Concawe
Environmental Science for European Refining

Review

Special Symposium Edition

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13th Concawe Symposium

18–19 March, Radisson Blu Astrid Hotel, Antwerp, Belgium

Monday 18 March 2019

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Tuesday 19 March 2019

Refinery safety and virtual reality

Harald Hess (OMV), Sam Vine (University of Exeter) and Toby de Burgh (Cineon Training)

The Concawe Safety Management Group has reported a reduction in incident rates across European downstream oil industry manufacturing and marketing activities over the past 24 years. However, with zero fatalities as its goal, the sector is not yet where it needs to be. While improvements in technology, training and management systems across member companies have supported the reduction in incident rates so far, it is clear that additional approaches need to be applied to achieve this goal.

One such approach is the examination of human performance factors, and human psychology concepts, that influence (positive and negatively) an individual's ability to work safely. Factors such as stress, time pressures, distractions, personal abilities and lack of direction are common, and frequently play an important role in incidents.

Simulation training is used extensively in many high risk and safety-critical industries, including military, aviation, medicine and sport. There is a growing and compelling evidence base to suggest that simulation is an effective and efficient way to train humans to perform safely under pressure. Advancements in technology, and developments in software, have enabled simulation training to become mobile, flexible, ergonomic and, therefore, cost-effective.

In the past year, Concawe, Cineon Training and the University of Exeter, have collaborated to exploit this potential for the benefit of the European petroleum refining industry. The consortium have developed a state-of-the-art virtual reality (VR) simulation training tool, which allows trainee operators to experience an operator tour of a refinery unit, and to practice observational, manual and complex decision-making skills. Within the virtual environment, and in supplementary training material, trainees will learn about the underlying human process relating to human perception (eye movements), based on eye tracking research

Refinery safety and virtual reality (continued)

undertaken with colleagues at the Total refinery in Antwerp. The consequences of missing or failing to act upon potential hazards are also communicated to trainees through feedback provided within the virtual environment.

The training tool was first tested with a small sample of refinery operators. The study provided some initial proof-of-concept, with evidence to support the face validity (the extent to which operators agree that the simulation is realistic and convincing) and the construct validity of the simulation. The face validity was corroborated by attendees of the Concawe Symposium in Antwerp in March 2019, in which 50 people experienced the simulation.

While face validity is important, perhaps more important was the evidence for construct validity. Here, through an assessment of the perceptual capabilities of operators in VR (how quickly and efficiently they detected hazards) we were able to show that their experience and skill advantage in the real world translated into the virtual world. More specifically, the virtual tool, and the metrics it provides, were able to discriminate the skill level of the user. This is an important validation step that is performed on simulations in many industries including aviation and medicine.

Following the successful analysis of the tool, psychologists and trainers at Cineon have developed a 'how to' guide, together with supporting educational material, to enable operators to undertake a training workshop that can be adopted within member companies. This workshop has the virtual reality tool at the centre of the experience, supported by presentations about the underpinning science and theory of the intervention. A demonstration version of the tool is available at the Concawe offices for members to try.

Exploring the future policy framework and potential opportunities for refineries

Chris Malins
(Cerulogy)

The past decade has been one of mixed results for European biofuels policy. On the one hand, the Renewable Energy Directive has driven a substantial expansion of European biofuels use, including increasing the use of wastes and by-products as biofuel feedstocks. On the other, research carried out in this period has identified fundamental sustainability challenges faced by first-generation biofuels, in the form of indirect land-use change (ILUC) and the food-versus-fuel issue. Despite confirming that ILUC is a major source of carbon dioxide emissions due to the expanding use of biofuels, the European Institutions have struggled through the decade to either agree on the magnitude of the ILUC problem, or to find a mutually acceptable resolution to the growing body of evidence which suggests that EU consumption of biodiesel from food crops may have led to increases, rather than reductions, in net carbon dioxide emissions. Also, while the consumption of first-generation fuels has grown broadly in line with targets, the second-generation biofuel industry has consistently failed to meet ambitious aspirations set in some quarters for its commercialisation and deployment; as a result, an indicative target for 2020 consumption of 'advanced' biofuels will almost certainly be missed by a wide margin. One explanation given for the underperformance of the second-generation biofuel industry has been the high level of uncertainty for investors about the future value of policy support—it is fundamentally difficult to predict how much a mandate will allow fuel to be sold for in several years' time when a new plant becomes operational, and harder still to predict that value in another twenty years as those investments reach the end of their lives.

The RED II legislation (Directive (EU) 2018/1001[1]) adds a new impetus in the push to next-generation alternative fuels, creating nested targets while giving additional flexibility to Member States to prioritise biofuels with the best environmental performance. The new regime will include limits on support for high ILUC-risk biofuels (presumptively palm oil) and enhanced incentives in aviation and marine modes. Looking forward, the outlook for advanced alternative fuels is improved, but the details of the value proposition from RED II will depend strongly on Member State choices in implementing the revised Directive. Until those choices are made, investment decisions remain difficult. While electrofuels and aviation fuels receive special attention, for the time being cellulosic biofuels for the road transport market look more likely to move towards commercial deployment in the next five years. A growing advanced alternative fuel market provides opportunity for refiners—many processes will produce intermediate molecules that could be upgraded at existing refineries, such as Fischer-Tropsch waxes and pyrolysis oils. The priority for the advanced alternative fuel industry between now and full implementation of the RED II should be to work with Member States to develop policies that can give the value certainty through the supply chain that has been so evasive for the past ten years.

1 European Union (2018). Directive (EU) 2018/2001 of the European Parliament and of the Council of 11 December 2018 on the promotion of the use of energy from renewable sources (recast). https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=uriserv:OJ.L_.2018.328.01.0082.01.ENG

Challenges for sustainable aviation and opportunities

Ralph-Uwe Dietrich
(German Aerospace Centre, DLR)

The global aviation industry is proactively agreeing on actions towards future climate change mitigation. The International Air Transport Association (IATA) has introduced a technology roadmap with three long-term goals:

- Improvement of fuel efficiency by about 1.5% per annum until 2020
- Carbon-neutral growth from 2020 onwards
- CO_2 emissions reductions of 50% by 2050 compared to 1990.

Measures to achieve these ambitious goals include ongoing improvements in aircraft efficiency, operations and infrastructure. Furthermore, economic measures will enable carbon-neutral growth. The International Civil Aviation Organization (ICAO), with 192 member states, adopted a global market-based measure, the Carbon Offsetting and Reduction Scheme for International Aviation (CORSIA[2]), to offset international aviation CO_2 emissions from 2020 onwards. Additionally, to reach the halving of CO_2 emissions until 2050, radical technology transition or huge amounts of alternative fuels will be required. Certified alternative jet fuels for up to 50% drop-in currently include:

- ethanol-derived synthetic paraffinic kerosene (AD-SPK);
- synthetic iso-paraffins/farnesane via the direct sugars to hydrocarbons (DSHC) pathway;
- synthetic paraffinic kerosene produced from hydroprocessed esters and fatty acids (HEFA); and
- synthetic paraffinic kerosene via Fischer-Tropsch synthesis.

Analysing these processes and their (theoretical) feedstock availability in relation to current European jet fuel demand (56.5 Mt/a in 2010), it becomes clear that only a combination of various production routes can cover the required kerosene demand. Supplementing renewable electricity provides a promising opportunity. Three concepts, based on biomass gasification (biomass to liquid, BtL), electrical power (power-to-liquid, PtL) and the combination of both (power and biomass to liquid, PBtL) have been compared, and present the opportunity to increase both the carbon efficiency as well as the energetic efficiency.

The evaluation process established at DLR allows the assessment of various fuel production concepts in terms of their technical, economic and ecological impacts. The economic assessment utilises the software tool, TEPET (Techno Economical Process Evaluation Tool), for standardized cost calculations for different production routes, plant size and location according to process engineering calculation standards. The ecological impact is based on the CO_2 footprint of resources, process efficiency and byproduct credits, calculating the CO_2 abatement costs of each option. The final goal is a merit order of all feasible options for sustainable jet fuel production in terms of their potential for lowering aviation CO_2 emissions.

The DLR's technical, economic and ecological assessment methodology can be applied to new approaches to alternative fuels production, helping technology development towards demonstration and deployment. The transparent justification of the costs and benefits of new production routes supports technology roadmap preparation and monitoring.

[2] www.icao.int/environmental-protection/CORSIA

One example was presented at the 13th Concawe Symposium. The EU Horizon 2020 project, COMSYN[3] (Compact Gasification and Synthesis Process for Transport Fuels), aims to reduce biofuel production costs by combining a number of innovative process steps (coordinated by VTT, Finland). Besides the new gasification concept and the subsequent hot gas filtration, a Fischer-Tropsch microreactor (developed by INERATEC, Germany) is attempting to substantially reduce biofuel production costs compared to alternative routes. The DLR is responsible for the techno-economic assessment and optimization work package of the project. A preliminary flowsheet model was developed together with the project partners and will be further improved with the incoming project data. Various process options can be evaluated using TEPET, even in the early stage.

New production routes for alternative jet fuels will need to be developed, demonstrated and introduced to support the international aviation industry's commitment towards future climate change mitigation. The DLR's mission is to support these efforts with expertise on the manifold aspects of this challenge.

[3] www.comsynproject.eu

ECORYS-coordinated project on R&I perspectives for advanced biofuels in Europe

Rainer Janssen
(WIP Renewable Energies)

Research and Innovation perspective of the mid- and long-term potential for advanced biofuels in Europe

(a study commissioned by the European Commission, Directorate-General for Research and Innovation)

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Synopsis

Research and Innovation (R&I) plays a central role in developing advanced biofuels technologies to help achieve the EU's climate and energy targets. This study examines the R&I potential for feedstock production, advanced biofuels production, and the use of advanced biofuels. The study quantifies R&I potential under future scenarios where EU targets are met. Improving feedstock supply and reducing conversion costs through research and innovation, resulting in an increase of feedstock availability by 40–50%, will contribute to the development of advanced biofuels. With successful R&I and attainment of the 2050 EU targets, advanced biofuels could achieve:

- close to a 50% share of the overall transport sector energy mix;
- 330 Mt of net emission savings if they replace fossil fuels, or 65% of the required emission savings needed, compared to 1990 levels, to meet transport sector emissions targets of 60%;
- a market volume of 1.6% of the EU's GDP; and
- a significant improvement in energy security.

This would result in a net increase in employment of 108,000 jobs, even taking into account the loss of 11,000 jobs in the fossil fuel sectors and the reduced employment in other sectors, without negatively impacting the EU's GDP. This is a particularly noteworthy positive impact, considering that it comes mainly from the substitution of currently existing energy demands.

In the extreme case of a transition to an energy system relying heavily on advanced biofuels, achieving EU targets would put considerable pressure on feedstock availability, driving up feedstock prices. Yet, in a system characterized by a balanced energy mix with several renewable options and an important role for advanced biofuels, R&I plays a paramount role in both (i) safeguarding the amount of affordable sustainable biomass and (ii) improving the efficiency of the whole biomass-to-biofuel process chain, necessary for the transition to a bioenergy system. The transition could take more than 15–20 years and require substantial efforts and extensive coordination between stakeholders.

The potential role of Power-to-X technologies

Christoph Gatzen
(Frontier Economics)

Background—towards a cleaner economy

The defossilisation of the economy is a challenging task. Direct electrification via plug-in hybrid electric vehicles (PHEVs) or battery electric vehicles (BEVs) will be an important pillar for the mobility sector. However, with higher penetration of electric vehicles, distribution networks will need to be expanded dramatically, an expensive public and private charging infrastructure will need to be set up (capable of covering peak demand for charging), and new cars will need to be bought by consumers. System costs will be high.

Within the housing sector, gas and oil heaters are commonly used across Europe; betting on direct electrification (e.g. heat pumps) would mean that these existing heating systems (including the distribution systems within each building) would need to be exchanged at high costs.

Power-to-X (PtX) will play an important role for the defossilisation of our economy

PtX fuels such as hydrogen, synthetic methane or e-diesel can play an important role in many sectors of our economy:

- Within the mobility sector, PtX applications such as hydrogen, e-diesel or methanol can, in particular, be used for heavy-duty or long-range applications requiring high energy density which cannot be provided by BEVs. Many e-fuels (e.g. blended hydrogen, e-diesel) will allow the use of existing infrastructure and existing cars, hence the mobility transition could begin soon. A more mixed approach with different solutions for different mobility applications (e.g. e-fuels for heavy-duty vehicles or buses, or as a range extender in PHEVs) and BEVs for passenger cars used for short-distance applications will allow for a more efficient and more accepted decarbonisation of the mobility sector.
- Within the heating sector, synthetic methane or natural gas blended with hydrogen could be used together with the existing infrastructure, be it a gas pipeline system, gas storage or even the standard heating systems in houses.
- Within the industry sector, many process emissions (e.g. in refining, steel production) can be avoided using PtX fuels such as (green) hydrogen.

Put simply: a turnaround of our economy in Europe requires both electrons and molecules to be successful.

… The potential role of Power-to-X technologies (continued)

The e-fuel market will be a global market

For many e-fuels, the market will be a global market: the costs of e-fuels are strongly driven by electricity costs (in addition to fixed costs for the hardware and the cost of a sustainable carbon source), while overseas transport costs are comparably low. Through international trade, the comparative cost advantages of countries with low renewable energy source (RES-E) costs, such as Australia, the Middle East or Chile, can be utilised.

Figure 1 Potential e-fuel exporting countries

Source: Frontier Economics

Screening possible exporting countries
(Costs/Potential/Regulation/local specifics)

A few examples….

Type	PtX Motivation and Readiness	Examples
Front-runners	Especially favourable in early stages of market penetration	Norway
Hidden Champions	PtX could readily become a serious topic if facilitated appropriately	Chile
Giants	Provide order of PtX magnitudes demanded in mature market	Australia
Hyped Potentials	Potential to lead technology development; may depend on solid political facilitation	Morocco
Converters	Strong motivation for PtX export technology; may require political facilitation	Saudi Arabia
Uncertain Candidates	May drive PtX technology development, export uncertain	China

Note: only a few example countries are depicted on the map.

At the same time, geopolitical considerations are also in favour of e-fuel markets, giving a perspective to countries that currently export and sell fossil fuels to the Western world (e.g. Middle East, Venezuela). E-fuels can be traded flexibly with many partners—the issue of import dependency experienced with other fuels (e.g. pipeline gas), from rare materials (e.g. material such as cobalt needed for battery production) or from electricity (via networks as in the planned Desertec project) does not exist for many e-fuels.

A look into different business models to process low-carbon feedstocks

The role of biorefining in accelerating the energy transition

Thomas Schrøder
(Novozymes)

Biorefineries are flexible platforms that transform biofeedstocks into low-carbon fuels, power, heat, feed and other value-added compounds such as chemicals and materials. As such, they can accelerate the clean energy transition. At Novozymes, we've tried to outline what the biorefining platform can offer, namely how it can address three key challenges routinely identified by observers of the climate debate:

Challenge 1: There is no silver bullet to reach net-zero emissions

Solution: The optimal solution is a mix of green energy technologies. Biorefining is key to this mix—not only because its products are sustainable, but also on account of its unique synergies with other green technologies. For instance, carbon-neutral electrification of transport holds great promise as a solution, but it cannot succeed on its own in the time we have to mitigate climate change. Biofuels are needed to achieve sufficient carbon emission reductions across all transport segments.

Biorefineries also complement other types of renewable energy generations, for example coproducts from biorefineries, such as lignin and biogas, which can supply electricity to balance intermittencies in a renewable energy grid.

Challenge 2: There is no crystal ball to determine the extent and speed at which different technologies will succeed in the future

Solution: Accurate prediction is not needed as long as the future energy system can adapt to market needs. In this context, biorefining is valuable because of its ability to adapt its outputs over time to meet future requirements for fuel and materials. Today, biorefineries primarily produce liquid fuel for passenger cars, but in the longer term they can be adapted to cater for other segments such as shipping, aviation and other applications, including biochemicals.

Challenge 3: There is a need for negative emissions to meet the international climate targets

Solution: The Intergovernmental Panel on Climate Change (IPCC) highlights the need for negative carbon emissions as soon as possible to keep the temperature rise below 2°C. Biorefining offers one of the easiest and cheapest forms of achieving negative emissions. The fermentation process emits a CO_2 stream that is relatively clean and concentrated, thereby enabling its cost-efficient capture and storage.

The Novozymes vision 'Bridging the gap to a sustainable future' is a call to define an effective pathway to mitigate climate change. It is a living document based on what we know works. More importantly, it is intended to start a conversation, as well as being an invitation to work together, as we are convinced this is the only way forward to meet our climate commitment.

The full Novozymes vision is available at www.novozymes.com/bioenergy, for all to access and use without restrictions.

Finding the right solutions: Concawe's NO_x/NO_2 source apportionment tool

Bino Maiheu
(VITO)

Air quality is a multi-scale phenomenon with a strong spatial variability depending on the pollutant and location type. Especially in the urban environment, there can be significant differences in NO_2 concentrations in neighbouring streets with very different traffic flows or street canyon properties. Furthermore, it is well-known from monitoring campaigns and detailed model-based assessments, that road-side gradients of NO_2 concentrations are equally large with a considerable drop in concentrations in the first few hundred metres from the road. The attribution of the pollutant concentrations to different source categories may therefore be equally variable in space, and should be carefully evaluated when looking at local measures to improve air quality in hotspots, to ensure that the right solutions are found.

To this end, VITO has created an online source apportionment tool for Concawe, based upon an EU-wide modelling methodology developed for the European Commission. This methodology uses local dispersion kernels at 125 x 125 m, as calculated by VITO's IFDM[4] Gaussian plume model, to account for the effect of roads in a much more detailed way than was previously possible at the European scale. The road transport emissions are calculated on a street network derived from OpenStreetMap, using the COPERT[5] national fleet compositions and VITO's FASTRACE traffic emission model. The tool includes a background source attribution at SNAP[6]-sector level, derived from the SHERPA[7] tool developed by the European Union's Joint Research Centre, combined with CAMS[8] background NO_2 concentration assessments for 2015. The source attribution is further detailed for the traffic sector (SNAP 07 — Road Transport), for different vehicle types, fuel types (petrol, diesel and CNG) and EURO norms.

The user of the tool is free to select any location on the map to view local traffic and/or regional background NO_x contributions. For the NO_2 concentrations, the user is presented with a dedicated analysis functionality which allows them to assess the contribution of a selection of traffic categories by removing these NO_x contributions and recomputing the new chemical equilibrium, yielding the difference in concentration with respect to the total NO_2 concentration.

For a selection of cities, a more detailed validation analysis was performed using the reported annual mean NO_2 concentrations in the EEA[9] e-Reporting database. For several cities, the results were satisfactory, but some underestimations at urban traffic locations remain present, largely due to the limitation in spatial resolution of ~125 m and the lack of street canyons. These points will be further pursued in an updated version of the tool. Nevertheless, the tool allows an investigation of the contribution of different vehicle and fuel types to NO_x and NO_2 concentrations, and gives a feeling for the distribution of these concentrations relative to the distribution of the population. The tool also provides an indication of the concentration gradients near roads (although the resolution is still limited), as well as an indication of the fleet composition and the share of different vehicle categories in an interactive way.

4 Immission Frequency Distribution Model.

5 Software tool developed for road transport emission inventory preparation in EEA member countries.

6 Selected Nomenclature for Air Pollution.

7 Screening for High Emission Reduction Potential on Air — a software tool designed to calculate how changes in emissions affect air quality.

8 Copernicus Atmosphere Monitoring Service — part of the EU's Earth observation programme: provides information related to air pollution and health, solar energy, greenhouse gases and climate forcing.

9 European Environment Agency.

Session: Water sustainability of renewable fuels

Water sustainability of renewable fuels

May Wu
(Argonne National Laboratory)

The energy industry continues to be challenged by a decline in the availability of fresh water from local sources as a result of increased and competing demands from urban development, resource depletion and a growing population. Recent climate trends indicate increased extreme weather events in various regions currently producing food, feed and energy feedstocks. A decrease in water availability could disrupt the production of these commodities, as well as cause a ripple effect that would be felt across various regions in multiple sectors. In the past decade, consumption of petroleum oil has decreased gradually in the United States and Europe, while the consumption of natural gas liquids and biofuels has increased. In the United States, biofuel production reached 16 billion gallons in 2017. Increasing the percentage of the liquid fuel supply that has a biofuel blend to more than 10% — a low-carbon goal for several countries— could have implications on the demand for fresh water.

In this multi-year study, we examined the water consumption of the biofuels that are the dominant water users in renewable fuels. We used an open-access web-based model, WATER (Water Analysis Tool for Energy Resources), that ties the hydrologic cycle to the water footprint of the supply chain at the county level in the United States to analyse the water footprint and fresh water available for the production of biofuel.

Biofuels produced from a range of raw materials, such as corn grain, corn stover, soybean, wheat straw, switchgrass, miscanthus, softwood, hardwood and short rotation woody crops, were evaluated. The water footprint of biofuels accounts for the water required to grow the biomass and convert it to fuels through various biochemical, physical and thermochemical processes in which water is required for cooling, steam, and unit operations. The study found that water consumption for biofuel production has extensive regional variation and temporal variability. Factors affecting the biofuel footprint include the type of biomass, where it is grown, and how it is converted, as well as the fuel blend of the biofuels. The impact of water consumption in historical biofuel production on annual renewable freshwater resources is further analysed by using water availability indices at the county level in the United States. This study identifies region-specific production scenarios that enable increased water-use efficiency while meeting the goal of producing one billion metric tonnes of biomass for bioenergy in the United States.

The study also compared water consumption in biofuel production with that in petroleum oil production — primarily the water consumption associated with oil exploration and production, and refining. Similarly, water use for petroleum depends on the type of energy feedstock and the geologic formation/regions of the oil field, the production technologies, the management of produced water, and refining technology and refinery design. Among them, produced water management plays a critical role in shaping the water footprint of petroleum. Although the breakdown of water use among refineries globally is similar on average, European refineries emphasise the use of unconventional water resources; brackish and saline water accounts for more than 90% of total refinery water use in European refineries.

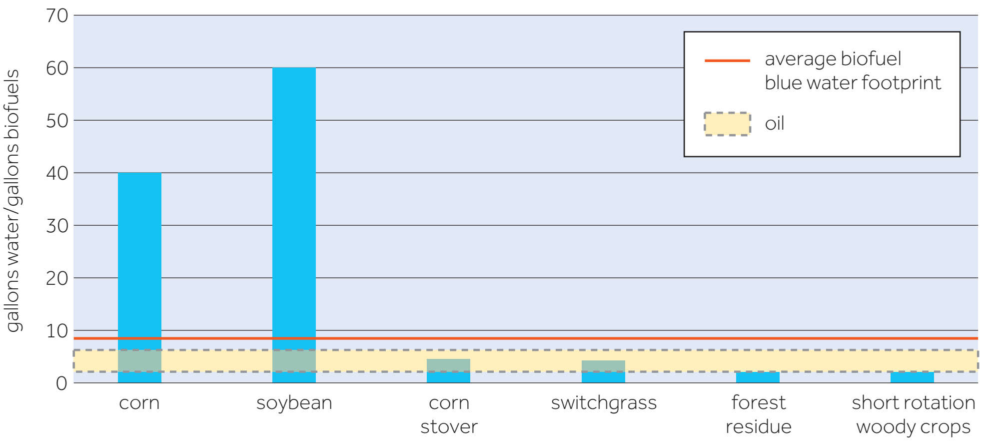
... Water sustainability of renewable fuels (continued)

Finally, the study evaluated the approach to formulating the feedstock of a biofuel blend to reduce the fresh surface water and groundwater footprint. As shown in Figure 1, the results demonstrate that:

a) by planning a biomass mix containing corn, soybean, corn stover, switchgrass, forest wood residue and short rotation woody crops grown in different regions, the overall demand for irrigation water would decrease significantly; and

b) the water footprint of biofuel blends can be reduced to a level that is comparable with that of petroleum gasoline.

Figure 1 Fresh surface-water and groundwater footprint of biofuel produced from various biomass feedstocks, compared with that of combined blends and petroleum oil



The water footprint is calculated for a total of 920 million dry tons of feedstock, including 15% from corn grain and soybeans, 30% from crop residues, 11% from perennial grass, 39% from wood residue, and 5% from short rotation woody crops grown in various regions across the United States.[1]

The findings suggest that the water footprint of a fuel blend with 10% biofuel can be maintained at current levels, and would therefore be sustainable in the context of freshwater resources. The study concludes that a fuel mix that contains petroleum and biofuel can be optimized (minimized) by (1) comparing feedstock type, feedstock production region, management options, and processing technology, and (2) selecting a fuel blend and the blending level of the individual fuels to reduce the overall water footprint. The WATER model, with its extensive climate, land use and water resource database, and water footprint framework, enables a smooth selection and comparison process for the energy industries.

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[1] Rogers *et al.* (2016). An assessment of the potential products and economic and environmental impacts resulting from a billion ton bioeconomy. In *Biofuels, Bioproducts and Biorefining*, Volume 13, Issue 3, May/June 2019. doi.org/10.1002/bbb.1728

Impacts of particulate emissions from international shipping on climate

Chien Wang
(MIT)

Ocean-going ships contribute about 2% of global annual anthropogenic emissions of long-lived greenhouse gases. In addition, these ships simultaneously emit primary particulate matter (PM) alongside precursors of particles such as sulphur dioxide (SO_2) and nitrogen oxides (NO_x). These small airborne particles could directly reflect, or cause clouds to reflect, more sunshine back to space (the latter effect is stronger than the former), cooling down our planet and partially counteracting global warming from greenhouse gases.

A Concawe-sponsored research project conducted at the Massachusetts Institute of Technology (MIT) used state-of-the-science climate models to demonstrate that international shipping emissions could be responsible for more than 10% of total anthropogenic aerosol forcing. This is disproportionately larger than their contribution to total anthropogenic sulphur emissions which amounts to about 5% (5.6 Tg S yr^{-1}), which is largely due to the fact that ocean-going ships travel across remote oceans that occupy a vast portion of Earth's surface and are hard to reach by aerosols from land-based emission sources.

In addition, to investigate the dependence of the climate effect on marine fuel types, the research group designed several scenarios based on ships using fuels with different sulphur contents, including:

- the current average of 2.70% sulphur;
- IMO's target for 2020 of 0.50% sulphur;
- an extreme case of 3.5% sulphur; and
- a case where about 32% of heavy fuel oils at 2.7% sulphur content would be replaced by liquefied natural gas (LNG).

The model simulations demonstrated that, with the fuels currently in use, international shipping would lead to a nearly 0.2°C cooling, averaged globally and annually, whereas by adopting the IMO's 2020 target of 0.50% sulphur, this effect would be largely eliminated.

Interestingly, over open oceans, marine emissions of dimethyl sulphide, $(CH_3)_2S$, (DMS) constitute an important natural source of sulphate aerosols. The research group studied the interplay between this type of natural aerosols and the anthropogenic emissions from ships, and identified a sublinear relationship between their combined climate effects and their combined concentration. Generally, a stronger cooling effect induced by DMS emissions would be seen when the shipping emissions were ignored, particularly in areas of intense shipping tracks, such as the North Indian Ocean, mid-latitude areas of the Pacific Ocean and Atlantic Ocean. On the other hand, the climate effects of ship-emitted aerosols would differ up to an order of magnitude when different DMS emission concentrations are used in the simulation. This critical finding suggests that the effectiveness of ship-emitted aerosols in influencing climate depends on the availability of natural aerosols, e.g. from marine DMS emissions. Therefore, any assessment of the climate effects of international shipping needs to be performed with adequate consideration of natural emissions in the framework.

Concawe publications (2019 to date)

Reports

Report number	Title
8/19	CO_2 reduction technologies. Opportunities within the EU refining system (2030/2050). Qualitative & Quantitative assessment for the production of conventional fossil fuels (Scope 1 & 2)
5 July 2019	Low Carbon Pathways Until 2050. Deep Dive on Heavy-Duty Transportation. Report produced by FEV Consulting for Concawe
6/19	European downstream oil industry safety performance. Statistical summary of reported incidents - 2018
5/19	Concawe Substance Identification Group Analytical Program Report (Abridged Version)
4/19	Air pollutant emission estimation methods for E-PRTR reporting by refineries
3/19	Performance of European cross-country oil pipelines. Statistical summary of reported spillages in 2017 and since 1971
2/19	Effect of Diesel Fuel Properties on Fuel Economy and Emissions of Three Passenger Cars

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SESSION: REFINERY SAFETY AND VIRTUAL REALITY

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SESSION: AIR QUALITY

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SESSION: WATER SUSTAINABILITY OF RENEWABLE FUELS

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SESSION: LOW-CARBON PATHWAYS AND REFINING TECHNOLOGIES

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SESSION: MARITIME TRANSPORT—OVERCOMING THE FUELS' CHALLENGES

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