CLEANER SHIPPING: TRADE OFF BETWEEN AIR POLLUTION, COSTS AND REFINERY CO_2 EMISSIONS

Hein de Wilde[1], Pieter Kroon[2]

1, Energy research Centre of the Netherlands, P.O. Box 1, 1755 ZG Petten, +31 (0)224 564917, dewilde@ecn.nl,
2, Energy research Centre of the Netherlands, +31 (0)224 564891, kroon@ecn.nl

ABSTRACT

Still subject to final approval in October 2008, the International Maritime Organisation (IMO) agreed on a maximum sulphur content of 0.5% for shipping fuels in 2020. This target will induce major changes in the global refinery industry. We have estimated the impact on the Dutch refinery industry, which annually produces about 8 million tons of heavy fuel oil for sea shipping, with refinery residues as main component. It is technically possible to convert all residues, although this process will cause an additional energy use of about one million tons of crude oil and a related CO_2 emission of about 4 million tons. The investment costs for these major changes in the Dutch refinery industry are estimated at about €1.5 tot 2 billion.

The recent IMO agreement enables a gradual introduction of cleaner shipping fuels, which will reduce market disruptions and peak prices. Nevertheless Rotterdam may not necessarily be able to develop a similar position in import, export and bunkering of future low sulphur fuels, compared to its present strong position in the market of heavy marine bunkers.

Extrapolation of our national study to the global scale suggests that the deep conversion of 350 million tons of heavy fuel oil for shipping would require refinery investments in the order of € 70-100 billion. The associated CO_2 emissions would amount up to 175 Mton. The net additional CO_2 emission, however, would be smaller since lighter shipping fuels result in less CO_2 emissions at sea. On balance, we expect that the improvements in fuel economy, driven by the expensive low-carbon shipping fuels, will decrease CO_2 emissions more than the increase in CO_2 emissions from additional desulphurization in the refineries. Nevertheless CO_2 emissions from sea shipping will continue to increase since marine transport is rapidly growing.

KEYWORDS: Cleaner shipping fuels, converting refinery residues, investment costs, emissions SO_2, CO_2,, fuel efficiency

INTRODUCTION

Recent studies indicate that the annual fuel consumption by international shipping amounts to about 350 million tons, annually increasing with approximately 3% (IMO, 2007). This quantity is more than 50% higher than previously assumed and results in an annual CO_2 emission of about 1100 million tons, equalling about 4% of the total global CO_2 emission. In addition, marine vessels emit large quantities of SO_2, NO_x and soot (PM_{10}), since the standard shipping fuel

(HFO) contains at present about 2.7% sulphur, which is very high compared to other transport fuels. Shipping emissions have been estimated to induce more than 60,000 premature deaths globally, of which about one third in Europe (Corbett et al., 2007). Land based sources have achieved an enormous reduction in air pollution over the last decades. In contrast, shipping emissions have substantially increased over the same time span, along with the gradual growth of marine transport (Hammingh et al., 2007). Consequently, it is clear that international shipping has to take a big step in emission reduction. Over the last year, several options for the global or regional use of low sulphur fuels have been discussed in the framework of the IMO. Still subject to final approval in October 2008, the IMO agreed in April that the global sulphur cap for marine heavy fuel oil will be reduced to 3.5% in January 2012, with a global maximum of 0.5% in 2020. This latter target, will be reviewed in 2018, enabling a potential postponement of the 0.5% cap till 2025. The maximum allowable Sulphur content in the present Sulphur Emission Control Areas (SECA's) North Sea and Baltic will be lowered from the present 1.5% to 0.1% in 2015. In addition, it is likely that new SECA's will be established, for instance off the coast of California. These developments will gradually increase the demand for low sulphur shipping fuel, towards the global switch to 0.5% in 2020.

Shipping emissions also have a substantial effect on the environment in the Netherlands. The land based emissions from the Netherlands are comparable to the shipping emissions in the Dutch territorial waters. In 2006 land based SO_2 emissions and maritime SO_2 emissions were almost equal. The NO_x emissions from ships in the Dutch waters equalled 38% of the land based NO_x emissions. Marine PM_{10} emissions in the Netherlands equalled 23% of the land based emissions (statistical data). Approximately 4% of the particulates in the Dutch atmospheric air result from shipping. About 5% of the nitrogen compounds and about 20% of the sulphur compound, underlying the acid deposition in the Netherlands, originated from ships (Hammingh et al., 2007). In November 2007 the North Sea became a SECA region. It is expected that this results in a measurable improvement of the air quality in the Netherlands.

DUTCH REFINERIES

The refinery industry will have to meet the growing demand for low sulphur shipping fuels. Concern has been expressed by the organisations of oil companies, including CONCAWE, EUROPIA and IPIECA, that there would be insufficient low-sulphur fuel available to meet the IMO's targets. The Dutch refinery industry annually produces about 8 million tons of refinery residues, the main component of the presently used heavy fuel oil. We have evaluated the technical, economic and energetic impact of converting these 8 million tons of refinery residues into lighter fuels with a lower sulphur content (De Wilde et al., 2007).

Technology for refining residual fuel oil

The approximately 8 million tons heavy fuel oil (HFO) produced in annually in the Netherlands largely consist of the residues remaining after the distillation of crude oil in refineries. If needed, the residues are blended with gasoil to reach the right HFO quality. The production of residual fuel oil can be reduced, firstly by subjecting all atmospheric residues to vacuum distillation. In the Netherlands, this would decrease (vacuum) residues to 5 million tons. It is technically possible to convert the heavy and viscous residues that cannot be distilled further into lighter products (deep conversion). Several refineries have shown in practice that this is technically possible and economically feasible. This conversion can be done by either separating carbon in processes such as flexicoking, as done by Exxon Mobil, or by adding hydrogen, as done in Shell's hycon process. In the Netherlands, the 5 million tons of residual fuel remaining after complete vacuum distillation could be processed by building 2 or 3 flexicokers. As an alternative to deep conversion, residual fuels can be gasified for power generation with gas turbines, and possibly combined with the production of hydrogen and/or heating. However, in this case the demand for low sulphur shipping fuels has to be met completely by additional primary conversion and a lot of additional crude oil is needed. Consequently, converting the HFO compounds to low sulphur distillate fuel is the preferred option.

Processing capacity and time required for adaptations
The current primary refining capacity is about 85 million barrels per capacity day or 4250 ton crude oil per year worldwide, of which 1.6% occurs in the Netherlands. The global capacity for deep conversion is about 250 million ton per year, corresponding to about 6% of the total primary refining capacity. The additional refining of all the residual fuel currently used for ship propulsion would require nearly an additional 150% of the present global capacity for deep conversion. The global deep conversion capacity has grown in recent years almost 4 times faster than primary processing capacity, a development that is mostly due to crude oil becoming heavier, as well as the comparatively strong increase in demand for relatively light products. Current increase in deep conversion capacity was therefore up till now independent of the forthcoming transition from heavy bunker fuel to lighter low sulphur ship fuels.

Worldwide, the primary conversion capacity has, according to the Oil & Gas Journal (2007)[1], increased by about 170 million tons over the last seven years (0.6%/y) to reach its level of 3,400 million ton per year at the end of 2006. Technically, it might also be possible to expand capacity for the deep conversion of the marine bunker fuels in about a decade. The main challenge will be to increase the deep conversion capacity concurrently with the autonomous activities involving expansion of primary conversion. Potential difficulties involve the availability of technical knowledge and production capacity for the construction of new deep conversion installations, as well as the production decreases due to temporary stoppages in refineries in order to incorporate the new installations. Furthermore, refinery capacity is, as far as possible, geared to regional demand for various types of fuel produced in the refining process. This can provide refineries with a reason to prefer expansion into growth markets such as Southeast Asia, where future sales of the entire spectrum of refinery products are very secure.

At present, the difference between available refinery capacity and the demand for oil production is smaller than it has been over the past 25 years. The pace of implementing the IMO agreement could greatly affect pricing on the oil-market, the oil products market and the market for sea transport. Negative impacts might include shortages and price perturbations for certain oil products, as well as shortages in the engineering and construction capacity for refining facilities. Gradual introduction over about 6 years, preceded by a preparation phase for the refineries of approximately 6 years, could limit the negative effects. Fortunately, the recent IMO agreement enables a gradual introduction of cleaner shipping fuels, for example by the 2015 reduction of fuel sulphur in the present SECA's to 0.1% S, and the expected gradual increase of these areas.

[1] In 2006 the total refinery capacity was 82 mln b/d according to the Oil & Gas Journal. BP mentioned for the same year 85.7 mln b/d.

The gradual increase of the demand for low sulphur shipping fuel will reduce market disruptions and peak prices.

Economics of the refining industry
At present, approximately 3,300 people work in refineries located in the Netherlands. Including personnel from contracting companies, the number rises to 4,000-5,000 employees. The Netherlands no longer have any industry or electrical energy plants that 'run' on heavy fuel oil. Dutch refineries therefore do not have any alternative domestic market on which to sell heavy fuel oil and that is why they mainly concentrate on the market for bunker fuels for shipping. The investments for further refining of the residues in the Netherlands are estimated at approximately € 1.5 to 2 billion, on the basis of the ECN refining model. The investments for additional deep conversion capacity as reported in literature vary substantially, depending on the extent to which costs have been included for: (1) fitting the installations in the refinery, (2) additional processing of the intermediate products, and (3) distinguishing between new constructions and retrofit. Based on past actual investments, the installation of the necessary flexicoker capacity would now require an investment of approximately € 3.5 billion, at least if renovations are done more or less at the same time. The Oil & Gas Journal (2006) indicates an investment that is substantially lower, around 0.3-0.4 billion for the same capacity. This, however, is a 'basic' price for the flexicokers, one that still needs to be increased by the (high) costs of installation and modification for the refinery, as well as the substantial additional investments in capacity expansion of the installations in which the raw products from the flexicokers have to be processed.

If no investments are made in the Dutch processing capacity of residual oil, the industry's competitiveness will decline in the long term, particularly if there is a return to a situation with overcapacity and the margins for the refineries start diminishing again. The investments will ultimately translate into pricing changes for various products (low sulphur fuel for ships has a substantial higher price than high sulphur HFO). As is the case in other markets, investment is in most cases recoverable from revenue.

ROTTERDAM BUNKER MARKET

About 1500 employees are directly involved in the bunkering industry. The Rotterdam bunker market processes both domestic and imported refinery residues. The residues are used to blend shipping bunker fuels, which are both sold to ships and exported to other harbours. Rotterdam has grown into one of the three most important players on the bunker market, due to (1) the bunker production at local refineries, (2) the deepwater harbour enabling the biggest ships to port, and (3) a favourable geographical position for bunker imports from Russia and the Baltic states. Given these advantages, bunker fuels can be offered in the Netherlands at a low price. The bunker market in Rotterdam would suffer a decline if the value of oil exports for the bunker market were to drop, and the same would hold true if some of the refineries were to decide to stop production of fuels for ocean shipping. The Netherlands produced around 9 million tons of residual fuels in 2005 and imported approximately 20 million tons. Of this, around 15 million tons was bunkered by sea-going vessels, around 12 million exported (to Singapore and other locations), and the remaining 2 million tons used for domestic consumption. The economic GE scenario (Huizinga and Smid, 2005) reveals that the bunkering of ship fuel in the Netherlands will grow from 600 PJ in 2005 to approximately 1060 PJ in 2030, an increase of 3% per year (Hoen et al., 2006).

If the fraction of low sulphur shipping fuel will increase, the natural position favoured by inexpensive HFO imported from Russia will decrease, although transit of this product will continue. Rotterdam will not necessarily be able to develop a similar position in import, export and bunkering of lighter low-sulphur shipping fuels. On balance, there is a reasonable chance that the bunker sector, where about 1500 people are employed, would decrease. Since the storage sector also processes crude oil and other products, the decline over the entire sector will be smaller. In addition, the expected gradual shift to low sulphur fuels gives the Rotterdam bunker market time to anticipate and adapt.

TRADE OFF BETWEEN CLEANER SHIPPING AND CO_2 EMISSIONS

Cleaner shipping is a trade off between reducing air pollution and associated health benefits on the one hand, and costs and refinery CO_2 emissions on the other hand. This complex trade off is getting more and more urgent, given the recent IMO agreement, the fast growth of international shipping and the steady decrease of land based emissions.

Pollutants and health

The IMO trajectory towards cleaner shipping fuels will result in improved health and fewer premature deaths, including a reduction of life lost in Europe by several percent (Hammingh, 2007). The regional establishment of SECA's, with cleaner shipping fuel in selected coastal regions with a large population, is more cost effective and has a smaller impact on the refinery industry. Such an approach, however, does not protect people in coastal regions outside the selected areas. For example, about one quarter of all premature death from shipping has been projected around the shipping lanes in Asia (Corbett et al., 2007), whereas little is known yet on plans for local clean shipping zones in this region. A major advantage of the present IMO agreement is that it will eventually protect people in coastal regions worldwide, even if local authorities do not pay attention to shipping pollution.

Refinery CO_2 emissions and costs

Deep conversion of residual fuel into lighter low-sulphur shipping fuel is associated with a fuel consumption of about 15%, compared to about 7% for conventional refinery processes. For this reason, deep conversion of bunker fuels will result in additional CO_2 emissions. The ECN refinery model SERUM was used to calculate the changes in the refining sector if all residual fuels would be converted into lighter products.

Calculations with the ECN refinery model SERUM (Oostvoorn et al., 1989) indicate that the conversion of 8 million tons of bunker oil in the Netherlands into lighter products containing 0.5% sulphur, would be associated with an additional crude oil consumption of about 1 million tons and an increase in CO_2 emissions by about 4 million tons (de Wilde et al., 2007). This extra emission would mean a 2% rise in the total CO_2 emissions in the Netherlands. Extrapolation of the calculations for the Netherlands to the global scale suggests that the deep conversion of 350 million tons of heavy fuel oil for shipping would require refinery investments in the order of € 70-100 billion. The associated CO_2 emissions would amount up to 175 Mton, depending on the type of refinery route. These numbers are largely in line with the study performed by Ensys Energy & Systems, Inc. on request of the IMO (IMO, 2007). The net additional CO_2 emission into the atmosphere resulting from a switch to cleaner low-sulphur shipping fuel would be smaller, since lighter shipping fuels result in less CO_2 emissions at sea (the carbon content per unit of energy of distillate fuels is lower compared to HFO, and so it the CO_2 emission).

Emission trading

The CO_2 emissions from international shipping are not covered by the Kyoto Protocol on climate change. In addition no international or European regulation is applied to fuel consumption or CO_2 emissions from shipping. Neither are fuels subject to any kind or tax or other market-based instruments (Kageson, 2007). The EU considers to include ship emissions in the EU emissions trading scheme (ETS), aiming to increase the use of renewable fuels and developing more efficient technologies to reduce emissions. The gradual increase of expensive low-sulphur shipping fuels will likely be a stronger incentive for International Shipping to reduce CO_2 emissions. The present price difference between standard bunker oil and low sulphur shipping distillate fuel of about 300 euro per ton, is equivalent to a price increase of about 100 euro per ton CO_2. This price level is higher than the present CO_2 price in the ETS system and thus a strong incentive for shipping companies to implement fuel saving strategies.

Fuel efficient shipping

Improving fuel efficiency is ever more important given the vast increase international shipping of 3% or more per year. In addition, the future low sulphur fuels will on balance result in an additional CO_2 emission on land. Rapidly rising oil prices have seen bunker fuel costs as a share of a ship's total operational costs increase from 20% to 50% in the last few years (Møller, 2008). Several options for fuel saving are available, and will become more cost effective as oil prices increase. Fuel saving options include (Zuidema, 2008):

- Speed reduction. Fuel consumption is approximately related to the square of speed, implying that a 20% reduction in speed results in a fuel saving of up to 40%. The net fuel saving, however, is partly reduced by additional shipping required to maintain the transport capacity.
- Improved hull coating (anti fouling) can save a few % (AET, 2008)
- Route optimisation software, taking weather and sea conditions into account with high time resolution, also enable to save a few %.

In addition non conventional options are being developed, including:

- Air bubbles screen, reducing friction and thereby saving up to 15% (Møller, 2008)
- Application of 'kite-like' sails (Sky Sails, 2008).

On balance, we expect that the improvements in fuel economy, driven by the expensive cleaner low-carbon fuels, will decrease CO_2 emissions more than the increase in CO_2 emissions from additional desulphurization in the refineries. Nevertheless CO_2 emissions from sea shipping will continue to increase since marine transport is rapidly growing.

CONCLUSIONS

The deep conversion of 350 million tons of heavy fuel oil for shipping would require refinery investments in the order of € 70-100 billion. The associated CO_2 emissions would amount up to 175 Mton. The net additional CO_2 emission into the atmosphere would be smaller, however, since lighter shipping fuels result in less CO_2 emissions at sea.

On balance, we expect that the improvements in fuel economy, driven by the expensive cleaner low-carbon fuels, will decrease CO_2 emissions more than the increase in CO_2 emissions from additional desulphurization in the refineries. Nevertheless CO_2 emissions from sea shipping will continue to increase since marine transport is rapidly growing.

REFERENCES

AET, 2008. Results on new fuel efficient hull coatings, implemented by the shipping company AET, as reported in Bunkerworld 2008 (www.bunkerworld.com)

Corbett, J.J., Winebrake J.J., Green E.H., Kasibhatla P., Eyring V., and Lauer Al. 2007. Mortality from Ship Emissions: A Global Assessment. Environmental Science & Technology 41 (24), 8233-8239.

De Wilde, H.P.J. de; Kroon, P.; Mozaffarian, M.; Sterker, Th. 2007. Quick Scan of the Economic Consequences of Prohibiting Residual Fuels in Shipping. Published by the Energy Research Centre of the Netherland, Report ECN-E--07-051 juli 2007; 76p.

Hammingh, P., J.M.M. Aben, W.F. Blom, B.A. Jimmink, W.J. de Vries, M. Visser (2007) Effectiveness of international emission control measures for North Sea shipping on Dutch air quality. Published by the Netherlands Environmental Assessment Agency (MNP), Report 500092004/2007

Hoen A., Van den Brink R.M.M., Annema J.A.. 2006. Verkeer en vervoer in de Welvaart en Leefomgeving; Achtergronddocument bij Emissieprognoses Verkeer en Vervoer (In Dutch). Published by the Netherlands Environmental Assessment Agency (MNP), MNP rapport 500076002/2006

Huizinga, F. and Smid B. 2005 Four Futures of the Netherlands; Production, labour and sectoral structure in four scenarios until 2040 Memorandum of the Netherlands Bureau for Economic Policy Analysis (CPB).

IMO. 2007. Report on the outcome of the Informal Cross Government/Industry Scientific Group of Experts established to evaluate the eff ects of the different fuel options proposed under the revision of MARPOL Annex VI (20 December 2007). IMO Document BLG 12/6/1.

Kågeson, P. 2007 Linking CO_2 Emissions from International Shipping to the EU ETS, Commissioned by the Federal Environment Agency, Germany

Møller, C.E. (2008), Chief Executive Officer DK Group, as quoted in Bunkerworld april 2007 (www.bunkerworld.com).

Oil & Gas Journal. 2006. Worldwide refineries-capacities as of January 1, 2007 (and comparable extra publications over 2000, up to and including 2006). 18 December 2006.

Oil & Gas Journal. 2007. Refinery Statistics. 24 December 2007.

Oostvoorn, F. van, A.V.M. de Lange, P. Kroon. 1989. SERUM, Een model voor de Nederlandse raffinage industrie. ESC-49, ECN, Petten (in Dutch).

Sky Sails. 2008. (www.skysails.info)

Zuidema, T (2008) Technisch weekblad, 10 mei, 2008 (In Dutch).