concawe

ENVIRONMENTAL SCIENCE FOR THE EUROPEAN REFINING INDUSTRY

review

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Environmental science for the European refining industry

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Foreword

Robin Nelson
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Looking ahead

As the world's population moves towards 9 billion, societal expectation is that we find solutions to the fundamental problems of meeting increasing energy requirements whilst reducing the impact on the environment by using precious resources in the most efficient way.

The Spring 2013 edition of the Concawe *Review* described the considerable improvements in environmental performance made by the European petroleum refining and fuels manufacturing industry over the past half-century, including removing sulphur from road fuels and reducing emissions from refineries.

This Concawe *Review* is a first in that we have invited a number of authoritative contributors to take a forward-looking view of developments in the transport industry towards meeting the challenge of improved environmental performance. I thank each author for their contribution, which is individually very interesting and informative. When combined with the articles from the Concawe staff, it becomes clear that we can look forward to further efficiency gains in our use of fossil fuels. The article on the JEC Consortium well-to-wheels work mentions the ongoing development of the internal combustion engine (ICE), which will result in lower overall fuel consumption and a lower CO_2 output per kilometre driven. As the car industry is investing billions to develop the ICE and various forms of hybrid drive trains, the petroleum refining industry is investing to develop fuels which are compatible with these vehicles.

Whilst much of the public's focus has been on automotive light-duty vehicles, the articles in this *Review* also illustrate the work to improve efficiency and reduce emissions in heavy-duty vehicles, in marine and in aviation transport. In each, a picture emerges of development of a triad of approaches, in the vehicles, the engines and the fuels.

Different solutions will most likely provide the most practical way of achieving emissions reduction in different forms of transport. Anders Röj discusses the pros and cons of FAME as a diesel component and then looks at other biofuels such as di-methyl-ether (DME).

As well as questions around which biofuels can be certified for use in aviation, Joanna Bauldreay raises the point that whilst Europe may take the lead on introducing biofuels for aviation, it is important not to become isolated. Any new aviation fuels will need to be certified and made available on a global basis.

The article by Nigel Draffin reveals that reducing the level of sulphur in marine fuels by investing in residue desulphurisation processes and by using low-sulphur distillate fuels are likely to result in higher costs for marine fuels. This could make alternatives, such as changing to LNG fuel in new ships or on-board scrubbing, economically viable. The latter solution would, in turn, allow the use of higher-sulphur residual fuels. It is not clear which will emerge as the preferred solution or combination of solutions.

The article on renewable fuels discusses the 2014 JEC Biofuels Study scenarios for the inclusion of biofuels in fuels used in cars and heavy-duty vehicles. Blending biofuels into road fuels is now standard practice, but the JEC Biofuels Study highlights that further growth in biofuels by 2020 is likely to be limited by the availability of advanced biofuels and by the pace of introduction and acceptance of higher biofuel grades. These factors point to a reduced level of attainment of the 10% renewables by 2020 target set by the EU Renewable Energy Directive, compared to the analysis in the 2011 JEC Biofuels Study.

The biggest emission reductions will occur where the fuel is combusted to create energy, but refineries have also invested to reduce emissions from the refining of crude into fuels. Since Concawe's inception in 1963, the petroleum industry has reduced the sulphur content in automotive fuels from more than 1% to 0.001% by installing hydrodesulphurisation capacity in their refineries, and has also reduced SO_x and NO_x emissions from the refinery by 95%. Similarly, since 1990, the total sector emissions of SO_x and NO_x have been reduced by 63% and 35% respectively. In a comparable time period, emissions of petroleum hydrocarbons in water discharges were reduced by as much as 99%, such that the refining industry is currently operating at the edge of what technology can achieve.

Europe is leading the quest for more sustainable ways of providing the mobility that our society now takes for granted. The European oil refining and distribution industry has evolved over the past 50 years, but more recently, the momentum of change has constantly increased. The final papers in this *Review* bring two different perspectives, the first by the oil and gas producers' association's Michael Engell-Jensen and the second by Hubert Mandery representing the European chemicals producers. Fuels derived from oil will continue to be a major source of energy in Europe for many years to come. The petrochemicals industry is the biggest supplier of feedstock for the chemicals industry in Europe and while there is some scope for greater use of renewables, petrochemicals will continue as the major feedstock for the foreseeable future.

We have observed a trend in both the developed and developing world toward lower ambient air pollution as a result of setting standards and the implementation of emission control measures. Over the past decade, much progress has been made in better understanding the relationships between air pollution and human health and in reducing emissions and human exposure. Nevertheless, important scientific questions remain about the characterised and relevant human exposures and reported health effects in epidemiology studies, and about the effectiveness of government actions to address these exposures and inform future decisions on air quality. These questions are explored in the article by Dan Greenbaum and Robert O'Keefe of the Health Effects Institute.

Most of the oil used in Europe, whether for fuels, for lubricants, or for chemicals, will continue to be imported. Thus, from both an economic and an environmental perspective, we must drive innovation so that we emerge as highly efficient consumers, setting a standard for others globally.

I hope this *Review* helps to show that the European petroleum refining industry, made up of the member companies that support Concawe, recognises the challenges it faces and welcomes debate on how to evolve both as energy providers and consumers.

Robin Nelson
Science Director, Concawe

Chris Beddoes, Director General of Concawe

In its last *Review* in 2013, Concawe looked back over its 50-year history. This review seeks input not only from its in-house experts, but also from some of the specialists in related industries with whom Concawe regularly works. I am convinced that Concawe will continue to contribute to the knowledge and sound science related to the safe, environmentally responsible and efficient manufacture and use of petroleum products for many more years. In doing so, Concawe will need to further develop its working relationships with other sectors, with other researchers and with the EU Institutions; this special edition of the *Review* is a reflection of the importance of such collaborations.

Chris Beddoes
Director General, Concawe

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Developments in EU refining: looking ahead to 2020 and beyond

An insight into the challenges faced by the European refining industry in meeting future product demand and quality requirements

Developments in EU refining: looking ahead to 2020 and beyond

Oil refineries are constantly adapting to changes in product quality legislation and market demand. This requires the industry to be aware of such changes and anticipate them. Awareness of product quality legislation changes is generally straightforward, since they require that new product quality specifications be met by target dates. Predicting product demand changes is more complex, as these depend on only a few invariable factors, such as legislative targets for vehicle efficiency, and a myriad of much less predictable factors, such as economic growth and consumer preference for diesel or gasoline vehicles. A further complicating factor in the demand picture in recent years is the introduction of biofuels, which displace a portion of the products produced by refineries from crude oil (i.e. 'refined products').

To guide the refining industry in the complex task of anticipating future changes, Concawe released the 'EU Refining 2020–2030' study in 2013 (report no. 1/13R). This study used the Concawe EU refining model to combine a detailed inventory of the expected product quality changes with a forecast for product demand changes and estimate the impacts on refineries in EU27+2 countries over the period 2008–2030. This article highlights the key outcomes of this study.

What are the expected product quality changes?

EU road transport fuels have not been required to undergo any further changes in quality since the major milestone reached in 2009, when road diesel and gasoline were required to be 'sulphur-free' (i.e. containing less than 0.001% sulphur, compared to 0.005% since 2005). In 2011 this 0.001% sulphur limit was extended to diesel consumed in non-road machinery and inland waterway vessels (previously 0.1% sulphur). Since 2011, 'sulphur-free' products for road and non-road engines constitute about 37% of the total output of EU27+2 refineries.

The biggest changes in product quality in the post-2010 period will be in residual marine fuels, which currently constitute about 7% (40 Mt) of EU refining output. The maximum sulphur content of marine fuels used in EU emission control areas (ECAs) was reduced to 1.5% in 2006 and to 1.0% in 2010. A further reduction to 0.1% sulphur will be required in ECAs from 2015, which can only be met by fuelling vessels with distillate marine fuel instead of residual marine fuel.

In non-ECA areas the marine fuel sulphur content is set to reduce from 3.5% to 0.5% in 2020 or 2025, dependent on an International Marine Organization (IMO) review of worldwide fuel availability due by 2018. The IMO marine fuel regulations allow for on-board exhaust gas scrubbing to be used to achieve the required emissions abatement instead of reducing fuel sulphur content. Some ship owners have announced exhaust gas scrubber retrofits or new-builds, but the number of scrubbers in operation is not likely to have a significant effect on the demand for 0.5% sulphur fuel if the sulphur reduction is imposed in 2020. In the absence of the availability review, the Concawe study base case assumed that the global change to 0.5% sulphur fuel would take place in 2020 and would be entirely supplied by refineries. This includes, de facto, the EU legislation[1] which will impose the 0.5% sulphur limit on all marine fuels used in EU territorial seas (i.e. up to 12 NM off the coast) and exclusive economic zones (EEZs) from 2020, regardless of the IMO decision. In a sensitivity case the opposite extreme was assumed, i.e. that all ships fuelling residual fuel at EU ports would be equipped with scrubbers by 2020.

What are the forecasted changes in refined product demand?

Final demand for refined road fuels is declining in EU27+2 countries due to steadily improving vehicle efficiencies and the penetration of alternative fuels (mainly biofuels) made from non-fossil feedstocks. The combined effect of these factors on refined road fuel demand was assessed using the Fleet & Fuels (F&F)

[1] Directive 2012/33/EU of 21 November 2012, amending Council Directive 1999/32/EC regarding the sulphur content of marine fuels.

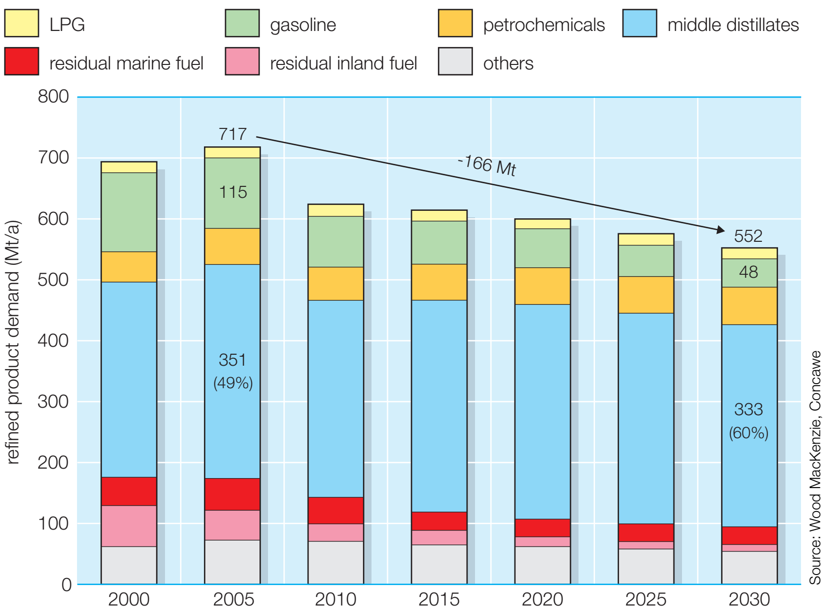
model developed by the JEC consortium, under the assumption that the 2020 vehicle fuel efficiency targets of 95 gCO_2/km average vehicle efficiency and 10% energy renewables would be met. Concawe extended the F&F modelling to 2030, assuming that vehicle efficiency would continue to improve to 75 gCO_2/km by 2030. The results show a continuing decline in gasoline demand (58% lower in 2030 than in 2005) while road diesel demand remains fairly stable up to 2020, then declines by about 9% to 2030. The ratio of refined road diesel to gasoline demand shows a continuous increase from 1.1 in 2000 to 2.0 in 2010, reaching 3.4 in 2030.

The main demand change in non-road transport fuels will be in 2015 with the switch in ECAs from residual marine fuel (1.0%S) to distillate marine fuel (0.1%S). This could remove about 13 Mt/a from residual fuel demand and add 13 Mt/a to distillate fuel demand.

Demand for non-transport refined products is also in decline, mainly due to substitution by natural gas. This is especially the case for heating oil (for domestic, agricultural and industrial uses) and inland heavy fuel oil (for industrial heat and power generation). Wood Mackenzie demand forecasts were adopted for these products in the study.

When these individual product demand trends are combined the overall result is a fall of 166 Mt (23%) in total demand for refined products from 2005 to 2030, as shown in Figure 1. It should be noted that while total demand is in decline from 2005 to 2030, the share of middle distillates[2] increases from 49% in 2005 to 60% in 2030. This will place a considerable strain on the refining system, as declining total demand is likely to lead to more refinery closures. The distillate production capacity lost in closed refineries would need to be replaced with additional energy-intensive distillate production capacity in the remaining refineries in order to meet demand without increasing the EU's reliance on imported distillates to complement domestic production.

Figure 1 Total demand for refined products in the EU27+2 (Mt/a)



How is the EU refining industry meeting the challenges in the short term?

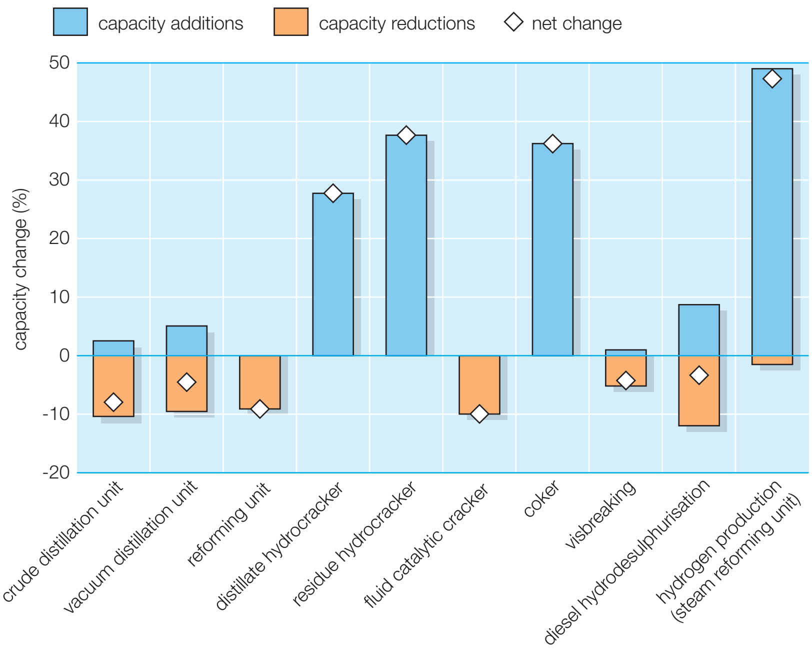
The European refining industry had 760 Mt/a of crude distillation capacity at year-end 2008. This had reduced to 698 Mt/a by year-end 2013 with the closure of 14 refineries under the combined impact of adverse economic circumstances, shrinking refining margins and declining demand. The closed refineries were on average smaller and less complex than the EU average and were oriented towards gasoline production.

Despite these adverse conditions, EU refineries have announced capital expenditure projects over the 2009–2015 period amounting to an estimated total of \$30 billion (€21 billion)[3]. These projects will increase capacities of EU refinery units that boost distillate production and reduce residue production, making a major contribution to meeting future product requirements, and in particular allowing the switch to 0.1%

[2] The term 'middle distillates' covers the range of refined products from kerosene fuel (for heating or jet engines) to diesel fuel (for road and non-road vehicles) to heating oil (typically used in oil-fired domestic boilers) and marine distillate fuel (for ships not equipped to burn residual fuel and for ships in port and in ECAs from 2015).

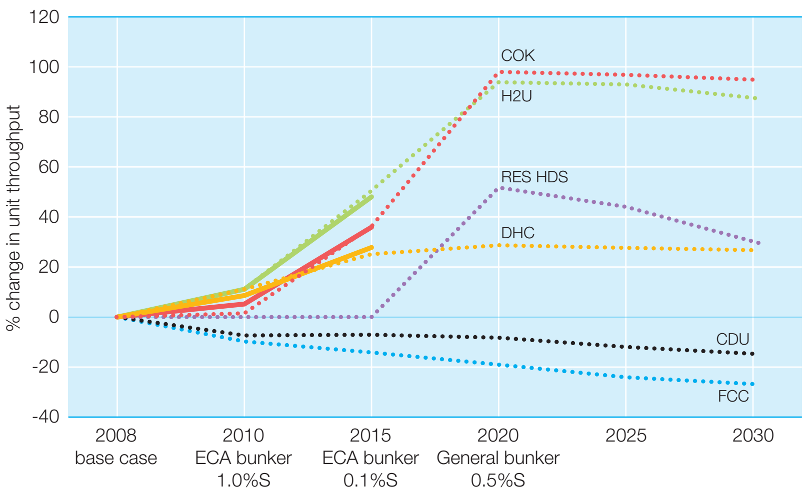
[3] All the capital investment figures in US dollars and Euros in this article are based on costs in 2011, unadjusted for inflation.

Figure 2 EU27+2 refinery projects, 2009–2015
(capacity change by process unit relative to year end 2008)



Above: Figure 2 is an updated version of Figure 2.1.2 in Concawe report no.1/13R. It includes six additional refinery closures that were not included in the report, totalling 43 Mt/a of CDU capacity (Petit Couronne, Berre, Coryton, Rome, Porto Marghera and Wilhelmshaven).

Figure 3 Percentage changes in unit throughputs relative to a 2008 baseline



sulphur marine fuel in ECAs in 2015 without needing additional imports of distillate fuels. The changes in process unit capacities resulting from announced projects and closures over the 2009–2015 period are shown in Figure 2.

How much more investment is required in the longer-term?

The announced EU refining projects in the 2009–2015 period do not address the additional equipment needed to reduce the sulphur content of non-ECA marine fuels to 0.5% in the scenario of a worldwide cap in 2020 which is an unprecedented step change. Under the assumption that the IMO decides to impose this reduction by 2020, and that the entire non-ECA demand for residual marine fuel at EU ports in 2020 (about 30 Mt) would be supplied by EU refineries and not by additional imported diesel, the Concawe refining model has estimated that €15 billion of additional investment would be required. The investment would chiefly be in coking units (which convert residual fuel to coke and lighter distillate products), residue desulphurisation units (which reduce sulphur content) and hydrogen units (which produce hydrogen feedstock for the desulphurisation units). The scale of the required changes in unit capacities is indicated in Figure 3 which shows the percentage changes in unit throughputs relative to a 2008 baseline. Solid lines show to what extent announced investments can achieve the required increases in unit throughputs.

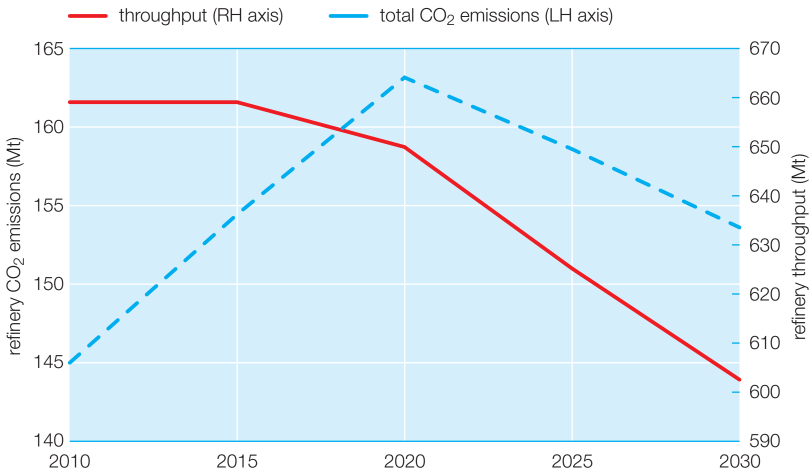
It will be exceptionally difficult for EU refiners to decide whether to make these major investments, which would be entirely dedicated to producing a marine fuel representing only about 5% (30 Mt/a) of the output of EU refineries. The future demand for this low-sulphur product will also be shaped by ships equipped with exhaust gas scrubbers allowing them to switch back to high sulphur marine fuel, or by ships adapted to burn LNG fuel.

These factors point to weak long-term demand prospects for low sulphur marine fuel, which could lead to progressive under-utilisation of any new investments in process unit capacity dedicated to its production. Such uncertainties could make it difficult to economically justify additional refining investments.

What is the expected impact on refining CO_2 emissions?

CO_2 is emitted in refineries by fuel burned to supply heat for the refining processes and by chemical reactions taking place in hydrogen production units, which reject the carbon in the feedstock as CO_2. In spite of declining throughput, CO_2 emissions from EU refining are expected to be driven higher from 2010 to 2020, mainly by the marine fuel sulphur reductions in 2015 and 2020 and, to a lesser extent, by the need to produce an increasing share of distillates to satisfy demand. Figure 4 shows the expected 13% increase[4] in CO_2 emissions from 2010 to 2020 and the subsequent decrease from 2020 to 2030, driven by steeply falling refining throughput. Hydrogen production accounts for 22% of refining CO_2 emissions from 2020 onward, up from 14% in 2010.

Figure 4 The expected 13% increase in CO_2 emissions from 2010 to 2020



Concluding remarks on the outlook for EU refining

EU refining faces many challenges in meeting product demand and quality requirements in the period from 2010 to 2030. The Concawe study gives some insight into the combined impact of these challenges under the important assumption that refiners will invest to meet the challenges without becoming more dependent on product imports and exports. In reality, refiners will make decisions affecting investment and import/export balances based on their own individual circumstances.

One of the study's key outcomes is that the €21 billion of announced investment projects over the 2009–2015 period should adequately equip EU refining with the appropriate conversion unit capacity to satisfy future demand and quality requirements, with the important exception of the IMO marine fuel sulphur reduction to 0.5% which would require additional investments estimated at €15 billion, and would incur additional refining CO_2 emissions. Without this further investment beyond 2015, the available conversion and desulphurisation capacity would permit the production of only 10% of the estimated demand for 0.5%S marine fuel in 2020. In this case, Europe would have to resort to imported diesel to satisfy the remainder of the demand, significantly increasing EU dependence on imports.

[4] The estimated 13% increase in CO_2 emissions assumes that the energy efficiency of refining process units remains unchanged from 2008. There could, in reality, be some margin for improvement in energy efficiency, which would mitigate the expected increase in energy-related CO_2 emissions but would not improve the 'chemical' CO_2 emissions from hydrogen production units.

Evaluating energy pathways: from well to wheels

How the JEC well-to-wheels study is evolving to take account of new vehicle, fuel and biofuel options that are likely to be available in the next 10 years and beyond

Over the past decade, the JEC Research Consortium[1] has been working together to better understand the complex issues associated with future vehicles and fuels. While some of this work has involved practical vehicle testing, much of the Consortium's work has been on vehicle and fuel pathways in the European context, from a 'well-to-wheels' (WTW) perspective. Other work that is also reported in this *Review* has focused on meeting future European requirements for renewable energy and greenhouse gas (GHG) reduction through the use of biofuels in European market fuels.

The JEC WTW studies have become a benchmark reference and planning tool for evaluating energy use and GHG emissions for different conventional and alternative fuels and vehicle options. The efficient production of fuel products and their use in vehicles are both important in order to choose and invest in the best technology options to meet future EU targets. Two new reports on 'well-to-tank' (WTT) production of fuels and 'tank-to-wheels' (TTW) use in vehicles were published in 2013 on the JRC website[1]. The results from these two studies, combined into a WTW perspective, were published in March 2014 and provide an overall assessment of fuel and vehicle pathways between 2010 and 2020+.

WTW and Life Cycle Analysis (LCA) studies have, of course, been conducted for many years but the importance of these methodologies to provide a sound scientific basis for guiding decisions related to European road transport only became apparent from about 2000. Before this time, the regulatory focus was primarily on vehicle performance and exhaust emissions, and on standards for reducing road fuel sulphur levels and harmonising

[1] http://iet.jrc.ec.europa.eu/about-jec

[1] What is the JEC Consortium?

If you have heard of the 'JEC Consortium' before, it is most likely through work related to the development of the Well-to-Wheels (WTW) methodology and results. Although this is still a central part of the JEC Consortium's work, the scope of its activities has grown considerably over the years.

In 2000, Concawe recognised the importance of joining forces with the European Council for Automotive R&D (EUCAR) and the Joint Research Centre (JRC) of the European Commission on topics of common interest. The 'JEC Consortium' formed by these three partners was designed to pursue scientific and technical studies and provide factual information in evolving areas of road transport. A Scientific Advisory Board consisting of senior managers and researchers from all three organisations is responsible for agreeing on the scope of new projects, stewarding the completion of results and their dissemination to a wider audience.

The first technical area identified by the Consortium was the development of scientifically robust tools for comparing different combinations of powertrains and fuels from 'Well to Wheels' (WTW), that is, from fuel production to its consumption in vehicles. It was quickly recognised that experimental measurements could not provide all of the answers on the energy requirements and GHG emissions for new vehicle and fuel technologies; the JEC WTW approach provided a new way to fill that identified gap.

The JEC's WTW work has stood the test of time with new updates published in versions 4 and 4.a of the Well-to-Tank (WTT) and Tank-to-Wheels (TTW) Reports in 2013 and 2014 respectively, and the WTW version 4 Report in 2014. The JEC approach has also been recognised by the European Commission as a 'sound science' way to value different energy pathways and products, and was used as essential input for European legislation on renewable and alternative fuel products for energy use adopted in 2009.

Although WTW has been its most visible work product, the JEC Consortium has also pursued research in other areas. Vehicle studies have focused on evaporative emissions, fuel consumption, and regulated emissions from ethanol/petrol mixtures. More recently, the Consortium also published results of the 'JEC Biofuels Study' in 2011, a project to assess the challenges associated with achieving the 2020 targets and objectives of the EU's Renewable Energy and Fuels Quality Directives through biofuel blending and alternative fuels uptake in the European road fleet. An update of the 2011 Biofuels Study was published in 2014 and the results of this update are described in the accompanying article.

Most importantly, all of the JEC's work is published on the Joint Research Centre's website and is freely available for download, review and critique by interested researchers and organisations. The Consortium members monitor an email address (infoJEC@jrc.ec.europa.eu) for those who have questions or find technical errors in the published work that should be corrected in future revisions.

quality across European states. These developments resulted in dramatic reductions in regulated emissions from road vehicles but energy consumption and GHG emissions from road transportation continued to rise.

The objective of the JEC WTW studies has been the same since the first report in 2004: to objectively evaluate the real energy use and GHG emissions for different technology options that are important to Europe. This work has been one of continuous improvement, especially for some biofuel pathways where commercial development is still in progress and process technology options are still under development. Presenting the results and input data in a transparent way is equally important, and, in the most recent Version 4 reports, all of the input data and assumptions, together with the appropriate references, have been presented in the form of easy to use, downloadable workbooks.

The JEC study is forward looking. In broad terms, the study examines vehicle, fuel and biofuel options that are likely to be available in Europe in the next 10 years and beyond. The production of biofuels and alternative fuels is based on best available process technology. This means that the results anticipate the performance of new production plants that will be built in the future. This performance level may not be matched by existing production plants that were constructed even a few years ago.

The study also assumes a `marginal' approach, that is, it asks from what source and through what process would additional quantities of a particular road fuel, for example electricity or CNG, be produced, what equivalent quantity of conventional fuel it would displace and through what process is that ‘marginal quantity of conventional fuel’ currently produced.

Methodology

The performance of new vehicle and fuel options is compared to a conventional vehicle and fuel scenario. To do this, Concawe’s refining model covering the European region provides a unique tool to evaluate the impact of changes in demand for conventional gasoline and diesel on marginal energy use and GHG emissions associated with fuel production. In particular, the model calculates slightly higher energy and GHG emissions for diesel fuel production compared to gasoline, reflecting the diesel quality specifications and high diesel to gasoline demand ratio in Europe.

Conventional crude oils are still plentiful, but other sources such as oil sands and shale oils are increasingly being exploited in some parts of the world. These new sources are more intensive in energy use and GHG emissions than is the production of conventional crude. While these new sources of crude products are described in the WTT Report, they are not expected to be used in significant quantities in Europe which will continue to rely on a mix of conventional crudes primarily from Europe, the Middle East, Africa and Russia. The GHG emissions associated with the production of this mix of crudes have been updated in the WTT Report using recent published information from production sites, including emissions from flaring and venting.

For most fuel options, a range of alternative production sources and processing methods are evaluated and described as different ‘pathways’. For example, CNG may be produced from gas reaching Europe by pipeline or as LNG. Factors such as the pipeline transport distance have a big impact on the energy and GHG emissions due to pressurisation and pumping losses which depend on distance. While much of the input information would be valid anywhere in the world, scenarios are as closely tailored to the European situation as possible.

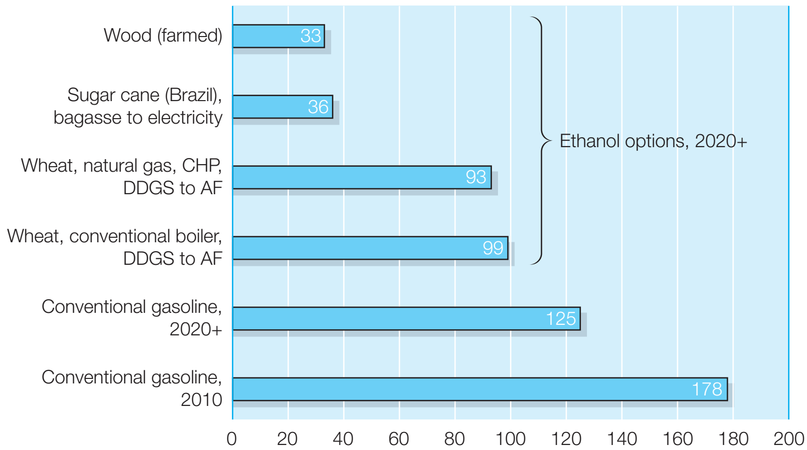
Since the first JEC WTW Study was published in 2004, the pathway emphases and priorities have evolved. In 2003, for example, much attention was given to the potential of hydrogen as a fuel for road vehicles. Hydrogen can be produced from a variety of sources, but its production is energy intensive. The first study showed that benefits only accrue if hydrogen is used in efficient fuel cell vehicles rather than in a conventional engine. While fuel cell vehicles have been demonstrated for many years, they have been slow to reach large-scale penetration in the vehicle market.

When the second study was published in 2006/7, biofuels had replaced hydrogen as the topic of interest and were quickly becoming commercially established. A major effort was put into understanding these biofuel production pathways better, including holding a workshop to obtain input from other groups and experts. Understanding of biofuels production pathways is undoubtedly much better today compared to only a few years ago, but new questions constantly arise. Biofuels remain the most challenging alternative fuel to model accurately, primarily because of the disposition and accounting of pathway co-products.

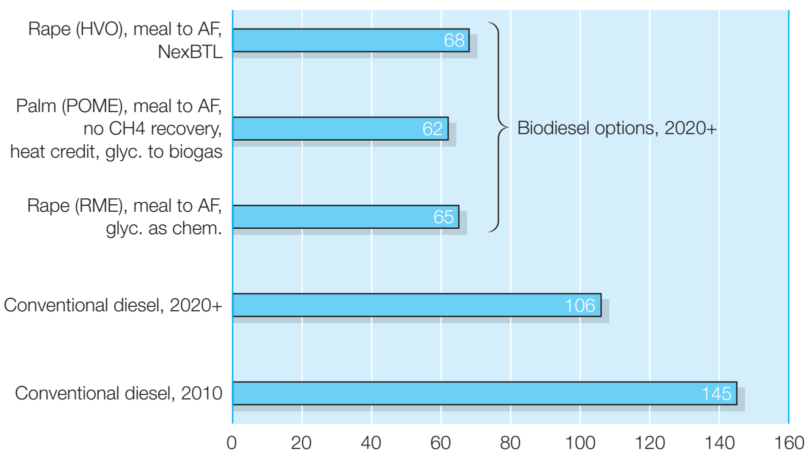
Vehicle technology has also evolved considerably since the first JEC WTW Study. The efficiency of conventional petrol and diesel engines is improving and helping to reduce the fuel needed to keep Europe moving. The baseline vehicle has been updated from a 2002 to a 2010 model year in the new TTW Study, and new vehicle types have also been modelled. For instance, plug-in hybrid and battery electric vehicles are becoming more common having the ability to recharge from street and home recharging points. This will bring electricity production into greater focus as an alternative road fuel. Considerable care has been taken in the TTW Study to compare different powertrains on a level playing field, using common performance criteria for different vehicle types to the greatest extent possible.

Figure 1 Impact of biofuels

a) GHG emissions—ethanol in 2020+ (gCO_2eq/km)



b) GHG emissions—biodiesel in 2020+ (gCO_2eq/km)



Biofuels

Biofuels are the most challenging fuels to model, because they involve processes and co-products that extend far beyond the limits of road transportation. Current production methods for ethanol and biodiesel (FAME)[2] use only part of the cereal or oil seed, respectively, in the production process. The residue is a useful co-product that can be consumed as an animal feed or used as an energy source. Selecting between these options will ultimately be done on economic grounds, but the study provides pathways that outline the effects of these selections on energy and GHG emissions (Figure 1). Hopefully, the results also help guide those who are interested in manufacturing biofuel products with ever-increasing energy and GHG efficiency.

While some biofuels are being produced from waste, the large volumes needed to meet current and future transport demand will mostly come from purpose-grown crops. Although this is not a major energy factor in a typical pathway, the farming of energy crops does represent a major source of GHG emissions. First, fuel and GHG emissions associated with farming equipment and the manufacturing of fertilisers and other agricultural chemicals must be counted. Second, GHG emissions can also be emitted directly from the soil, and these are more difficult to estimate with precision. Much of the nitrogen in the soil is taken up by the growing crop, but some is emitted directly to the atmosphere as nitrous oxide (N_2O). Although the absolute amounts emitted are small, N_2O is a potent greenhouse gas and can have a significant impact on the overall GHG emissions from biofuel production. Experimental data show that measured N_2O emissions from individual fields can vary by up to three orders of magnitude, depending on the soil characteristics, climate, cultiva-

[2] Fatty Acid Methyl Esters

tion methods, fertilizer rates and the type of crop. Estimating these emissions is challenging and depends on detailed input information; uncertainty levels are still quite high. The new WTT Study includes an improved model to calculate N_2O emissions, developed by the JRC, to balance the need for precision with the level of input data that are available around the world.

GHG emissions are also associated with changes in land use. For example, when land is cultivated with a particular vegetation (forest, grassland or agricultural crops) for many years, the level of carbon in the soil reaches an equilibrium level which is generally higher for forest and grassland than it is for soil used for agricultural crops. After land use changes, the carbon level in the soil will gradually move to a new equilibrium, a process that takes many years or even decades. Because the first biofuels for road transport were produced from land that was already in agricultural cultivation, no significant change in GHG emissions from land use change was expected. As demand increases, however, there is increasing pressure to bring more forest or grassland into agricultural production to meet the growing need. Where this occurs, carbon will be released from the soil into the atmosphere. While the process is slow, the quantities of released GHG are significant, particularly in the case of peaty soils where large amounts of carbon are stored.

The production and demand for biofuels have now reached a point where their production has effects on a global level. Cereals, oilseeds or finished biofuels are increasingly traded on world markets. The amount of land being used for biofuel production has raised concerns that additional land may be brought into cultivation to make up shortfalls in food production. Such indirect land use change (ILUC) could also release more carbon into the atmosphere as explained above. Some argue that the improved use of already available farming land should enable food demand to be met without bringing more forest or grassland into cultivation. These ILUC effects are potentially significant for assessing the real GHG emissions impacts of biofuels but the experts agree that ILUC effects cannot be calculated with certainty today. This area remains a challenge for the future and we have not attempted to include ILUC effects in this version of the JEC Study.

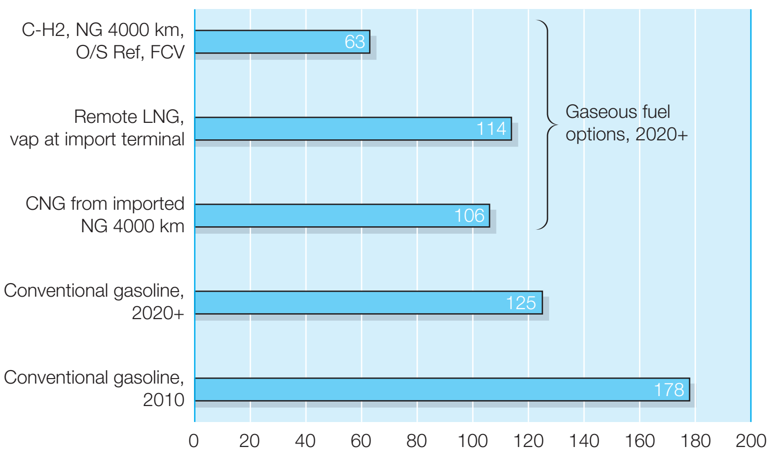
Gaseous fuels

Concerns are periodically raised about the dependence of road transport on crude oil. Liquid biofuels have an advantage that they can be blended into existing petrol and diesel and used in normal vehicles, but the fuel volume they can replace is limited by what the land can produce.

Gaseous fuels provide a possible alternative to biofuels, so their effect on overall energy use and GHG emissions is also of interest (Figure 2). Natural gas is available in very large quantities worldwide and the technology to use it in road vehicles already exists. Although the energy and GHG emission figures have changed very little since the first study, we have refined the energy needed for long distance gas pipelines in this update. We have also included an 'EU mix' natural gas case and have increased the average pipeline distance to 2,500 km which is more representative of current practice compared to the distance used in previous studies.

Based on technology and cost hurdles, the generalised use of hydrogen in road vehicles still seems to be a long way off. If hydrogen is needed in large quantities, however, it would probably be produced from natural gas, or possibly by electrolysis of water, so these production pathways have also been modelled. Hydrogen only has an overall WTW GHG emissions advantage over conventional liquid fuels when it is used in efficient fuel cell vehicles (FCVs).

Figure 2 GHG emissions—gaseous fuel options in 2020+ (gCO_2eq/km)



Electrification

The use of hybrid electric vehicle (HEV) technology has advanced steadily over the past decade and this trend is expected to continue. Hybridisation may correspond to fairly simple modifications such as stop/start systems to full hybrids where power is provided by a combination of a conventional engine and an electric motor.

Battery electric vehicles (BEVs) have also developed significantly due to improvements in battery technology, but they still struggle for public acceptance because of their limited range and high cost. An alternative development is the plug-in hybrid vehicle (PHEV). A third category is the range-extended electric vehicle (REEV) where a small conventional engine is used simply to recharge the battery.

While HEV technology improves the overall efficiency of the vehicle, the conventional engine still relies entirely on fuel on board the vehicle for its energy. BEVs, PHEVs and REEVs, in contrast, utilise electricity from the grid as their road fuel.

In this update of the TTW Study, much attention has been given to accurately model these new developments, and BEVs, PHEVs and REEVs, all using lithium-ion batteries, are included for the first time.

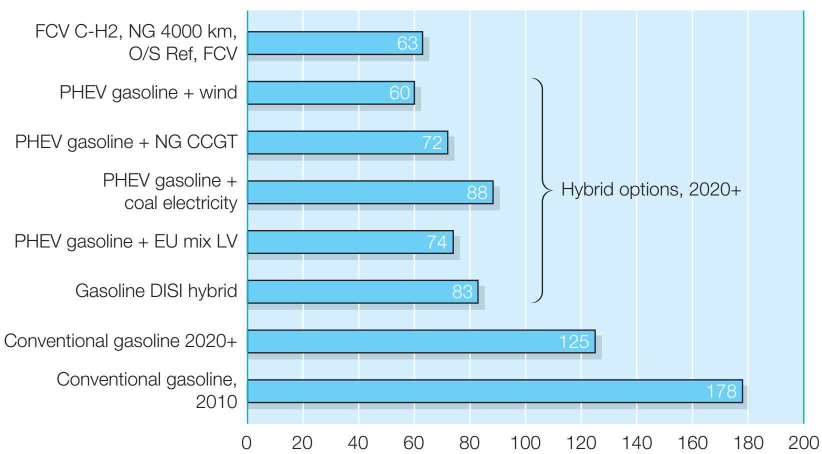
This increased attention on electricity is also reflected in the WTT report. The 'EU mix' figures for electricity generation have been updated with the help of JRC experts. In addition to different pathways for producing electricity from coal, gas and nuclear in best available technology power plants, an estimate has also been made of the average GHG emissions from today's 'EU mix' electricity based on national statistics.

An alternative use of electricity for road transport is to electrolyse water and produce hydrogen for use in FCVs. This pathway has also been modelled (Figure 3).

Where next?

The WTW methodology continues to be a valuable scientific tool for comparing the energy and GHG emissions for different fuel and vehicle options. Both within the JEC Consortium and among those in the international research community, substantial work is in progress to continuously improve the input data so that important energy and GHG-related decisions can be made more quickly and reliably on a 'well-to-wheels' basis. New developments are already in progress to validate land use change projections using remote sensing measurements and extend WTW methods to include material fabrication and end-of-use recycling. The JEC Consortium intends to remain actively involved in this exciting field for the foreseeable future.

Figure 3 GHG emissions—hybrid vehicle options (gCO_2eq/km)



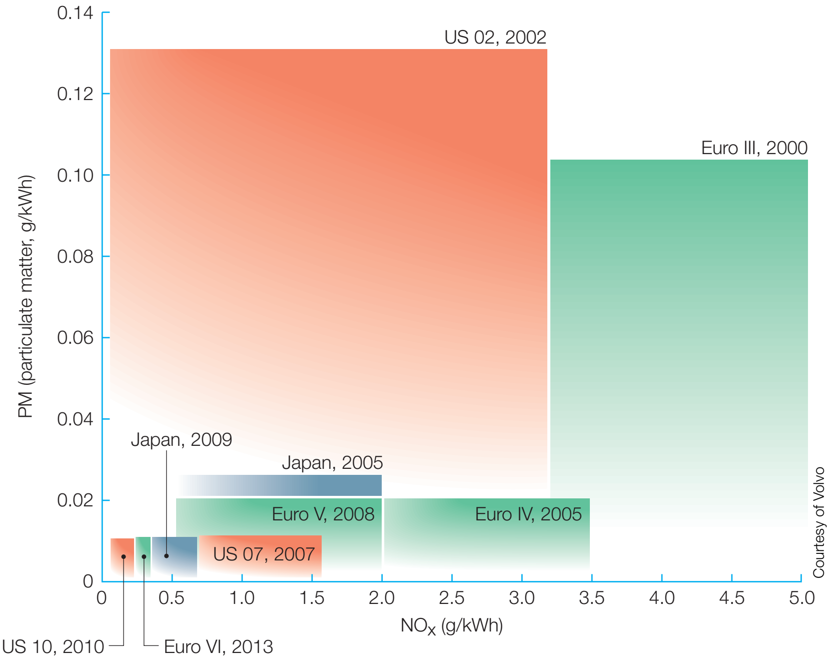
Transportation and fuels: looking ahead at heavy-duty vehicles

To be able to meet future overall efficiency and CO_2 targets, the focus should not be on the engines and the vehicles alone: the entire transportation system must be optimised.

Looking back on developments in heavy-duty vehicle (HDV) technology over the past 20–25 years, one could rightly describe them as a 'total makeover'. The improvements are particularly obvious for exhaust emissions but also for fuel consumption, durability and safety, where progress has been substantial. Improvements in diesel fuel quality have also been an important enabler for making these steps in engine technology possible. The parallel development of engine technology and fuel quality will have to continue into the future, not only in Europe and other developed countries but also, and perhaps even more importantly, in the developing countries around the world.

In everyday language, HDVs are what we usually call trucks and buses. In the EU legal system, they are defined as 'vehicles with a technically permissible maximum laden mass greater than 3,500 kg (N2, N3 for buses; M2, M3 for trucks). Transportation of goods and people is the 'blood circulation system' for economic life in modern society—more than 70% of all goods in Europe are transported by road. Efficient, durable and environmentally adapted trucks and buses are therefore essential, now and well into the future.

Figure 1 Emissions regulations for heavy-duty vehicles



Engine technology and fuel quality developments

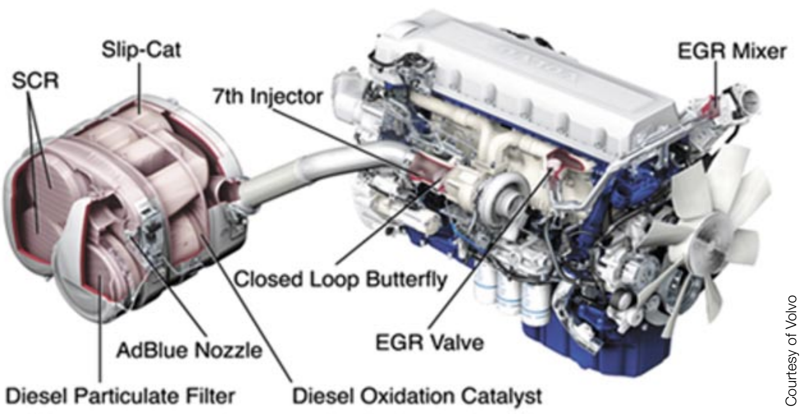
European emissions legislation for HDVs dates back to the mid 1980s (Figure 1). At that time, regulations only limited emissions of smoke and nitrogen oxides (NO_x). In 1992, the legislation on emissions requirements was expanded to include particulate matter (PM), carbon monoxide (CO) and gaseous hydrocarbons (HC). This so-called 'Euro I' regulation was the first step in a sequence of increasingly stringent legislative controls leading to the introduction of 'Euro VI' in 2014. Under Euro VI, all regulated emissions are drastically reduced, by about 95% for PM and by about 90% for NO_x, compared to Euro I some 25 years ago.

In the early years, engine technology improvements were mostly related to increased fuel injection pressure and improved combustion characteristics. The development of technology for electronically controlling fuel injection and combustion events began in the mid-1990s. This introduced new possibilities for affecting emissions formation inside the combustion chamber and for reducing fuel consumption.

The importance of fuel quality, particularly sulphur (S) content, became increasingly pronounced over time. In the late 1980s diesel fuel sulphur was limited to 2000–3000 ppm; this limit moved to 500 ppm for Euro II and 350 ppm for Euro III. When Euro IV was introduced in 2004 a 'step change' in emissions control occurred: exhaust aftertreatment systems (EATS) were also introduced into the various HDV segments (Figure 2). Euro VI, coming in 2014, will require the use of almost all emissions reduction technologies that are technically and economically viable, including exhaust gas recirculation (EGR), diesel particulate filters (DPF) and selective catalytic reduction (SCR).

Europe has been relatively successful over the years in matching fuel quality to changes in legal emissions limits and in-use compliance demands on the engine/vehicle side. The first European diesel fuel standard (EN590) was published by the European Committee for Standardization (CEN) in 1993, about the time that the Euro I HDV regulations came into force. EN590 has been revised periodically to reflect increasing engine requirements. In 1998 the EU Fuel Quality Directive

Figure 2 A typical exhaust aftertreatment system for Euro VI vehicles



(FQD) was put in place to govern environmental parameters (Directive 98/70/EC, amended 2009/30/EC).

The role of fuel quality has grown in importance at each regulatory step. Thanks to good cooperation between the automotive and oil industries through CEN, coherence between vehicle emissions and the necessary improvements in fuel quality has been maintained. This relationship was formalised through the Auto/Oil I and II programmes in the late 1990s, and the conclusions from these important joint industry studies formed the basis for the requirements of the FQD.

About 20 years ago, biodiesel (fatty acid methyl esters or FAME) began to appear as blending components in European diesel fuels. France and Austria introduced national standards or decrees to allow this, and eventually more countries supported the introduction of FAME into their markets. About 10 years ago a European FAME standard (EN14214) was introduced and a limit for FAME was introduced into EN590. Presently this limit is 7% vol. maximum (commonly called B7) and has been specified in the FQD since 2009. The automotive industry expects that, for general market fuels (EN590), this limit will not be changed in the foreseeable future.

As a fuel blending component, FAME has some inherent weaknesses. In particular, the stability and the cold operability characteristics are still of concern, and it is hoped that CEN will continue to work on ensuring the robustness of EN14214 and EN590 in these respects.

Microbial growth is another issue that has been accentuated because of increased FAME use. Because water is more soluble in fuels that contain FAME, microbial growth in fuel tanks can occur leading to problems with fuel filter plugging. Good housekeeping has become even more important than before.

Looking ahead—challenges and solutions

Powertrains and vehicles

For commercial transportation activities in general—and for heavy duty vehicles in particular—fuel efficiency has always been a key criterion. The reason for this is obvious: for a trucking company, the fuel bill is a major cost item, typically 30–35% of the total fleet operational costs, sometimes even more. Thus even a small increase in fuel cost could wipe out a significant part of the yearly profit for a trucking company.

Even before CO_2 emissions became a global concern, customer demands and the competition between vehicle manufacturers have kept fuel consumption at lowest possible levels for each type of application. Therefore, and without any specific regulatory requirements, the HDV industry has been able to significantly lower average fuel consumption over the years. For typical long haul truck applications, the average yearly improvements have historically been in the range of 1% or more. And notably, these improvements have been accomplished at the same time as exhaust emissions have been dramatically reduced.

Mandatory fuel economy requirements for HDVs are in place today in China and Japan. In the USA, the first stage of regulation will come into force in 2014 and the regulatory framework is being finalized in the EU. European legislation will build on a vehicle simulation tool, which will provide flexibility to simulate a large number of vehicle configurations and utilization patterns. The EU Commission, through its Joint Research Centre, is leading the verification of this tool, and the heavy-duty industry (through the European Automobile Manufacturers' Association, ACEA) is heavily involved and supporting this work.

A first step in the EU CO_2 legislation for HDVs will be a fuel economy labelling requirement, possibly coming into force in 2017 or 2018. The timing for the following step, which is likely to include mandatory CO_2 limits, is not yet clear but will probably be well beyond 2020.

Through the EC's 2011 White Paper on Transport, the EU has set some extremely ambitious long-term goals including lowering CO_2 emissions by 60% from the transport sector by 2050. However, commercial transport on highways is foreseen to increase steadily up to 2050, and even today the HDV fleet represents about two-thirds of total diesel fuel consumption in Europe. Consequently, a significant part of transport CO_2 emissions is likely to come from HDVs also in the future.

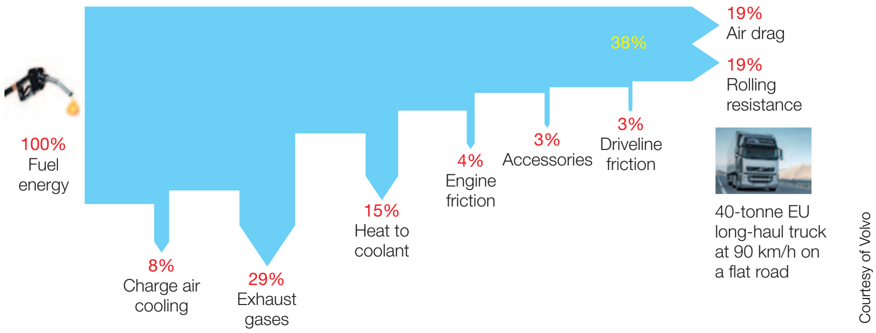
To support the 2050 targets, an estimated 3% per year improvement in fuel economy is likely to be needed from new sales of HDVs. To achieve this, within reasonable cost and complexity, will be a major challenge. Whether this contribution from HDVs will be enough is largely dependent on other factors, for example how transport demand develops over time, the extent to which electrification of the transport system takes off, and the quantity of sustainably-produced biofuels that will be available in the future.

It is important that the vehicle-specific fuel consumption requirements, as well as the long-term EU targets, build on relevant conditions and metrics. The metrics should be based on 'work done' principles, which for trucks means 'per tonne-kilometer' or possibly 'per m^3-kilometer'. In this respect, trucks should definitely not be treated just as 'supersized cars'.

To be able to meet future overall efficiency and CO_2 targets, the focus should not be on engines and vehicles alone: the entire transportation system must be optimised. This involves developments in intelligent logistics (higher average load factors and optimised freight routing), higher allowed cargo weights and improved road infrastructure in general. There will also need to be a contribution from the fuels, particularly biofuels and other renewable types of fuels.

To meet these ambitious regulatory and customer demands, a number of developments are already ongoing or foreseen.

Figure 3 Energy flow 'from fuel to wheels' in a typical HD long haul truck



Developments at the powertrain and vehicle level

The main thrust at the powertrain and vehicle level will be to maximise the efficiency of the combustion process, while minimising energy losses in the powertrain and in the rest of the vehicle setup (Figure 3).

This will require even higher injection pressures (above 2,500 bar) with more sophistication of the fuel injection strategy and phasing. It will also require better and more optimised exhaust catalysts and filter systems, as well as minimising heat losses. Heat recovery systems for exhaust and braking energy will be important elements in the future. To optimise the thermodynamic cycle(s) and move closer to the energetic limits dictated by the 'laws of nature', new combustion systems will be utilised and this may require new fuel properties.

There will be increasing focus on vehicle aerodynamics (including trailers) and 'right sizing' of the engine for the job to be done. Allowing larger and heavier vehicles on highways will also lower the per tonne-kilometer CO_2 footprint of goods transported on European roads. Hybridisation will be a key technology for lowering fuel consumption, especially for duty cycles that require a high degree of 'stop and go'. For city buses and distribution vehicles, the benefits of hybridisation include potential energy savings of up to 35%; such savings can be even greater in some non-road machinery. In the longer term we are likely to see more electrification even in segments that are today completely oriented towards internal combustion engines.

Fuel quality requirements and future fuels

As already noted, it is important that market fuel quality goes hand in hand with the emissions regulatory steps.

This link became mandatory when EATS were introduced by Euro IV. Thanks to the well-established EN590 standard and legal fuel requirements, EU diesel fuel quality is reasonably well under control today. The main quality items that still need to be worked on in CEN are related to:

- Fuel stability (mainly FAME-related): for biodiesel blending components, HVO (hydrotreated vegetable oils) are preferred due to their good combustion and handling properties.
- Cold flow performance and fuel filterability: today's methods and limits are not enough to ensure good cold operability, and efforts are ongoing in CEN to establish better tests.
- Injector deposits: modern common rail systems are more sensitive to internal diesel-injector deposits (often abbreviated to 'IDID').

There are also concerns regarding cross-border traffic travelling outside the EU. East of the EU borders, sulphur-free fuels are not widely available and the situation can be even worse for HDV traffic travelling towards the Middle-East. Only a few tank refills of high sulphur fuel can create significant damage to Euro VI EATS.

As vehicle emissions legislation is introduced and made more stringent around the world, the required fuel quality improvements must take place at the same time. To aid this process, the world automotive industry has issued a fuel quality guidance document, the so-called 'World-wide Fuel Charter' (WWFC). The WWFC can be found on the ACEA web site at www.acea.be.

Figure 4 Volvo DME trucks

Source: Maria Fäldt

Volvo strongly supports the inclusion of adequate market fuel specifications in the global emissions regulations that are being developed by UN ECE WP29 in Geneva. The EU has shown how cooperation between the industries and with the legislator can create a coordinated legal framework for market fuels and engine emissions requirements. The EU example can be favourably used also in other parts of the world.

The coming legal requirements, combined with societal and customer demands, are likely to bring improved and new engine concepts as well as new fuels. For many years to come, however, the mainstream engine technology will be based on diesel or 'diesel like' combustion. This will require:

- more developments in conventional diesel engines: increased importance of fuel cleanliness (FAME related, impurities) and tighter fuel specifications may be needed;
- new combustion concepts: new fuel characteristics may become important, such as volatility, ignition behaviour and oxygen content;
- dual fuel concepts: for example, methane (biogas, LNG/CNG) as the main fuel, with diesel fuel as an ignition enhancer; and
- optimised and sustainable biofuels: well-specified bio-products from non-food sources, methane and oxygenates (for example dimethyl ether, DME).

Increasingly, specially-adapted engines for new fuels and for new energy carriers will enter the market. By adapting the combustion system, the unique characteristics of, for instance 'single molecule' fuels, like alcohols, DME and methane, can be fully utilised.

The well-to-wheels performance (energy efficiency and CO_2), as well as the availability of a large and sustainable raw material base for fuel production, will be key to the success of any biofuel in the future. Volvo considers biomass gasification, with subsequent synthesis to DME, to be a very promising route to lower-CO_2 from transportation in the future. A test fleet of DME vehicles has been running successfully in Sweden over the past few years and DME activities are now being carried out by Volvo in the USA together with industry partners.

Author: Anders Röj

Anders has been working in fuels and lubricants for more than 30 years and joined Volvo Technology in 1989. Before that he worked on FCC catalysts (Katalistiks BV) and additives for fuels and lubricants (Esso Chemical/Paramins). His present role within Volvo Group is as technical and policy advisor for fuels and energy related issues.

Anders is heavily involved in external industry groups, including ACEA WG F&L (Chairman since 2001), EUCAR EG Fuels, CEN TC19 and CEC (Chairman since 2013). He has an MSc degree from Abo Akademi and Licentiate Engineering degree from Chalmers University in Gothenburg Sweden.

Transportation and fuels: looking ahead at aviation

Aircraft and engine designers have always tended to assume that jet fuel is jet fuel. Could there be fuel changes to respond to environmental pressures that would still allow the industry to expand?

After more than a century since the Wright Brothers took off, we have become accustomed to the conveniences and inconveniences of air transportation. As high speed rail and slower options, like long distance buses and ships, find their place in our transportation future, advanced aircraft will continue to play an important role for the foreseeable future—and they will need to be fuelled! Our growing global population seems likely to demand more and more rapid transportation over great distances unless technology offers viable alternatives, for example through virtual communication, or we have stay-at-home vacations and greater patience in receiving ordered goods.

Compared to road vehicles, new aircraft, like the Airbus A380, the Boeing Dreamliner and others, have long working lives and will be a major part of the global fleet 40 years from now. Today's aircraft and those in the design stage have been developed with certain assumptions about the properties and availability of the fuel that will power them. The sheer amount of fuel that must be on-board, often more than 30% of the plane's take-off weight, has a major impact on the airframe's centre of gravity, the strength of its structural components, and its overall performance. Even if a significantly new and different fuel from today were readily available at all airports, retrofitting aircraft to work with this fuel would be difficult. Completely new aircraft and engine combinations, with a new fuel supply and distribution infrastructure, probably would be needed to use such a fuel.

This has massive implications—and costs—that will probably discourage the emergence of a very different type of aviation fuel from today's liquid hydrocarbons, unless major performance advantages and the 'it must work everywhere' model for fuels and aircraft are put to one side. However one looks at it, aviation demands more from its fuel than do ground, rail or marine transportation: most of the alternatives being considered in other transport sectors simply will not fulfil the performance and safety requirements for aviation. Liquid hydrocarbon fuels, either from crude oil or from advanced renewable sources, will remain the main aviation fuels for the foreseeable future.

The path to today

The earliest manned flights were powered by motor gasoline, later replaced by a high octane aviation gasoline (avgas). Then Whittle designed his first jet engine to run on lamp kerosine, a petroleum product that took over from whale oil—a commodity that was renewable but hardly sustainable in today's terms. Within a further 20 years or so, jet engines had taken over the market from piston-engined aircraft and large volumes of jet fuel were needed to fuel the growing fleet. For the next 40 years, jet fuel properties were continuously improved as jet engine technology matured. From a fuel perspective, crude sources were expanded and new refinery processes were introduced while the relative demands for gasoline and diesel affected which refinery streams were available for jet fuel production.

The first major change in fuel thinking occurred in 1999 when the first semi-synthetic fuel, using Sasol's coal-to-liquids (CTL) kerosene, was approved for jet fuel blending. Two additional steps occurred a decade later when up to 50 vol% Fischer-Tropsch (FT) synthetic paraffinic kerosenes (FT-SPKs) were approved followed by similar levels of HEFAs (hydroprocessed esters and fatty acids). Change is speeding up with Shell now making commercial Jet A-1 fuel using Gas-to-Liquids (GTL) paraffins and others making HEFA blends also being used. Although these products are today's preferences, other novel candidates covering a broader range of hydrocarbons are in various stages of the international approval process for future jet fuel use.

Drivers for change

What will drive fuel changes—and what will slow them down—in the next 10 to 40 years? Until quite recently, the principal driver for changing jet fuel was improved safety, with security of supply the only other serious concern. In fact, supply security was the main reason that South Africa pushed for approval of CTL products, to ensure that the rapidly expanding business of flying from South Africa would not be limited by fuel availability. This was also the driver for the US Air Force's (USAF's) later initiative to approve FT fuels. Much of today's progress with new fuels, including a robust ASTM process to approve and certify them, is thanks to these early efforts by Sasol (with support from the UK's Ministry of Defence) and by the USAF.

Today, fuels must still be technically robust (safe) but, increasingly, their production should be sustainable and help to limit the aviation sector's CO_2 footprint. And, because aircraft emissions contribute to the air quality around us, from ground level to the stratosphere, the sky is indeed the limit for the future of aviation fuels, in a very literal sense.

Aviation today

By volume, more than 99% of worldwide aviation fuel today falls into the 'jet fuel' category. Most piston engined aircraft, however, fly on leaded aviation gasoline (avgas). It too is under pressure to adapt. Environmentalist and other organisations have called for the removal of lead and the Federal Aviation Authority (FAA) have created the Piston Aviation Fuels Initiative (PAFI). The US-driven FAA's 'Aviation 2025' programme is targeting 2018 for an unleaded replacement to be available that is usable by most general aviation aircraft. The avgas community are responding, with various groups and individual oil companies working on appropriate test procedures and/or fuel formulations to replace avgas fuels with ultralow or zero lead content alternatives.

Europe imports about a third of its jet fuel and may need to import more in the future, particularly from the Middle East and India, as the European refining footprint is shrinking. While global demand continues to grow, jet fuel manufacturers are under increasing pressure to reduce jet fuel's CO_2 footprint to ensure future sustainability and reduce the impact of the aviation sector on global warming. This is a market, however, where security of supply and fuel price sensitivity are extremely important. Anything that can reduce overall fuel burn will also reduce fuel demand and contribute to CO_2 reduction; 'sustainability' of the fuel is desirable but not the only way to achieve these outcomes.

In 2009, the International Air Transport Association (IATA) published ambitious CO_2 reduction targets for the aviation sector, including: improving fleet fuel efficiency by 1.5% per year to 2020; capping net emissions from 2020 onwards through carbon neutral growth; and halving carbon emissions by 2050 compared to 2005. Four pillars of activity were identified to enable these outcomes: efficient ground and sky operations; improved engine and airframe technology; effective infrastructure; and new technologies including biofuels. History has shown that aircraft efficiency has improved dramatically with each new generation of airframes and engines, and improvements to air traffic control and flight patterns can make important contributions without aircraft changes. In June 2012, the 'Perfect Flight', made by Air Canada and Airbus, included optimisation of every aspect of a flight as well as the use of a 50/50 HEFA/jet fuel blend; it resulted in a 40% CO_2 saving compared with normal operations.

Among the latest aspirations are those of the European 2020 and 2050 Flightpath Projects, which include the Advanced Biofuels Flightpath objective of producing 2 million tonnes of sustainably produced biofuel per year by 2020. Equally ambitious projects exist in other parts of the world with similar timescales and similar challenges. The latest Flightpath update (August 2013) envisioned nine biofuel production plants, with some expected to be operational by 2015–2016. From a fuel manufacturing perspective, however, the timing and volume of biofuel production are almost certainly too ambitious to achieve either IATA's or Flightpath's objectives. Interesting technologies are emerging but they will take more time to develop and attract the required major investments. Clearly, industry, regulators and bankers must continue to work together to identify viable technical and business solutions for the longer term.

The future—what can we expect?

The further we look ahead, the less likely we are to predict what will actually happen. Instead, scenario planning can describe a range of potential future possibilities as well as the uncertainties within them. Several groups have completed such scenarios and these provide some general conclusions on what can be anticipated in the next 40 years or so.

Jet fuel products

Aviation fuel producers know how to make on-specification fuels by traditional methods and get them to their point of use in large volumes. Previously this meant that jet fuel was only produced from crude oil or similar starting materials but this has changed with the approval of semisynthetic components. While FT and HEFA fuels can be made from at least one feedstock today, it is almost certain that feedstocks will continue to diversify in the future, although not without considerable research, development and engineering (RD&E). Gasification of solid feedstocks for FT processing can be complicated, and natural oils for HEFAs can require costly pretreatment and tailored processing. Algal oils are an interesting future source of hydrocarbons for HEFA production because they have the potential not to compete with food stocks and could help deal with CO_2 emissions from power and industrial units. These oils, however, present considerable challenges and much more RD&E is needed.

Looking forward, processes that make 'drop in' replacements for jet fuels seem most likely to be approved for aviation use in the nearer term. Candidates today must be approved by following the ASTM D4054 plus ASTM D7566 route, and are all kerosene-type fuels. Chemically, most contain only a subset of molecules normally found in petroleum jet fuels and the D4054/D7566 approval approach would allow them to be blended and introduced into commercial Jet A or Jet A-1 at up to 50 vol%.

New fuel concepts are in various stages towards D7566 approval and task forces have been formed to progress them through ASTM. Those closest to approval are the FT SPKs with aromatics (e.g. Sasol). There are also two classes of alcohol-to-jet products based on ethanol or other alcohol precursors. One class makes SPKs (e.g. Gevo, Cobalt, Swedish Biofuels/Lanzatech) while the other class makes aromatics (Byogy). Other products start with sugar but avoid an alcohol step. For example, Amyris's 'direct sugar to hydrocarbons' (DSHC) route produces a single branched alkane called farnesane. There are also synthetic kerosene (SK) and aromatic (SAK) products from aqueous phase reforming of sugars or cellulosic feedstocks (Virent, partnered by Shell).

Hydrotreated depolymerised cellulosic jet (HDCJ) fuels (e.g. Kior, UOP, Licella) are aromatics-rich products made by pyrolysis of lignocellulosic feedstocks such as corn stover, switch grass or forest waste. Catalytic hydrothermolysis (CH) products (e.g. ARA, ReadiJet) are made from animal and vegetable oils, as are HEFAs, but produce a full range synthetic product with aromatics. Swift Fuels makes an aromatic product potentially from bioderived acetone, but this process is not as advanced as others that are already in the approval process. Some technologies being submitted for ASTM endorsement will target a blending level much lower than 50 vol%.

Co-processing options are also being considered: can vegetable or other non-petroleum oils be processed with crudes or distillate streams in conventional refinery units? This approach could substantially reduce capital investments while retaining the economy of scale, although process unit reliability could be a challenge.

With only minor modifications, turbine engines can run on a variety of fuels so 'drop in' fuels may not be a limiting factor in the longer term. Nevertheless, many compromises would still be required, depending on the specific fuel of choice. Technically, aircraft could use cryogenic fuels such as liquefied natural gas (LNG) or hydrogen but these would require radical redesign both of the airframe, to accommodate large-volume cryogenic tanks, and the fuel supply infrastructure. While we do not have much insight into the potential environmental benefits or economics of these alternatives, the current state of R&D in these areas suggests that non-drop-in aviation fuels are unlikely in the short to medium term.

Feedstocks

While more ingenious ways are found to use fossil fuels, biomass fuel production will also get more attention. In addition to Fuel Readiness Levels, various groups have already defined Feedstock Readiness Levels. There is considerable activity focused on growing the 'best' feedstock for a given set of conditions, maximising yields, optimising land and water use, and improving farming methods and agrochemicals, for all sorts of conditions and crops. Crops that perform well on poor land, like salty soils, are particularly attractive, and this is an area where local interests may see actual or 'in kind' subsidies.

There are also considerations about the best ways to harvest, store, dry or treat materials and then get them to upgrading units; few biomass products can be put through industrial scale process units without some pretreatment and concentration steps. Pyrolysis routes could be particularly appropriate for making biocrude that could then be upgraded by conventional refinery processes, with little or no alteration.

Manufacturing

Manufacturing petroleum-derived jet fuel will continue to change, partly to increase refinery flexibility and partly to accommodate heavier crudes. Improvements will be made to FT processes, through new catalyst technologies, and new solid feedstocks will be found to make FT syngas. For example, BA's work with Solena is looking at producing FT fuel from municipal waste, although the fuel production facility build has yet to start. Other feedstock and gasification routes to syngas are bound to emerge, e.g. the new SOLAR-JET route, and these would add to the FT SPK product pool.

In general, economics should improve with process scale-up but there may be new business models that confound this, allowing smaller production units to be built though not necessarily ones designed to make the final jet fuel. Co-processing options, where some fuel precursor is brought to an existing refinery to go through one or more upgrading steps and distillation, may make sense for economics, product quality control and distribution to airports via existing infrastructure.

Approval process

Continuing revisions of the ASTM and military approval processes will be needed. The D4054 standard will be amended, adding in new materials and test methods, removing redundancies, etc. while the D7566 standard will add more annexes to cover more production pathways. In the short to medium term, however, this standard could transition from one that specifies 'neat' blending components to one that also specifies final blends; this would benefit some options such as the co-processing of biomass-derived products. Moving forward, looking for low % approvals, say up to 5% volume, may make it easier to introduce new materials using a shorter version of the D4054 process.

Russia and other CIS countries do not yet approve non-crude derived fuels in their jet fuel specifications but this is certain to change, probably in the next 10 years and as indicated by a Russian biojet feedstock conference being organised. These countries may choose to follow the ASTM process or develop new processes that are more suited to their own operations. China has just approved its first biofuel using the D7566 route into its international specification.

Sustainability

More biofuel feedstocks will be identified and there will be new processes and more ingenuity to convert these into usable components for aviation fuels. Sustainability criteria at all points in the production, conversion and distribution systems have been proposed and adopted, for instance by the Roundtable for Sustainable Biofuels, but these will need regular revision. Without appropriate intervention, parallel certification systems could develop in different parts of the world, creating artificial constraints as well as challenges to ensure that criteria stay aligned. The same is true for the criteria being used to evaluate the 'well-to-wake' equivalent CO_2 impacts for jet fuels. While existing well-to-wake models have much in common, land-use change effects, both direct and indirect, are not included in all.

Aircraft and engines

Next-generation aircraft and engine combinations will continue to enter the market. Those that will appear in the next 10 years, such as those using geared turbofans, are well on their way to commercial introduction. Those concepts that are 20 to 40 years in the future are either on the drawing board or in brainstorming within the aeronautical R&D and OEM communities.

Governments

Individual or aligned governments can, and probably should, play a role. Do governments believe in the aviation sector as an employer and a tool for economic growth? Will they fund the necessary R&D or do they expect that incentives, penalties and taxes will drive efficiency and the growth of sustainable jet fuel? Do they support alternative approaches? Will governments and aviation groups continue to demand sustainability if new fuels are much more expensive than traditional petroleum-derived fuels?

Environmental emissions

How will aviation emissions affect the atmosphere in the long term? While CO_2 is a clear climate 'warmer', the full impact of other, non-CO_2 emissions from aircraft are less certain. Aircraft emit water, SO_x, NO_x, smoke, unburned hydrocarbons, etc. and these contribute to atmospheric chemistry that is location-sensitive, including the formation of contrails, cirrus clouds, etc. Because CO_2 persists longer in the atmosphere, this may be a valid reason to focus first on CO_2 reduction knowing that other emissions will also be reduced with better fuel consumption. However, as we move to the sustainable fuels, which when burned generally produce far less SO_x and soot but more water, should we be accounting for the non-CO_2 impacts in our assessment of what is an acceptable fuel, and not just looking at the CO_2 well-to-wake life-cycle assessments? Several R&D groups have started to consider this issue.

Aircraft and engine designers have always tended to assume that jet fuel is jet fuel. Could there be design-driven requests for fuel changes that would improve safety, performance and efficiency of future aircraft? Will airports put in place requirements that would encourage the use of cleaner fuels? Improved local air quality could be a driver for changes in both jet and avgas formulations.

Future challenges

There will be many! If history is any guide, serendipity, politics and at least one economic slump can be expected over the next 40 years, but when, where and how is not predictable. The availability of potential feedstocks could become unreliable or endangered if there are longer-term periods of floods or droughts. This possibility may favour biofuel upgrading plants that are either portable and/or flexible, to reduce the impact of climate on production.

Will sustainable fuels be the only new fuels introduced? Or will pragmatism mean that any new fit-for-purpose fuel will be acceptable, in the face of fuel demand, economics and supply security concerns? Will alignment between fuel grades continue to be important or will there be a push to focus some fuels on specific parts of the world, perhaps with constraints on flight patterns and greater airplane servicing needs? Will the water-food-energy 'stress nexus' dynamic described by Shell[1] create an environment where significantly different factors drive aviation developments? In a world demanding more and more energy, aviation is one transport mode with little scope for alternatives to liquid fuels. In this future, will the aviation sector go up instead, say, towards space travel?

Future aviation fuels will depend on many factors, with uncertainty bound to play an important role. Let's just hope that fuel technology remains fit-for-purpose, with opportunities to redesign aviation airframes and engines for better fuel properties, and that worthy projects receive the funding they need to enter a competitive market.

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1 Peter Voser (2012). A talk on the theme of 'The Energy Water Food Stress Nexus' delivered at the headquarters of the Royal Geographical Society in London as a part of their discussion series on *21st Century Challenges*. 12 December 2012.

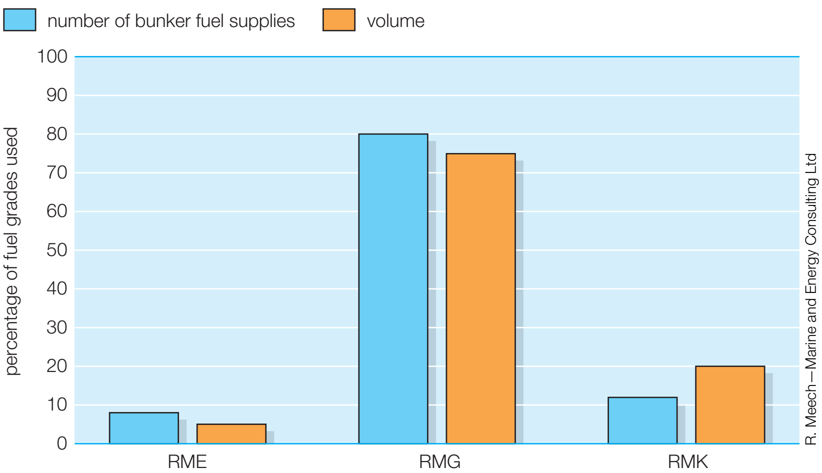
Transportation and fuels: looking ahead at the future of marine fuels

The International Bunker Industry Association (IBIA) takes a look at where we have come from, where we are and the possibilities for marine fuels in the years to come.

The global marine fuel market is generally accepted to be about 250 million tonnes per annum (pa). Today's marine fuel would be recognisable to those who bought, sold and used marine fuels for the past 70 years, except for new requirements a few years from now to reduce sulphur content. The storage and delivery logistics are fundamentally the same, and the worries, concerns and attitudes of the users are unchanged (chief engineers have always complained about poor quality fuel). Most of today's market is for residual fuel categorised as ISO grade RMG380. Almost all ocean-going ships over 5,000 deadweight tonnage (dwt) use this product as their main fuel grade. An increasing number of larger ships are now using heavier, more viscous fuels such as the RMK grade, that are proving to be more economic.

The fraction of vessels that are fuelled with lighter residual fuels is decreasing; the ubiquitous ISO RME180 fuel (180 cSt grade) used by general cargo vessels of the 1970s has been largely replaced by the RMG380 grade for all but the most demanding engines. The demand for distillates, once heavily biased towards heavier diesel and blended diesel, is now concentrated on gas oil of ISO grade DMA (Figure 1). The majority of vessels use this for their auxiliary machinery (only 10% of the vessel's total requirement) but almost all fishing vessels, seismic, offshore, warships, small coasters and high speed craft use distillates as their only fuel grade. The international marine distillate requirement today is about 40 million tonnes pa. This volume will increase dramatically when the regulations requiring the use of 0.1% sulphur fuels at sea come into force in specific regions in 2015. This will have a significant effect, because it will require ships to switch between residual and distillate fuels when entering and leaving an emission control area (ECA). These regulations have three main effects on the market: (1) the imposition of more fuel grades, with most grades split into high and low sulphur; (2) the need for segregation of on-board storage; and (3) an estimated 40% increase in fuel cost based on today's cost difference between residual and distillate fuels. The use of very low sulphur fuels (below 0.1% S) in certain areas is also leading to complications with the management of fuel storage and on-board systems. This is because operators must store a wider range of fuel types and manage the changeover process from fuel oil heated to over 140°C at the engine and distillates which may need to be chilled to 30°C.

Figure 1 Most common residual fuel grades (globally, 2012)



In January 2015, sulphur limits in ECAs will be mandated from 1.0% S down to 0.1% S. Besides managing the temperature at changeover (as described above), the operators must also manage the increase in distillate fuel costs and change the allocation of on-board storage to manage much higher volumes of distillate than were needed when the vessels were built. A typical oil tanker or bulk carrier of 100,000 tonnes dwt would have been built with storage for 2,500 m^3 of residual fuel and about 250 m^3 of distillate fuel. This will need to be reconfigured to about 1,800 m^3 high sulphur residual and 700 m^3 low sulphur distillate, in addition to the existing 200 m^3. This conversion will be needed to accommodate today's ECAs and allow for the expected classification of additional ECAs in the future.

Changes in the bunker market are initially linked to variation in global trade. It is anticipated that growth will reflect the expected increase in global GDP of about 4% pa over the next 5–10 years, according to the International Monetary Fund (IMF)[1]. The resulting increase in tonne-miles is predicted to grow at a slightly slower rate influenced by many factors including changing domestic/export ratios in major developing economies and shorter vessel routings. The marine

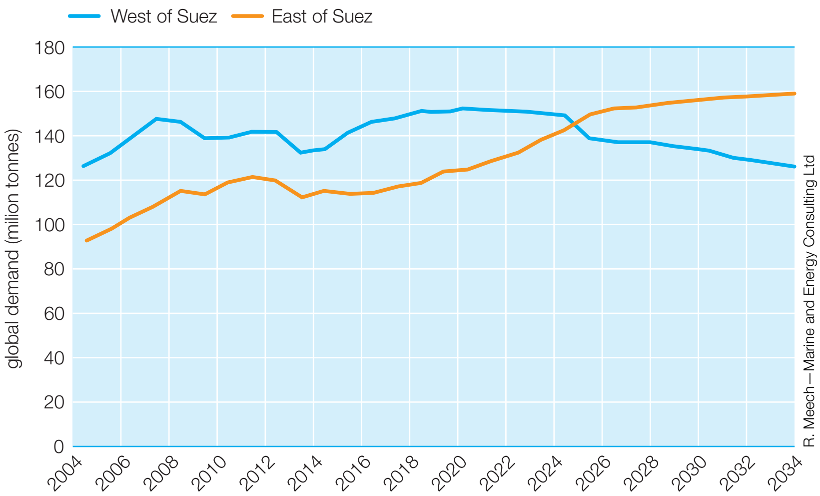
[1] IMF, *World Economic Outlook: Hopes, Realities, Risks* (April 2013); *World Economic Outlook: Transitions and Tensions* (October 2013).

fuels market growth will be lower than this, at about 1.6% pa over the next decade, reflecting the reduction in the age of the world fleet, newer ships being more efficient than older ones, improvements in ship efficiency recently mandated by International Maritime Organization (IMO), and the continued use of slow steaming as one important tool in reducing carbon dioxide levels. The higher price of bunkers, particularly lower sulphur fuels, will mean that the most fuel-efficient operators will survive. Over the coming decade, growth will be less than 2% in the market for residual and distillate bunkers because of slower trade flows, and the fuel efficiency of vessels will further improve. (LNG is likely to be less than 5 million tons in 2023, so not a real cause of reduced conventional bunker demand growth). We expect that the growth in marine fuel demand will be concentrated in the Middle East and Asia, while demand west of the Suez Canal will flatten at best and decline in North America (Figure 2).

The European and North American ECAs will increase global demand for 0.1% S by an additional 40–50 million tonnes of distillate. The minimum 60°C flash point for this product is expected to challenge refiners. While global availability will be adequate, some local difficulties are expected due to a mismatch between geographical demand and availability. This will require the movement of fuel cargos from one area to another with associated costs. The continued lack of consistency internationally on legislative requirements is a concern. For example, between 2014 and 2020, the industry must supply all residual grades with max 3.5% S, 1.5% S, and 1.0% S and distillate fuels with max 2.0% S, 1.5% S, 0.5% S and 0.1% S (Figure 3).

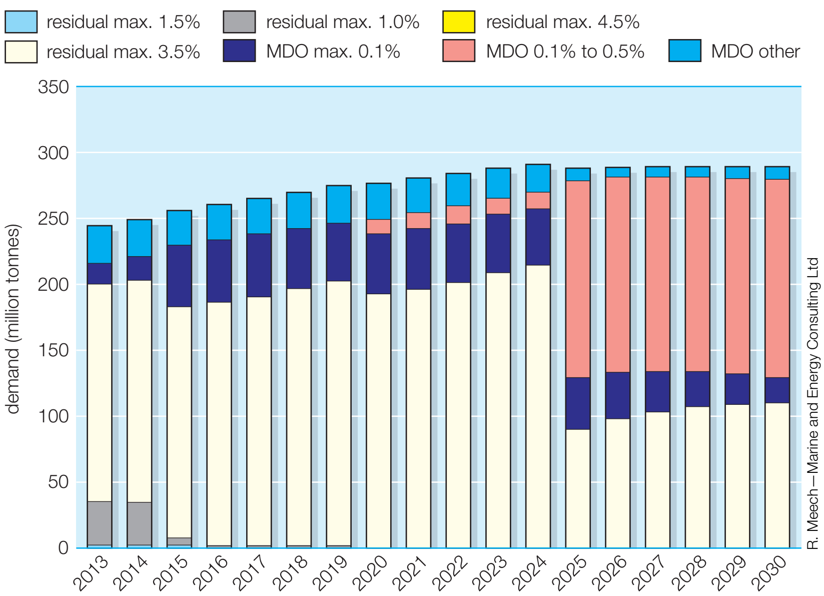
In Annex VI of the MARPOL Convention, the IMO requires that the global limit on marine fuel sulphur must be reduced from max 3.5% S to 0.5% S in 2020. At this time, this will effectively mean a switch from residual fuels to distillate fuels. However, the same Convention recognises the impact that the additional demand for 150 million tonnes of fuel could have on availability. Hence, the MARPOL Convention expects to complete a fuel availability study before 2018 with an option to defer the reduction in the global S limit from 2020 to 2025 if sufficient 0.5% S fuel is not likely to be available in 2020.

Figure 2 Global demand for marine fuels, 2004–2034



Unfortunately, IBIA is not in a position to answer this question, even though it is very important to know when sufficient product will be available to meet the demand. Indeed, the EU has already voted to switch to the new lower S limit in 2020 in all European Economic Exclusion Zones even though the IMO may choose to delay the introduction of the new S limit to 2025. The start date is obviously important because it will have an impact on ship, refinery and fuel supply investments.

Figure 3 Global demand for marine fuels by fuel grade, 2013–2030
Assumes 0.50% global limit implemented in 2025



Of course, R&D projects are looking at novel ways to produce 0.5% S blends, produce fuels from biomass and use conversion techniques to meet the market demand, but there is little optimism that these approaches can produce the commercial volumes required by the market in the short time available.

MARPOL limits on sulphur have focused to date on a global limit and on a special ECA limit for the fuel that is received on-board vessels. However, Regulation 4 of Annex VI allows the use of other techniques to achieve equivalent results, namely that ship emissions are at or below the level achieved when using fuel with the specified sulphur content. At the moment, the most common equivalent is aftertreatment of the exhaust (scrubbing) to permit the use of fuel with higher sulphur content. Exhaust gas scrubbing can be achieved through wet open-cycle scrubbers (salt water), wet closed-cycle scrubbers (fresh water with chemical treatment) and dry scrubbing (calcium hydroxide). These are all mature technologies but have some particular issues for the marine sector.

In addition to perceived technological risks in scrubbing equipment, investments have been limited because ship operators in ECAs can choose before 2015 between 0.1% S gas oil at about $900/tonne or invest in a scrubber and use higher-sulphur residual fuel at about $600/tonne. For a vessel operating in an ECA for more than 100 days pa, the payback time for the scrubbing investment is expected to be about three years. When the global limit has been fully introduced, all vessels will benefit by scrubbing higher-sulphur residual fuels rather than by consuming 0.5% S fuels that will be predominantly distillates and about $200–300/tonne more expensive on the basis of current market prices. There is also an interesting view that if scrubbing systems are fitted to most new ships in the future, then the demand for residual fuel, which is diminished in the near term by the adoption of lower sulphur distillate fuels, could have a resurgence. With continuing refinery investments to further convert low-priced residual to higher-value products, there may not be enough residual fuel available after 2035.

MARPOL also specifies limits for nitrous oxide (NO_x) emissions in ECAs. A combination of engine improvements and the use of selective catalytic reduction (SCR) will achieve the most stringent regulations which will apply to vessels constructed after 2016 operating in the

North American and Caribbean ECA. Technical issues associated with operating SCRs in combination with sulphur scrubbers are being addressed and seem unlikely to present major problems on future new ships.

The emissions regulations can also be met by using alternative fuels, most notably biodiesel and LNG. Biodiesel has significant cost disadvantages as well as some problems with long-term storage, microbial growth, and sensitivity to water and elevated temperatures, all of which are inherent in marine fuel systems. LNG is seen as the future fuel because it has far lower emissions than conventional fuels. In some regions, especially off the US coast, LNG could also be cheaper once the supply infrastructure is sufficiently developed to economically deliver LNG into ships' bunker tanks.

Under current IMO regulations, LNG can only be used by LNG tankers or when operating in restricted trade areas. This is being addressed by the IMO, which is producing a new set of rules for conventional vessels using methane as fuel with fuel storage as a cryogenic liquid. There are now more than 70 non-LNG tanker ships operating in restricted trade areas that are already storing and using LNG fuel. Many authorities see LNG as a significant solution for reducing energy and GHG emissions, some predicting that it will be used on up to 25% of new ships within the next 10 years. Much work is in progress on the supply infrastructure.

One worry for the shipping sector, especially in the ECA zones, is that pressure to use high priced 0.1% S gas oil will increasingly lead to intermodal shift, where cargo that is currently transported by sea will shift to land-based transport. While this could reduce the sulphur footprint for shipping, it will also result in a much higher overall GHG footprint, congestion on highways, and a higher burden on consumers and taxpayers. Shipowners will probably pick the 'least cost and best fit' option that meets their needs based on their own trading pattern.

Clearly, the bunker fuel industry is entering interesting times with tighter fuel specifications, shifting demand, and new fuel qualities and operating regimes. A transport sector that hasn't changed a lot over the past 70 years is about to experience the biggest change since the shift from coal to bunker fuels.

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Renewable fuels: looking ahead to 2020

Modelling realistic biofuel implementation scenarios to 2020

Increasing renewable energy and reducing GHG emissions from transport

It is widely recognised that mobility and transport are fundamental to satisfy socio-economic needs and curbing mobility is not an option. Demand for mobility and transport services is expected to continue growing in Europe until 2050, while at the same time a reduction in greenhouse gas (GHG) emissions from the sector of 60% compared to 1990 level is targeted.

As part of an ongoing strategy to address GHG emissions and energy use from transport, the European Union in 2009 enacted a package of regulations and directives intended to reduce GHG emissions from the transport sector. These included required improvements in the CO_2 emissions performance of passenger vehicles and light-duty vans, as well as the increasing use of renewable and alternative energies in transport fuels before the end of this decade. At the same time, there will be increased attention on even tighter limits for regulated pollutants. Legislation for new refuelling infrastructures for alternative fuels are expected to encourage greater diversification in both vehicles and fuels.

Two of these Directives are changing the composition of road fuels over the coming decade and beyond. The 2009 Renewable Energy Directive[1] (RED) mandates a 10% share of renewable energy in transport by 2020.

Advanced biofuel products are being developed that will be manufactured from biomass, like straw and wood. However, the biofuels that will be available in large volume by 2020 will either be ethanol fermented from sugars and starch, or esterified or hydrogenated vegetable oils and animal fats. Ethanol can be blended today at up to 10% volume in petrol (E10) while esterified oils, called fatty acid methyl esters (FAME), can be blended at up to 7% volume in diesel fuels (B7)[2]. Smaller volumes of speciality biofuel blends, like E85 or B100, are also available in some countries for specially adapted vehicles. The European Committee for Standardization (CEN) is constantly working to revise the EU-wide fuel standards and ensure that they remain 'fit for purpose' for use in European vehicles.

At the same time as the 2009 RED was enacted, the Fuel Quality Directive[3] (FQD) mandated that fuel suppliers must also reduce the GHG intensity of transport fuels by 6% in 2020 compared to a 2010 baseline. Although efficiency improvements in the fuel manufacturing process can contribute to meeting this target, the growing and increasingly disparate gasoline and diesel demand means that the majority of this GHG performance improvement must be achieved through biofuel blending.

Although the 2020 RED and FQD targets have been clearly stated, the path to achieve these targets has not, and has largely been left to Member States and the transportation sector to work out. Each Member State documented in 2010 how they intend to meet their specific obligations through National Renewable Energy Action Plans (NREAPs). These plans varied significantly from one country to the next depending upon the specific weights of each country's transport components, the energy policy priorities, and the availability of alternative energy options.

The 2011 JEC Biofuels Programme

Understanding technically achievable options for meeting both the RED and FQD mandates is a complicated task. With different priorities and pace of implementation in each Member State, the potential for increasingly uncoordinated changes in fuel blends and vehicle types is considerable, which could make it even more difficult to achieve the 2020 targets.

Before the 2009 EU legislative package was enacted, the three partners in the JEC Consortium—the Joint Research Center (JRC) of the European Commission, the European Council for Automotive R&D (EUCAR)

[1] Renewable Energy Directive (2009/28/EC)

[2] Biofuel contents are expressed as the percentage of bio-component in fossil fuel on a volumetric basis. For example, B7 stands for 7% v/v FAME in diesel fuel while E5 stands for 5% v/v ethanol in gasoline.

[3] FQD = Fuel Quality Directive (2009/30/EC)

and Concawe (see page 8)—decided to look closely at this problem. This resulted in the first 'JEC Biofuels Study', published in 2011, which examined possible biofuel and alternative fuel uptake implementation scenarios for mass market fuels that could potentially achieve the 10% RED target for transport fuels by 2020. Using the scenario results and the FQD's GHG intensity default values for different renewable products, the 2020 GHG emissions reductions were also calculated associated with different biofuel blending options and volumes.

Nine scenarios were evaluated using reasonable assumptions for the development of the on-road vehicle fleet over the coming decade and the likely penetration of new vehicle technologies, such as plug-in hybrids, electric vehicles, CNG- and LPG-powered vehicles, etc. A reasonable contribution to the RED mandate was also assumed from non-road transport, including inland waterways, rail, aviation and off-road modes.

The 2011 Biofuels Study concluded that the reference scenario based on currently approved biofuel blends (B7, E5, E10) for broad market road fuels would almost meet the RED 10% renewable energy target. However, none of the considered scenarios achieved the minimum 6% GHG reduction target mandated in FQD Article 7a with the assumptions taken for the FQD calculations.

The 2013 JEC Biofuels Study update

In only a few years, much has changed. New legislative proposals have been introduced to revise the 2009 Directives. These included a new proposal by the European Commission in October 2012 (EC, 2012b), which was amended by the European Parliament in September 2013 (EP, 2013), and revised again by the Environment Council in December 2013 (CEU, 2013). Each of these legislative concepts for RED and FQD implementation have significant differences from the original legislation and from each other, and would therefore have an impact on the feasibility of achieving the 2020 targets in different ways. The main features of these three legislative proposals are compared in Table 1.

The FQD and RED Directives invited the European Commission to review and advise on GHG emissions associated with biofuel production and, if appropriate, propose ways to minimise GHG emissions while respecting investments already made in European biofuels production. A key factor in this review was the effect of so-called indirect land use change (ILUC) emissions.

In its October 2012 proposal the European Commission issued a new proposal to minimise ILUC emissions by incentivising advanced biofuels. This was to be done mainly by capping the contribution of biofuels produced from food crops, raising the GHG savings thresholds for

Table 1 Main characteristics of legislative concepts for the RED and FQD amendment

European Commission (EC) ILUC proposal, October 2012	European Parliament (EP) vote, September 2013	Council compromise proposal, December 2013
5% cap on 2011 estimated share of first generation biofuels (energy crops not included)	6% cap on final consumption in 2020 of first generation biofuels and DLUC/ILUC energy crops	7% cap on final consumption in 2020 of first generation biofuels and DLUC/ILUC energy crops
No sub-targets for advanced biofuels	2.5% target for advanced biofuels. MS obliged to ensure renewable sources in gasoline to make up 7.5% of final energy in gasoline pool by 2020	Voluntary sub-targets at MS level for advanced biofuels
ILUC factors in Annex VIII only for reporting by MS	Not required in MS reporting	MS required to report amount of biofuels/bioliquids from ILUC feedstock groups BUT only the Commission to use the ILUC factor in its report. Not required for reporting.
Multiple counting factors for non-ILUC biofuels	Single, double and quadruple counting for feedstocks in Annex IX Parts A and B	Double counting for feedstocks and fuels in Annex IX Parts A and B.

new installations, and incentivising the market penetration of more advanced biofuels. Importantly, ILUC emissions values were introduced for the first time for different crop groups, like cereals, sugars and oil crops, as a reporting obligation.

Because of these important developments, the JEC Consortium decided to update the 2011 Study by completely revising the vehicle fleet development, resulting fuel/energy demand, and biofuel blending assumptions. The 2013 Study (published in 2014) also widened the scope to analyse the potential effects of the legislative concepts put forward by the European Commission, the European Parliament and the European Environment Council in the RED and FQD amendment process.

The JEC Biofuels Study can be summarised as:

- analysing road transport energy demand and including an analysis of other transport modes;
- analysing possible fuel demand scenarios within the 2010–20 time period while focusing on potential market barriers to the uptake of alternative fuels;
- analysing the supply outlook of conventional and advanced biofuels and their projected availability on the European market; and
- consideration of other aspects, such as requirements for phasing in fuel standards, infrastructure requirements, fuel production and distribution, and customer acceptance of higher biofuel grades.

The 'Fleet and Fuels' model

To evaluate different biofuel implementation scenarios, the JEC team first developed a robust spreadsheet-based modelling tool called the 'Fleet and Fuels' model. This model is based on historical vehicle fleet data for the EU27+2 countries (including Norway and Switzerland) and was benchmarked against actual fuel consumption data from the 1990s and 2000s. The model allows independent inputs for seven types of passenger vehicles, including flexi-fuel, plug-in hybrid electric, battery electric and fuel cell, three classes of commercial vans, and five classes of heavy-duty vehicles and buses. Each vehicle type was described by reasonable parameters estimating the annual growth rate, typical annual mileage, vehicle fuel efficiency and years of useful life. Fuel alternatives were also considered for each vehicle type.

Outputs from the model included total vehicle fleet composition plus the projected demand for different fossil fuels, renewable fuels and alternatives. Because the RED counts renewable and alternative energy used in all transport modes, estimating the RED contributions that could be expected from railroads, inland navigation, aviation and other off-road uses was also important. Credible estimates from public sources for non-road transport demand were evaluated so that the RED percentage could be calculated for each scenario using the legislated formula.

The 'Reference Scenario'

With a model of this type, there is no limit to the number of biofuel implementation scenarios that can be tested. A Reference Scenario was assumed that represents a reasonable scenario based on already endorsed market fuel standards. Two gasoline grades are assumed, an E5 'protection grade' for older vehicles and an E10 'main grade' for most vehicles marketed since 2000. The experience from E10 introduction in Finland, France and Germany, has been used to include a realistic market uptake of E10 throughout Europe. One diesel grade was assumed, a B7 grade that can be used in all passenger and heavy-duty diesel vehicles. A small contribution for E85 from flexi-fuel vehicles was included as well as reasonable assumptions for the development of alternatively-powered vehicles including plug-in hybrid and battery electric, and vehicles operating on gaseous fuels, including hydrogen.

All of the vehicle, fuel and biofuel data were re-evaluated and updated in the 2013 Study. The model was then used to estimate the biofuel demand volumes and their overall contribution to the RED mandate. Figure 1 shows that this Reference Scenario would require about 15 Mtoe/a of FAME for diesel blending and about 5 Mtoe/a of ethanol for petrol blending. The contribution to the RED target from road use only is about 7.9% with an additional approx. 0.8% contribution from non-road transport modes. Thus, the Reference Scenario is projected to fall short of the 10% RED target using quite optimistic assumptions about the pace of advanced biofuel implementation and the willingness of customers to select fuel grades containing higher biofuel contents. Significant questions must also be addressed related to implementation costs, implications for refining and the fuel supply and distribution system, and the availability and certification of sustainable biofuels.

Beyond the Reference Scenario

In addition to the Reference Scenario, three other biofuel implementation scenarios were evaluated that assume different total fuel demand composition using an assumption of fuel grades that are not on the market today. There are two main differences between the Reference Scenario and the three fuel demand scenarios: (1) the market introduction of E20 gasoline blend and (2) the market introduction of a B10 diesel blend for captive fleets representing a small fraction of the total heavy duty diesel demand.

Scenario 2 assumed that an E20 blend could be introduced into the market in 2019. All gasoline vehicles sold in 2019 are therefore assumed to be E20-compatible and from 2019 onwards all vehicles from 2018 and older would be E10 compatible. The same market uptake assumption is used as for the introduction of E10 in the Reference Scenario.

Scenario 3 assumed that the B10 diesel grade for captive fleets is introduced representing 2.5% of the total heavy duty diesel demand. Scenario 4 is a combination of Scenarios 2 and 3. All other assumptions were kept the same in order to fairly compare the various regulatory proposals. The results are compared in Figure 1.

Figure 1 Fuel blend scenario results for 2020 from the 2013 JEC Biofuels Study

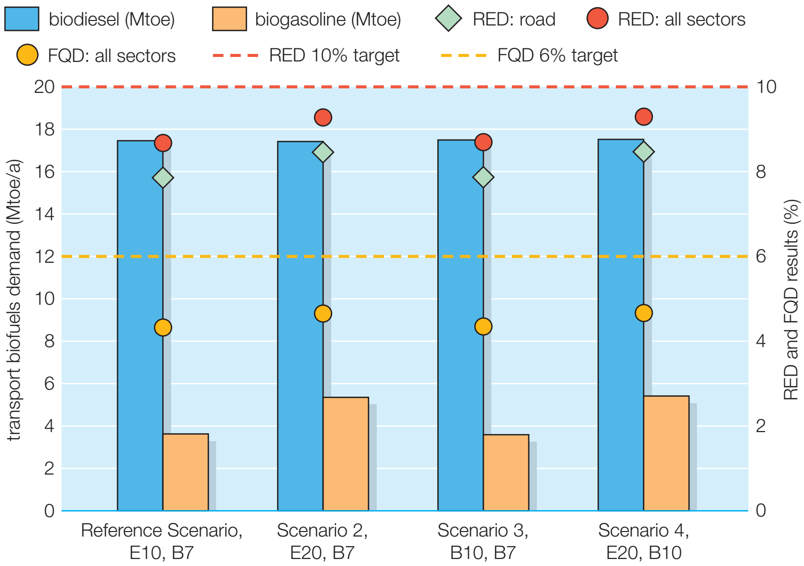

Figure 1 shows the demand in Mtoe/a[4] for ethanol and FAME in 2020 for the reference scenario and three additional biofuel implementation scenarios, together with the projected contributions for renewable energy percentage from on-road use and from all transport uses.

Conclusions from the 2013 Biofuels Study

The new results show lower attainment levels than the JEC Biofuels Study 2011 (Table 2). The old reference scenario indicated a level 9.7% renewable energy content (against the RED target of 10%) compared with 8.7% in

Table 2 Comparison of RED and FQD results from v2011 and v2014

For Reference Scenario:		RED	FQD (without IUC)	FQD (with ILUC)
Target:		**10%**	**6%**	**n/a**
2011 JEC Biofuels Study	2009 RED and FQD	9.7%	4.4%	n/a
2013 JEC Biofuels Study	2009 RED and FQD	8.7%	4.3%	n/a
	2012 EC proposal	7.8%	4.3%	1.0%
	2013 EP first reading	8.2%	n/a	1.0%
	2013 Council text	8.7%	4.3%	1.0%

[4] Mtoe /a = Million tonnes oil equivalent/year

the 2013 revision. Including default values for ILUC effects results in a less than 1% reduction in GHG intensity (against the FQD reduction target of 6%) due to a different biofuel blending. Several findings from the updated Study are especially noteworthy:

- the pace of development and the supply volumes of advanced biofuels assumed in the base case are not projected to be sufficient to fill the RED gap by 2020;
- multiple counting factors on different feedstock types are not enough to close the gap towards reaching the RED target;
- market introduction, customer preferences and acceptance to use available vehicle and fuel alternatives play an important role in approaching the RED and FQD targets;
- lower-than-expected vehicle sale trends point towards a slower renewal of the vehicle fleet resulting in an overall lower efficiency of the fleet stock and a limited uptake of alternative-fuelled vehicles, including electric and other alternatives, resulting in a bigger gap towards achieving the RED and FQD target; and
- the projected strong increase in the demand for diesel relative to gasoline for European vehicles will reduce the likelihood of attaining the FQD GHG intensity reduction target, because of the lower renewable energy content and higher GHG intensity of diesel compared to gasoline.

Additional considerations

This Study did not assess the viability, costs, logistics, or impact on the supply chain and vehicle industry of the different demand scenarios, and additional work would be needed to determine the technical and commercial readiness of any one scenario. Realising any one of these 'technically feasible' scenarios will depend on a combination of factors: the associated costs, and the timelines and coordination of decisions across the EU.

Given the turbulent state of policy considerations and the market factors that impact the JEC Biofuels Study analysis, the JEC partner organisations intend to continue to closely watch developments in this area, given the relatively short time before the 2020 EU renewable energy and GHG targets must be attained.

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Air quality and health: looking ahead

Over the years significant progress has been made in understanding the relationship between air pollution and health, and in reducing emissions and human exposure.

Evolving scientific insights over the past twenty years

The past twenty years have seen major changes in the techniques and findings of studies on air pollution and health, changes which set today's stage for looking forward to what remains to be learned. Beginning in 1993 and 1995, with the publication of the first modern population studies of long-term effects of air pollution in the Harvard Six Cities Study (Dockery *et al.*, 1993) and the American Cancer Society (ACS) Study (Pope *et al.,* 1995), a number of studies published in North America and Europe have found associations with premature mortality and other health effects at lower and lower levels of ambient air pollution (Hoek *et al.,* 2013).

These two studies have received intensive independent reevaluation (Krewski *et al.*, 2000) and extended analyses in these two cohorts (Krewski *et al.,* 2009; Lepeule *et al.,* 2012) have become the main contributors to national and worldwide estimates of the potential health impacts of air pollution. This work has in turn been used to support public actions to reduce exposure to air pollution in a number of settings. Most recently these studies and others of higher exposures have been combined into an integrated exposure response curve that has served as the basis for estimates of the global burden of disease (GBD) for outdoor air pollution. These estimates place outdoor air pollution in the context of larger health risk factors associated with smoking and diet.

This evidence and actions have been accompanied, at the same time, by substantial progress in reducing both emissions from the main sources of air pollution and ambient levels of air pollution. Industry innovation in fuels and vehicle technologies have resulted in significant reductions in individual source emissions. Many of these changes (e.g. US 2010 and Euro VI emissions limits for heavy-duty engines) promise continued progress as new technologies come into use and older technology is retired from the vehicle fleet.

Looking ahead—key questions remaining

In spite of this progress, a number of important scientific questions remain that deserve attention as governments worldwide consider what further actions, if any, they might choose to take. Some of the key questions are discussed below.

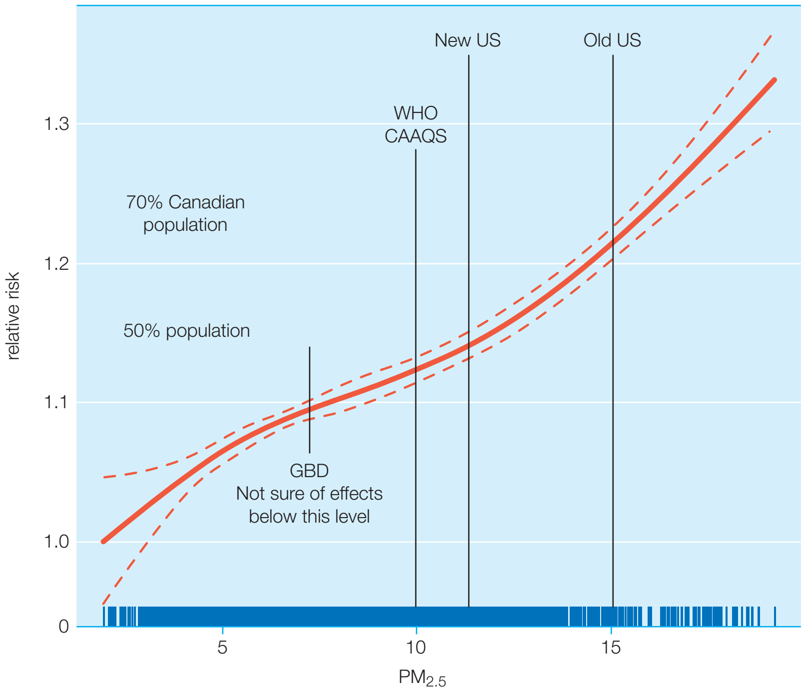
Can health effects really be measured at very low pollutant levels?

The world has seen a trend in both the developed and developing world toward lower ambient air pollution standards and the emission control measures that come with them. This has included the establishment of air quality guidelines for particulate matter (PM), ozone, and other pollutants by the World Health Organization, the setting of increasingly stringent US ambient air quality standards for PM and ozone, the establishment of $PM_{2.5}$ standards by the European Union, and the establishment of the first standards for $PM_{2.5}$ in developing countries such as India and China.

These actions have been accompanied by substantial reductions in air pollution, but, as governments consider further regulations, important questions about the robustness of effects at very low air pollution levels remain. In large measure, this is due to significant constraints on the statistical robustness of analyses done at the lowest levels of air pollution where fewer people are exposed. To address these issues for ozone, the Health Effects Institute (HEI) is supporting an extensive, multi-centre, controlled human exposure study of the effects of exposure to low levels of ozone on the cardiovascular system in 90 older subjects. This Multicenter Ozone Study in Elderly Subjects (MOSES) is designed to have sufficient rigor and statistical power to determine whether effects can be seen at the lowest levels.

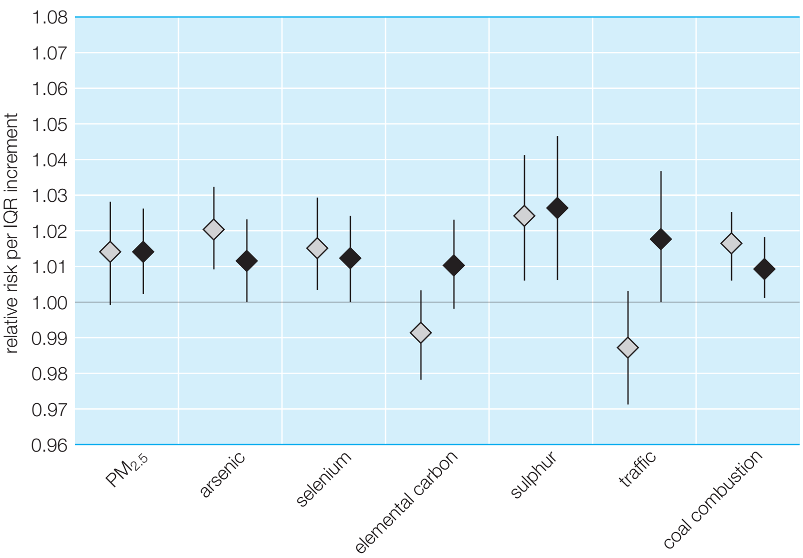
In the epidemiologic area, a new study of 2.1 million Canadians offered better statistical robustness and suggested evidence for associations between cardiovascular and other mortality causes at $PM_{2.5}$ levels as low as 8.5 µg/m^3 (see Figure 1). This level is well below even the current WHO air quality guideline. The Canadian study began to take advantage of emerging techniques for using big data to address these questions. It is only one study, however, and did not evaluate some important health-related information on the subjects (e.g. their smoking behaviour). Substantial new efforts to test this concentration-response relationship at these low levels will be important.

Figure 1 The shape of the Canadian concentration-response function for $PM_{2.5}$



From Burnett 2013, adapted from Crouse 2012

Figure 2 NPACT Study: relative $PM_{2.5}$ mortality risks from all causes



The results presented in Figure 2 are those that demonstrated the most consistently positive associations; the remaining results were not positive or significant. The grey and black diamonds depict results from the random effects Cox models without and with contextual ecologic covariates, respectively. Note that the IQR (interquartile range) varied by pollutant; e.g. the IQRs for $PM_{2.5}$ and sulphur were 3.13 µg/m^3 and 0.53 µg/m^3, respectively.

Are some PM components or sources more or less toxic?

PM is well understood to be a highly complex mixture of organic and inorganic components that are emitted from many sources. PM can be formed from both primary emissions and from secondary reactions with other gases in the atmosphere. One of the significant questions about the potential health effects of PM comes from this complexity of sources and composition.

A number of individual studies have used toxicologic or epidemiologic techniques to examine whether certain PM components or sources might contribute more to human toxicity than others, but no systematic, multidisciplinary approaches had been used until recently. In October 2013, HEI published results of its National Particle Component Toxicity (NPACT) study, which is the most systematic effort to date to combine epidemiologic and toxicologic analyses in an attempt to answer these questions. The NPACT study found health effect associations between secondary sulphate and, to a lesser extent, traffic sources (see Figure 2). But the HEI NPACT Review Panel, consisting of 14 experts who had no prior role in the study, concluded that:

> *"… the studies do not provide compelling evidence that any specific source, component, or size class of PM may be excluded as a possible contributor to PM toxicity. If greater success is to be achieved in isolating the effects of pollutants from mobile and other major sources, either as individual components or as a mixture, more advanced approaches and additional measurements will be needed so that exposure at the individual or population level can be assessed more accurately. Such enhanced understanding of exposure and health will be needed before it can be concluded that regulations targeting specific sources or components of $PM_{2.5}$ will protect public health more effectively than continuing to follow the current practice of targeting $PM_{2.5}$ mass as a whole."*
>
> (Lippmann *et al.*, 2013, Vedal *et al.*, 2013).

Clearly, more work and new approaches will be needed to continuously improve our understanding of the effect of $PM_{2.5}$ on human health.

What about health effects due to traffic exposure?

Although substantial progress has been made in reducing emissions from modern vehicles, many studies continue to assess the potential health effects of exposure to traffic. As HEI concluded in its Special Report no. 17, *Traffic-Related Air Pollution: A Critical Review of the Literature on Emissions, Exposure, and Health Effects* (HEI, 2010), only a small number of these studies were conducted in a way that accurately characterised traffic exposure. However, attention to the effects of such exposures is likely to increase as government officials in both the EU and USA turn to roadside monitoring of PM and nitrogen dioxide to measure compliance with ambient air quality standards. With this emphasis, there is a strong and continuing need for better techniques to accurately estimate population exposure to traffic, and to better understand the relative contribution of traffic compared to other sources. Recently, HEI solicited applications for studies aimed at 'Improving Assessment of Near-Road Exposure to Traffic Related Pollution' and has identified a number of studies of this important topic which are expected to move forward in the coming year.

What is the future of diesel vehicle technology?

Diesel engines have long offered significant power, endurance, and reliability benefits. In recent times, as GHG reduction issues have grown in importance, they are increasingly valued for their better fuel efficiency compared to gasoline engines. Emissions regulations in both the USA and Europe have also resulted in substantially lower emissions of regulated pollutants. There are, however, two important aspects where issues remain regarding the future of diesel engine technology in spite of this progress:

- Recent occupational studies of exposure to exhaust emissions from older diesel engines in mining and trucking environments have been cited by the International Agency for Research on Cancer (IARC) as a major rationale for upgrading diesel exhaust emissions from a probable human carcinogen to a Group 1 human carcinogen (IARC 2012). This escalation has resulted in careful scrutiny of the exposure in these studies and the suitability of these studies for quantitative risk assessment.
- Advances in new technology diesel vehicles, using diesel particulate filters, advanced NO_x control, and other enhancements, is substantially reducing diesel exhaust emissions compared to the older technology evaluated by IARC. These newer engines are being rigorously tested in the Advanced Collaborative Emissions Study (ACES) conducted by HEI and the US Coordinating Research Council. Initial results from this study have shown dramatically lower emissions and few health effects; final testing and analysis is in progress.

Together, these developments suggest that substantial progress is being made to advance the use of diesel engine technology. This can be done while also facing the developing world's challenge where vehicle regulations and fuel sulphur levels do not yet enable the introduction of the latest engine and aftertreatment technologies. The continuing need to document advances in these new vehicle technologies and fuels will be aided substantially by the upcoming publication in 2014 of all ACES' results for emissions and health, including rigorous comparison to health results from earlier diesel experiments. Continuing communication of these results will be required to ensure that the newest diesel vehicle technologies are introduced worldwide.

How do we know if we are making progress?

Assessing accountability of health outcomes

After more than 30 years of actions to improve air quality, one important question to ask is whether we can, after some time has passed, prove whether an action taken to improve air quality has had the predicted positive effects on ambient air pollution and health. This area of investigation has been growing in recent years, with HEI taking a leadership role in defining the field of health outcomes, or 'accountability' research. This has been done by defining the key approaches, and then funding and completing nine studies covering a range of interventions, from congestion charging zones to wood stove 'change outs'. These studies have included, for example, an analysis of London's congestion charging zone which found improvements in traffic but not in air pollution. Another study evaluated bans on coal use implemented across a number of Irish cities, and found that there was no improvement in cardiovascular health beyond that which could be attributed to broader changes in cardiovascular care and health, although there were improvements in air quality and respiratory health. HEI has four more similar studies in progress evaluating broader transport and stationary sources policies. These types of studies will play an increasingly important role as air quality regulations are tightened and the likely benefits of additional actions become smaller.

Progress, but there is more to be learned

The past decades have seen much progress in better understanding the relationships between air pollution and human health, and, importantly, in reducing emissions and human exposure. In spite of this progress, important scientific questions remain about exposures and health effects, and about the effectiveness of government actions taken to address these exposures and inform future decisions on air quality in Europe and the rest of the world.

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Dan is President and Chief Executive Officer of the Health Effects Institute (HEI), an independent research institute that provides public and private decision makers around the world with high-quality, relevant and credible science about the health effects of air pollution and at the air-climate interface. He leads HEI's efforts, supported jointly by government and industry to provide public and private decision makers—in the USA, Europe, Asia and Latin America—with high quality, impartial, relevant and credible science about the health effects of air pollution to inform air quality decisions in the developed and developing world. He has been a member of the U.S. National Research Council Board of Environmental Studies and Toxicology and vice chair of its Committee for Air Quality Management in the United States. He recently served on the NRC Committee on The Hidden Costs of Energy. He serves as well as Chair of the Board of the International Council on Clean Transportation (ICCT).

Dan has more than three decades of governmental and non-governmental experience in environmental health. He served as Commissioner of the Massachusetts Department of Environmental Protection from 1988 to 1994, where he was responsible for the Commonwealth's response to the Clean Air Act, as well as its award-winning efforts on pollution prevention, water pollution and solid and hazardous waste. He holds Bachelor's and Master's degrees from MIT in City Planning.

Robert is Vice President of the Health Effects Institute. He is responsible for management of key programmes, including the Institute's international programme to assess the health effects of air pollution in developing countries, and leadership in implementing HEI's ongoing research and review programmes on the health impact of particulates, ozone air toxics and other pollutants, and emerging technologies and fuels, including those driven by climate concerns. He oversaw the Institute's efforts to define and implement a programme of research on Accountability, a first-of-its-kind programme designed to understand the health impacts of environmental regulation. He is regularly called on to address prominent institutions, including the US Congress, the European Parliament, the National Academy of Science's National Research Council and Institute of Medicine and many other domestic and international bodies. Prior to coming to HEI he served for nine years at the Massachusetts Department of Environmental Protection, as Assistant Deputy Commissioner for Policy and Program Development and as Director of Planning and Budget. He is currently a member of the USEPA's national Clean Air Act Advisory Committee and is Chair of the Board of Directors of the Clean Air Initiative for Asian Cities.

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The future of water quality management for the refining industry

The refining industry has continued to respond to water-related environmental issues in a responsible manner and remains committed to doing so.

Introduction

It is often assumed that the environment is deteriorating due to continuous emissions from industry and that new adverse effects can be attributed to chemical mixtures and unknown substances in these emissions. This dogmatic thinking was probably correct in the late 1960s and early 1970s but, due to the reduction in those emissions and a better understanding of what is emitted by industry, it is unlikely to be the case today.

Europe's environment is probably better today than at any time since 1900, thanks to the enhanced environmental control measures taken by industry, both voluntarily and in response to the legislation developed in the EU. This is substantiated by the European Environment Agency in their 2010 report on the state of the European Environment[1] which states that, 'Considerable success has been achieved in reducing the discharge of pollutants to fresh and coastal waters, leading to considerable freshwater water quality improvements'. In turn this has contributed to the still increasing life expectancy in Europe[2].

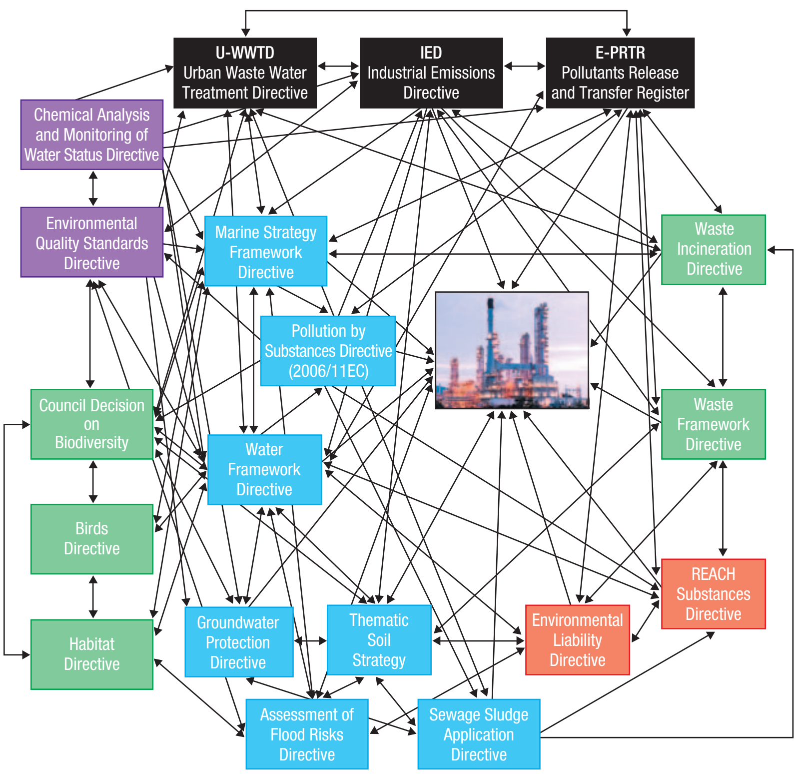


Figure 1 Main EU-Legislative frame controlling releases into the aquatic environment

The European Commission review (2012)[3] of the River Basin Management Plans (RBMP), that were required from Member States (MS) under the Water Framework Directive (WFD, 2000/60/EC)[4], recognised that Good Ecological Status (GES) and Good Chemical Status (GCS) have been achieved or maintained for many European water bodies. This demonstrates that the WFD has delivered several of its objectives before the specified final deadline of 2027. Consistent execution of the 2nd and 3rd RBMP cycles are expected to deliver further improvements.

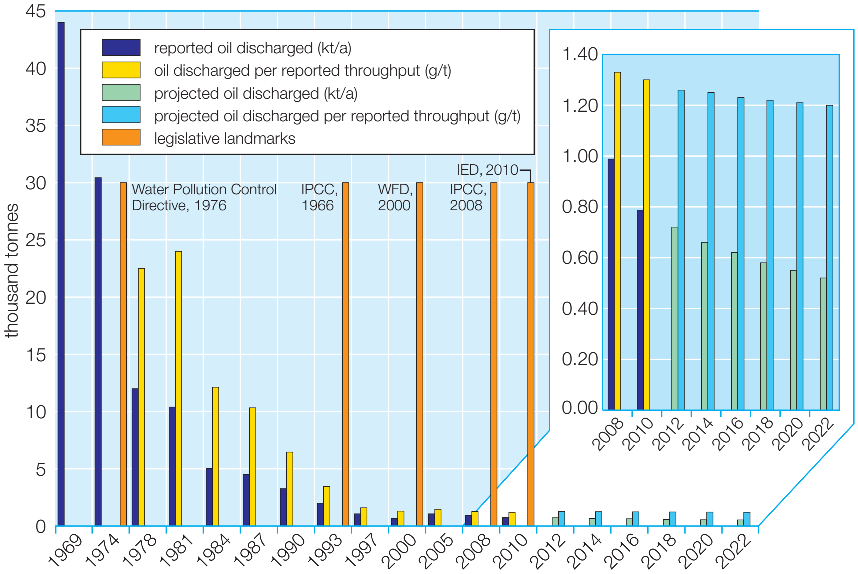
This article looks at emerging contaminants under the WFD from the perspective of the European refining industry, starting with a short description of the relevant legislative framework that covers discharges into the aquatic and soil environment, ultimately demonstrating that the potential for these discharges to cause environmental effects has declined significantly. An analysis of the impact of the sector on the GES and GCS is also provided for those RBMPs that have been completed.

The four main key environmental issues in the field of water that the downstream oil industry is facing in the near future are discussed and put into context on the basis of existing factual information.

The EU refining industry and water

In 2008, the 43 Concawe members operated 125 refinery locations with a total processing capacity of 840 million tonnes of crude oil throughput, equivalent to a ~90% utilisation rate. These refineries produce almost 40% of the total production of the EU petrochemical and chemical industry[5,6]. The water use in the refining industry is considerable. In 2010, the water discharges amounted to a total of 1,583 Mm^3 containing a total of 798 tonnes of total petroleum hydrocarbons (TPH) or 1.3 gTPH/tonne of crude processed[7]. These discharges are all subject to treatment before release and most (at 113 locations) are receiving a final biological treatment, whereas the remaining locations apply a final treatment with equivalent results, compliant with their permit requirements.

Figure 2 Trend in TPH discharges from the refining industry in Europe



There are several legislative and regulatory requirements which need to be met in order for industry to both produce within the EU and place their products on the EU-market. The requirements which are relevant to the protection of the aquatic environment are presented in Figure 1.

This total regulatory framework has all the required elements to adequately manage and control the desired environmental improvement to create a sustainable and diverse ecosystem that can provide the natural resources required to maintain and improve today's and tomorrow's living standards. The Commission concluded the consistent implementation of this framework by the MS is all that is needed to achieve this[8].

The two directives that have had the most impact on water quality are the WFD and the new Industrial Emissions Directive (IED)[9]. The IED aims at reducing emissions into the environment through the application of Best Available Techniques (BAT), an approach that has been embedded into EU legislation, since 1996 (Council Directive 96/61/EC).

Figure 2 shows the reduction in TPH emissions from 82 Western European refineries in 1969[7] to 116 refineries in the whole EU in 2010. These data show that the TPH emissions have been reduced from 45,000 tonnes in 1969 to only 798 tonnes in 2010. In 2010 all EU crude oil processing facilities reported their emissions. When looking at the growth in throughput over the past 40 years, the relative reduction of TPH emissions is well over 99%[7]. Whilst there is no hard data available before 1969, reports on the installation of emission reducing measures since 1955[10] are available and allow us to conclude that, even before the EU was founded and their regulations were introduced, the refining Industry took significant steps reducing its emissions to water.

Figure 2 also includes a projection of future reductions in TPH emissions, indicating that the relative emissions in grammes per tonne is not likely to reduce further. The projected total mass reduction is therefore most likely to result from the sector's response to the economic situation, leading to a sector rationalisation including changing refinery activities at current locations to distribution only[11].

Returning to the WFD and the published RBMPs, Concawe has evaluated the status of the River Basin Districts (RBDs) where the refineries are located. RBMPs have been published covering 88 refinery locations. Of these, 38 are located in RBDs that fail GES, and 53 fail GCS for surface water. A further in-depth analysis of the RBMPs associated with those RBDs, revealed that only 5 RBD failures could possibly be linked with past refinery emissions.

For groundwater the equivalent numbers are 44 failures related to GCS and 18 related to Good Quantitative Status (GQS). Again, the analysis of causatives that lead to these status failures revealed that potentially 5 refineries may have had an impact on two groundwater bodies, as 4 are located on the same groundwater body. From this analysis we would conclude that the refining industry can best improve the status of failing water bodies by focusing on these few whilst maintaining the good performance of the remaining refineries.

The above demonstrates that the refining industry has taken significant strides to improve the quantity and quality of their discharges and that the contaminant levels obtained by current water treatment do not give significant cause for concern. Therefore, Concawe trusts that the Competent Authorities will focus on the real causes that have to be managed today, to obtain the desired WFD water quality objectives. However, as in the past, Concawe will continue to support its members in their endeavours to improve their environmental performance.

Current environmental issues faced by the refining industry

As explained above, the refining industry has continued to respond to water-related environmental issues in a responsible manner and will remain committed to doing so. However, the focus is shifting, with today's priorities, being:

- resource efficiency;
- mixture effects;
- emerging contaminants; and
- enhanced monitoring efforts.

These are discussed further below.

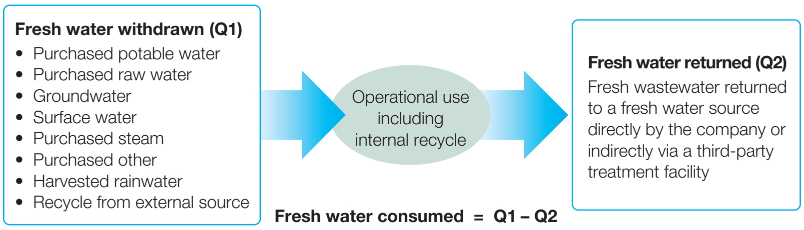
Resource efficiency

In the refining industry several resources are constantly evaluated to optimise their use and to minimise the potential environmental and health impacts. Today's focus is on feedstock and production optimisation, with minimal losses and waste generation, minimal energy use and balanced water consumption.

As energy efficiency and water consumption are already incorporated into the IED, new legislative instruments (under the WFD) aimed at reducing water consumption may be superfluous for industrial resource management.

In the context of this paper the water use and discharges are of most interest, in regions where fresh water is a scarce commodity. In this respect the refining industry questions whether total water use is the correct parameter to manage. In line with the IPIECA guidance on sustainability reporting[12], Concawe is of the opinion that this should concern only the fresh water that is actually consumed. Figure 3 takes into account the difference between fresh water intakes that are utilised in the production processes and the amount discharged into freshwater bodies. The rationale behind this way of defining fresh water consumption is found in the fact that fresh water returned to fresh water bodies remains available for other users.

Figure 3 Fresh water consumption accounting (Source: IPIECA, OGP & API, 2010)



This water accounting method was applied to the refining industry for the first time in the refinery effluent survey of 2010, the results of which revealed that, of the total fresh water intake of 1,140 million m^3, approximately 225 million m^3 was consumed (data from 101 refineries). Minimising the consumption of fresh water has several advantages for both cost and environment. Concawe is working with its members to establish the trend in water consumption over time and produce an inventory of the consequences.

Mixture effects

The substances that are produced by the refining industry are hydrocarbons of variable, and complex composition. The hydrocarbons in refinery discharges differ in composition. Within Concawe there is ample understanding of the impacts of these discharges, which are either measured or estimated using Quantitative Structure-Activity Relationships (QSARs).

Hydrocarbons found in the environment emanate from product spills and/or refinery discharges as well as from natural sources (oil seeps, vegetable oils and decaying organic matter). The anthropogenic sources have been around for more than a century but, as mentioned previously, the discharge reductions (Figure 2) and environmental improvements indicate that these hydrocarbon mixtures will not lead to any new environmental effects.

Emerging contaminants

Emerging contaminants are defined as 'pollutants that are new or present in the environment but whose presence and significance are only now being elucidated' (US EPA).

As the refining industry is a mature industry, the issue of emerging contaminants should not exist, because the products and unintended by-products that are discharged have been in the environment for a long time and any adverse effects will have surfaced and will already be understood. Our understanding of the effect of specific contaminants present in refinery discharges will develop due to progress in scientific understanding or identification of the causative components due to better analytical techniques. Concawe will follow these developments and advise its members if relevant developments occur.

Any new substances or materials introduced into refinery products and processes that may end up in the environment must be registered and hence evaluated under the current legislation (REACH[13]) which includes an assessment of potential human health and environmental risks. This should ensure that these substances or materials will not end up in the environment at levels that can cause harm to human health or the environment.

Enhanced monitoring efforts

The refining and other Industries will continue their effluent quality monitoring efforts, demonstrating that the achievements reported above are at least maintained. The obligation to assess and monitor the water quality under the WFD and associated legislation rests with the Member States, who are therefore responsible for organising and resourcing this activity where it concerns the surface and groundwater bodies that they are responsible for. Involving a refiner in monitoring outside the refinery boundaries should only occur when a causal relation between an observed environmental stressor or impact and the activities of an Industrial site is proven by the Competent Authority.

Concawe will follow these developments and, where required, update its existing guidance for the membership.

Conclusions

Europe's waters are constantly improving and will continue to do so when the WFD and other key environmental regulations are applied in a consistent manner by all EU Member States. The refining industry has been and is delivering actively; their contributions to these environmental improvements are reflected in the factual decrease of relative and absolute emissions and discharges over time.

Emerging issues from mixture or 'chemical cocktail' effects associated with refinery discharges are unlikely to trigger scientifically well-understood environmental or human health impacts that have not already been observed, as the contaminant loads were already present in the environment long before their reported reductions. The exceptions may be new effects, or new products and materials that can only be introduced to the market when registered and authorised after an assessment of potential risks.

Concawe will continue to assist its membership in maintaining past achievements, responding to new scientific and regulatory developments and enabling the management of the further environmental improvements that are required for sustainable water management in cost efficient way.

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Petroleum products and REACH: looking ahead

Concawe is continuing to strengthen the support it provides to guide registrants through the successive stages of REACH; however, it remains essential that member companies recognise the need to maintain their own REACH expertise.

The petroleum refining industry successfully met the first REACH[1] deadline in December 2010 with the registration of all petroleum substances. This was a commendable achievement in view of the complexity of REACH itself and the additional difficulties of dealing with UVCBs[2] and was possible only thanks to the extensive involvement of Concawe contracted and member experts.

After the 2010 registration deadline, many companies seemed to think that compliance with REACH was achieved. However, it has become clear that REACH will require substantial and sustained efforts, probably through to 2020. This review highlights the work we can currently identify to successfully navigate the successive stages of Evaluation, Authorisation and Restriction that follow the registration of our products. Whilst 2018 (the date of the last REACH registration deadline) will be an important milestone, the Evaluation, Authorisation and Restriction work to follow up is likely to continue for several years thereafter.

In recognition of the ongoing work required to support our members and all registrants of petroleum substances through these successive stages, Concawe reorganised its REACH focused activities in 2013, adding additional resources to strengthen the support we provide. However, the Concawe team is just the tip of the iceberg, as much of the work has to be done by member company staff dedicated to REACH, and here we emphasise the need for member companies to maintain their REACH expertise.

Under the REACH legislation, all registrants of the same chemical substance are obliged to collaborate with each other through Substance Information Exchange Fora, or SIEFs. ECHA's guidance introduced the concept of a SIEF Formation Facilitator (SFF) for facilitating the pre-registration of substances by companies. Concawe volunteered to act as the SFF for all petroleum substances. Concawe's SFF role has already proved to be of great value to registrants by coordinating the scientific and specialist aspects of the REACH process and substantially simplifying their involvement in the SIEFs.

Although these activities have gone relatively smoothly, much more effort will be required over the coming years to ensure that the common elements of Concawe's registration dossiers remain compliant under REACH. Some information on this was already provided in the spring 2013 Concawe *Review* article titled 'Petroleum products: looking back over the past 50 years'. The current article extends this discussion by reviewing the main drivers for REACH activities between now and 2020.

Testing proposals

In preparing the 2010 registration dossiers, Concawe proposed that petroleum substances should be grouped and registered in a limited number of well-defined 'categories' that would recognise the variability in composition that can be observed among similar products covered by the same substance description and CAS number. Where important gaps in the scientific information were identified, REACH required submission of Testing Proposals to generate the missing data when the testing involves vertebrate animals. The Concawe registration dossiers include testing proposals for pre-natal developmental and/or reproductive toxicity for certain categories. ECHA issued draft decisions on these testing proposals which were discussed by the Member State Committee (MSC) in November 2013.

The draft decisions on the testing proposals relate to the two following elements:

1. Categories of petroleum substances

Concawe proposed grouping petroleum substances into categories to provide a common data set for all substances within each category. Where there were insufficient data Concawe proposed to test a single substance from each category, as representative of the worst actor[3] within that category.

[1] REACH: Registration, Evaluation, Authorisation and Restriction of Chemicals

[2] UVCB, or 'substances of unknown or variable composition, complex reaction products or biological materials', is used to describe these substances in the REACH Regulation.

[3] A worst actor is defined as a substance most likely to demonstrate the highest effect for the hazard under consideration.

ECHA and the MSC have not accepted this grouping as they considered that there were insufficient data to demonstrate chemical similarity between the different substances within a category.

The MSC agreed an alternative approach in which testing on a single substance from a category would be allowed and the results then read across to other members of the category (one-to-one read-across). This outcome is favourable in that we can proceed with testing a single substance as per our testing proposals and could only be reached thanks to the hard work invested to demonstrate the chemical similarity of petroleum substances. However, ECHA will only accept the applicability of the data to the whole category if the testing results support the read-across hypothesis.

ECHA is requesting additional information to be included in the dossiers when, after completion of the testing, they will have to be updated. This information would need to ensure that the results of the testing do not underestimate the toxicity of other substances and can be applied to all members of the same category. ECHA may request more testing to be carried out after reviewing the updated dossiers with the outcome of the testing.

In addition to the testing programme, Concawe will need to improve the characterisation of all petroleum substances that have been registered. This will involve a comprehensive analytical and data collection programme from all registrants of petroleum substances, due to be launched in 2014. At the same time, there will be a need for further discussions with ECHA and Member States regarding their concerns with the category approach. Doing so will provide additional support to the category approach as well as for the use of read-across in addressing both eco-toxicity and human health endpoints.

ECHA has also launched two new projects on the substance identification of UVCBs. These include the characterisation, chemical representation and modelling of UVCB substances which will further develop ECHA's understanding on the issues of categories and substance identification. Petroleum substances have been specifically identified as one class of UVCBs ECHA will focus on.

2. Testing method for reproductive toxicity

REACH stipulates the use of a standard methodology for reproductive toxicity testing, based on two-generation testing. Several Member States are promoting an alternative methodology based on the Extended One Generation Reproductive Toxicity Study (EOGRTS). The MSC did not reach unanimous decision regarding the method to be used for testing reproductive toxicity and hence the draft decisions were referred to the Commission for a decision. Whilst this has been an issue for several months, we understand that the Commission is likely to revise the testing regulations to stipulate the EOGRTS as the preferred method. This is not unique to petroleum substances as it will apply to any substance that requires reproductive toxicity testing under REACH.

It is not clear at this time when the Commission will issue its decision and therefore when the proposed testing can be started. Once final decisions are issued, it is expected to take 24 to 45 months to complete the testing and to update the dossiers. Concawe is already preparing for the testing programmes by working with the specialised laboratories and planning sample collection.

Compliance checks

ECHA performs compliance checks on the REACH registration dossiers to validate the completeness and adequacy of the information submitted by registrants, e.g. regarding substance identification. These compliance checks can result in draft decisions being sent to registrants.

Following compliance checks, ECHA issued draft decisions in October 2013 that questioned the derivation of the environmental effects endpoints. ECHA's reservations concern the suitability of the tool (PETROTOX) developed by Concawe for the prediction of eco-toxicity endpoints and the undertaking of environmental risk assessments for petroleum substances. Concawe has prepared an action plan that will be discussed with ECHA before the draft decisions are submitted to the Member State Competent Authorities (MSCAs).

In anticipation of further compliance checks, Concawe has initiated discussions with ECHA on several topics, e.g. substance identity, and will continue this dialogue to develop a common understanding. The results of all this work will be included in a thorough revision of the dossiers submitted in 2010. A work plan to address this major activity has been developed for discussion with ECHA.

Evaluation, Authorisation and Restriction

Member States perform 'substance evaluations' under the Community Rolling Action Plan (CoRAP) to scrutinise substances for potential concerns. The outcome of these evaluations could lead to requests for even more testing or the identification of substances as Substances of Very High Concern (SVHCs). This may lead to some substances being added to the REACH candidate list, causing these to potentially fall under the REACH Authorisation process.

In 2013, the Commission issued its SVHC roadmap to define a process for ensuring the incorporation of all SVHCs in the REACH candidate list by 2020. Petroleum substances are explicitly mentioned in the SVHC roadmap, with a 'development of an approach' phase through 2013–2015 and a 'systematic assessment' beginning in 2016. Whilst uses of petroleum substances as fuels or intermediates are exempt from Authorisation, non-fuel uses will be scrutinised. A revision of the uses currently supported in the Concawe registration dossiers will probably be necessary to ensure that the Evaluation of petroleum substances is driven by realistic end-use applications.

Any petroleum substances which are classified as CMR (Carcinogens, Mutagens or Reproductive toxicants) or those containing constituents above 0.1% which are identified as PBT (Persistent, Bioaccumulative and Toxic) or vPvB (very Persistent and very Bioaccumulative) may be included in the REACH candidate list. One possible outcome for a petroleum substance that is included on this list could be to restrict some of the non-fuel uses of that substance.

The Commission will launch a Working Group, the 'Petroleum Substances Expert Group', in 2014 which will require the involvement of Concawe experts. Concawe also participates in the ECHA PBT Working Group to ensure that the identification of substances as PBTs is based upon robust application of the available science.

The Commission is considering the use of Risk Management Options (RMOs) and is in debate with Member States on how this may be included as a step before Authorisation. Concawe needs to understand and, if possible, influence how the RMO process will be developed and applied.

The Authorisation process under REACH is intended to stop the manufacture and marketing of substances that are deemed to pose an unacceptable risk to human health or the environment, unless it can be demonstrated that the risk associated with handling such substances can be managed safely. While there are provisions in the regulation for obtaining 'authorisation' to continue manufacturing and marketing substances that are subject to the Authorisation process, the process itself is very complicated and demanding, requiring significant effort and resources. Concawe must be prepared to help registrants of petroleum substances manage this Authorisation process.

Dossier updates

Chemical Safety Assessments (CSAs) are required by REACH for substances manufactured in quantities in excess of 100 tonnes per annum. For substances classified as hazardous, these CSAs must include risk assessments for human health and for the environment. 'Exposure scenarios' were developed by Concawe in 2010, to identify the conditions under which the substance can be used in a safe manner without causing harm to humans or the environment. ECHA, in collaboration with industry partners, formed the Exchange Network on Exposure Scenarios (ENES) and has issued a roadmap for 2013–15 work to improve the overall quality of exposure scenarios. In addition to participating in the ENES Steering Group, Concawe is also prepared to provide significant effort and resources if there is a need to fundamentally re-work the exposure scenarios for petroleum substances.

In late 2015, ECHA will once again radically overhaul IUCLID, the software used to submit and update dossiers to ECHA under REACH. The next version of IUCLID (IUCLID6) is expected to require more information on exposure scenarios and the assessment of PBT properties in highly structured data-entry fields to facilitate the automated screening by ECHA of exposure data and other information. Consequently, Concawe will have to update all of the dossiers to allow registrants of petroleum substances to keep their registrations compliant and up-to-date.

Communication with registrants

Most of the issues described above also require an ongoing and intensive communication with the registrants of petroleum substances, i.e. with the members of the respective SIEFs. Because Concawe is acting as SFF for all petroleum substances, this communication will also involve substantial work. Following the initial registrations in 2010, there have now been over 4,300 registrations of petroleum substances and this figure provides a good estimate of the communication effort required. Concawe's SIEF Team will continue to manage this communication and the ongoing process of licensing dossiers to non-Concawe members. The costs involved in dossier preparation and updating must be shared amongst all registrants in a fair and transparent manner. This is another important aspect of Concawe's role as SFF

Conclusions

Concawe now has a better understanding of where the petroleum substances dossiers have to be improved to ensure their ongoing compliance with REACH. By addressing the draft decisions, and thanks to our ongoing dialogue with ECHA and the Commission, Concawe will be best placed to support all registrants through the successive stages of REACH. This has allowed us to develop long-term work and resource plans needed to support registrants of petroleum substances. In developing these plans we have had to make assumptions, particularly around the cost and duration of testing.

Concawe will update these plans reflecting the learnings from our dialogues with ECHA and others. We would like to stress once more that this work will only be possible with the continuing commitment of our member companies.

Forward-looking perspective on oil and gas production in Europe

Access to resources remains the major challenge for the oil and gas industry for the foreseeable future.

In 2010 world energy demand was equivalent to about 260 million barrels of oil equivalent per day (boepd), and oil and gas represented 54% of this global demand.

According to the International Energy Agency (IEA), demand is expected to increase by about 35% by 2035, reaching about 350 million boepd. This increase will mostly be driven by the economic development of emerging countries and the increase in world population. While the share of oil and natural gas in the energy mix will remain stable at around 52%, the demand for gas is expected to increase relative to oil because gas resources are abundant and because gas combustion emits significantly less greenhouse gas (GHG) emissions than coal, in particular.

During the same time period, existing oil and gas fields will naturally see their production decline. The UK Continental Shelf is a good example: despite huge investments in the past decade to extend field life, production has continued to decline—from 4 million boepd at the end of the 1990s, to only about 1.5 boepd in 2012. In this context, industry must help the world find answers to its demand for energy.

First, the oil and gas industry, led by the efforts of key companies, has developed a global response strategy to minimise the risks it continuously faces when drilling exploration wells in new geological environments. The need for such a response strategy was re-emphasised in 2010 by the Macondo Well blowout disaster in the Gulf of Mexico.

A Well Engineering Committee (WEC), including top experts from many member companies, has been set up within the International Association of Oil and Gas Producers (OGP). The WEC is an ideal forum for sharing expertise and analysing well incidents. On the operational side, the industry has developed and implemented several capping systems which can be used in water depths of up to 3,000 metres to cap wells that could be approaching an uncontrolled blowout. On the regulatory side, a new Offshore Safety Directive, adopted by the EU, is being implemented in the European countries.

Second, the industry must manage the need to continuously renew its access to new resources. Although the shale gas revolution has dramatically changed the game in the USA, this revolution has not yet been exported outside of the USA. There are many reasons for this, including public acceptance of the technology required to extract oil or gas from shale deposits.

Access to resources remains the major challenge for the oil and gas industry for the foreseeable future. This is particularly true for Europe where more than 90% of oil demand will be imported from other parts of the world. The trend for gas is not very different; today, European domestic production meets 32% of EU gas demand (or 52% if Norwegian production is also included). By 2035, however, domestic production will be less than 20% and the remaining 80% of gas demand will need to be imported. Developing new ideas for Europe's existing production sites is therefore of major importance to limit this future dependence.

Maximising oil and gas recovery from existing and often mature fields is the first way to grow domestic production. This is an ongoing challenge, for all North Sea fields, for example. Recovery factors are currently about 30% and increasing them by only a few percent could allow the additional recovery of several billions of barrels. To achieve this recovery, today's most efficient technology is infill drilling with well trajectories optimised based on the latest generation of seismic data. Enhanced oil recovery (EOR), using water or gas injections, are also traditional means to increase oil recovery and are likely to be a real source of progress in the future. Maintaining adequate pressure in the reservoir in an 'optimised' way is key to successful EOR. This can be done by adding polymers to the injected water to adjust viscosity and optimise the pushing effect of the injected fluid, or by injecting surfactants to reduce residual oil in the reservoir pores. Another step change will be to increasingly use these technologies at early stages of field development, not just for already mature fields.

Exploration and discovery of new resources is the other route to increase domestic European production. Thousands of wells have already been drilled and most known sedimentary basins have already been explored, even if new discoveries of limited size are regularly made in the middle of existing fields. Here also, new seismic imaging of the subsurface has offered prospects which were not visible only a few years ago. New areas of exploration are also offering opportunities for 'big cat' discoveries, for example, in the East Mediterranean, where several huge gas discoveries were recently made.

More generally, deep water drilling in the Mediterranean Sea remains a clear opportunity for Europe. Most of the technologies required for this type of development have already been implemented west of Africa. Floating production units of large size could play the role of central hubs surrounded by satellite field developments. When pressure boosting is required, technologies using processing facilities on the ocean floor could be considered consisting of two phase separator systems and subsea pumping of the liquid phase. Facilities of this sort have already been implemented on some ultra-deep water developments.

Having completely different environmental conditions and challenges, the great North provides another important opportunity for Europe. Production has already started west of the Shetland Islands and liquefied natural gas (LNG) is already being delivered from the Snøvhit field in northern Norway.

In addition, new discoveries are regularly being made above the Arctic Circle. Is this just the beginning of exploration in the extreme Arctic? For some, the Arctic is going to offer an incredible opportunity for development; for others, it is an area which should be protected regardless its potential. In the next decade, upstream activities will probably be conducted in the ice free zones during the mildest months of the year, from April to October. Low temperatures, requiring winterisation of equipment, and darkness will be constraints that the industry should overcome easily. Ice coverage, logistics adapted to the remote conditions and a robust strategy to respond efficiently to incidents remain topics requiring considerable research and development before large-scale exploration of such frontier areas can be envisaged.

Even if energy demand were to remain stable in Europe through 2035, and even if legislation continues to push the development of renewable products, which has been the emphasis over the past few decades, it will be important not to forget oil and gas as key elements in Europe's energy future. These products are key to guaranteeing security of energy supply to European consumers. The overall potential in Europe is still considerable and, with the right policies in place, could be tapped to 2050 and beyond.

Oil and gas has brought us to where we are in European economic development. The industry can be proud of the access to energy that it has provided to consumers all year round. Cars are running, houses are heated, and gas-fired power plants are supplied and delivering electricity on demand. Not many other energy sources today can claim the same.

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Michael has more than 30 years of experience in the upstream oil and gas industry. Previous positions include Managing Director of Mærsk Oil in respectively the UK and Qatar, and corporate Senior Vice President Carbon and Climate for Mærsk Oil.

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Petrochemical feedstocks: the cornerstone of competitiveness

While the chemicals industry will remain largely reliant on petrochemical-based feedstocks for decades to come, the scope for greater use of renewables as feedstocks cannot be ignored.

Future outlook

The future of much of Europe's chemical industry depends heavily upon the availability of affordable petrochemical feedstocks.

In the Middle East, where petrochemical feedstocks are cheap, and in China, where demand is surging, producers are substantially increasing capacity for a wide range of petrochemicals including polypropylene and polyethylene. In the USA, cheap shale gas and economic recovery are driving a chemical industry investment bonanza. But demand growth in the European Union is weak and output growth is modest.

The challenge for the chemical industry is two-fold. First, Europe is highly dependent upon imported feedstock. Oil, the most important, is globally traded, and input prices are competitive. But because European gas prices are generally high, we are at a competitive disadvantage for chemicals that use natural gas as a feedstock, such as ammonia, hydrogen and the precursors of polyamides and methanol. Second, many industrial processes for petrochemicals are energy intensive: cheap gas or electricity elsewhere leaves European chemical producers at a competitive disadvantage.

The industry is not about to throw in the towel, however, but must be able to access affordable feedstocks if it is to thrive and win its share against increasing global demand.

The 2009 report of the European Commission's High Level Group on the Competitiveness of the European Chemicals Industry concluded that the industry will remain largely reliant on petrochemical-based feedstocks for decades to come. But it also showed that dependence on fossil hydrocarbons, combined with high oil and gas prices and a drive to reduce the carbon footprints, have powered big efforts by the European chemicals industry to broaden its feedstock base. And, to do this, the scope for greater use of renewables as feedstocks was highlighted.

Growing our own

The chemical industry has long been involved in the so-called 'bio-economy'. Carbohydrates from sugars and starches are used today to make speciality chemicals

including enzymes, vitamins, organic acids, amino acids, polymers and thickeners for industries ranging from advanced materials to the pharmaceutical, food and feed industries. Animal fats and vegetable oils are used in the production of detergents and coatings, and natural extracts are turned into additives for personal care and cosmetics products.

More recently, consumer demand has powered the adoption of renewable raw materials and biotechnological processes such as fermentation to produce plastics. Instead of using natural gas as a feedstock, ethanol and isobutanol derived from biomass are turned into high-volume commodity chemicals, including ethylene, propylene, isobutylene and p-xylene for making polyethylene used in packaging or polyethylene terephthalate (PET) used in plastic bottles.

Although many chemical substances can theoretically be made from organic plant material, doing so is both technically and logistically challenging. Chemical feedstocks need to be of consistently high quality, and huge volumes of plant matter would be needed. Although ongoing research programmes may overcome the quality challenge, it is difficult to conceive how Europe could deliver enough bio-derived ethanol to assure the industry's current annual ethylene production of 20 million tonnes.

To justify massive investments in processing biochemical feedstocks, the European chemical industry would need access to large volumes, including imports, at competitive prices. Yet, food production should and will take precedence in the use of farm land. Already, targets within the Renewable Energy Directive are taking away renewable feedstocks from the chemical industry, driving up the price of animal fats and pulling in imports of bio-ethanol that face heavy import duties.

Biomass from forestry products, agricultural residues and organic waste has great potential as a future source of bio-based chemicals, when the technology has been perfected, but producers of pulp, paper and renewable energy also compete for these limited materials. Bio-based feedstocks are only likely to be widely adopted in Europe if they are available in large volumes at global, cost-competitive market prices.

Converting carbon

Cefic's recently published report, *European chemistry for growth—Unlocking a competitive, low carbon and energy efficient future*[1], outlines technological developments that will influence feedstock changes in our industry. Prominent among these is the potential use of carbon dioxide as a renewable chemical industry feedstock, directly combatting global warming. Many national, regional and private company research initiatives are under way, both in Europe and elsewhere. In collaboration with more than 20 experts from academia and companies, Cefic now aims to produce a strategic research and innovation plan leading to the use of CO_2 to make chemicals, polymers and fuels. We believe that implementing this plan will help to ensure Europe's global leadership in related technologies.

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Hubert holds a degree in Organic Chemistry and Food Chemistry and a PhD from the Technical University of Karlsruhe. He started his career in 1986 at BASF in research and became Group Leader in the BASF Central Analytical Laboratory. In 1993 he was appointed Director Product Safety and promoted to Vice-President International Economic Affairs in 2000. In 2004 he became Senior Vice-President for Trade Policy and General Political Issues. From January 2007 to August 2009, he was Managing Director Business Centre South Africa and Sub-Sahara and Head of BASF South Africa. He joined Cefic (Conseil Européen de l'Industrie Chimique) in September 2009, and has been Director General of Cefic since November 2009.

The shale gas revolution

The programmes mentioned above will take decades to deliver commercial fruit. In the meantime, the availability of cheap shale gas as a feedstock and energy source is reinvigorating the US chemical industry and putting European rivals and manufacturers at a competitive disadvantage. Shale gas will be around for many decades, providing US chemical firms with affordable feedstock and cheap electricity from gas-fired power plants.

Europe also has significant shale gas reserves. Delaying their development will increase Europe's dependence on imports, reduce the competitiveness of European industry, reduce investments in our industry, and—over time—lead to fewer jobs and a decline in Europe's share of global manufacturing. This is why the European chemical industry is calling on Europe and its member states to accelerate the responsible exploration and production of indigenous shale gas. More imports of liquefied natural gas (LNG) and natural gas liquids (NGLs) will also be required as an additional source of energy and petrochemical feedstock. EU and US trade negotiations should give high priority to addressing the barriers to such trade.

Sustaining competitiveness

Today, chemistry is developing the technical capability to turn plant-based raw materials and even CO_2 into feedstocks for producing a wide range of plastics and other chemicals. But large-scale adoption of alternatives is a distant prospect, depending upon consumer preferences, biomass sustainability and commercial viability. Any incentives for the uptake of particular feedstocks must comply with European competition rules and state aid guidelines: discrimination against fossil-based feedstocks will only put the European chemical industry at a disadvantage. Europe's chemical industry can only thrive if it is nourished by affordable feedstocks, as are its rivals in other parts of the world. Petrochemical feedstocks will therefore continue to play a dominant role in the coming decades, and bringing the shale gas revolution to Europe can only strengthen their position.

[1] Cefic (2013). *European chemistry for growth—Unlocking a competitive, low carbon and energy efficient future*. European Chemical Industry Council, Brussels, April 2013. www.cefic.org/Documents/PolicyCentre/Energy-Roadmap-The%20Report-European-chemistry-for-growth.pdf

Abbreviations and terms

ACEA	Association des Constructeurs Européens d'Automobiles/ European Automobile Manufacturers' Association
ACES	Advanced Collaborative Emissions Study
ACS	American Cancer Society
ASTM	American Society for Testing and Materials
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)
CDU	Crude Distillation Unit
CEN	European Committee for Standardization
CH	Catalytic Hydrothermolysis
CMR	Carcinogens, Mutagens or Reproductive toxicants
CNG	Compressed Natural Gas
CO_2	Carbon dioxide
CoRAP	Community Rolling Action Plan
CSA	Chemical Safety Assessment
CTL	Coal-to-liquids
DLUC	Direct Land Use Change
DME	DiMethyl Ether
DPF	Diesel Particulate Filter
DSHC	Direct Sugar to HydroCarbons
EATS	Exhaust AfterTreatment System
ECA	Emission Control Area
ECHA	European Chemicals Agency
EEA	European Environmental Agency
EEZ	Exclusive Economic Zone
EGR	Exhaust Gas Recirculation
EN14214	European Standard: Automotive fuels—fatty acid methyl esters (FAME) for diesel engines—requirements and test methods
EN590	European Standard: Automotive fuels—diesel—requirements and test methods
ENES	Exchange Network on Exposure Scenarios
EOR	Enhanced Oil Recovery
EPA	Environmental Protection Agency
EU27+2	European Union with 27 Members plus Switzerland and Norway
F&F	Fleet & Fuels
FAME	Fatty Acid Methyl Ester—known as Biodiesel
FQD	Fuel Quality Directive
FT	Fischer-Tropsch
GBD	Global Burden of Disease
GCS	Good Chemical Status
GES	Good Ecological Status
GHG	GreenHouse Gas
GQS	Good Quantitative Status
GTL	Gas-To-Liquids
HD	Heavy Duty
HDCJ	Hydrotreated Depolymerised Cellulosic Jet
HDV	Heavy Duty Vehicle
HEFA	Hydroprocessed Esters and Fatty Acids
HEI	Health Effects Institute
IARC	International Agency for Research on Cancer
IATA	International Air Transport Association
IBIA	International Bunker Industry Association
ICE	Internal Combustion Engine
IDID	Internal Diesel-Injector Deposits
IEA	International Energy Agency
IED	Industrial Emissions Directive
IMF	International Monetary Fund
IMO	International Maritime Organization
ILUC	Indirect Land Use Change
IPIECA	Global oil and gas industry association for environmental and social issues
IQR	InterQuartile Range
ISO	International Organization for Standardization
IUCLID	International Uniform Chemical Information Database
JEC	JRC, EUCAR, Concawe consortium
LNG	Liquefied Natural Gas
LPG	Liquid Petroleum Gas
MARPOL	1973 International Convention for the Prevention of Pollution from Ships
MOSES	Multicenter Ozone Study in Elderly Subjects
MS	Member States
MSC	Member State Committee
NGL	Natural Gas Liquid
NM	Nautical miles
NOx	Nitrogen oxides
NPACT	National Particle Component Toxicity
OECD	Organisation for Economic Co-operation and Development
OEM	Original Equipment Manufacturer
OGP	International Association of Oil and Gas Producers
PBT	Persistent, Bioaccumulative and Toxic
PET	PolyEthylene Terephthalate
PETRORISK	Concawe's spreadsheet tool developed to perform environmental risk assessments for petroleum substances using principles provided by the European Chemical Agency (ECHA) for fulfilling stakeholder obligations under the EU REACH regulation
PETROTOX	Concawe's spreadsheet model, designed to calculate the toxicity of petroleum products to aquatic organisms
PM	Particulate Matter or Mass
QSAR	Quantitative Structure-Activity Relationship
R&D	Research and Development
RBD	River Basin Districts
RBMP	River Basin Management Plan
REACH	Registration, Evaluation, Authorisation and Restriction of Chemicals
RME	Rapeseed Methyl Ester
RMG/RMK	Grades of Residual Marine fuels defined by ISO
RMG/RMK	Grades of Residual Marine fuels defined
S	Sulphur
SAK	Synthetic Aromatic Kerosene
SCR	Selective Catalytic Reduction
SFF	SIEF Formation Facilitator
SFF	SIEF Formation Facilitator
SIEF	Substance Information Exchange Forum
SK	Synthetic Kerosene
SOx	Sulphur oxides
SPK	Synthetic Paraffinic Kerosene
SVHC	Substances of Very High Concern
TPH	Total Petroleum Hydrocarbons
USAF	United States Air Force
UVCB	Substances of Unknown or Variable composition, Complex reaction products or Biological materials
vPvB	very Persistent and very Bioaccumulative
WEC	Well Engineering Committee
WFD	Water Framework Directive
WHO	World Health Organization
WTW	Well-to-Wheels
WWFC	World-Wide Fuel Charter

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Concawe publications

Reports published by Concawe from 2013 to date	
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2/13	Predicting refinery effluent toxicity on the basis of hydrocarbon composition determined by GCxGC analysis
3/13	Performance of European cross-country oil pipelines: Statistical summary of reported spillages in 2011 and since 1971
4/13	Refinery effluent analysis methodologies for relevant parameters from EU—regulatory regimes
5/13	European downstream oil industry safety performance. Statistical summary of reported incidents—2012
6/13	Acute and chronic aquatic toxicity of aromatic extracts—summary of relevant test data
7/13	Aquatic ecotoxicity and biodegradability of cracked gas oils—summary of relevant test data
8/13	Marine fuels and hydrogen sulphide
9/13	Challenges in addressing phototoxicity and photodegradation in the environmental risk assessment of Polycyclic Aromatic Hydrocarbons in the aquatic compartment
10/13	Laboratory Oxidation Stability Study on B10 Biodiesel Blends
11/13	Supplementary guidance for the investigation and risk-assessment of potentially contaminated sediments: a companion volume to Energy Institute/Concawe report E1001
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13/13	Assessment of the impact of ethanol content in gasoline on fuel consumption, including a literature review up to 2006
2014	
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7/14	Impact of FAME on the performance of three Euro 4 light-duty diesel vehicles—Part 2: Unregulated emissions

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2013	Guidance on characterising, assessing and managing risks associated with potentially contaminated sediments
2013	Effect of oxygenates in gasoline on fuel consumption and emissions in three Euro 4 passenger cars
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