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Environmental science for the European refining industry

Foreword

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Welcome to the 2nd Concawe Review in 2015, which will reach most readers as the year comes to a close. As I write this foreword, the world is looking to the COP 21 Climate talks in Paris for future inspiration and leadership. What we may hope for is unity of purpose on climate change, resulting in multilateral action, as opposed to a unilateral approach that damages the competitiveness of EU industry. Over the last 20 years our industry has a strong record of improved environmental performance, the result of investing billions in capital projects to reduce emissions to air and water and to improve energy efficiency. In this Review, the first article, on the forward cost of EU legislation, shows very clearly that further investments are required to meet existing legislation as it comes into effect.

The second article, on the marginal CO_2 footprint of European refinery products, reveals that the marginal CO_2 intensities during refining of heavy products, including heavy fuel oils and bitumen, are negative. These results illustrate that increasing conversion in EU refineries to reduce the yield of these heavy products, increases the CO_2 emissions from refining, and the marginal CO_2 intensities of the lighter products. However, the article stresses that these results should only be used in consequential life cycle assessment studies covering overall European refining production and cannot be applied to individual refineries which each have their specific configuration, feedstocks and product demands. The third article introduces Natural Capital Accounting (NCA) as an emerging approach which recognises the value and promotes the sustainable exploitation of natural resources. An overview of global and EU level developments in NCA is provided, together with examples of where NCA approaches may be used by the downstream business. These include assessment of risks associated with natural resource dependency (for example water availability), and how the environmental footprint of operations can be most cost- effectively reduced.

Then on to the fourth article and to a very practical issue that concerns operational safety for our refineries and for our people. Since the 1970s aqueous film- forming foam (AFFF) has been the product of choice for fighting flammable liquid fires in refineries as well as other industrial sites and airports. In recent years, however, it has been shown that many of the fluorochemicals used in AFFF manufacture are Persistent in the environment and that some are PBTs, being also Bioaccumulative and Toxic. This article provides an overview of EU legislative developments concerning fluorochemicals and how these may affect the future use of AFFF foam stocks held by downstream sites.

Contents

Estimating the forward cost of EU legislation for the EU refining industry

CONTEXT AND BACKGROUND

EU legislation has had, for many years, cost implications for EU industry in general and the EU refining sector in particular. A number of recently adopted EU laws and implementing acts have the potential to further significantly increase this financial burden. For the refining sector the most relevant regulations are:

- The European Union Emissions Trading System (EU-ETS, Directive 2009/29/EC);
- The Industrial Emissions Directive (IED, Directive 2010/75/EU) and its Commission Implementing Decision of 9 October 2014 establishing Best Available Techniques (BAT) conclusions;
- The REACH Regulation (EC) No 1907/2006;
- The Sulphur in Liquid Fuels Directive (SLFD, Directive 1999/32/EC) and more specifically the regulation relative to marine fuels as amended by Directive 2012/33/EU, commonly referred to as the Marine Fuels Directive (MFD);
- The Renewable Energy Directive (RED, Directive 2009/28/EC);
- The Fuels Quality Directive (FQD, Directive 2009/30/EC) and more specifically its article 7a.

This article presents the main findings of Concawe report no 11/14 in which the cost burden imposed on EU refineries by the current embodiment of these regulations is estimated for the period from 2010 to 2020.

METHODOLOGY

Costs have been assessed in 2013 "money-of-the-day" Euros and no attempt has been made to account for future inflation or apply a discount rate. Costs have been annualised to arrive at a total cost of EU legislation in 2020 expressed in both G€/a and $ per barrel of refinery intake using a fixed €/$ exchange rate. Details of the standard data used, the common assumptions and detailed calculations for each piece of legislation can be found in the report.

The cost estimates are for the EU refining sector as a whole. It should, however, be kept in mind that actual costs for individual refineries may vary considerably depending on their location, configuration, specific markets etc.

EU-ETS

The EU-ETS seeks to reduce industrial GHG emissions in the EU by creating a carbon price through a cap and trade system. In the third trading period, running from 2013 to 2020, the default allowance distribution mechanism is regular auctioning by individual EU Member States. Industrial sectors exposed to international competition, of which refining is one, are, however, granted some free CO_2 emissions allowances on the basis of a sector "best-in-class" benchmark (this excludes emissions related to all electricity generation). After accounting for a "cross-sectoral" correction designed to bridge the gap between the total allowances that would be granted according to all sector benchmarks and the overall absolute cap set by the ETS Directive, it is estimated that the refining sector will receive 67% of its baseline emissions as free allowances in 2013, reducing to 58% in 2020.

Permits for the balance of emissions have to be purchased either through regular auctions held by Member States or on the secondary trading market. In its 2008 impact assessment, the EU Commission used a CO_2 price of 30 €/t. Much lower actual prices led to a reassessment of the projections and current assumptions lead to a price of 16.5 €/t at the 2020 horizon. We have considered these two price levels as a low and high scenario.

At this point in time, it is not known what regime will be in place after 2020. If the current scheme is extended, the costs should remain broadly the same. Any change to the current rules could, however, have a marked impact.

IED AND RELATED REGULATIONS

Replacing the IPPC Directive, the IED sets quality limits on the effluents of industrial installations to air and water. It is a complex piece of legislation that seeks to achieve emissions consistent with so-called best available techniques (BAT). By October 2018 the refining sector will have to comply with challenging reduction targets for their emissions to air, their water use and their water effluent quality.

Concawe has carried out a thorough estimate of the investment cost to EU refineries required to meet the new air emissions limits for SO2, NOx and dust. For the EU refining sector as a whole, the investment cost varies by a factor 3 depending on the stringency stipulated in the final implementation of the legislation. It could be reduced by approximately a third while achieving the same environmental benefits if the limits were applied to the refinery as a whole rather than to each individual emission source (the so-called "bubble concept"). The cost associated with VOC emissions and to emission monitoring is not included in this estimate.

Other regulations that may impact the air emissions compliance costs are the Ambient Air Quality Directive and the National Emission Ceilings Directive. There are, however, too many uncertainties to derive a credible cost estimate at this stage. With regard to effluent water quality, only five EU refineries would have to upgrade their water treatment facilities in order to comply with the lowest stringency scenario (which is widely expected to be applied by local authorities).

Although significant for these individual sites, the total sectoral cost is relatively small. Under the Water Framework Directive effluent water quality targets beyond the IED requirements may have to be introduced which, together with proposed regulation to minimise net water consumption under the Commission's "Blueprint to Safeguard Europe's Water Resources" initiative, could significantly increase the estimated average cost of water use. This aspect has not been included in the present analysis. Concawe is planning to conduct a detailed survey of EU refineries in 2015 to obtain a firmer estimate of this potential increase in water cost.

REACH

The REACH legislation has created a significant additional burden on product suppliers into the EU market. Once-off costs have been incurred for the development of appropriate analytical methodologies, the preparation of the registration dossiers and registration fee payments. There are also potential costs for additional testing as well as on-going costs for additional personnel directly dealing with the administration of the scheme.

While the overall financial impact estimate may be relatively low, REACH has caused a significant draw on technical support resources in the refineries.

Under certain circumstances the REACH regulation may result in a product being banned for certain applications. There is therefore a potential for loss of certain markets for specific products. For refineries this may be the case for special non-fuels niche products which, although representing small volumes, may offer high added value and may make a significant contribution to the profitability of certain refineries.

SLFD (MARINE FUELS)

With increasing sea traffic, sulphur oxides emissions from shipping has become a global concern leading to legislation to reduce the maximum sulphur content of bunker fuel under the auspices of the International Maritime Organisation (IMO).

Measures were first introduced in particularly sensitive so-called Emission Control Areas (ECA) where the maximum sulphur content of fuel burned by ships was limited to 1.0% m/m in 2010 and has been cut down to 0.1% in 2015. In 2008, the IMO adopted the principle of a global reduction of the maximum allowable sulphur dioxide emissions from all ships consistent with a bunker fuel maximum sulphur content of 0.5% m/m (from the current 3.5%). The limit can, however, be met by installing flue gas scrubbers on ships. Subject to a review by 2018 this will enter into force in 2020 or 2025. Through the Marine Fuels Directive (MFD) the EU has enshrined the IMO limits into EU legislation although the Directive also stipulates that the 0.5% m/m limit will be introduced in non-ECA EU waters by 2020, irrespective of the IMO final timing.

Adapting to these new sulphur limits presents a major challenge for refiners, involving increased use of distillate fuels which are already in high demand in Europe and desulphurisation of residual streams, both of which have serious implications in terms of capital costs for new plants and refinery energy use and CO_2 emissions.

In view of the uncertainty on the timing of implementation of the IMO global sulphur cap and the alternative for ships to install scrubbing facilities, two cases have been illustrated where either 50% or 100% of the non-ECA bunker fuel sold by EU refineries in 2020 would meet that specification.

RED

The overwhelming impact of the RED on EU refiners is the forced introduction of biofuels in a stagnant if not shrinking road fuels market. In order to comply, refiners would in principle have two alternatives: either maintain throughput and rebalance the market through import/export or reduce throughput to reduce product sales. There are many uncertainties related to the availability of products for import and the extent to which export markets will be available to EU refiners in the medium and long term. The associated costs are difficult to assess.

Throughput reduction would result in a loss of margin over the entire product range. This provides a sounder basis for a cost estimate and has been used in this analysis.

The introduction of biofuels also entailed costs related to storage and blending. However, these additional facilities had by and large already been built by 2010 and the attendant costs have therefore not been included the in this analysis.

FQD

The 2009 revision of the FQD introduced the obligation for providers to gradually reduce the GHG intensity of road fuels. A large contribution to the reduction is expected to come from the introduction of biofuels under the RED. Options for closing the remaining gap will depend on the final accounting rules (e.g. for advanced biofuels, electricity, etc.) and on the definition of upstream emission reductions which may be used as credits. In addition, recent discussions have focussed on the extent to which it would be desirable and/or practical to assess and take into account the actual GHG profile of individual crude oils in the calculation of the GHG intensity of road fuels. Quite apart from the difficulties that the industry would face in putting in place, enforcing and policing GHG reporting, this could create significant distortions in the crude oil market with potentially very large cost implications (of a magnitude similar to the current total refinery operating costs).

There are, however, many uncertainties with the final implementation of the legislation and these costs have not been included in the overall assessment.

OVERALL ANALYSIS: RANGE OF ESTIMATED COST TO THE EU REFINING INDUSTRY AND POTENTIAL IMPACT ON COMPETITIVENESS

The estimated investment, operating and total annual costs are summarised in the table 1.

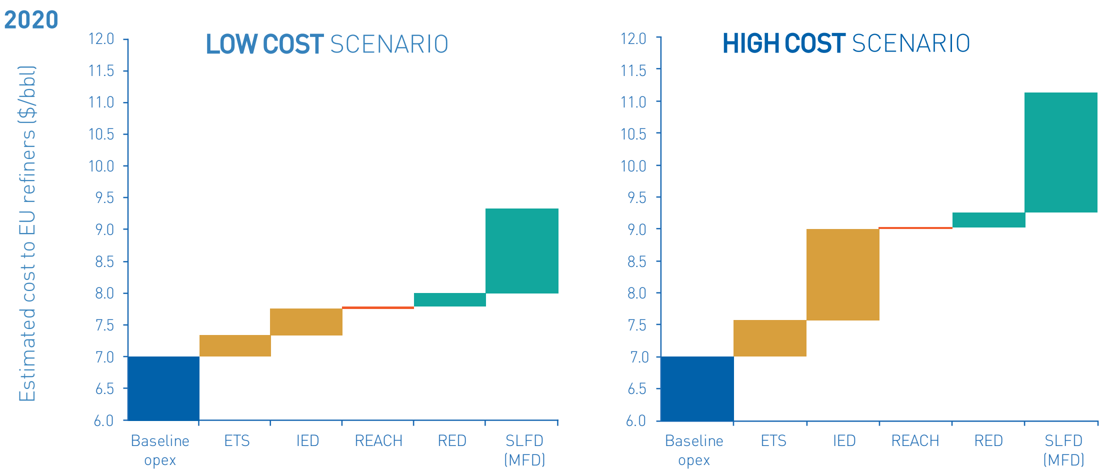
Table 1: Estimated cost of EU legislation to EU refining industry (2020 horizon)

LEGISLATION	TOTAL	ETS	IED	REACH	RED	SLFD (MFD)
Estimated investment (G€)	24.3 - 47.2		6.6 - 22	0.2		17.5 - 25
Annualised investment (G€/a)	3.6 - 7.1		1 - 3.3	0.0		2.6 - 3.8
Estimated operating cost (G€/a)	3 - 5.2	1 - 1.8	0.4 - 1.2	0.1		1.6 - 2.2
Estimed total annual cost (G€/a)	7.4 - 13	1 - 1.8	1.4 - 4.5	0.1	0.7	4.2 - 5.9

The figures 1a/b show the estimated cumulative cost impact of the analysed EU legislative measures in 2020, expressed in $/bbl of refinery intake. Concawe's internal estimate of the 2000-2012 average EU refinery cash operating cost of 7 $/bbl (excluding investment costs) has been used as a starting point. These estimated cost impacts should be seen in the context of the average EU refinery net margin which was less than about 3 $/bbl in several recent years.

The costs associated with the EU-ETS and the IED (coloured mustard) are unavoidable and specifically apply to EU facilities, thereby directly affecting the competitive position of EU refiners. The costs associated with REACH (coloured orange) are equally unavoidable but apply to all EU fuel suppliers. Other costs related to marine fuels (SLFD) and the RED (coloured blue green) only apply to EU refiners but are more uncertain because they will be the result of investment decisions and market adjustments.

Figure 1a/b: Cumulative cost impact of the analysed EU legislative measures in 2020



Considering that the total EU refinery cash operating costs are around 7 $/bbl on average (although there are considerable differences between sites), it is clear that the regulations under consideration have the potential to significantly increase the operating costs of the EU refining industry, thereby impairing its competitive position relative to other world regions where similar legislation is not enacted or is enforced at later dates.

Estimating the marginal CO_2 footprints of refinery products

CONTEXT

The climate change issue has brought GHG emissions into focus, and with it, the GHG footprint of the various goods and services used in the economy. When it comes to petroleum products the main issue is their potential substitution with less GHG intensive alternatives.

The main source of GHG emissions from oil products is of course CO_2 emitted when they are combusted as fuel (which is the case for the majority of these products). There are, however, additional emissions arising from the various production and transport steps starting from crude oil and ending in a commercial product. Although there are some emissions of other GHGs on the way, the overwhelming contribution to total GHG emissions is in the form of CO_2. A significant fraction of these is incurred at the refining stage where crude oil is transformed into marketable products through a series of energy-intensive processes.

In addition, refining generates so-called "process" emissions where CO_2 is produced as a result of a chemical reaction (e.g. decarbonisation of hydrocarbons to produce hydrogen). These refining CO_2 emissions are the inevitable consequence of the need to satisfy market demand for transportation fuels while making optimal use of the available range of crude types.

Total CO_2 emissions from refineries are accurately monitored and measured and therefore well documented. Difficulties arise, however, when it comes to apportioning total emissions to the numerous products produced by a refinery. This is a typical example of a co-production process whereby several products are produced simultaneously through a collection of mutually dependent processes, making it impossible to isolate the production path of one particular product and therefore the CO_2 emissions attached to it. Several allocation methods to estimate average CO_2 intensities have been proposed from a simple apportionment based on mass or energy content, to more complex schemes aimed at relating each process to a number of finished products. Methods based on a static view of the refining operation ignore the complex interactions between processes and between products when the outputs change. As a result, the average CO_2 intensity values produced by static allocation methods do not reveal the interdependence of the multitude of CO_2 emission sources involved in producing each product and are unsuitable for predicting marginal intensities.

Concawe has in the past addressed the issue of apportionment of CO_2 emissions by considering marginal production i.e. what happens when, starting from a known base case, a small change to the product demand is introduced. In this way, the CO_2 footprint of the marginal production of each product can be determined. Concawe has used this incremental approach in their European Refinery Linear Programming (LP) model to estimate such values for gasoline and diesel and has incorporated these values in the JEC Well-to-Wheels study[1].

However, it is not practical to do this for all refinery products. Also, even if this was done, the total of all footprints would not exactly match the total CO_2 emissions from the base case (because each separate change represents a slightly different case), which represents a major deviation from the rules applicable to LCA (Life Cycle Assessment) studies.

In this article, we describe an innovative and scientifically rigorous method, exploiting the specific properties of Linear Programming models whereby the marginal CO_2 footprints of all refinery products produced in a base case can be determined simultaneously. A major advantage of this approach is that the sum of the CO_2 footprints remains equal to the total CO_2 emissions of the refinery.

[1] JEC (Joint Research Centre-EUCAR-Concawe) collaboration, "Well-to-Tank Report" Version 4.a, available at: http://iet.jrc.ec.europa.eu/about-jec/downloads

MODELLING AND OPTIMISING REFINERIES THROUGH LINEAR PROGRAMMING

Refinery operation is characterised by multiple real constraints arising from feedstock supply, product demand (quantity and quality) and process unit limitations. Yet there are many ways of operating within these constraints and refiners have always strived to optimise their operation in order to maximise profit or minimise costs to supply a given market demand within a given set of product prices and input costs. The mathematical tool used to that end by refiners worldwide is known as Linear Programming (LP).

In an LP model the refinery constraints are represented by a system of linear equations linking the different variables. Because there are invariably more degrees of freedom (or variables) than there are constraints, the system has an infinite number of possible solutions. Provided that appropriate cost factors are defined as model inputs (i.e. cost of feedstocks, energy, additional plant capacity, price of products etc.), a so-called "objective function" can be derived, describing the quantity to be optimised (maximum profit or minimum cost). The LP technique then provides a pathway towards the optimum solution.

For a given set of desired products, the LP solution tells the refiner how much of each available feedstock should be processed, the level at which each plant will be utilised and, more generally, which amongst all the constraints will actually be binding. Crucially it also provides information on the impact on the objective function of a marginal change in each of the binding constraints (the so-called "marginal values"). It is this last feature that can be used to access the marginal CO_2 footprint of products.

THE CONCAWE EUROPEAN REFINING LP MODEL AND CO_2 EMISSIONS MODELLING

Since the mid-90s Concawe has operated a refinery LP model representing the combination of all refineries operating in the EU. This was originally devised to estimate the cost to EU refiners of EU legislation (mostly affecting product quality) and of expected changes in EU market demands. In response to the CO_2 emissions challenge, the model was adapted to include appropriate CO_2 emission factors, feed and products carbon contents so that CO_2 emissions for a certain operating case can be estimated while the whole model remains carbon-balanced (i.e. the amount of carbon entering the refinery in the form of feedstocks and possibly fuels equals the amount that leaves the refinery in the form of CO_2 and product carbon content).

As part of the LP solution, a marginal emission value (in tonnes of CO_2 per unit of each constraint) is generated for any constraint that has a bearing on CO_2 emissions. These constraints include product demands (tonnes), product quality specifications (e.g. ppm sulphur), but also feedstock availability (tonnes of crude) and process unit capacities (tonnes). These emission values are "marginal" in the sense that they represent the CO_2 emissions attributable to a certain limiting constraint (for example, if the model is required to meet a certain gasoline demand, the marginal value for gasoline would represent the emissions incurred in producing the last tonne of gasoline that satisfies that demand constraint).

Crucially, the sum of all marginal emission values multiplied by the value of each respective constraint is, by design of the LP, equal to the total tonnes of refinery CO_2 emissions.It must be noted that the set of marginal values produced by the LP is specific to a certain case, i.e. they will change if any of the premises are changed such as product demands, product specifications, process unit capacities or feedstock availability.

In a scenario where oil products would be partly and gradually replaced by alternatives, one would have to reassess the marginal values on a regular basis by adjusting the basic assumptions to reflect the current reality.

A METHODOLOGY[2] FOR GENERATING CO_2 INTENSITY FOR REFINERY PRODUCTS

The availability of the marginal emission values provides a systematic and transparent way to generate marginal CO_2 intensities for refinery products that takes into account all interactions within the refinery operation. Before this can be done, the modelling strategy has first to be adapted.

The ultimate objective is to attribute all refinery CO_2 emissions to the final products. To achieve this, all product demand constraints are set to a fixed quantity to ensure that a marginal emission value is generated for each product. These product demand constraints typically account for around 90% of all emissions.

Process unit capacity constraints also generate non-zero marginal values whenever the model solution fully utilises the available capacity of a certain process unit. The model is set up in such a way that other constraints do not generate marginal values so that the only marginal values that do not directly relate to products originate from process unit capacity constraints.

The next step is to reapportion these unit capacity constraint marginal values to the final products. The LP solution includes so-called "Marginal Rates of Substitution" (MRSs) which describe the interdependencies between process units in terms of capacity utilisation. In a first step, MRSs can be used to reallocate the marginal CO_2 from each process unit capacity constraint to those that are in fine "responsible" for these emissions.

In a second step the aggregated CO_2 emissions from each process unit need to be allocated to finished products. The LP solution provides factors for distributing each intermediate stream between process unit feed and finished products. In order to fully allocate a tonne of unit feed to finished products, an iterative calculation is required, to completely replace the process unit feed factors by finished product factors.

In this way the reallocation of the contribution of the capacity constraints to the finished product CO_2 intensities is done solely on the basis of the LP solution and is therefore entirely consistent and non-arbitrary, representing the actual interactions modelled in the LP.

[2] Full theoretical details of the methodology can be found in this reference: Tehrani Nejad M., A. Allocation of CO_2 emissions in petroleum refineries to petroleum joint products: A linear programming model for practical.... Energy Economics 02/2007; 29(4)(4-29):974-997

A CASE STUDY

Concawe have used the above methodology to estimate the CO_2 intensity of EU refinery products in 2010. The model was run with conditions fixed to represent the actual situation in 2010 in terms of product demands, product quality, crude slate, imports, exports, other feedstocks availability and installed refinery process unit capacities.

The results for CO_2 intensities for 2010 are shown in the table below.

Table 1: Estimated CO_2 intensities for production from EU refining and petrochemicals in 2010

	CO_2 INTENSITY (tCO_2/t)			CO_2 INTENSITY (gCO_2/MJ)
	MARGINAL COMPONENT	RE-ALLOCATED COMPONENT	TOTAL	TOTAL
Petrochemicals	1.46	-0.09	1.37	
LPG	0.28	-0.04	0.24	5.3
Gasoline	0.27	-0.02	0.25	5.8
Kerosene	0.31	-0.05	0.27	6.1
Road diesel	0.35	-0.04	0.31	7.2
Heating oil	0.26	-0.05	0.21	4.8
Marine gasoil	0.20	-0.07	0.13	3.1
HFO	-0.24	0.07	-0.18	-4.3
Bitumen	-0.45	0.02	-0.43	
Lubes & Wax	0.39	0.22	0.61	
Pet Coke	-0.89	0.02	-0.87	-24.8

The first column shows the marginal intensities calculated by the LP for each main product. The second column shows the additional amount originating from process unit capacity constraints and reallocated to each product according to the methodology described above. The third column shows the total CO_2 intensities.

The total amount reallocated is relatively small compared to the grand total although it can represent up to some 30% of the total for certain products.

Apart from petrochemicals which represent a special case in that they require specific, usually very energy intensive processes, all the fuel products have relatively small refining CO_2 intensities when compared to their combustion emissions, which release in the region of 73 g CO_2 /MJ. However, in relative terms the differences are significant and can be related to the level of processing required for each product type. For instance road diesel is more CO_2 intensive than heating oil (more stringent quality specifications). Road diesel is also more CO_2 intensive than gasoline which is due to the specific European situation with a very large road diesel market coupled with very stringent specifications.

An apparent anomaly is the negative marginal CO_2 intensity for heavy products (which include heavy fuel oils and bitumen).

This suggests that total EU refining CO_2 emissions would increase if production of, say, bitumen, was reduced (while continuing to satisfy the total EU demand for all other refined products). Although this may appear counterintuitive, it reflects the specific operational degrees of freedom available to the LP model to achieve an increase in bitumen yield with, for example, crude runs being constrained to mirror the 2010 crude diet. Reducing the production of a heavy product implies that crude throughput must be slightly reduced while the proportion of light products in the product slate from this reduced crude input must be increased, which requires additional conversion and therefore leads to an increase in CO_2 emissions.

The figures generated through this method are strictly only valid for the given set of base conditions. Different base cases would correspond to different total CO_2 emissions and different distributions of marginal CO_2 intensities between products. For the same reason, the figures generated for EU as a whole cannot be applied to individual refineries that all have their specific configuration, feedstocks and product demands. Although the same methodology could be used to generate specific CO_2 intensity figures for individual refineries, these would be of limited value and could be misleading, especially for simple refineries that specialise in the production of bitumen or lubricants. Indeed refineries are to a large extent interdependent, exchanging intermediate and finished product either directly or through the market and focussing on a particular refinery would ignore this interdependence.

It is recognised that the CO_2 intensities will change according to the assumptions made in the modelling, which makes it important to carry out a sensitivity analysis around the given set of assumptions to ensure that the marginal emissions are stable [3]

POTENTIAL APPLICATIONS

The new methodology described above provides a novel route to generate a consistent set of marginal CO_2 intensities for all major oil refinery products. Because all refinery emissions are distributed between the products this complies with one of the basic requirements of LCAs.

The values of the marginal intensities generated in the case study are not "averages" but reflect the effect of perturbations to European refinery output with the crude diet of 2010.

The methodology presented here is based on a marginal analysis and the resulting marginal CO_2 intensity figures for refining should only be used in consequential LCAs. An example of its use is to analyse the issues around the substitution of products, such as part of the refined gasoline, kerosene and diesel transport fuels by renewable fuels.

NEXT STEPS

A Concawe report will be released in the first quarter of 2016 to provide full details of the marginal CO_2 intensity methodology and its use in estimating the marginal refining CO_2 intensities of the products manufactured by the European refining sector in the year 2010.

[3] In this case study, model sensitivity cases were run to determine how sensitive the diesel and gasoline CO_2 intensities were to variations in the demand for these products ranging from -2.5% to +2.5% of the base case demand. All the resulting CO_2 intensities remained within three standard deviations of the base result. The minimum-maximum range of CO_2 intensities was from 4.8 to 7.0 gCO_2/MJ for gasoline (base result = 5.8) and from 6.2 to 7.3 gCO_2/MJ for diesel (base result = 7.2). In addition, a robustness test was run in which bitumen demand was reduced by 50%. The resulting CO_2 intensity for bitumen was 40% lower (-0.59 tCO_2/t compared to the base result of -0.43 tCO_2/t).

Natural Capital Accounting and the Downstream Business

INTRODUCTION

Natural capital accounting (NCA) is a relatively new approach for analysing and recording natural capital and it's various uses in the economy. There is an increasing interest from policy makers in NCA, as articulated in, for example, the European Union's seventh Environmental Action Programme (EAP). The EAP entered into force in January 2014, and lists as its first priority "to protect, conserve and enhance the Union's natural capital". Another European policy document that expresses an interest in NCA is the EU Biodiversity strategy (EC, 2011), which calls upon individual Member States to "assess the economic value of ecosystem services, and promote the integration of these values into accounting and reporting systems at EU and national level by 2020".

Also in the business community, there is an increasing interest in NCA. A recent study by Ernst and Young highlights the importance of natural capital for businesses, stating "natural capital will become as prominent a business concern in the 21st Century as the provision of adequate financial capital was in the 20th Century" (EY, 2014). The World Business Council on Sustainable Development, which includes several member companies of Concawe, has expressed a vision that by 2050 a business should be measured by its 'True Value' and should mention 'True Costs' and 'True Profits' in its internal and external reporting. In this context, 'true' implies that value, costs and profits would be "redefined to consider longer-term environmental and social impacts" (WBCSD, 2014).

Given this increasing attention for NCA, and the relative intangibility of some of the concepts underlying natural capital, there is a need to examine in some more detail what is meant with NCA as well as its relevance for the Downstream sector.

RECENT DEVELOPMENTS IN NATURAL CAPITAL ACCOUNTING

There are a number of different definitions of natural capital. In general terms, natural capital relates to the extension of the economic notion of produced capital to the natural environment, in terms of a 'stock' of natural systems that yields a flow of valuable goods or services into the future (Rademaker and Steurer, 2014). The 7th EAP defines natural capital as the Union's "biodiversity including ecosystems that provide essential goods and services, from fertile soil and multi-functional forests to productive land and seas, from good quality fresh water and clean air to pollination and climate regulation and protection against natural disasters".

Commonly, also sub-soil assets such as oil and natural gas, minerals and ores are included in natural capital (UN et al., 2014a). Hence, natural capital can be divided in what could be labelled 'ecosystem capital ', relating to ecosystem assets and the services they provide, and sub-soil (mineral and energy) assets.

Methodologies for recording mineral and energy assets are now well-established. Mineral accounts providing physical inventories and monetary values of these inventories are produced in a range of countries, and companies whose core business relates to mineral assets, regularly report on their reserves.

Recently, there has also been a strong increase in efforts to establish guidelines for accounting for ecosystem capital. Efforts aimed at systematically analysing ecosystem capital have, for example, been carried out in the context of the TEEB initiative (Suhkdev et al., 2014) and, in Europe, by the European Commission's Joint Research Centre MAES project (European Commission, 2013).

Among the various efforts directed at understanding natural capital, the System of Environmental-Economic Accounts (SEEA) is arguably the leading international effort. SEEA provides a consistent methodology for measuring natural capital, which is aligned with the system of national accounts that is implemented world-wide to measure economic activity and produced capital. SEEA is coordinated by the UN Statistics Division under auspices of the UN Statistical Commission, which includes Chief Statisticians representing statistical agencies from around the world.

The SEEA has been developed in partnership with a range of international organisations including the European Commission, the OECD, the World Bank and the International Monetary Fund. The SEEA comprises two main approaches: the Central Framework and the Experimental Ecosystem Accounting approach.

In the SEEA Central Framework (SEEA CF) (UN et al., 2014a), environmental assets are viewed in terms of the individual components that make up the environment, classified as follows: (i) mineral and energy resources (oil, gas, coal, metallic and non-metallic mineral resources); (ii) land; (iii) soil resources; (iv) timber resources (cultivated and natural); (v) aquatic resources (cultivated and natural); (vi) biological resources other than timber and aquatic resources (livestock, orchards, crops and wild animals) and (vii) water resources (surface, groundwater and soil water resources).

The accounts describe the opening and closing stocks of these resources as well as the changes in these assets. The assets can be analysed in both physical and monetary terms, even though monetary estimates may be difficult to compile for several of the assets (e.g. soil resources). As of 2013, following endorsement by the UN Statistics Commission, the SEEA CF is a statistical standard, to be followed by statistical agencies world-wide in the compilation of environmental-economic accounts.

SEEA Experimental Ecosystem Accounting (in short 'Ecosystem Accounting') is a more recent development, with a first set of guidelines published in 2012 (UN et al., 2014b). Contrary to the SEEA CF, Ecosystem accounting takes a holistic approach to analysing ecosystems, recognising that the combination of water, soils, biotic components, and management by people, lead to the generation of human benefits. The concept of ecosystem services is used to analyse the value of natural capital, including the three main types of provisioning (goods extracted in an ecosystem), regulating (beneficial ecological processes regulated by ecosystems such as pollination or regulating water flows) and cultural services (non-material benefits from ecosystems including tourism). Ecosystem accounting includes the physical and monetary analysis of both flows of ecosystem services and stocks of ecosystem assets. Stocks of ecosystem assets are related to the capacity of ecosystems to sustain ecosystem service supply at present and into the future (Hein et al., 2015).

The ecosystem accounting approach is currently being tested by a range of international organisations (including the UN Statistics Division and the World Bank) and national statistical agencies in Australia, the Netherlands and the UK. Contrary to the SEEA CF, the Ecosystem Accounting approach is spatially explicit, making use of maps to depict stocks of ecosystem assets and flows of ecosystem services for individual spatial units (see for instance Remme et al., 2015). The SEEA Ecosystem Accounting approach is a guideline to be tested by statistical agencies and other partners, requiring further work before it can reach the status of a standard.

The monetary valuation approach of the national accounts and therefore of the SEEA framework is about measuring the value of production and not welfare. In other words, in accounting, the consumer surplus (basically the difference between the willingness-to-pay and the actual price) is excluded from the value estimates.

Monetary values are, where possible, based on (derived-) market prices. This means that a narrower interpretation of value is used, compared to a welfare-based valuation approach (the latter is commonly applied in cost-benefit analysis). An accounting approach needs to be based on market prices since it is essential in the accounts that the value of production matches the value of consumption, which would not be the case in a welfare-based valuation approach. Consequently, value estimates from the SEEA approach can be compared with economic statistics such as GDP. A side-effect is that overly high value estimates derived from people's expressed (but perhaps not actual) willingness-to-pay are excluded.

In spite of recent developments, NCA still faces a number of methodological issues. A first limitation is that it is generally data intensive to set up a natural capital account. A diverse set of physical and monetary information is required, including on values of resources (and in the case of ecosystem accounting on the value of non-market ecosystem services).

It is anticipated that the accounting approach will increasingly draw upon Earth Observation systems in order to provide high-resolution, detailed data on the status of natural resources. Over time, this should reduce some of the development costs. Second, ecosystem accounting does not provide a tool to understand and design measures to deal with long-term effects and risks, for example from climate change. Risks are not made explicit in accounts and long-term effects only have a small effect on discounted current values of ecosystem assets, depending upon the discount rate used.

Third, there is still controversy on how to best include values of some of the regulating and cultural ecosystem services. Further research is needed to develop and test accounting and valuation techniques that reflect exchange values and hence exclude consumer surplus (Obst et al., 2015).

NATURAL CAPITAL ACCOUNTING AND BUSINESSES

Business interests and NCA. There are several factors that contribute to a general increase in interest in NCA in businesses – with the relative importance of these factors differing considerably between types of businesses. First, there is an increasing recognition that natural capital is increasingly becoming scarce, and that this increasing scarcity may lead to reduced availability and/or higher prices for raw materials in the future. This is illustrated by, for example, recent, pervasive water shortages in parts of the world where water traditionally was not regarded as particularly scarce, ranging from agricultural areas in California to urban metropolis such as Sao Paulo and Manila. Such changes have significant business implications, for instance for agriculture and the food processing industry. Consequently, companies dependent upon natural resources as input in their production process may have an interest in an information system that records changes in the availability of these resources, at different locations, over time.

Second, NCA provides for a tool to analyse, better understand, and optimise the use of natural resources in a company. There is still limited experience with company level NCA, but in principle the approach allows obtaining a detailed, time and location specific, overview of the use of natural resources in the various steps in the production line, as well as the efficiency of use of these resources in different production environments.

An example of a company that applied the 'true-cost' approach to NCA to its supply chain is the sportswear company, Puma. Puma quantified a range of environmental impacts (externalities) including water use, greenhouse gas emissions, land use and waste arising from its operations, including transport and manufacturing. Puma focused on the leather and cotton in its products, and monetised the environmental impacts, reporting that this has helped them to enhance strategic planning and to identify low-hanging fruit for resource use optimisation (EY, 2015). In this same space, Coca Cola analysed the use of water in its supply chain, following up on a stated commitment of replenishing as much water as it uses by 2020. Third, NCA enhances the possibilities of companies to understand, deal with and potentially capitalise on the impacts of environmental and climate change. Even though the risks themselves are not included in the accounts, NCA provides detailed information on natural resources that may be affected by climate change, such as risks related to droughts or floods. For instance, the CEO of Unilever recently stated that the costs of climate change for Unilever are estimated by the company at 400 million euros annually. This relates to both pressures on supply of raw materials (crops, dairy products, fish) and to responses in market behaviour. He also indicated that this offers new opportunities, for instance for more water-efficient consumer products.

Fourth, there are potential Corporate Social Responsibility (CSR) motivations for supporting the use of NCA. Testing or supporting new approaches to measure natural capital could be elements in a CSR strategy. One of the companies that has expressed ambitious targets in reducing its environmental footprint, for instance, is the DIY retailer, Kingfisher plc. The company depends on a 40,000 km2 forest area to supply the timber for its products. One of Kingfisher's ambitions is to create more forests than it uses and to source all of its wood from responsibly-managed sources by 2020 (EY, 2015). A NCA approach can be used to measure performance vis-a-vis these targets, and report the performance to stakeholders, including clients and investors.

Business initiatives. In addition to the aforementioned WBCSD initiative, there are three main international initiatives involving businesses and other stakeholders. The 'Natural Capital Declaration' focuses on the financial sector, and aims to promote the integration of natural capital considerations into loans, equity, fixed income, insurance products, and reporting frameworks. It has been endorsed by some 40 CEOs mostly from banks and insurance companies. The signatories pledge to (i) build an understanding of the impacts and dependencies of natural capital relevant to our operations, risk profiles, customer portfolios, supply chains and business opportunities; and (ii) support the development of methodologies that can integrate natural capital considerations into the decision making process of all financial products and services.

The Natural Capital Coalition (NCC) has a broader focus and includes as members a range of production companies, service providers to companies including consultancy and accounting companies, NGOs and research organisations. It is supported by several international organisations such as the United Nations Environment Programme and the International Finance Corporation. The NCC aims to develop a Natural Capital Protocol, a framework that will help standardise how natural capital is accounted for and valued in businesses. The Coalition started pilots in a range of companies in various economic sectors and attempts have started to harmonise the Natural Capital Protocol with the SEEA framework.

The Natural Capital Business Hub is a platform for companies to showcase projects in the realm of innovative approaches to more efficient natural resource management. Some 60 companies have joined the Natural Capital Business Hub, including Shell. The platform is not aimed at developing methodologies for NCA, but provides information on analysing the use of natural capital in business, setting natural capital targets, and how to engage with other companies and NGOs. The Shell pilot project in the Hub involves a 360 hectares wetland that was constructed for waste-water treatment in the Oman desert (Natural Capital Business Hub, 2015).

NATURAL CAPITAL ACCOUNTING AND THE DOWNSTREAM BUSINESS

From the above it is clear that NCA approaches are still under development. At the national level, fast progress towards standardisation is made in the context of the SEEA. The SEEA Central Framework is already a statistical standard that is the basis for recording environmental-economic statistics by the statistical agencies in the EU member states, as well as Eurostat. Development and testing of the SEEA Ecosystem Accounting approach is ongoing, and may result in a statistical standard in the time frame of potentially some 8 to 10 years. The stated interests of the Commission and the requirements posed on member states ensure that further testing of NCA at country level will continue in Europe in the coming years.

At the company level, approaches for NCA are, as yet, less standardised. Various degrees of business interest have been expressed by the CEOs of several dozens of large companies, and efforts are ongoing in order to prepare conceptual and methodological frameworks for NCA in businesses. Building a comprehensive approach to NCA for businesses may be somewhat more complex than NCA at the national level, given that this requires singling out the environmental impacts and resource uses of a single company in an environment where the status of natural resources is often influenced also by other stakeholders using these resources.

In the downstream business, NCA has a number of potential applications. First, it will allow companies to better understand natural resource dependency and risks associated with this dependency. This relates for instance to water use for process or cooling purposes. Second, it allows getting a more comprehensive overview of externalities providing insights in where the environmental footprint can be most cost-effectively reduced, or where cost-savings in natural resource use are possible. In some cases such an analysis can be requested by a regulator to steer environmental permitting, and in other cases, such analysis can be used to discuss environmental mitigation strategies with a regulator. Third, companies can use NCA for specific sites in order to specify the positive externalities they generate, in particular where sites comprise green areas or buffer zones that supply ecosystem services such as air filtration, noise reduction, providing a more attractive landscape, or a habitat for rare species. Fourth, companies can use NCA to quantify efforts that are being made to reduce emissions to air or discharges to water, and the positive environmental impacts created by these reductions. Such activities could be, but do not necessarily need to be, part of a broader CSR strategy.

The downstream business faces the option of engaging in the development of NCA guidelines and/or protocols, potentially through joining one of the business initiatives, with the Natural Capital Coalition possibly being most relevant. This would allow remaining up-to-date on developments in the field of NCA as well as provide the possibility to influence these developments. It is important for the sector that methodologies to be developed would not be potentially adverse to the downstream sector. Potential benefits from testing NCA may include further insights in international standards and best practices for the development of scientifically robust information systems to identify options for enhanced environmental management and/or engaging with environmental regulators and other stakeholders.

BOX: KEY CONCEPTS IN NCA

Asset
A store of value representing a benefit or series of benefits accruing to the economic owner by holding or using the entity over a period of time (UN et al., 2009).

Benefits
Goods and services that are used and enjoyed by people and which contribute to individual and societal well-being.

Ecosystem
A dynamic complex of plant, animal and micro-organism communities and their non-living environment interacting as a functional unit (Convention on Biological Diversity, Article 2).

Ecosystem service
The contributions of ecosystems to benefits used in economic and other human activity (UN et al. 2014b), e.g. providing standing timber for harvesting or air filtration.

Natural capital
The set of renewable (e.g. ecosystems) and non-renewable (e.g. mineral deposits) environmental assets that directly or indirectly produce value or benefits to people.

Natural capital accounting
The systematic and comprehensive recording of natural capital assets and it's uses, in physical and/or monetary units.

SEEA
System of Environmental Economic Accounting. SEEA guidelines have been produced since 1993, and in the last version comprise two different but complimentary approaches, the SEEA Central Framework and the SEEA Experimental Ecosystem Accounting Approach.

References

Edens, B. and L. Hein, 2013. Towards a consistent approach to ecosystem accounting. Ecological Economics 90, 41-52
Ernst and Young, 2014. Accounting for Natural Capital; The elephant in the boardroom. Chartered Institute of Management Accountants, Ernst & Young LLP, International Federation of Accountants and Natural Capital Coalition, 2014
European Commission, 2011. Our life insurance, our natural capital: an EU biodiversity strategy to 2020, 244COM, Brussels
European Commission, 2013. Mapping and Assessment of Ecosystems and their Services An analytical framework for ecosystem assessments under Action 5 of the EU Biodiversity Strategy to 2020.
European Commission, 2015. Reference document on Natural Capital Accounting, Prepared as part of the EU MAES process (Mapping and Assessment of Ecosystems and their Services). Revised draft for consultation, 6 January 2015. European Environment Agency, Copenhagen and Ministry of Environment and Waters.
Hein, L C Obst, B Edens, RP Remme, 2015. Progress and challenges in the development of ecosystem accounting as a tool to analyse ecosystem capital. Current Opinion in Environmental Sustainability 14, 86-92
Natural capital hub, 2015. Website, accessed on 10 June 2015. http://www.naturalcapitalhub.org/web/natural-capital-business-hub/
Obst, C, L Hein, B Edens, 2015. National Accounting and the Valuation of Ecosystem Assets and Their Services. Environmental and Resource Economics, 1-23.
Radermacher, W., A. Steurer, 2014. Do we need natural capital accounts1, and if so, which ones? Paper for HLEG meeting, 22-23 Sept. 2014 in Rome, Session 1: Do we need capital accounts for other types of capital than economic capital (e.g. human capital, natural capital, social capital)? Eurostat, Luxembourg.
Remme, RP B Edens, M Schröter, L Hein, 2015. Monetary accounting of ecosystem services: A test case for Limburg province, the Netherlands. Ecological Economics 112, 116-128
Sukhdev P.,Wittmer, H., and Miller, D., 'The Economics of Ecosystems and biodiversity (TEEB): Challenges and Responses', in D. Helm and C. Hepburn (eds), Nature in the Balance: The Economics of Biodiversity. Oxford: Oxford University Press (2014)
UN, European Commission, IMF, OECD, World Bank 2009. System of National Accounts, UN, New York, USA.
UN, European Commission, FAO, IMF, OECD, World Bank, 2014a. System of Environmental-Economic Accounting, Central Framework, New York, USA.
UN, European Commission, OECD, World Bank, 2014b. System of Environmental-Economic Accounting 2012, Experimental Ecosystem Accounting. United Nations, New York, USA (2014)
WBCSD, 2014. Redefining value. Board charter, 10th November 2014.

Ongoing EU regulation of fluorochemicals: Implications for downstream users of fire - fighting foams

INTRODUCTION

The main fire-fighting foams used for the suppression of class B (flammable liquid) fires at airports, refineries and other major petroleum facilities are Aqueous Film Forming Foam (AFFF), Fluoroprotein (FP) and Film Forming Fluoroprotein Foam (FFFP) foam. These fire-fighting foams were first introduced in the 1960's but more recently their use has been challenged due to concern that certain poly and perfluoroalkyl substances (PFAS), used in their formulation, exhibit PBT characteristics (Persistent, Bioaccumulative and Toxic). In particular, the use of PFOS based foams has been banned in the EU since 2011. While alternative PFAS-free foams are now commercially available, concerns have been raised that these may currently be less effective for fighting large-scale flammable liquid fires and that other issues such as shelf life, compatibility with conventional application equipment and suitability of different materials for storage have not been fully evaluated. This article provides an overview of legislative developments concerning PFAS, and how these may affect fire-fighting foam use and management of legacy impacts in the EU.

POLY AND PERFLUORINATED SUBSTANCES (PFAS)

Poly and Perfluorinated substances (PFAS) comprise a large group of compounds (>6,000) consisting of a hydrophobic and oleophobic alkyl chain of varying length, typically 2 to 16 carbon atoms, which is completely fluorinated (perfluorinated alkyl substances) or partly fluorinated with at least two fully fluorinated carbons (polyfluorinated alkyl substances). Historically, PFAS have been used in a wide range of industrial applications and commercial products due to their unique surface tension/levelling properties. These include textile stain and soil repellents, grease-proof paper, fluoropolymer manufacture, coatings, and aqueous film-forming foams (Buck et al. 2011).

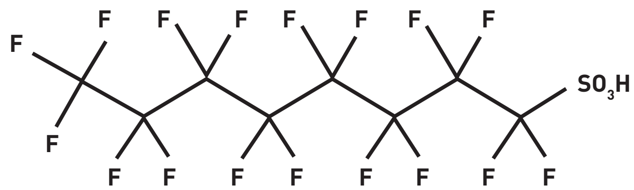
Concern around the environmental effects of PFAS use began in the late 1990s when it was realised that, due to their resistance to biodegradation, PFOS and PFOA were ubiquitous in in various biological (wildlife and humans) and environmental (water bodies) matrices, and could biomagnify (Giesy and Kannan, 2001). The degree of biomagnification is proportional to perfluorocarbon chain length and so regulatory initiatives to restrict the use of PFAS have focussed on substances with >6 fully fluorinated carbon atoms. Buck et al. (2011) note that "the global regulatory community is specifically interested in "long-chain" perfluoroalkyl sulfonic acids ($C_nF_{2n+1}SO_3H$, $n \geq 6$, PFSAs) and perfluoroalkyl carboxylic acids ($C_nF_{2n+1}COOH$, $n \geq 7$, PFCAs) and their corresponding anions, which have been shown to be more bioaccumulative than their short-chain analogues".

HISTORY OF PFAS USE IN FIRE-FIGHTING FOAMS PFOS AND BY-PRODUCTS (MANUFACTURED FROM 1970S TO C.A. 2001)

The first AFFF foams used by the US Navy in the 1970s contained perfluorooctane sulfonate (PFOS) as their primary PFAS component at a concentration of around 0.5 wt%. Researchers found that the addition of PFOS produced a fire-fighting foam that was able to wet the surface of liquid hydrocarbon, resulting in a much higher foam spreading rate than was possible using only hydrocarbon-based surfactants. Fast foam spreading rates maximised foam performance by rapidly excluding oxygen from the fuel and suppressing the production of fuel vapour (thereby extinguishing the fire and also preventing re-ignition). PFOS consists of a chain of 8 fully fluorinated carbon atoms with a sulfonate group on the terminal carbon and is a mixture of linear (ca. 70%) and branched (ca. 30%) isomers, dependent on the production process.

PFOS

The linear structure of PFOS is illustrated below:



PFOS manufacture continued until the late 1990s, when concerns were raised that PFOS displayed PBT characteristics. Subsequently, in May 2000 the primary US producer of PFOS (3M) announced that production would be phased out during 2001.

The primary synthesis route for PFOS (electrochemical fluorination) was only 35-45% efficient, producing a range of PFCAs and PFSAs in addition to the target compound. This is reflected in the spectrum of PFAS reported as present in the environment, with PFOS being the dominant PFAS, followed by the various by-products. In an EU-wide survey of 37 persistent polar organic pollutants in over 100 rivers in 27 countries (Loos et al., 2009), PFOS was among the most frequently detected chemical, with other PFAS also frequently detected (see table below).

Table 1. PFASs and PFACs in European surface waters (Loos et al., 2009)

CHEMICAL	FREQUENCY (%)	MAXIMUM (ng/l)	MEAN (ng/l)	MEDIAN (ng/l)	90TH PERCENTILE (ng/l)
Perfluorohexanoate	39	109	4	0	12
Perfluoroheptanoate	64	27	1	1	3
Perfluorooctanoate	97	174	12	3	26
Perflurononanoate	70	57	2	1	3
Perfluorodecanoate	40	7	1	0	1
Perfluoroundecanoate	26	3	0	0	1
Perfluorooctane sulfonate	94	1371	39	6	73

In 2006 the European Union legislated to restrict the use of PFOS in new products to ≤0.005wt% (2006/122/EC) and in 2010 the limit was reduced to ≤0.001wt% (EU 757/2010). In 2009, PFOS was added to Annex B of the Stockholm Convention on Persistent Organic Pollutants (POPs), meaning that measures must be taken to restrict it's production and use. The use of legacy firefighting foam stocks containing >0.001wt% PFOS has been banned in the EU since 27th June 2011, with the best practice disposal route being high temperature incineration.

In 2013, PFOS and its derivatives were included in the EU Directive on Environmental Quality. The Annual Average environmental quality standard (EQS) for surface freshwater is set at the extremely low concentration of 0.00065 µg/l (0.65 ng/l), based on the calculated risk of secondary poisoning in humans due to fish consumption. It should be noted that the permitted PFOS impurity level in fire-fighting foam concentrates (≤0.001wt%) is not a guarantee of compliance with the extremely low environmental EQS (factor of 15000 concentration difference).

Drinking water standards developed by EU member states are generally between 0.1 and 0.3 µg/l PFOS, which is significantly higher than the EQS. In those countries where target values for groundwater have been derived, these vary between 0.1 and 0.5 µg/l for PFOS. Drinking water standards may also encompass the PFAS by-products of PFOS manufacture and ≤C6 PFAS currently permitted for use in fire-fighting foams, such as perfluorobutane sulphonate (PFBS). For example, in the state of North Rhine Westphalia, Germany the precautionary action value for babies and vulnerable groups (VMWs) for all PFAS is 1 ug/L and the action value for adults (MW) is 5 ug/L (LANUV-Fachbericht 34).

While the use of PFOS is now restricted, legacy soil and groundwater issues may remain at sites where PFOS-based fire-fighting foams have been manufactured or used in the past. In particular, PFOS (and by-products from its synthesis) may be present in soil and groundwater below former fire- fighting training areas, where AFFF foam has been applied repeatedly over a number of years. The persistence and mobility of PFOS increases the potential for long groundwater plumes that may reach offsite receptors.

PFOA, PRECURSORS AND FLUOROTELOMER SULFONIC ACIDS

Since the cessation of PFOS manufacture by 3M in 2001, firefighting foam suppliers have used alternative fluorosurfactants with similar surface-tension lowering properties. PFAS used in current foam formulations include perfluorobutane sulfonic acid (PFBS) and fluorotelomer-based (polyfluorinated) substances containing the $C_nF_{2n+1}CH_2CH_2S$–R or $C_nF_{2n+1}CH_2CH_2SO_2$–R moiety, where R is a hydrophilic functional group that provides surfactant properties (Buck et al. 2011).

In recent years, however the use of PFAS in commercial products has again come under scrutiny due to increasing evidence that long-chain (≥C8) polyfluorinated chemicals can break down in the environment to form long chain PFCAs, such as perfluorooctanoic acid (PFOA) that also exhibit PBT characteristics (Dinglasan et al. (2004); Wang et al.(2009)).

In 2006 the US EPA invited the eight major fluoropolymer and telomer manufacturers to join in a global stewardship program with the objective of working toward the elimination of PFOA, precursor chemicals that can break down to PFOA, and related higher homologue chemicals from emissions and products by 2015: http://www2.epa.gov/assessing-and-managing-chemicals-under-tsca/20102015-pfoa-stewardship-program-0.

In a restriction proposal submitted to The European Chemicals Agency (ECHA) in 2014, Germany and Norway requested that the concentration of PFOA and possible PFOA precursors in products placed on the market be limited to <2 ppb, which is 5,000 times lower than the current limit for PFOS (0.001 wt%, or 10,000 ppb). On 10th September 2015 the ECHA Socio-Economic Analysis Committee (SEAC) published its draft opinion: http://echa.europa.eu/documents/10162/13641/pfoa_seac_draft_opinion_en.pdf.

This supports the restriction proposal but recommends higher limits of:

- 25 ppb of PFOA or its salts and 1,000 ppb of one or a combination of PFOA-related substances.
- a derogation for firefighting foams, with the limit being ≤1 mg/kg (1,000 ppb) per substance, for both PFOA or for each PFOA-related substance.
- a derogation to allow the continued use of legacy fire- fighting foam stocks purchased prior to the restriction date.

SEAC proposes to reconsider this concentration limit (1,000 ppb) with an aim to lower it in the proposed review of the restriction 5 years after entry into force. In making this recommendation SEAC took into account the following feedback from stakeholders:

- PFOA or PFOA-related substances may be present as impurities in the ppb range in C6-based fluorinated substances, which are the main alternatives available. Implementing the 2 ppb concentration limit would therefore prevent the use of the C6 alternative to PFOA and PFOA-related substances.

- The possibility of unintentional cross contamination in the ppb range in the long and complex supply chains, since PFOA is widespread in the environment (for instance in water used in industrial processes, and to dilute AFFF concentrate prior to use). Implementing the 2 ppb concentration limit would prevent many articles made from fluoropolymers from being placed on the market.
- Thorough and expensive cleaning and decontamination of production, storage and transportation equipment used in the processing of materials containing PFOA or PFOA-related substances would be needed to prevent contamination of materials processed after the transition to alternatives, because of the adherence of PFOA and PFOA-related substances within such equipment.
- Lack of reliable and standardised analytical and extraction methods at such low concentrations, potentially leading to serious concerns for enforcing and implementing the restriction.

IMPLICATIONS FOR USE OF FIRE-FIGHTING FOAMS

The outcome of the PFOA restriction proposal currently under consideration by ECHA will determine the extent to which fire-fighting foam suppliers have to modify existing PFAS- based foam formulations to maintain compliance.

While the PFOA restriction report submitted by Germany and Norway proposes a total ban on the manufacture, marketing and use of PFOA and PFOA precursors, the opinion of SEAC is that a derogation is appropriate because replacement of all foams containing PFOA or PFOA-related substances would incur high costs over a relatively short period. The foam types currently permitted for use on sites may be grouped according to the impact of current and proposed future EU legislation:

- Foams formulated using longer chain fluorotelomers, including 8:2, 10:2 and 12:2 moieties, which are considered to degrade to PFOA in the environment and so would be subject to the restriction proposal under REACH.
- Foams formulated using high purity ≤C6 PFAS substances (including high purity 6:2 fluorotelomers), for which the breakdown products are persistent but have lower bioaccumulation potential (cannot degrade to PFOA).
- Fluorine-free foams: biodegradable but use may require modifications to existing delivery systems/ deployment protocols. Also subject to ongoing debate with regard to their performance on larger in-depth fires (e.g. storage tank fires).

Given the different environmental risk profile for these foams, it is suggested that sites consult with foam suppliers to determine the best fire-fighting options and environmental risk mitigation strategy for their facilities. Options for environmental risk management may include the use of fluorine-free foams for training purposes and the preferential use of lower risk high purity ≤C6 PFAS foams, where possible.

The forthcoming Concawe report: Environmental fate and effects of Poly and Perfluoroalkyl substances (PFAS), which is due to be published later in 2015, has been produced to help CONCAWE members understand and manage the potential environmental risks around current and also legacy fire-fighting foam formulations.

References

Buck, R. C., Franklin, J., Berger, U., Conder, J. M., Cousins, I. T., de Voogt, P., Jensen, A. A., Kannan, K., Mabury, S. A. and van Leeuwen, S. P. (2011), Perfluoroalkyl and polyfluoroalkyl substances in the environment: Terminology, classification, and origins. Integr Environ Assess Manag, 7: 513–541. doi: 10.1002/ieam.258

Giesy JP, Kannan K. 2001. Global distribution of perfluorooctane sulfonate in wildlife. Environ Sci Technol 35:1339–1342.

Verbreitung von PFT in der Umwelt Ursachen – Untersuchungsstrategie – Ergebnisse – Maßnahmen. LANUV-Fachbericht 34

Loos, R., Gawlik, B.M., Locoro, G., Rimaviciute, E., Contini, S. and Bidoglio, G. (2009). EU-wide survey of polar organic persistent pollutants in European river waters. Environmental Pollution 157, 561-568.

2010/2015 US EPA PFOA Stewardship Program: http://www2.epa.gov/assessing-and-managing-chemicals-under-tsca/20102015-pfoa-stewardship-program-0

Dinglasan, M. J. A., Ye, Y., Edwards, E. A., & Mabury, S. A. (2004). Fluorotelomer alcohol biodegradation yields poly-and perfluorinated acids. Environmental science & technology, 38(10), 2857-2864.

Wang, N., Szostek, B., Buck, R. C., Folsom, P. W., Sulecki, L. M., & Gannon, J. T. (2009). 8-2 Fluorotelomer alcohol aerobic soil biodegradation: Pathways, metabolites, and metabolite yields. Chemosphere, 75(8), 1089-1096.

ECHA Committee for Socio-economic Analysis (SEAC) Draft Opinion on an Annex XV dossier proposing restrictions on Perfluorooctanoic acid (PFOA), its salts and PFOA-related substances: http://echa.europa.eu/documents/10162/13641/pfoa_seac_draft_opinion_en.pdf

Abbreviations and terms

AFFF	Aqueous Film Forming Foam
BAT	Best Available Techniques
CO_2	Carbon dioxide
CSR	Corporate Social Responsability
EAP	Environmental Action Programme
ECA	Emission Control Area
ECHA	European Chemicals Agency
EQS	Environmental Quality Standards
FP	Fluoroprotein
FQD	Fuel Quality Directive
GDP	Gross Domestic Product
GHG	GreenHouse Gas
IED	Industrial Emissions Directive
IMO	International Maritime Organization
IPPC	Integrated Pollution Prevention and Control
JEC	JRC, EUCAR, CONCAWE consortium
LCA	Life Cycle Assessment
LP	Linear Programming
MAES	Mapping and Assessment of Ecosystems and their Services
MFD	Marine Fuel Directive
MRSS	Marginal Rates of Substitution
NCA	Natural Capital Accounting
NCC	Natural Capital Coalition
NOx	Nitrogen oxides
OECD	Organisation for Economic Co-operation and Development
PBT	Persistent, Bioaccumulative and Toxic
PFAS	Poly and Perfluorinated Substances
PFBS	Perfluorobutane
PFCA	Perfluorinated Carboxylic Acid
PFOA	Perfluorooctanoic Acid
PFOS	Perfluorooctane Sulfonate
REACH	Registration, Evaluation, Authorisation and Restriction of Chemicals
RED	EU Renewable Energy Directive
SEAC	Socio-Economic Analysis Committee
SEEA	System of Environmental Economic Account
SEEA CF	System of Environmental Economic Account Central Framework
SLFD	Sulphur in Liquid Fuels Directive
SO2	Sulfur dioxide
TEEB	The Economics of Ecosystems and Biodiversity
VOC	Volatile Organic Compound
WBCSD	World Business Council for Sustainable Development

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