewExt recommendations are k€ 188 for the mean value and k€ 52 for the median value. The latter is sometimes rounded down to k€ 50.

Following up on the work done under NewExt, a recent Integrated Project sponsored by DG Research called NEEDS[2] extended the survey work to eight European countries (France, Spain, United Kingdom, Denmark, Switzerland, Czech Republic, Hungary and Poland). These surveys are fundamentally based on VOLY and not on VPF and are *mean* rather than median values. A final paper (deliverable D6.7 RS 1b) published in September 2006 and available from the NEEDS project website

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[1] *Clean Air For Europe*

[2] *New Energy Externalities Developments for Sustainability*

(www.needs-project.org) gave a first set of recommended VOLY estimates. Another version of the final paper, dated February 2007 (not yet available from the NEEDS project website), is based on the same country surveys, but with the addition of Germany, so now covering a total of nine countries. This latest version also involves a recalculation of some of the results. The recommended figures are summarised in Table 1.

In their February 2007 version of the NEEDS report the authors opt for the mean, because in their opinion determining a VOLY for environmental policy is a matter of degree. However, we have a strong preference for using the median, because it does make the VOLY determination for environmental policy decision much more robust and also fairer. There is no clear rationale for giving more weight to some survey answers than others. This applies especially to the situation of individuals making a conscious decision to give a reply with value 'zero' (0), the so-named *non-protest zeros* which often form a significant group in this type of survey. Compared to individuals whose answer would be high, the non-protest zero individuals would receive the same weight in the 'median approach', but in the 'mean approach' they would be accorded much less weight.

At the very least, values from different sources should only be compared when they have been calculated on the same basis. Both NEEDS papers compare their mean-based VOLYs with the NewExt k€ 50 value which is based on medians. The correct comparison should be to the NewExt mean value which is estimated at k€ 118. The NEEDS VOLY estimates are therefore a factor 3.0 to 3.4 lower than the NewExt VOLY estimates. The equivalent NEEDS median-based VOLY would be about k€ 18, i.e. also a factor of 3 lower than the corresponding NewExt value.

Within each study the ratio between mean and median values seems to be the same. In both the NewExt and NEEDS studies, the mean value is a factor of about 2.2 higher than the median.

We therefore maintain our view that VOLY estimates should be based on *medians*. These can be calculated by dividing the mean values from Table 1 by a factor of 2.2.

Table 1 VOLY estimates (based on means) from the NEEDS project (k€)

Source	September 2006	February 2007 update
EU-16*	40	41
New Member Countries	25	33
Recommended for all EU-25 countries	35	40

* EU-15 + Switzerland

The latest results of the NEEDS project then lead to the following recommended VOLY estimates:

For EU16:	k€ 19
For New Member Countries	k€ 15
For EU25:	k€ 18

Some comments on cost-benefit analysis

Before discussing the IPPC Directive case study, two relevant points have to be made concerning the CBA methodology in general.

Marginal analysis

When performing a CBA, there has to be a reference situation against which one or more policy options can be considered. When these policy options are mutually exclusive it is correct to compare the outcome of each option to the reference case. When, however, the policy options are additive (or build on each other) one should look at the incremental costs and benefits of going from one option to the *next best* option. In this case, calculating all costs and benefits for the different options *relative to the reference case* produces only average values and masks the different cost levels that may occur when going from one option to the next.

Breakeven value

Normally in a CBA, all the relevant marginal costs and benefits are calculated for a range of options using the correct VOLY figure to evaluate the changes in life expectancy for each option. The optimal policy choice will then be around the point where marginal costs are approximately equal to marginal benefits.

Another way to analyse the cost-benefit of a particular policy option is to compare the recommended VOLY to

Cost-benefit analysis for air quality policies

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the ratio of the additional costs over the years of life lost (YOLL) associated with that option (Cost/YOLL ratio).

If the Cost/YOLL ratio is lower than the recommended values given above, then the option would be justifiable, but if the Cost/YOLL ratio is clearly higher than the recommended values it must be concluded that the proposed option cannot be justified by its effects on human health in terms of a life expectancy increase.

A case study: the proposal for a new IPPC Directive

On 21 December 2007 the EU Commission adopted a proposal for a new Integrated Pollution Prevention and Control Directive (IPPCD), covering the legislation that is concerned with the environmental permitting of most industrial and agricultural activities in Europe. The accompanying Impact Assessment (IA) contains a CBA of the newly proposed Directive. Although there are many aspects to the new IPPCD, in this article we will restrict the discussion to the CBA.

The IA presents two policy options for dealing with emissions of SO_2, NO_x and total PM, both based on applying the new IPPCD to Large Combustion Plants (LCPs). The first uses the ***upper*** value of the range in BAT Associated Emission Levels (BAT AELs) as mentioned in the BREF for Large Combustion Plants (LCP BREF) and the second (stricter) option is based on the ***lower*** value of that range.

A first issue is the choice of the two policy options. The first policy option should reflect the analysis that led to the development of the Thematic Strategy on Air Pollution (TSAP) as the outcome of the CAFE programme. The TSAP was adopted in September 2005 and it is the basis for the current revision of the National Emissions Ceiling Directive (NECD). It is a policy option which is *optimised* for cost-effectiveness over the whole of Europe. The TSAP delivers quantitative reductions for all relevant emissions while still ensuring *full compliance* with the current IPPCD everywhere in Europe. This scenario should therefore be the policy situation that we want to improve upon using a revised IPPCD and the TSAP should therefore serve as our first policy option in the IA. The second policy option can be considered as the strictest possible implementation of IPPC and is therefore akin to applying maximum emission reductions everywhere in Europe.

A second issue is that, in the IA, the costs and benefits for both options are calculated relative to the same reference case, an NECD Baseline based on the national energy projections. Because the two options are additive rather than mutually exclusive, the correct way of making this marginal analysis is to compare each option to the previous one in terms of stringency.

If we then repeat the CBA of the two IPPCD policy options, firstly using the TSAP, secondly the maximum emission reductions and applying a proper marginal analysis, we find two 'Cost/YOLL' ratios. For the step from the reference case to the first option (TSAP) we find a Cost/YOLL ratio of about k€ 50. Using the NewExt recommended median VOLY value (k€ 52) as was used for the CAFE programme, it can be concluded that the TSAP was indeed justifiable at the time (2005). However, using the updated NEEDS recommended VOLY value (k€ 18), we must conclude that the TSAP option is *no longer justified* by the benefits in life expectancy increase for the European population.

For the step from the first option (TSAP) to the second option (maximum reductions) we find a Cost/YOLL ratio of about k€ 100, clearly *much higher* than any of the recommended values mentioned above. We conclude that this step *cannot be justified* by the benefits in increased life expectancy for the European population.

Conclusions

Based on the latest scientific research, the VOLY estimate used in CBA of impacts of air pollution needs to be adjusted downwards from k€ 52 as used in the CAFE programme to k€ 18.

Using this information to check the CBA given in the Impact Assessment supporting the Commission proposal of a new IPPC Directive, it is very clear that the increased life expectancy benefits for the European population are insufficient to justify the high costs of a strict IPPC implementation (maximum reductions in emissions).

The Integrated Pollution Prevention and Control (IPPC) Directive

The justification for its proposed revision is further challenged by the findings of the Euro-Delta Project

In the Autumn of 2005, during the preparatory work by DG Environment to revise the current Integrated Pollution Prevention and Control (IPPC) Directive, CONCAWE published the results of a small but important study examining the consequences of a departure from the concept of a 'local BAT' approach to a common Europe-wide concept of BAT[1]. The concept of 'local BAT' (i.e. a BAT that accounts for the specifics of a given plant and its impact on human health/the environment) is an integral part of the existing IPPC Directive and is at the heart of the optimised cost-effective design of the Commission's Thematic Strategy on Air Pollution (TSAP). A significant finding of the study was that, for the same environmental goal in the EU as a whole, the overall cost of meeting the TSAP ambition for reduced exposure to fine particulates would double as a result of a move away from the local BAT concept to a rigid, common EU-wide BAT. The study also highlighted the fact that for some individual Member States, the cost burden could increase sevenfold or more.

At the end of 2007, the European Commission adopted their proposed revision of the current IPPC Directive[2]. Formally, the proposal as adopted is a 'Recast' Directive which seeks to consolidate some seven Directives[3] into a single IPPC Directive. Disappointingly though, one key structural change in this proposal is that, in essence, the concept of 'local BAT' has been abandoned in favour of a common Europe-wide BAT. While the repercussions of this departure from local BAT have already been exposed in an earlier CONCAWE study, in this article, we explore the implications of a more extensive study, called Euro-Delta, on the justification for some other key elements of this 'Recast' proposal.

The Euro-Delta project (ED Phase I) was initially designed as a comparative exercise between five European Transboundary air pollution models/modelling teams i.e. exploring the variation in results from the different models for the same emission scenarios and their implication for robust policy design. Included in the five models was the European Monitoring and Evaluation Programme (EMEP) model which, up to the present time, has been the sole model used to support policy development at both the EU and wider UNECE level. The more recent availability of similar 'Eulerian Models' in France (the CHIMERE model), Germany (the REM-3 model), The Netherlands (the LOTOS model) and Sweden (the MATCH model) justified and enabled such a project. The Commission's Joint Research Centre (JRC) acted as co-ordinator of this project as well as a clearing house for all modelling results.

The second phase of the project (ED Phase II) focused on a larger number of emission reduction scenarios. The majority of these were 'terrestrial' scenarios, designed to explore sector-specific emission reductions. The aim here was to determine whether the same unit emission reduction in different sectors gives significantly different impacts on human health and the environment. This is an important policy question, since the main tool used to develop air-related legislation is Integrated Assessment Modelling (IAM)[4]. Currently these models do not differentiate between the impacts of emission

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[1] *'EU-wide BAT—an expensive suit that doesn't fit everybody!' CONCAWE* Review, *Volume 14, Number 2, Autumn 2005.*

[2] *Com(2007) 844 final, December 21, 2007.*

[3] *Three TiO_2 Directives: 78/176/EEC; 82/883/EEC; 92/112/EEC; the original IPPC Directive 96/61/EEC; The VOC Solvents Directive 1999/13/EC; The Waste Incineration Directive 2000/76/EC and the Large Combustion Plant Directive 2001/80/EC.*

[4] *The IIASA RAINS and now GAINS Integrated Assessment Models have been extensively used to inform the development of the UNECE Gothenburg Protocol, the current EU National Emission Ceilings Directive (NECD), the EU Thematic Strategy on Air Pollution and the current work associated with the revision of the NECD.*

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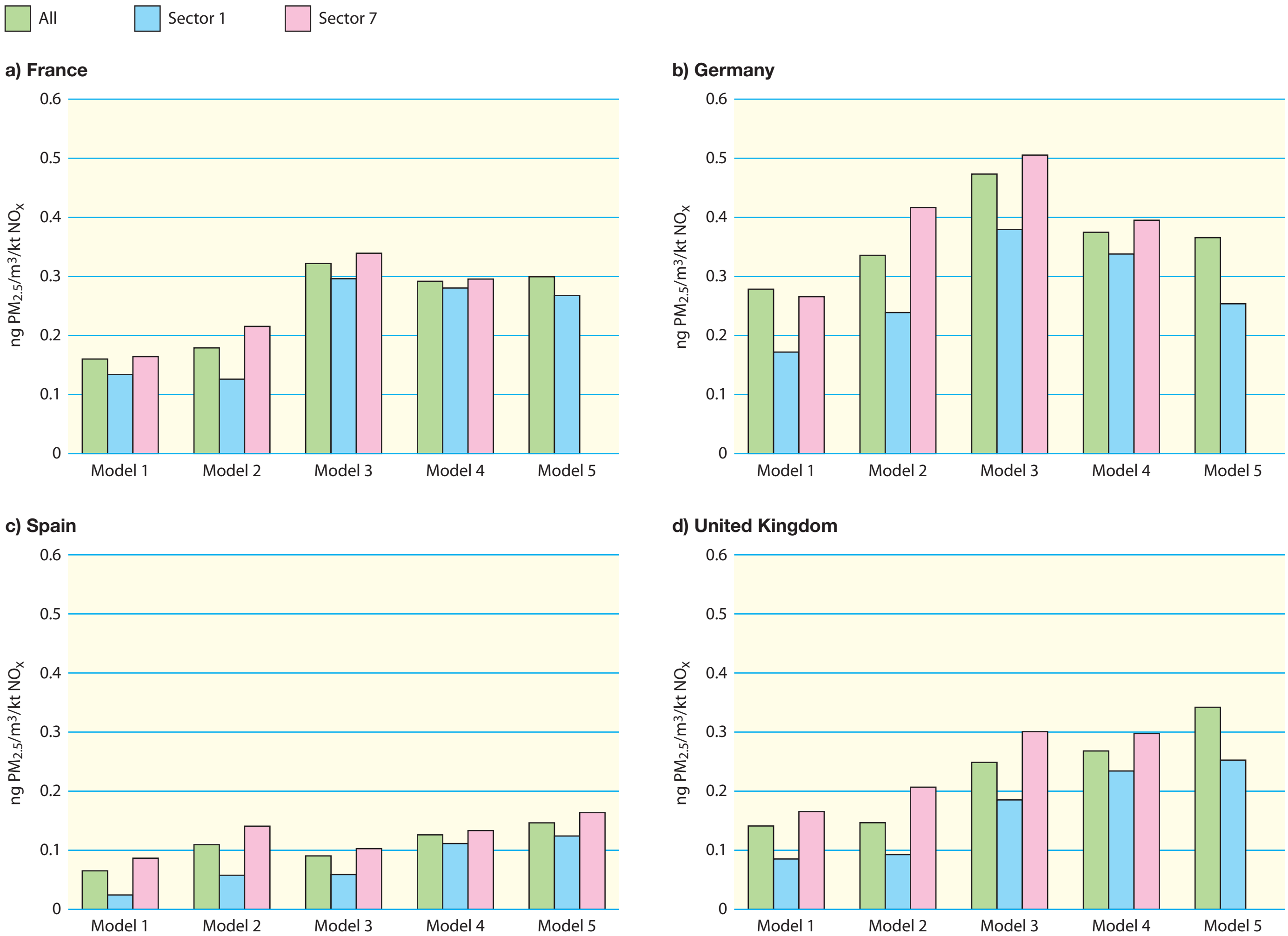
Figure 1 Impacts of NO_x emission changes in France, Germany, Spain and UK on population weighted $PM_{2.5}$ concentrations over EU-25



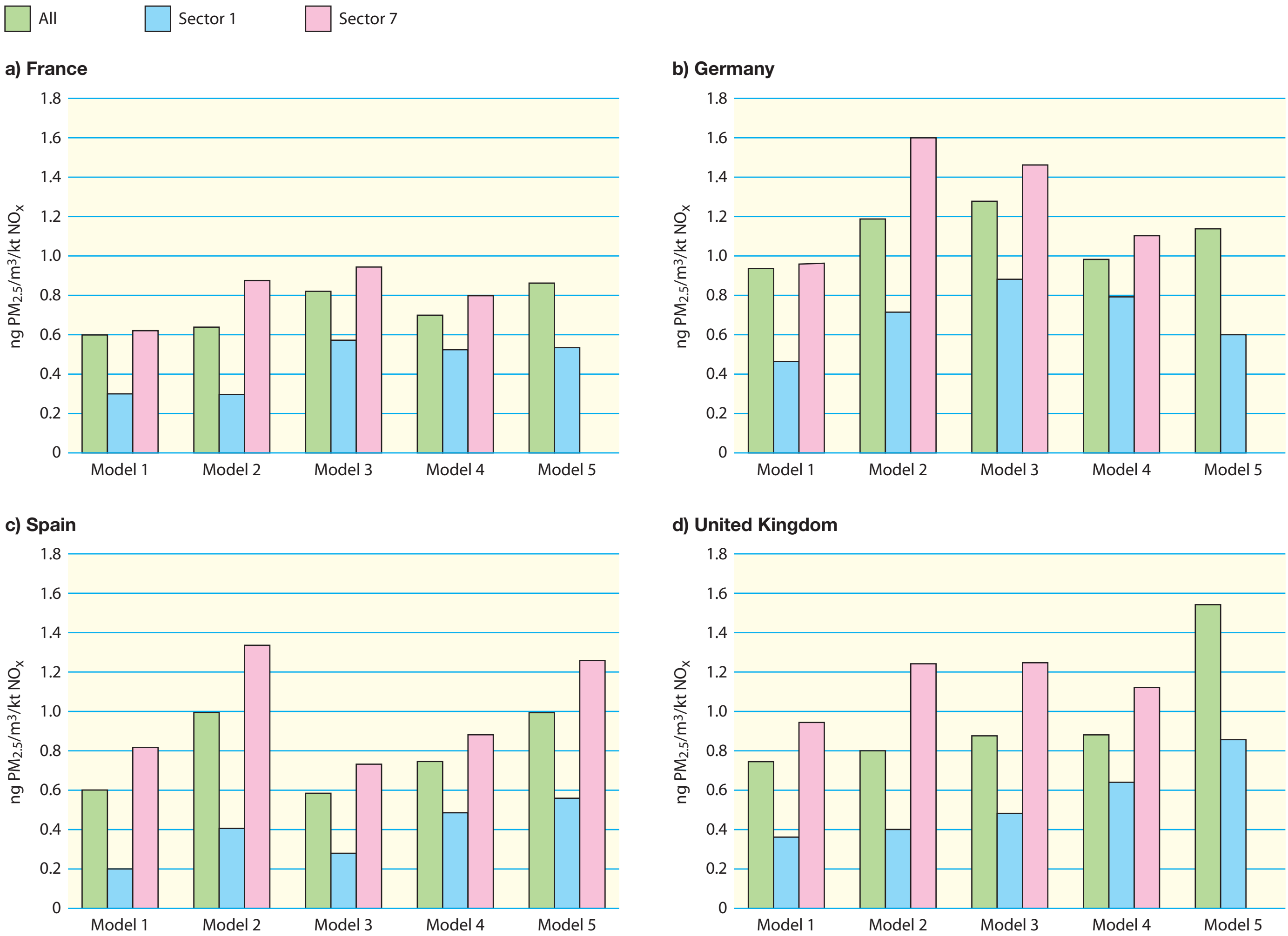
changes from different sectors in their so-called source-receptor functions[5]. These are derived from simultaneously applying the same percentage emission reduction to all sectors in a given country.

Some 50 emission reduction scenarios were run by each of the five modelling teams. These scenarios focused on France, Germany, Spain and the UK. For each of these countries, separate scenarios were run simulating reduced emissions in a single sector (e.g. the power generation sector), and in all sectors by the same percentage. To ensure that reductions remained within the 'policy range' they were confined to 90% of that achievable by Maximum Technical Feasible Reductions (MTFR).

In order to make it possible to compare the results of different scenarios with each other on a common basis, the change in impacts (measured from a common 'Base Case') were expressed 'per unit of emission change'. This metric expresses an 'emission potency' i.e. the change in impact for a unit change in emissions.

[5] *Source-receptor functions are derived from multiple runs of a regional trans-boundary air pollution model (in the case of RAINS/GAINS, the EMEP model) the results of which are regressed into linear relationships which relate an emission change in a country to the change in impact at each receptor (i.e. a 50x50 km EMEP grid).*

Figure 2 Impacts of NO_x emission changes in France, Germany, Spain and UK on population weighted $PM_{2.5}$ concentrations within each country



Secondary PM impacts

As noted above, human exposure to fine particulates continues to be a priority concern in the development of air quality-related regulation in the EU. This was clearly reflected in the EU Clean Air For Europe (CAFE) programme and the resulting EU Commission's TSAP. Therefore the results presented in this article focus on this concern.

For each of the five models, Figures 1 and 2 show the change in $PM_{2.5}$ health impact indicator (expressed here as change in population-weighted $PM_{2.5}$ concentration per kilotonne of NO_x emission reduction) for three reduction scenarios:

1. A fixed percentage emission reduction across all NO_x emitting sectors in each country (as represented currently in RAINS/GAINS): the 'All' case.
2. A NO_x emission reduction in 'Sector 1' (combustion in energy industries, e.g. power generation plants): the 'Sector 1' case.
3. A NO_x emission reduction in 'Sector 7' (road transport): the 'Sector 7' case.

Figure 1 shows the population-weighted impact for EU-25 as a whole, Figure 2 the population-weighted impact for the country in which the emission reduction takes place.

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What is clear from both series of charts is that a unit reduction in NO_x emissions in Sector 1 (large point sources in the energy industry) gives a significantly smaller reduction in population weighted $PM_{2.5}$ exposure than Sector 7 (road transport) or the fixed percentage reduction across all sectors simultaneously. In the case of Spain and the UK, this difference in 'emission potency' is more than twofold. In the case of 'change in impacts in the countries where the emission change is made', the difference in potency is between two and fourfold. Importantly, these significant differences in potency are reflected in the results from all five models.

Given that population exposure is a function of proximity to source, the fact that large point sources have significantly lower potencies than road transport is not, in principle, surprising. What is perhaps unexpected is the magnitude of the differences, at least in some countries.

Similar results were also found in emissions reduction scenarios for both primary $PM_{2.5}$ and, to a lesser extent, SO_2. This has potentially significant implications for the current generation of Integrated Assessment Models if they are to be made fit for purpose as input into the design of sectorally specific policies such as the revision of the IPPC Directive.

Implications for the 'justification' of the IPPC Directive

In a companion article in this *Review*[6], the justification of the European Commission's proposed revision of the IPPC Directive is called into question in the light of updated scientific data on the monetary valuation of health impacts (VOLY values) and with regard to methodological issues in the marginal benefit analysis that was undertaken as part of the Commission's associated impact assessment. The analysis underpinning this article is based on the source-receptor functions currently used in the EU Commission's RAINS/GAINS models. As discussed above, these are derived from EMEP modelling runs which, for a given country, simulate emission reductions across all sectors by the same percentage. This is equivalent to the 'All' scenarios in Figures 1 and 2. In the case of Sector 1 (covering a significant proportion of the large combustion plants), the health impacts benefit for reductions in emissions (and other similar large point source sectors) will be overstated, and in the case of France and Spain, significantly overstated by RAINS/GAINS.

By adjusting the potencies of emissions from sectors associated with large point sources (in line with the findings of Euro-Delta discussed above), it has been possible to make a first assessment of the implications of the lower potency on the 'justification' of the IPPC proposal using CONCAWE's in-house IAM[7]. Even when the adjustments are confined to the four countries examined in Euro-Delta (France, Germany, Spain and the UK) the implied Cost/YOLL ratio measured from the TSAP optimised case increases from about k€ 100, as mentioned in the companion article, to some k€ 150; this needs to be seen in the light of the latest recommended VOLY of k€ 18.

At an individual Member State level, the situation is even more dramatic: in Spain the Cost/YOLL ratio based on the non-sector specific potencies is about k€ 165. This rises to about k€ 500 when the lower potency for large point sources is accounted for.

These findings highlight the need for further development of the current IAM tools if they are to continue to be 'fit for purpose' in supporting sectorally differentiated policies. They also raise serious questions on the justification of the Commission's proposed revision of the IPPC Directive as set out in the associated Impact Assessment. In recent years, the Commission has committed itself to basing new environmental legislation upon sound science supported by thorough technical analysis and impact assessment. It is essential that these principles are adhered to in the review of the IPPC Directive, a piece of legislation which has a major impact on the industries concerned.

[6] *'Cost-benefit analysis for air quality policies: an update and an IPPC Directive case study'—**see page 10.*

[7] *CONCAWE's in-house IAM utilises the same source-receptor functions, emissions and cost databases as the IIASA RAINS/GAINS model.*

Advanced combustion engines for low emissions and high efficiency

CONCAWE literature review on HCCI combustion technologies

European road traffic has increased dramatically over the past several decades and the same growth is now being seen in many other parts of the world. This increased demand has brought new challenges for the vehicle and fuel industries, especially the need to lower exhaust emissions from vehicles while improving fuel economy. Fortunately, improvements in engine and aftertreatment technologies are dramatically reducing emissions and cleaner fuels are enabling their performance.

While vehicle emissions continue to fall, attention is increasingly focused on vehicle efficiency and fuel consumption in order to address new concerns over future energy supplies and greenhouse gas (GHG) emissions. Among the technologies able to deliver significant improvements, alternative power plants, such as fuel cells, still face many research and development challenges and most projections show them making relatively little impact on the vehicle market before at least 2030. Hybrid electric vehicles, including plug-in hybrids, seem more likely to contribute although cost and performance relative to more conventional options may limit their penetration. For this reason, internal combustion engines (ICEs) are expected to continue to provide almost all of the engine needs for road vehicles in the near future.

Light-duty vehicles, powered by advanced ICEs, are evolving rapidly to respond to these new challenges. In the search for lower emissions, improved performance, and better fuel consumption, research and development is concentrating on new and advanced combustion concepts. Because these concepts combine the best features of both spark-ignition and compression-ignition engines, the optimum fuel characteristics could be quite different from those needed by today's conventional gasoline and diesel engines.

CONCAWE's literature review

In order to better understand the state of development of these new concepts and the potential implications for future fuels, CONCAWE recently completed a review of the rapidly expanding body of technical literature[1]. This review focused on two advanced combustion schemes generically known as Homogeneous Charge Compression Ignition (HCCI) for diesel engines and Controlled Auto-Ignition (CAI) for gasoline engines. Highlights from this literature review are reported here and address three important questions:

- What is HCCI/CAI?
- What engine improvements will enable HCCI/CAI performance?
- What fuel properties will influence HCCI/CAI performance?

The HCCI/CAI concept

Broadly speaking, HCCI and CAI describe advanced combustion concepts in which the fuel and air are premixed, either outside the engine cylinder or by early injection of fuel into the cylinder. After injection, the fuel-air mixture is compressed to the point where ignition occurs without the aid of a spark or glow plug. Combustion takes place at relatively low temperatures with a rapid and complete heat release. Higher levels of cooled exhaust gas recirculation (EGR) are often used to lower the combustion temperature even further and reduce the oxygen content of the combustion air. This approach helps to simultaneously reduce the formation of soot and nitrogen oxides (NO_x) from the combustion process, breaking the so-called NO_x/PM trade-off that is typical of conventional diesel engines (Figure 1).

The search for practical systems has inevitably led to many new acronyms describing different variations of engine hardware and fuel injection strategies, some of

[1] *CONCAWE Report 4/08:* Advanced Combustion for Low Emissions and High Efficiency: a Literature Review of HCCI Combustion Concepts.

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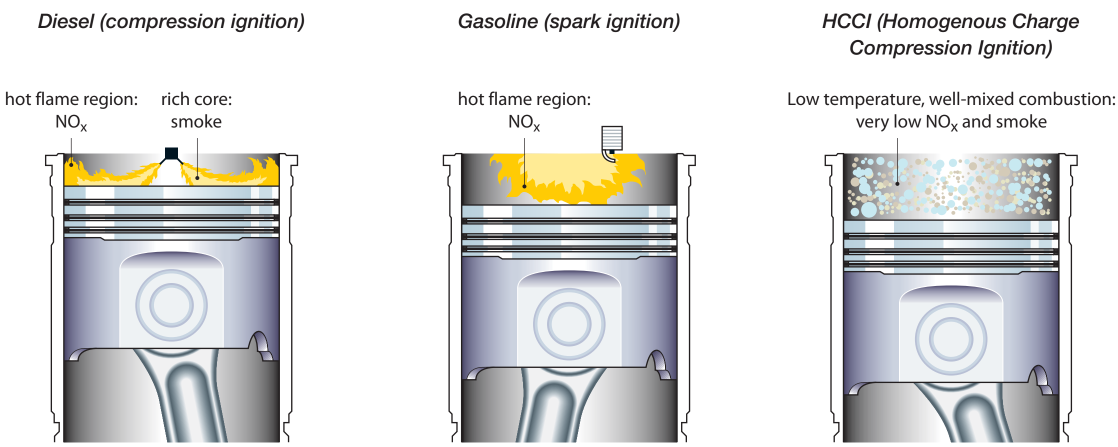
Figure 1 HCCI combustion is a cross between compression-ignition and spark-ignition approaches



Some examples of advanced combustion concepts

ACCP	Advanced Common Rail Combustion Process
CAI	Controlled Auto-Ignition
HPCC	Highly Premixed Cool Combustion
HCCI	Homogeneous Charge Compression Ignition
HCLI	Homogeneous Charge Late Injection
HPLI	Highly Premixed Late Injection
NADI™	Narrow Angle Direct Injection
PCCI	Premixed Charge Compression Ignition
pHCCI	Partial HCCI

which are shown in the box above. To simplify this discussion, the term 'HCCI' is used in this review to describe all of these advanced combustion concepts that seek to provide:

- low engine-out emissions (CO, HC, NO_x, PM etc);
- low fuel consumption (comparable to, or better than, today's compression-ignition engines); and
- stable engine operation over a wide load range.

The engine challenge

'True' HCCI combustion involves injecting fuel into the combustion chamber very early in the engine cycle so that there is sufficient time to achieve thorough fuel-air mixing. Although this achieves good dispersion of the fuel in air, it also makes it more difficult to control the ignition process. Most researchers now favour injecting fuel later in the engine cycle in order to retain most of the benefits of HCCI combustion while achieving better control of the auto-ignition process.

HCCI combustion can be achieved most easily at lower engine loads and becomes increasingly difficult as the engine power increases. For this reason, early production engines are expected to be 'part-time' HCCI engines, reverting to conventional diesel or gasoline operation at higher load conditions. As long as this is the norm, these engines will need fuels similar to today's and will cope with the fuel's properties as best they can under part-time HCCI conditions.

Based on the technical literature, good performance has been demonstrated under test bench conditions, and under steady state speeds and loads. Extending this performance to transient conditions remains a significant challenge and engine designers face a number of hurdles to develop robust engines. Here are a few examples:

- In conventional engines, the start of combustion is controlled by the spark plug in spark-ignition engines or by fuel injection in compression-ignition engines. In HCCI combustion, however, these control mechanisms are not available. In fact, the temperature and pressure at the desired ignition timing determine the start of combustion and these are governed by conditions that are defined well before the combustion process actually begins. For example, the temperature of the intake air mixture, the composition of the fuel-air mixture, the compression ratio, and other factors determine when combustion starts and how rapidly it progresses. Controlling the combustion process is therefore challenging, particularly for engines where operating conditions can vary quite rapidly on a second-by-second basis.

- In order to achieve the benefits described earlier, HCCI combustion must retain good thermal efficiency through rapid and complete combustion. If not properly controlled, however, combustion can be too rapid, producing, in the worst case, explosive heat release within the cylinder. This not only produces very high engine noise levels but can also lead to engine damage, especially at high engine loads.
- Like diesel engines, HCCI engines are throttle-less and engine power is varied by increasing or decreasing the amount of fuel injected. Complete combustion can be difficult to achieve, especially at the very lean air-fuel ratios or high EGR levels needed for light load operation. While HCCI combustion can produce very low levels of soot and NO_x at these conditions, significant increases in HC and CO emissions can occur at the same time and oxidation catalysts will probably be needed to reduce these to acceptable levels.

Because of these problems, an engine that uses HCCI combustion throughout the entire load range seems to be some way down the road. In the near term we are more likely to see engines that use HCCI at lower loads and then revert to conventional operation at higher loads.

Diesel or gasoline engine?

Since HCCI combustion shares characteristics of diesel and gasoline combustion, practical advanced combustion designs begin from either a compression-ignition or a spark-ignition engine platform.

Starting from a diesel engine, HCCI helps to reduce engine-out PM and NO_x emissions, especially under light and intermediate load conditions. Even if this does not completely eliminate the need for PM filters and NO_x traps, the cost and complexity of these aftertreatment devices could be reduced if the engine-out emissions are low enough over a large enough portion of the driving cycle. The diesel engine also provides a good platform for advanced engine developments because of its robust construction and use of high pressure fuel injection which aids fuel dispersion.

Starting from a gasoline engine platform where exhaust emissions are already very low, HCCI is expected to improve fuel consumption. Reductions in fuel consumption have been demonstrated at low loads but the effects are reduced over driving cycles that emphasise higher speeds and loads, such as the New European Driving Cycle (NEDC). Gasoline HCCI must also compete with other less expensive developments in conventional gasoline engines, such as engine downsizing, that offer similar improvements. For gasoline CAI to win over these alternatives, the relative cost of engine hardware and improvements in fuel consumption could be the determining factors.

If HCCI operation can only be used at part load conditions, the benefits will be limited to the load conditions where it can be effectively and routinely used. There is also a risk that, whilst advanced combustion vehicles may be able to meet emissions limits over the regulated cycles, this may be at the price of higher emissions outside the cycle limits or during transient operation.

On the other hand, part-time HCCI offers a way for advanced technology to be introduced progressively into otherwise conventional gasoline and diesel engines. Investments in some hardware improvements seem likely to enhance even conventional engine performance in the shorter term and enable HCCI operation in the longer term. This provides a path for gradual expansion of the speed and load range for HCCI combustion as engineering experience and innovation develop.

At the current stage of development, diesel engines seem more likely than gasoline engines to provide a basis for full-time HCCI since they provide high fuel injection pressures, large amounts of EGR, and high turbocharger boost that are not readily available on gasoline engines.

Advanced combustion engines for low emissions and high efficiency

CONCAWE literature review on HCCI combustion technologies

Much more work is needed, however, to turn current research results into practical engines that can use HCCI combustion throughout the operating range. Increasing the maximum power for HCCI remains a significant challenge and cycle-by-cycle engine control systems using combustion pressure sensors (called Closed Loop Combustion Control) will be needed in order to help the engine management system respond to rapidly changing conditions.

While engines having some of these capabilities are likely to be introduced over the next few years, a practical and robust full-time HCCI engine remains a long-term objective and seems unlikely to be commercialized within the next decade. Continuous improvements in conventional engine technology could also surpass the performance and cost benefits of full-time HCCI engines in the meantime.

The influence of fuel properties

HCCI engines rely on the right fuel-air mixture conditions to start and sustain combustion. Without an ignition source, the engine must be closely matched to the characteristics of the injected fuel and respond quickly to changing speed and load conditions. On the test bench, HCCI operation has been achieved with a wide range of fuels but the preferred fuel for advanced combustion is still an open question. Some researchers suggest that completely new fuels or even dual-fuelling will be needed to successfully achieve HCCI operation. Whether these are practical options depends on whether HCCI operation can be sustained up to full load conditions. If an HCCI engine must revert to conventional diesel or gasoline operation at high loads, then the fuels will also need to retain the essential characteristics of diesel or gasoline.

Previous studies have suggested that three fuel properties are especially important to promote HCCI combustion:

- longer ignition delays—to lengthen the time available to achieve fuel-air mixing after fuel injection;
- higher volatility—to reduce the time needed to achieve fuel-air mixing before auto-ignition occurs; and
- fuel composition—to promote combustion and reduce engine-out emissions.

The importance of the fuel's ignition delay depends on the starting point for the combustion concept. Since gasoline engines are designed to avoid uncontrolled auto-ignition, measures are needed to encourage gasoline-like fuels to auto-ignite under controlled conditions through, for example, higher intake air temperatures, higher compression ratios, or lower octane fuels. If the starting point is a diesel engine, the problem is reversed and ways must be found to slow down the auto-ignition process. Practical measures to achieve this include lower compression ratios, lower intake air temperatures, higher EGR, or lower cetane levels compared to today's fuels.

Many HCCI studies have studied fuels in the gasoline-diesel boiling range. Ignition quality has played a prominent role in most of these studies since it is a key factor in controlling the degree of mixing before combustion starts. Although HCCI performance has been demonstrated with a wide range of fuels, it seems clear that the current European diesel and gasoline grades are not the ideal choice for full-time HCCI. High cetane number diesel fuels have ignition delays that are too short while high octane number gasolines are too resistant to auto-ignition.

Lower cetane numbers then make it easier to achieve HCCI combustion and some researchers suggest that cetane numbers should be in the 40–45 range. Others propose more radical changes, for example, using gasolines having cetane numbers below 35. HCCI engines could potentially utilise gasoline components that are already in the marketplace but only if HCCI combustion could be sustained throughout the whole load range or the engine reverted to spark-ignition at higher loads.

The second fuel property influencing mixture formation is fuel volatility. If the objective is to create a more homogeneous fuel-air mixture in a diesel engine, then fuels with a higher volatility are expected to promote rapid evaporation and mixing. For this reason, the successful performance of gasoline fuels in HCCI engines is not very surprising.

The evidence is mixed, however, on the importance of fuel volatility compared to ignition delay. High pressure fuel injection systems already achieve good dispersion of diesel fuels and can deliver a high degree of mixing if the ignition delay is long enough. In fact, a completely homogeneous mixture is now seen as rather undesirable because it gives no effective means to control the timing of the combustion event. For this reason, research is increasingly focused on intentionally introducing some degree of fuel-air inhomogeneity. Higher volatility should improve mixture formation but ignition quality seems to be much more important.

The third fuel property is molecular composition, especially the fuel's aromatics content. HCCI combustion has now been demonstrated on a wide range of fuel compositions and there seems to be little evidence that molecular composition is an important factor in sustaining combustion, except through its impact on ignition delay.

The literature contains many studies of HCCI combustion using alternative fuels such as ethanol, DME or natural gas. When used as neat fuels, none of these alternatives seem to offer significant advantages compared with fuels in the gasoline/diesel range. Natural gas is difficult to ignite while ethanol shows advantages in some areas and problems in others. Radical fuel changes can only be considered if full-time HCCI is feasible.

With the trend toward greater use of biofuels, a more meaningful question is whether the presence of biodiesel or ethanol in a fuel blend is likely to cause any additional problems for HCCI combustion. Current evidence suggests that low-level biofuel blends present no new problems, but more work will be needed in this area as the engine technology moves toward commercialization.

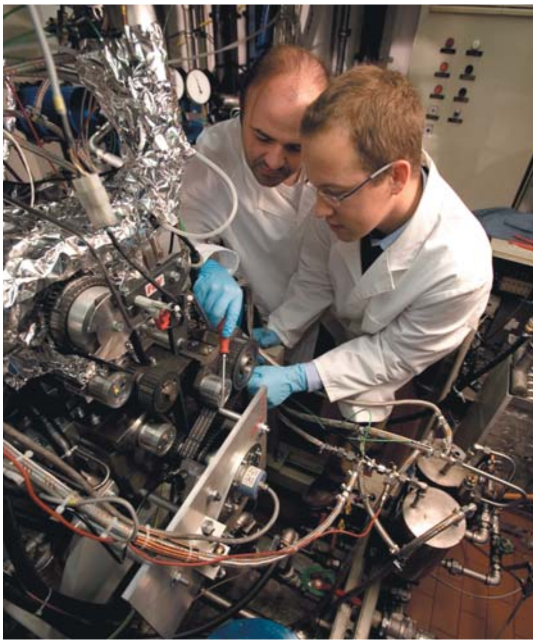
Based on our literature review, significant progress has clearly been made in the development of advanced combustion engines but much more work is needed before full-time HCCI becomes a commercial reality. At the same time, more work is also needed to determine the influence of fuel properties on advanced combustion performance.

CONCAWE's HCCI test programme

Although HCCI is a promising new technology, it is not yet possible to predict precisely how it will develop. For this reason, CONCAWE has completed an HCCI engine test programme together with FEV Motorentechnik in Aachen, Germany.

In this programme, a single-cylinder diesel engine (see photograph), benchmarked for Euro 6 emissions, has been used to investigate what HCCI performance can be achieved by different engine hardware configurations and by changes in fuel properties. The basic engine hardware was enhanced through stepwise changes that included a lower compression ratio, higher maximum cylinder peak pressure and rail pressure, enhanced swirl inside the combustion chamber, adjustment of fuel injection timing and intensified EGR. After this work was completed, a broad range of fuels was evaluated on an optimized engine configuration to study the influence of ignition delay, volatility, and molecular composition on engine-out emissions, performance and noise.

This programme is providing further insights on the relative importance of engine hardware and fuel properties for HCCI combustion performance. The results of this research will be reported in an upcoming CONCAWE *Review*.



CONCAWE is investigating the influence of engine hardware and fuel properties on advanced combustion at FEV's facilities in Germany.

Mandatory collaboration of all registrants under REACH

CONCAWE has established early contacts with potential SIEF members

Introduction

Under the new REACH Regulation[1] all chemical substances will have to be registered with the European Chemical Agency (ECHA). This includes petroleum substances that are manufactured in, or imported into, the European Economic Area (EEA), either as such or in preparations or—depending on certain criteria—in articles. Registration is an obligation for each individual legal entity that manufactures or imports a substance.

In addition, the REACH legislation foresees mandatory collaboration between all registrants, both during the preparation of registration dossiers and during registration itself. There are two objectives behind this requirement for collaboration:

1. To reduce the need for animal testing by mandatory sharing of animal test data; and
2. To harmonise substance information and consequently the hazard classification and labelling of chemical substances.

Collaboration between registrants requires information and communication:

- Registrants need to know who the other registrants of the same substance are; and
- There has to be an effective system of communication between the registrants of the same substance.

The ECHA plans to set up a REACH IT system that will allow pre-registrants to establish contact with each other before the deadline for pre-registration (see timeline in Box 1). However, such contacts would be voluntary. Definitive information about all pre-registrants will only be available when the ECHA informs all co-registrants on 1 January 2009 of the identity of, and contact names in, all other legal entities that had pre-registered the same substance. Through their pre-registration, the legal entities will have automatically become members of a so-called Substance Information Exchange Forum (SIEF).

REACH does not foresee any legal structure, communication system or leadership for the SIEFs. On 1 January 2009, the SIEF will just be a set of legal entities with the same level of knowledge of who the other registrants are and whether a legal entity had indicated in its pre-registration submission that it volunteers as a SIEF Facilitator (see Box 1). It is obvious that the voluntary early contacts between co-registrants through the ECHA REACH IT system ('pre-SIEF formation') will facilitate the process.

In line with the first of the two objectives of collaboration among SIEF participants, REACH allows parties that hold relevant substance information, but that have no

Box 1: Timelines for pre-registration and the SIEF process

- 1 June 2008: Pre-registration starts; voluntary pre-SIEF formation possible
- 1 December 2008: Pre-registration ends
- 1 January 2009: ECHA informs pre-registrants of:
  - Identity and contact details of all other pre-registrants of the substance
  - Identity and contact details of data holders who are not pre-registrants

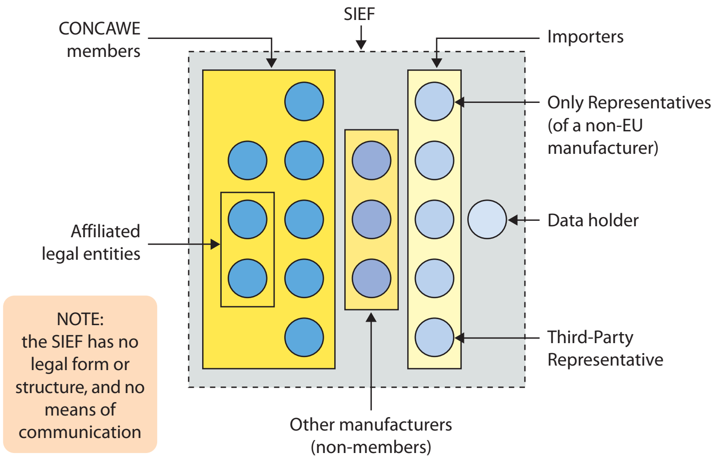
  NOTE: No further involvement of ECHA in the process!
- 30 November 2010: Registration period ends for phase-in substances ≥ 1,000 t/a, for CMRs cat 1/2, substances harmful to the environment

[1] *Corrigendum to Regulation (EC) No 1907/2006 of the European Parliament and of the Council of 18 December 2006 concerning the Registration, Evaluation, Authorisation and Restriction of Chemicals (REACH), establishing a European Chemicals Agency, amending Directive 1999/45/EC and repealing Council Regulation (EEC) No 793/93 and Commission Regulation (EC) No 1488/94 as well as Council Directive 76/769/EEC and Commission Directives 91/155/EEC, 93/67/EEC, 93/105/EC and 2000/21/EC (OJ L 396, 30.12.2006), OJ L136, volume 50, 29 May 2007.*

Mandatory collaboration of all registrants under REACH

CONCAWE has established early contacts with potential SIEF members

Figure 1 Composition of a typical Substance Information Exchange Forum



Box 2: Actors in the pre-registration process

• Manufacturers:	as future registrants
• Importers:	as future registrants
• Data holders:	can offer data to future registrants
• Only Representative:	as future registrant; represents a non-EU manufacturer
• Third-Party Representative:	represents and acts on behalf of a future registrant

Option also available to CONCAWE for its members

Option also available to CONCAWE members

obligation to register the substance, to join SIEFs as data holders. Such data holders could be downstream users, trade associations, universities, governmental or independent research organisations or non-governmental organisations (NGOs). The rights of data holders in the SIEF are limited to selling access rights to the substance information they hold. Nevertheless, they add an extra dimension to the complexity of collaboration within SIEFs (see Figure 1 and Box 2).

In addition to the legal obligation to collaborate among SIEF participants (see Box 3), REACH provides the option for registrants to collaborate beyond the legally required scope. CONCAWE's preparation for the registration of petroleum substances under REACH aims to maximise the amount of information that members will be able to submit jointly during the registration process. However, even in this case, there are still certain parts of the registration dossier that each legal entity of CONCAWE Member Companies will have to submit to the ECHA separately and individually (see Box 4).

Moreover, the registrants, i.e. the legal entities that wish to register a substance, will have to submit the registration dossier themselves. Whereas during pre-registration and during the phase of collaboration in a SIEF, a legal entity can choose to be represented by a third party—and consequently hide its identity from the other SIEF participants—this is not possible during the registration as such. The only exception is where a non-EEA manufacturer chooses to appoint a so-called 'only representative', e.g. an importer who registers all import volumes including those that are imported directly by other legal entities. These other importing legal entities have no obligation to register. In the terminology of REACH, they become downstream users.

Box 3: SIEF scope—the legal minimum

- Share animal testing data (and agree cost sharing mechanism)
- Agree substance data (study summaries)
- Agree testing proposal (if required)
- Agree classification and labelling
- Agree on Lead Registrant
- Collaboration initiated by a 'SIEF Formation Facilitator'
  - Identity and contact details of all other pre-registrants of the substance

Box 4: Registrant specific information

- Identity of the registrant
- Identity of the substance (linked to the category)
- Manufactured and/or imported volume
- Type of substance (intermediate or not)
- Manufacturing process (reference to generic CSR)
- Manufacturing or other relevant sites (reference to coded information in the generic CSR)
- Uses and relevant Exposure Scenario(s) (reference to the generic CSR)
- Any additional uses and associated Exposure Scenarios

Mandatory collaboration of all registrants under REACH

CONCAWE has established early contacts with potential SIEF members

How CONCAWE has structured collaboration among its members

Collaboration between CONCAWE members started in 2001 when the CONCAWE Board decided to embark on a comprehensive programme for risk assessments of petroleum substances. These risk assessments were conducted according to the Technical Guidance Document (TGD) of the Council Regulation (EEC) 793/93, the Existing Substances Regulation or ESR. Under the ESR, Member State Competent Authorities (MSCAs) carried out risk assessments for priority substances, none of which were petroleum substances. Companies manufacturing or importing these priority substances were obligated to make substance data available to the so-called rapporteur, i.e. a MSCA that carried out the risk assessment of a particular substance. It has to be noted that, in reality, it was the trade associations, for example Cefic sector groups, that collected data from their members and submitted them to the rapporteur. Unfortunately, the authorities did not involve all market participants including importers. Within the trade associations it was common practice to share substance information among all member companies without financial compensation.

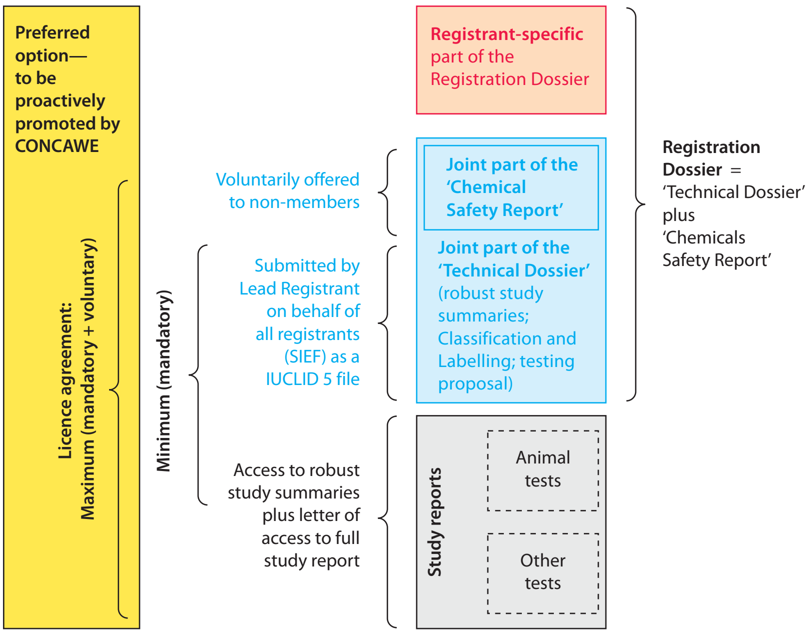
REACH has forced a dramatic change, by putting a sudden end to the common practice of sharing substance information between manufacturers in legal or voluntary programmes without compensation for the cost of the underlying studies. Since the registration is now a prerequisite for the licence to operate in the market and since substance information is needed to prepare a registration dossier, substance information has a commercial value and becomes a marketable good.

When the requirements for registration dossiers under REACH were eventually fixed[2] CONCAWE had voluntarily completed risk assessments for three groups of petroleum substances as 'ESR risk assessments'. These covered naphtha/gasoline, gasoil/diesel and kerosine.

Meanwhile CONCAWE has instructed its contractors to apply the approaches and methodologies of REACH to their work on the risk assessment programme and to provide the results in a REACH-compliant format for all remaining groups of petroleum substances.

Questions of ownership of substance information, sharing such information among CONCAWE member companies and access for CONCAWE member companies to the output from the risk assessment were addressed in a licence agreement between CONCAWE and its member companies. The licence agreement also reflects the structure of the registration dossiers and the maximum scope of collaboration among registrants (see Figure 2).

Figure 2 Scope of the CONCAWE REACH licence agreements



How CONCAWE intends to structure collaboration with non-members

There are several factors that are unique to petroleum substances—and possibly to other substances of unknown or variable composition (UVCBs)—that will determine the collaboration between CONCAWE

2 *It should be noted that at this stage the final details are still not certain because Annex I of REACH that describes the details of the Chemicals Safety Report (CSR) is under review by the Commission. Full certainty will be lacking until October 2008, i.e. after approval of the final version of Annex I by the legislator.*

members and non-members in the SIEFs. The main factors are:

1. The minimum information that needs to be shared among SIEF participants will not enable a legal entity to register a petroleum substance in those cases where a Chemicals Safety Report including a risk characterisation is required.
2. CONCAWE has developed a strategy to support the registration of individual substances by the use of categories of substances having the same physico-chemical, toxicological and eco-toxicological properties.
3. CONCAWE has developed new methodologies for the risk assessment of petroleum substances. The methodologies have been presented to the MSCAs in the context of the risk assessments for the ESR and extended to all groups of petroleum substances.

Non-members are obviously free to develop their own methodologies for performing chemical safety assessments. However, in view of the complexity involved and the short time that remains before registration is required, CONCAWE intends to offer to non-members the legally possible option of jointly submitted information. One vehicle for sharing this jointly submitted information could be an external licence agreement.

Whereas the licence agreement between CONCAWE and its members covers all groups of petroleum substances, there would be several licence agreements with non-members, each covering a specific group of petroleum substances, for example naphthas/gasoline or gasoils/diesel. This takes into account the fact that most of the non-members can be expected to be independent importers, trading only in a few substances.

It was mentioned earlier that initially SIEFs will have no legal structure and no established means of communication. The REACH guidance published by ECHA foresees that SIEF participants will form consortia. Cefic has embarked on a project to develop a communication tool for SIEF participants. There is consensus in industry that creating and managing consortia will be complex and enormously time consuming. This is based on experience from the implementation of the ESR and from voluntary industry initiatives like the 'HPV Initiative' of the International Council of Chemical Associations (ICCA) or the 'HERA project' of the detergent raw material producers and the detergent formulators.

A licence agreement would drastically simplify the relationship between SIEF participants and minimise the need for extensive communication within the SIEF.

It is therefore in CONCAWE's interest to promote this way of working as early as possible at the beginning of the pre-registration period. It is inconceivable that CONCAWE will be able to contact all potential SIEF participants before the pre-registration period is over and the exact composition of the SIEFs is known (1 January 2009). Contacts should therefore be established through 'multipliers' such as trade associations .

A 'REACH conference for petroleum substances' was the most efficient vehicle for CONCAWE to not only promote the system of licence agreements as a tool of simplifying the collaboration in the SIEFs, but also to:

- promote common interpretations of REACH requirements (e.g. the definition of the importer under REACH).
- express its intention to volunteer to act as the SIEF formation facilitator, a role that has to be offered during pre-registration; and
- address the issue of CAS registry numbers (CAS RNs) for traded imported substances.

It was mainly the latter that determined the timing for the conference. To avoid confusion a common understanding of traded CAS RNs needs to be established before the pre-registration process starts. The conference was held on 23 May 2008 in Brussels.

Besides representatives of its member companies, CONCAWE invited delegates from relevant trade associations, for example the Cefic sector groups for lower olefins and aromatics, associations of importing industries (mainly industries that import fuel for their own consumption), associations of importing traders and associations of tank farm operators. The outcome of this conference will be separately advised.

Abbreviations and terms used in this CONCAWE *Review*

ACCP	Advanced Common Rail Combustion Process
AEL	Associated Emission Level
AGO	Automotive Gas Oil (diesel fuel)
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)
C1	Methane
C2	Ethane
CAFE	Clean Air For Europe
CAI	Controlled Auto-Ignition
CAS	Chemical Abstracts Service (the CAS Registry is a database of chemical substance information, each substance in the database being identified by a unique number, the CAS Registry Number)
CAS RN	CAS Registry Number
CBA	Cost-Benefit Analysis
CCS	Carbon Capture and Storage
Cefic	European Chemical Industry Council
CHP	Combined Heat and Power
CMR	Carcinogenic, Mutagenic or toxic to Reproduction
CSR	Chemicals Safety Report
DME	Dimethyl Ether
ECHA	European Chemicals Agency
ED	Euro Delta
EEA	European Economic Area
EGR	Exhaust Gas Recirculation
EMEP	UNECE's cooperative programme for Monitoring and Evaluation of the long-range transmission of air Pollutants in Europe
ESR	Existing Substances Regulation
FCC	Fluid Catalytic Cracker
FQD	Fuels Quality Directive
GAINS	Greenhouse gas-Air pollution Interactions and Synergies model (An extension of the RAINS model—see below)
GHG	Greenhouse Gas
GO	Gas Oil
HCCI	Homogeneous Charge Compression Ignition
HCLI	Homogeneous Charge Late Injection
HPCC	Highly Premixed Cool Combustion
HPLI	Highly Premixed Late Injection
HPV Initiative	High Production Volume (HPV) Chemicals Initiative A voluntary programme launched by the ICCA in cooperation with the OECD to produce harmonised, internationally agreed data and initial hazard assessments for approximately 1,000 HPV substances
IA	Impact Assessment
IAM	Integrated Assessment Modelling
ICCA	International Council of Chemical Associations
ICE	Internal Combustion Engine
IPPC	Integrated Pollution Prevention and Control (EU Council Directive 96/61/EC of 24 September 1996 concerning integrated pollution prevention and control)
IUCLID	International Uniform Chemical Information Database
LCP	Large Combustion Plant
MSCA	Member State Competent Authority
NADI™	Narrow Angle Direct Injection
NECD	National Emission Ceilings Directive
NEDC	New European Driving Cycle
NEEDS	New Energy Externalities Developments for Sustainability
NewExt	New Elements for the Assessment of External Costs from Energy Technologies: Project financed by the European Union, DG Research, Technological Development and Demonstration (RTD)
NG	Natural Gas
NGOs	Non-Governmental Organisations
PAH	Poly Aromatic Hydrocarbons
PCCI	Premixed Charge Compression Ignition
pHCCI	Partial HCCI
PM	Particulate Matter or Particulate Mass
PQ	Product Quality
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)
REACH	Registration, Evaluation and Authorisation of Chemicals
RMF	Residual Marine Fuel
SECA	SO_x Emissions Control Area
SIEF	Substance Information Exchange Forum
SLFD	Sulphur in Liquid Fuels Directive
SRF	Source-Receptor Function
TGD	Technical Guidance Document
TSAP	Thematic Strategy on Air Pollution
UNECE	The United Nations Economic Commission for Europe
UVCB	Substance of Unknown or Variable composition, Complex reaction products or Biological materials
VOLY	Value of a Life Year
VPF	Value of a Prevented Fatality
YOLL	Year of Life Lost

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