Background Document

Reducing Emissions from Goods Movement via Maritime Transportation in North America

Assessment of 2030 Mexico and Global Fuels Supply and Cost Impacts

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List of Abbreviations and Acronyms

AMISBAC	*Asociación Mexicana de Industriales de Servicio a Buques*
BAU	business as usual
bbl	barrel (42 US gallons; 159 litres)
bn	billion
bpd	barrels per day
DMA	a standard for marine distillate fuel under ISO 8217 (Kinetic Viscosity [mm^2/s] at 50ºC = 1.5-6.0, with Density [g/cm^3] at 15ºC <0.890)
DMB	a standard for marine distillate fuel under ISO 8217 (Kinetic Viscosity [mm^2/s] at 50ºC <11, with Density [g/cm^3] at 15ºC <0.900)
ECA	Emissions Control Area
EERA	Energy and Environmental Research Associates, L.L.C.
EIA	(US) Energy Information Administration
EPA	(US) Environmental Protection Agency
HDS	hydrodesulfurization
HFO	heavy fuel oil; a residual fuel oil (No. 6, Bunker C)
IEA	International Energy Agency
IEO	International Energy Outlook
IFO	intermediate fuel oil (blend of MGO and HFO, with less gasoil than MDO)
IMO	International Maritime Organization
ISO	International Standards Organization
LPG	liquefied petroleum gas
mbd	million barrels per day
MCE2	Molina Center for Energy and the Environment
MDO	marine diesel oil (blend of MGO and HFO)
MGO	marine gas oil; a distillate fuel oil (No. 2, Bunker A)
mmbfoed	million barrels of fuel oil equivalent per day
mmtpa	million metric tonnes per year
PEMEX	*Petróleos Mexicanos*
tpa	tonnes per annum (year)
ULS	ultra low sulfur (content in gasoline or diesel [ULSD])
WORLD	EnSys' World Oil Refining Logistics & Demand Model

Executive Summary

This document presents the key premises and results of the fuel supply and cost analysis, developed by EnSys Energy (Ensys), in support of Mexico's submission of an Emission Control Area (ECA) designation proposal to the International Maritime Organization (IMO), under Annex VI of the International Convention for the Prevention of Pollution from Ships (Marpol Convention).

For this analysis, EnSys employed its World Oil Refining Logistics and Demand (WORLD) model to assess the total global impacts of a shift, in 2030, to a 0.1% sulfur-content fuel (the IMO's ECA fuel standard), within Mexico's 200-nautical mile ECA zone. The methodology mirrors previous analyses undertaken by EnSys to support final amendments to MARPOL Annex VI enabling the establishment of Emission Control Areas, and the US Environmental Protection Agency (EPA)'s North American ECA submission. The year 2030 was selected in order to be consistent with the horizon used in a previous air quality modeling study by the Commission for Environmental Cooperation (CEC). The 2030 global modeling took into account Mexico's energy reform, introduced in 2013, while recognizing that at this early stage the potential longer term impacts of the reform are not clear. Within the modeling, the main assumption was that there would be a gradual improvement in the production of crude oil and natural gas liquids in Mexico.

Two scenarios – a "Base Case" and an "ECA Case" – comprised the analysis. In the 2030 Base Case, the 0.5% IMO global (Annex VI) marine fuel sulfur standard was assumed as being in force. Since there remains significant uncertainty about whether any fuel formulations other than marine distillates can fulfill the need, at scale, to meet the 0.5% sulfur standard, and to be conservative with regard to future scrubber potential, the Base Case marine fuel mix assumed that the 0.5% standard would be met predominantly by using 0.5% sulfur marine distillate fuel. It was further assumed, both to be conservative and to mark a contrast between the global and ECA fuels, that the global 0.5% sulfur fuel would correspond to the DMB marine distillate fuel standard and that the 0.1% sulfur ECA fuel would correspond to the DMA standard.

Global marine fuel consumption in 2030 was projected by applying data from the Third IMO Greenhouse Gas Study from July 2014, and using the average of the IMO's four "business as usual" (BAU) scenarios as the basis for the 2030 demand. This led to a projection for total global marine fuel demand of 7.86 million barrels per day (bpd), versus an IMO base level of 5.5 million bpd in 2011-2012. For consistency, the 2030 Mexican ECA fuel volume estimated in the CEC air modeling study used to support the Mexican ECA designation proposal was also applied in the present study. The projection was taken from work by Energy and Environmental Research Associates (EERA) and equated to 2.98 million bpd. This figure was considered to be very high, but it was applied by spreading the ECA conversion volume across most world regions, thus reflecting a scenario more akin to one in which several ECAs were established.

Refining, supply, demand, quality and transport premises were applied to be consistent with the marine fuel demand figures outlined by the US Energy Information Administration (EIA)'s 2014 International Energy Outlook reference case for 2030. Particular attention was focused on Mexico's refining system, crude production, product demand, and marine fuel sales. The analysis determined that in 2014, marine fuel sales at Mexican ports were relatively low: a total of approximately 14,000 bpd made up of sales (of mainly marine diesel) listed in *Petróleos Mexicanos* (PEMEX) statistics, along with sales listed as exports that were in fact blends sold by local distributors as Intermediate Fuel Oil (IFO).

The results obtained corresponded to switching 2.98 million bpd of 0.5% sulfur global fuel (assumed DMB quality) to 0.1% sulfur ECA fuel (assumed DMA quality). This switch was projected to increase global refining investments by US$6.4 billion (in 2012 US$), versus the Base Case. The associated capacity additions corresponded to increases in desulfurization and supporting hydrogen and sulfur plant capacity, as well as additional upgrading capacity (this since DMA is a somewhat lighter product than DMB). Capacity changes were assessed as being needed across world regions (recognizing that—as stated—the shift to ECA fuel was necessarily spread across the world's region). Impacts on Mexico's refining system were minor (which was expected as the total marine fuel volume sold there was assessed as small). The refining system adjustments were projected as raising marine fuels prices (global 0.5% marine fuel price dropping and ECA 0.1% fuel price rising because of a change in volume, representing a net increase); but also raising prices of other distillate products, namely inland diesel/gasoil and jet/kerosene. These increases were partially offset by reductions in prices for the lighter products—liquefied petroleum gas (LPG), naphtha, gasoline—but the net impact was assessed to be an increase in total global supply costs (all regions, all products) of just over US$4 billion (2012 US$) per year.

The resulting assessment is subject to its underlying assumptions. Assuming a narrower quality gap between the global and ECA fuel quality levels (e.g., both at DMB or DMA versus the assumed global fuel at DMB level, and ECA fuel at DMA level) would have reduced the incremental supply cost associated with the fuel switch. Conversely, assuming some mix in the Base Case of other formulations such as low sulfur IFO or intermediate (vacuum gasoil) fuel would have raised the costs of conversion. Assuming a switched volume lower than the 2.98 million bpd would have lowered the total associated annual dollar costs roughly proportionately, but may have reduced costs per barrel or tonne only moderately – since the same mix of refinery processing changes would have been called for. Assessed impacts on 2030 product supply costs in Mexico were projected to be small, in line with the limited volume of marine fuel sold in the country.

1. Introduction

In support of amendments to Annex VI of the International Maritime Organization (IMO)'s Marpol Convention, and upon request by the American Petroleum Institute (API) and the International Petroleum Industry Environmental Conservation Association (IPIECA), EnSys undertook substantial assessments of the potential impacts of stricter marine fuel sulfur standards. Over broadly the same period—from 2007 through 2009—EnSys also undertook extensive analyses for the US EPA to support the North American ECA submission to the IMO. The current study seeks to present a similar analysis to support the Government of Mexico's planned ECA submission.

The objective of this analysis has been to demonstrate the impacts on oil refining and markets of those countries adopting an ECA, with specific focus on the producibility and cost of the directly affected marine fuel volumes, and the broader impacts on product supply costs. The approach has been to use the highly proven and widely recognized integrated World Oil Refining Logistics and Demand (WORLD) model of the global petroleum supply system. Additional information about this model is available at www.ensysenergy.com.

2. Approach and Premises

EnSys was requested to establish a 2030 Mexico and global outlook using data consistent with the emissions analysis used to assess the impacts of implementing the Mexican ECA (CEC 2018)[1]. Two WORLD cases were run:

1. 2030 No Mexican ECA (Base Case), and
2. 2030 With Mexican ECA (ECA Case).

Since WORLD is an integrated model of the total oil "liquids" system, many premises had to be developed in order to establish the Base Case against which the Mexican ECA Case was compared. WORLD matches top down supply, demand, and world oil price scenarios (at a macro scale) with bottom up (micro scale) details.[2] This section focuses on the top down outlooks and projections applied together with the data and premises specific to Mexico.

In any analysis, the option exists to employ premises which are either more or less conservative. Given the intent here was to assess the fuels supply and cost impacts of a Mexican ECA, the decision was taken to err on the side of being conservative, i.e. to use premises that would increase rather than decrease the difficulty of supplying the ECA fuel and which would increase rather than decrease their costs.

2.1 Global Supply-Demand Price Outlook

A good example of the relevance of opting for a conservative approach (higher cost) relates to the decision about which global oil price, supply and demand scenario to use for the main premises of each of these three key parameters. Reflecting recent oil price reductions, the US Energy Information

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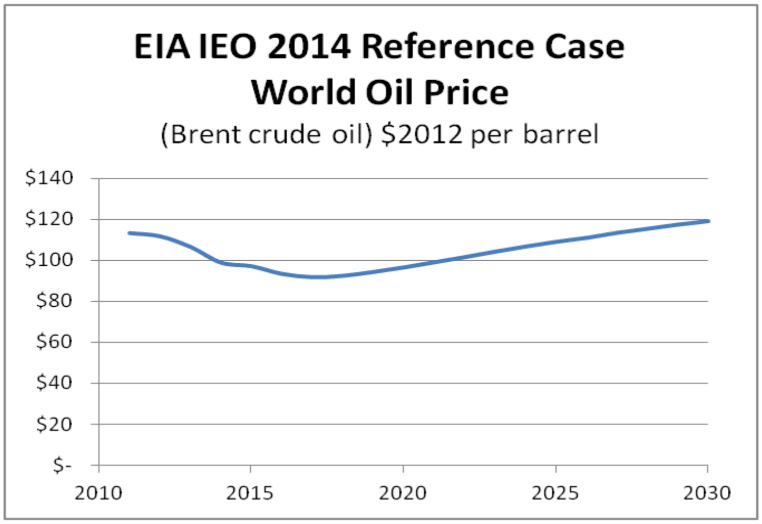
[1] CEC. 2018. Reducing Emissions from Goods Movement via Maritime Transportation in North America: Evaluation of the Impacts of Ship Emissions over Mexico. Commission for Environmental Cooperation.

[2] The "top down" outlooks EnSys works with are generally the IEA World Energy Outlook (IEA 2014) or the EIA Annual or International Energy Outlook (EIA 2014). These provide projections for world oil price and for "liquids" supply and demand at the regional and global levels. EnSys employs these in the WORLD model, together with extensive "bottom up" data which cover, *inter alia*: detail of crude supply by type and of non-crudes supply, (natural gas liquids, biofuels and other non-crude streams), regional breakdowns of major petroleum product groups by quality, capacity and known projects by refinery worldwide, detail of marine and pipeline transport options with costs and (for pipelines) capacity.

Administration developed both Reference and Low Price outlooks in its September 2014 *International Energy Outlook* (IEO).[3] For this study, the decision was taken to use the Reference outlook, since that would tend to generate wider light / heavy petroleum product differentials and would therefore tend to lead to a higher cost for implementing the Mexican ECA than would be the case under a low world oil price scenario.

As Figure 1 shows, the EIA 2014 IEO Reference case profile is for rising world oil prices, leading, as discussed above, to higher rather than lower projected costs for introducing the Mexican ECA.

Figure 1. World Oil Price According to the EIA's International Energy Outlook 2014 Reference Case



Source: EIA 2014

Tables 1, 2, and 3 set out the key "top down" supply and consumption projections contained in the IEO Reference case.[4] These projections were applied and refined using details of crude and non-crude petroleum supplies and product demand to 2030. These bottom-up trends and premises embodied *inter alia* the following:

- Middle distillates (diesel/gasoil) as the primary growth product by 2030 (more than 6 million bpd);
- Continuing growth in other light clean products, notably jet/kero, gasoline, naphtha and LPGs;
- A continuing decline in inland residual fuel demand (approximately -2 million bpd by 2030);
- IMO demand and growth for marine fuels as summarized in Table 7;
- Progressively stricter gasoline and diesel fuel standards leading to widespread ultra-low sulfur levels (and EURO IV/V standards) by 2030;

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[3] EIA 2014. At the time the study was undertaken, the September 2014 EIA International Energy Outlook was also the latest available outlook that readily fits into the WORLD Model. The EIA Annual Energy Outlook was not expected to be released until second quarter 2015, i.e., after the deadline for completion of the Fuels Analysis. The September 2014 IEO Reference case did not include the drop that has since occurred in crude oil prices. However, EnSys' modeling focus was on 2030.

[4] http://www.eia.gov/forecasts/ieo/

- An increasing volume and proportion of non-crude streams (natural gas liquids, biofuels, CTL/GTL) in the total supply;
- A short-term shift to a lighter global crude slate (driven by US light oil growth) reverting to a slate with overall quality not that different from today by 2030, but embodying high volumes of both light crudes (US, Caspian, Africa) and heavy conventional and non-conventional crudes (Canada, Brazil, Venezuela) as well as growth in mainly medium sour Middle East volumes;
- Pipeline and rail expansions in the United States and Canada that will enable crudes to reach coastal markets (but with no major expansion in allowed US crude oil exports) and expansion of the East Siberia–Pacific Ocean pipeline, resulting in increasing volumes of Russian crude moving to Asia;
- A recovery to a "balanced" state in the tanker market, but with freight rates that also allow for fuel cost increases driven by the assumed shift to mainly distillate fuels; and
- In terms of crude distillation capacity, some 6.5 million bpd of firm refining projects, (down from over 8 million bpd a year ago and impacted by the current drop in crude prices leading to deferrals), together with substantial firm additions to upgrading (coking, FCC and hydro-cracking), desulfurization and supporting units.

Table 1. World Crude and Lease Condensate[a] Production by Region and Country, Reference Case, 2009-2040

Region	History			Projections					Average annual percent change, 2010-2040
	2009	2010	2011	2020	2025	2030	2035	2040	
OPEC*	**31.0**	**32.0**	**32.2**	**34.4**	**36.1**	**39.5**	**42.9**	**46.2**	**1.2**
Middle East	**20.8**	**21.7**	**23.0**	**23.8**	**25.2**	**28.4**	**31.5**	**34.5**	**1.6**
North Africa	3.3	3.2	2.0	2.9	2.9	2.9	2.9	3.0	-0.3
West Africa	4.1	4.4	4.3	4.9	5.0	5.1	5.2	5.3	0.6
South America	2.8	2.7	2.8	2.9	2.9	3.0	3.2	3.5	0.9
Non-OPEC	**41.9**	**42.9**	**42.8**	**48.3**	**49.4**	**50.4**	**51.4**	**52.9**	**0.7**
OPEC	**15.3**	**15.4**	**15.2**	**19.5**	**19.5**	**19.4**	**19.5**	**19.6**	**0.8**
OECD North America	10.8	11.2	11.5	16.8	17.0	17.1	17.2	17.2	1.4
United States	5.5	5.6	5.8	9.8	9.3	8.6	8.2	7.8	1.1
Canada	2.6	2.9	3.0	4.4	4.9	5.5	5.8	5.9	2.4
Mexico and Chile	2.7	2.6	2.6	2.6	2.8	3.0	3.2	3.5	0.9
OECD Europe	3.9	3.6	3.3	2.2	1.8	1.7	1.6	1.7	-2.5
North Sea	3.4	3.1	2.8	1.8	1.5	1.3	1.3	1.4	-2.6
Other	0.5	0.5	0.5	0.4	0.3	0.3	0.3	0.3	-2.2
OECD Asia	0.5	0.5	0.5	0.5	0.6	0.7	0.7	0.8	1.1
Australia and New Zealand	0.5	0.5	0.5	0.5	0.6	0.7	0.7	0.8	1.1
Other	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	-1.7
Non-OECD	**26.6**	**27.5**	**27.5**	**28.8**	**29.9**	**31.0**	**31.9**	**33.2**	**0.6**
Non-OECD Europe and Eurasia	**12.4**	**12.7**	**12.8**	**13.3**	**13.9**	**14.4**	**15.1**	**15.8**	**0.7**
Russia	**9.5**	**9.7**	**9.8**	**10.2**	**10.1**	**10.4**	**10.8**	**11.1**	**0.5**
Caspian Area	**2.7**	**2.8**	**2.8**	**3.0**	**3.7**	**3.9**	**4.1**	**4.5**	**1.6**
Kazakhstan	1.5	1.6	1.6	1.9	2.7	2.8	2.9	3.1	2.3

Other	1.2	1.3	1.2		1.1	1.0	1.1	1.2	1.4	0.3
Other	**0.3**	**0.2**	**0.2**		**0.2**	**0.1**	**0.1**	**0.1**	**0.2**	**-0.9**
Non-OECA Asia	**6.9**	**7.3**	**7.2**		**7.5**	**7.3**	**7.0**	**6.7**	**6.6**	**-0.3**
China	3.8	4.1	4.1		4.5	4.7	4.6	4.4	4.1	0.0
India	0.7	0.7	0.8		0.8	0.7	0.7	0.8	0.8	0.3
Other	2.4	2.4	2.3		2.2	1.9	1.7	1.6	1.7	-1.3
Middle East (Non-OPEC)	**1.5**	**1.5**	**1.5**		**1.0**	**0.9**	**0.8**	**0.8**	**0.7**	**-2.4**
Africa	**2.2**	**2.2**	**2.2**		**2.2**	**2.3**	**2.4**	**2.5**	**2.7**	**0.7**
Central and South America	**3.6**	**3.8**	**3.9**		**4.8**	**5.5**	**6.3**	**6.9**	**7.4**	**2.3**
Brazil	2.0	2.1	2.1		2.6	3.2	3.8	4.2	4.5	2.6
Other	1.6	1.7	1.8		2.2	2.3	2.5	2.7	2.9	1.8
Total World	**72.9**	**74.9**	**75.0**		**82.7**	**85.5**	**89.9**	**94.3**	**99.1**	**0.9**
OPEC Share of World Production	**42%**	**43%**	**43%**		**42%**	**42%**	**44%**	**45%**	**47%**	
Persian Gulf Share of World Production	**29%**	**29%**	**31%**		**29%**	**30%**	**32%**	**33%**	**35%**	

[a] Crude and lease condensate includes tight oil, shale oil, extra heavy oil, field condensate and bitumen.

[b] OPEC = Organization of the Petroleum Exporting Counties (OPEC-13).

Note: Totals may not equal sum of components due to independent rounding.

Units in million barrels per day

Sources: History: US Energy Information Administration (EIA), Office of Energy Analysis and Office of Petroleum, Natural Gas & Biofuels

Analysis Projections: EIA, Generate World Oil Balance application (2014), run IEO2014_GWOB_RefCase.xlsx.

Table 2. World Other Liquid Fuels[a] Production by Region and Country, Reference Case, 2009-2040

Region	History				Projections					Average annual percent change, 2010-2040
	2009	2010	2011		2020	2025	2030	2035	2040	
OPEC[b]	**3.1**	**3.3**	**3.5**		**4.3**	**4.6**	**4.9**	**5.3**	**5.9**	**1.9**
Natural gas plant liquids	3.1	3.3	3.4		4.0	4.2	4.5	4.9	5.4	1.7
Biofuels	0.0	0.0	0.0		0.0	0.0	0.0	0.0	0.0	--
Coal to liquids	0.0	0.0	0.0		0.0	0.0	0.0	0.0	0.0	--
Gas to liquids (primarily Qatar)	0.0	0.0	0.1		0.3	0.3	0.4	0.4	0.4	14.1
Refinery gain	0.0	0.0	0.0		0.0	0.0	0.0	0.1	0.1	0.9
Non-OPEC	**8.5**	**9.0**	**9.3**		**10.6**	**11.7**	**12.6**	**13.5**	**14.4**	**1.6**
OPEC	**5.8**	**6.1**	**6.3**		**6.8**	**7.1**	**7.3**	**7.4**	**7.6**	**0.7**
Natural gas plant liquids	3.4	3.5	3.6		4.0	4.2	4.3	4.3	4.4	0.8
Biofuels	0.8	0.8	1.0		1.1	1.2	1.2	1.3	1.3	1.6
Coal to liquids	0.0	0.0	0.0		0.0	0.0	0.0	0.0	0.0	12.7
Gas to liquids	0.0	0.0	0.0		0.0	0.1	0.1	0.1	0.1	--
Kerogen	0.0	0.0	0.0		0.0	0.0	0.0	0.0	0.0	0.6
Refinery gain	1.6	1.7	1.7		1.7	1.7	1.7	1.7	1.7	0.0
Non-OECD	**2.7**	**2.9**	**3.0**		**3.8**	**4.6**	**5.4**	**6.1**	**6.8**	**2.8**
Natural gas plant liquids	1.6	1.6	1.7		1.9	2.2	2.4	2.7	2.9	1.9
Biofuels	0.4	0.5	0.5		0.7	0.9	1.2	1.4	1.6	4.1
Coal-to-liquids	0.2	0.2	0.2		0.3	0.5	0.7	0.8	1.0	6.1
Gas-to-liquids	0.1	0.1	0.1		0.1	0.1	0.1	0.1	0.1	2.0
Refinery gain	0.5	0.6	0.6		0.8	0.9	1.0	1.1	1.2	2.3
Total World	**11.6**	**12.3**	**12.8**		**14.9**	**16.3**	**17.6**	**18.8**	**20.3**	**1.7**
Natural Gas Plant Liquids	**8.1**	**8.4**	**8.7**		**9.9**	**10.6**	**11.2**	**11.9**	**12.7**	**1.4**
United States	1.9	2.1	2.2		2.6	2.9	3.0	3.0	3.0	1.2
Russia	0.4	0.4	0.4		0.5	0.6	0.8	0.9	1.0	2.9
Biofuels[c]	**1.2**	**1.3**	**1.5**		**1.8**	**2.1**	**2.4**	**2.7**	**3.0**	**2.7**
Brazil	0.3	0.3	0.3		0.4	0.5	0.7	0.8	0.8	3.0
China	0.0	0.0	0.0		0.1	0.1	0.2	0.3	0.4	9.2
India	0.0	0.0	0.0		0.0	0.0	0.0	0.0	0.0	7.8
United States	0.5	0.6	0.7		0.7	0.7	0.7	0.7	0.7	0.5
Coat-to-liquids	**0.2**	**0.2**	**0.2**		**0.3**	**0.5**	**0.7**	**0.9**	**1.1**	**6.2**
Australia/New Zealand	0.0	0.0	0.0		0.0	0.0	0.0	0.0	0.0	--
China	0.0	0.0	0.0		0.1	0.2	0.3	0.5	0.6	14.9
Germany	0.0	0.0	0.0		0.0	0.0	0.0	0.0	0.0	0.3
India	0.0	0.0	0.0		0.0	0.1	0.1	0.1	0.2	--
South Africa	0.2	0.2	0.2		0.2	0.2	0.2	0.2	0.2	1.0
United States	0.0	0.0	0.0		0.0	0.0	0.0	0.0	0.0	--
Gas to liquids	**0.1**	**0.1**	**0.1**		**0.3**	**0.4**	**0.5**	**0.6**	**0.6**	**7.6**
Qatar	0.0	0.0	0.1		0.2	0.3	0.3	0.4	0.4	13.6
South Africa	0.0	0.0	0.0		0.0	0.0	0.0	0.1	0.1	0.7
Refinery Gain	**2.2**	**2.3**	**2.4**		**2.5**	**2.6**	**2.7**	**2.8**	**2.9**	**0.8**
United States	1.0	1.1	1.1		1.1	1.0	1.0	0.9	1.0	-0.4
China	0.2	0.2	0.2		0.3	0.4	0.4	0.5	0.5	2.6

[a] Crude and lease condensate includes tight oil, shale oil, extra heavy oil, field condensate and bitumen.

[b] OPEC = Organization of the Petroleum Exporting Counties (OPEC-13).

Note: Totals may not equal sum of components due to independent rounding.

Units in million barrels per day

Sources: History: US Energy Information Administration (EIA), Office of Energy Analysis and Office of Petroleum, Natural Gas & Biofuels

Analysis Projections: EIA, Generate World Oil Balance application (2014), run IEO2014_GWOB_RefCase.xlsx.

Table 3. World Liquids Consumption by Region, Reference Case, 2009-2040

Region	**History**			**Projections**					**Average annual percent change, 2010-2040**
	2009	**2010**		**2020**	**2025**	**2030**	**2035**	**2040**	
OPEC									
OECD Americas	**23.1**	**23.5**		**24.3**	**24.0**	**23.6**	**23.4**	**23.5**	**0.0**
United States[a]	18.6	18.9		19.2	19.0	18.6	18.5	18.4	-0.1
Canada	2.2	2.2		2.3	2.2	2.2	2.2	2.1	-0.1
Mexico/Chile	2.4	2.4		2.7	2.8	2.8	2.8	2.9	0.7
OPEC Europe	**15.0**	**14.8**		**14.1**	**14.1**	**14.0**	**13.9**	**14.0**	**-0.2**
OPEC Asia	**7.7**	**7.7**		**8.0**	**7.9**	**7.7**	**7.4**	**7.2**	**-0.2**
Japan	4.4	4.4		4.3	4.2	4.0	3.9	3.6	-0.6
South Korea	2.2	2.3		2.6	2.6	2.5	2.5	2.4	0.2
Australia/New Zealand	1.1	1.1		1.2	1.1	1.1	1.1	1.1	0.1
Total OECD	**45.8**	**46.0**		**46.4**	**45.9**	**45.3**	**44.8**	**44.7**	**-0.1**
Non OECD									
Non OECD Europe and Eurasia	**4.8**	**4.8**		**5.5**	**5.5**	**5.6**	**5.7**	**5.6**	**0.5**
Russia	3.0	3.0		3.3	3.2	3.2	3.2	3.0	0.0
Other	1.8	1.8		2.2	2.3	2.4	2.5	2.6	1.2
Non-OECA Asia	**18.4**	**19.8**		**26.5**	**30.2**	**34.8**	**39.0**	**43.2**	**2.6**
China	8.5	9.3		13.1	14.7	16.9	18.8	20.0	2.6
India	3.1	3.3		4.3	4.9	5.5	6.1	6.8	2.5
Other	6.7	7.2		9.1	10.7	12.3	14.2	16.4	2.8
Middle East	**6.5**	**6.7**		**8.4**	**8.8**	**9.6**	**10.3**	**11.1**	**1.7**
Africa	**3.3**	**3.4**		**3.9**	**4.3**	**4.8**	**5.4**	**6.2**	**2.0**
Central and South America	**5.7**	**6.0**		**6.9**	**7.0**	**7.4**	**7.9**	**8.6**	**1.2**
Brazil	2.5	2.6		3.1	3.2	3.4	3.7	4.1	1.5
Other	3.3	3.4		3.8	3.8	4.0	4.2	4.5	0.9
Total Non OECD	**38.7**	**40.7**		**51.2**	**55.9**	**62.1**	**68.3**	**74.7**	**2.0**
Total World	**84.5**	**86.8**		**97.6**	**101.8**	**107.4**	**113.1**	**119.4**	**1.1**

[a] Includes the 50 States and the District of Columbia.

Totals may not equal sum of components due to independent rounding.

Units are in million barrels per day

Sources: History: US Energy Information Administration (EIA), International Energy Statistics database (as of November 2013), (EIA 2015) www.eia.gov/ies.

Projections: EIA, Annual Energy Outlook 2014, DOE/EIA-0383 (EIA 2014) (Washington, DC, April 2014), AE02014 National Energy Modeling System, run REF2014, D102413A, www.eia.gov/aeo; and World Energy Projection System Plus (2014), run 2014.03.21_100505) (Reference case).

2.2 Marine Fuels Outlook

Central to the study was the task of developing projections for global marine fuel demand. Table 6 below summarizes the data analyzed and projections used.

Global consumption was derived from the CO_2 data and projections contained in the Third IMO GHG Study (IMO 2014) and in particular, Table 29 (which is Table 4 in the present document), which provides historical CO_2 emissions from “HFO” (IFO fuels), “MDO” (marine distillates DMA and DMB) and “NG” (LNG) for three categories of shipping: international, domestic and fishing. Table 5 provides IMO projections for CO_2 emissions under a range of scenarios for international shipping (IMO 2014). Given the range of scenarios used by the IMO, EnSys elected to use the average of their four BAU scenarios (scenarios 13 through 16) as the projection for 2030 international shipping CO_2 emissions. The growth rate obtained for international shipping was then applied to the historical data for domestic shipping and fishing, to arrive at projected CO_2 emissions for those two categories for 2030.

Table 4. International, Domestic and Fishing CO_2 Emissions 2007–2012, Using Bottom-up Method

Marine sector	Fuel type	2007	2008	2009	2010	2011	2012
International shipping	HFO	773.8	802.7	736.6	650.6	716.9	667.9
	MDO	97.2	102.9	104.2	102.2	109.8	105.2
	NG	13.9	15.4	14.2	18.6	22.8	22.6
International total	All	884.9	920.9	855.1	771.4	849.5	795.7
Domestic navigation	HFO	53.8	57.4	32.5	45.1	61.7	39.9
	MDO	142.7	138.8	80.1	88.2	98.1	91.6
	NG	0	0	0	0	0	0
Domestic total	All	196.5	196.2	112.6	133.3	159.7	131.4
Fishing	HFO	1.6	1.5	0.9	0.8	1.4	1.1
	MDO	17.0	16.4	9.3	9.2	10.9	9.9
	NG	0	0	0	0	0	0
Bottom-up fishing total	All	18.6	18.0	10.2	10.0	12.3	11.0
All fuels, bottom-up (detailed data)		**1,100.1**	**1,135.1**	**977.9**	**914.7**	**1,021.6**	**938.1**

Note: HFO = heavy fuel oil; MDO = marine diesel oil; NG = natural gas.
Source: IMO 2014

Table 5. CO_2 Emission Projections

Scenario	Base year	2015	2020	2025	2030	2035	2040	2045	2050
1	810	800	890	1.000	1.200	1.400	1.600	1.700	1.800
2	810	800	870	970	1.100	1.200	1.300	1.300	1.400
3	810	800	850	910	940	940	920	880	810
4	810	800	850	910	960	1.000	1.000	1.000	1.000
5	810	800	890	1.000	1.200	1.500	1.800	2.200	2.700
6	810	800	870	970	1.100	1.300	1.500	1.700	2.000
7	810	800	850	910	940	1.000	1.100	1.100	1.200
8	810	800	850	910	960	1.100	1.200	1.300	1.500
9	810	810	910	1.100	1.200	1.400	1.700	1.800	1.900
10	810	810	890	990	1.100	1.200	1.300	1.400	1.400
11	810	800	870	940	970	980	960	920	850
12	810	810	870	930	990	1.000	1.100	1.100	1.100
13 (BAU)	810	810	910	1.100	1.200	1.500	1.900	2.400	2.800
14 (BAU)	810	810	890	990	1.100	1.300	1.600	1.800	2.100

15 (BAU)	810	800	870	940	970	1.000	1.100	1.200	1.200
16 (BAU)	810	810	870	930	990	1.100	1.300	1.400	1.500

BAU = business as usual.
Source: IMO 2014

The results in terms of total projections are shown in Table 6. IMO data on CO_2 emissions in million tonnes per annum were first converted to corresponding million tonnes per year of fuel using typical factors and then to million barrels per day, again using typical factors.[5] Projected demand at 2011-2012 fuel mix was 7.31 million bpd for 2030.

Table 6. IMO and EERA Fuel Emission and Consumption Projections

	CO_2 Emissions (mmtpa)			Fuel (mmtpa)			Fuel (mbd)		
	2010	2011-2012	2030	2010	2011-2012	2030	2010	2011-2012	2030
Third IMO GHG Study (2014)									
HFO	696.50	744.45	990.30	222.52	237.84	316.39	3.85	4.12	5.48
MDO	199.60	212.75	281.51	65.87	70.21	92.91	1.30	1.39	1.84
includes international, domestic and fishing									
Total HFO+MDO	896.10	957.20	1271.81	288.40	308.06	409.30	5.15	5.51	7.31
Growth Rate 2012-2030			*1.53%*			*1.53%*			*1.53%*
c.f. IEA 2014							3.82		
international fuel only									
EERA Study for the Battelle Institute (2012)									
EERA Global Emissions / Fuel		952.17	2404.35		307.15	775.60		5.49	13.86
Growth Rate 2011-2030			*5.00%*			*5.00%*			*5.00%*
Mexican ECA emissions		178.20	467.11		57.49	150.68		1.14	2.98

Notes: mmtpa =million metric tonnes per year; mbd = million barrels per day.
Data from Table 29 of the Third IMO GHG Study (2014); projections for international shipping from Table 78 Domestic and Fishing vessels were assumed to have same growth rate as for international vessels (IMO data); projections do not include military fuel.
EERA data from a 2012 memorandum to Battelle Memorial Institute (EERA 2012), published in the technical report, EPA-160-R-15-001: <www.epa.gov/sites/production/files/2015-07/documents/steem-report-final-s508.pdf> (emissions corresponding to fuel tonnes per year).

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[5] The factors to convert from tonnes of CO_2 to tonnes of fuel were derived first by comparing EERA tables containing data expressed in tonnes of CO_2 and tonnes of fuel <www.epa.gov/sites/production/files/2015-07/documents/steem-report-final-s508.pdf>, to establish an overall total marine fuels factor that was then compared with in-house EnSys data from previous marine fuels work to arrive at a factor for each of HFO and MDO. The factors for conversion from tonnes to barrels of fuel were taken from those built into the WORLD Model, which reflect typical specific gravities for marine HFO and MDO.

The final step was to create the projected demand for 2030, which first reflected the 0.5% global standard (Base Case) and then a scenario in which the Mexican ECA was established (ECA Case). Those projections are summarized in Table 7.

Table 7. Marine Fuel Demand, 2030: Base Case and ECA Case

		WORLD	WORLD	WORLD
Million bpd	**IMO**	**Base**	**ECA**	**Change**
	Pre standard shift			
MGO 0.5% DMA		1.06	1.06	0.00
MGO ECA 0.1% DMA		0.44	3.40	2.96
MDO Global 0.5% DMB		5.92	2.97	(2.96)
IFO180 HS		0.05	0.05	0.00
IFO380 HS		0.38	0.38	0.00
Total Marine distillate	1.84	7.42	7.43	0.00
Total IFO	5.48	0.43	0.43	0.00
Total	7.31	7.86	7.86	0.00

Note: Shift to distillate raises total barrels by a factor of about 1.06 for the same energy.
HS = high-sulphur content.

The 7.31 million bpd “2011-2012 fuel mix” projection was adjusted to the 0.5% global standard using a conservative assumption that scrubber penetration would be low (confined to limited use within certain ECAs) and thus that the majority of IFO fuel would have to be converted to marine distillate. The global 0.5% sulfur fuel was assumed to be ISO-8217 DMB specification. For the ECA Case, some 2.98 million bpd of global 0.5% sulfur DMB fuel were switched to 0.1% sulfur quality fuel assumed to be at DMA standard. One reason for using entirely DMB for the global fuel and entirely DMA for the ECA fuel was to widen the quality gap beyond just the sulfur change. DMA specifications are stricter than DMB on parameters such as density (lighter) and viscosity (lower), and pour point (lower). As a result, DMA tends to be a somewhat lighter diesel fuel and is more costly to produce than DMB – this before adding any incremental cost because of a difference in sulfur level. Thus, this was another instance of using a conservative assumption that would tend to increase the cost of shifting global standard fuel to ECA standard fuel.

In the process of establishing Base and ECA Case demands, the energy content difference between IFO and marine distillate was taken into account. Broadly, to deliver the same energy content, approximately 1.06 barrels of DMA/DMB is needed to replace 1 barrel of IFO. Consequently, expressed in barrels, the volume of fuel under the global standard and with the shift to an ECA is higher at 7.86 mbd than the pre-shift projection of 7.31 mbd for 2030 (Table 7). Shifting between DMB and DMA was assumed to not have any significant impact on required fuel volumes.

This fuels study needed to be consistent, in terms of the assumed volume of “Mexican ECA” fuel in 2030, with the air quality modeling study conducted through the Commission for Environmental Cooperation (CEC) to support the Mexican ECA proposal. Those data were taken from a 2012 EERA analysis for the Battelle Memorial Institute (EERA 2012). As indicated in Table 6, the EERA assessment of 952 million tonnes per year (mtpa) of global CO_2 emissions in 2011-2012 agreed closely with the IMO’s assessed 957 mtpa. Of this global total, EERA assessed the 2011 Mexican ECA fuel emissions at 178.2 mtpa of CO_2 - i.e., about 19% of the global total. EERA then applied a 5% per year growth rate to both the global and

Mexican ECA volumes through 2030, to arrive at a projected global of 2,404 mtpa for 2030.[6] The IMO average of four BAU scenarios, in contrast, embodies a 1.53% per year growth rate to 2030, with the result that the EERA 2030 projection is twice that of the average of these four IMO scenarios. Translated into bpd, the average of the four IMO scenarios equates to 7.31 mbpd in 2030 (with the 2011-2012 fuel mix), whereas the EERA projection of 13.86 mbpd is essentially twice that. The EERA projection for Mexican ECA fuel equates to 2.98 million bpd.

Since the IMO's reported marine fuel volumes are higher to begin with than those generally embodied in EIA and International Energy Agency (IEA) projections, and since using the EERA projection for global fuel would, in EnSys' view, have been excessive and have led to a distorted outlook, the decision was taken to use the IMO projection for global marine fuel demand in the WORLD modeling analysis. Conversely, the decision was taken—as mentioned, for the sake of consistency with the air modeling analysis—to use the EERA Mexican ECA volume of 2.98 million bpd. In practice, this meant shifting approximately half the projected Base Case volume of global 0.5% sulfur fuel to the 0.1% sulfur ECA fuel standard. As such, the view was that this could more realistically reflect potentially several regions shifting to ECAs, and thus represented again a highly conservative approach to assessing potential costs. The 2.98 million bpd shift was necessarily spread across multiple regions in the WORLD Model ECA Case. As discussed later in the report, the effect was to significantly raise the absolute levels of total refining investment and the increase in global product supply cost, but may not have greatly overstated costs when expressed as dollars per tonne or barrel of fuel shifted to the ECA standard.

2.3 Mexico Supply and Demand

The EIA's International Energy Outlook (IEO) includes general projections for Mexico and Chile in terms of total petroleum production and total liquids consumption, as shown in Tables 1 and 3. EnSys separated the projected values for Mexico from those for Chile. The projections for Mexico are discussed in more detail below.

2.3.1 Supply

As shown in Table 1, the total production in Mexico and Chile is projected in the IEO to grow appreciably by 2030. This increase was taken to reflect an assumption by the IEO that Mexico's energy reform would take effect and would reverse the recent decline in production. The EnSys outlook thus had Mexico crude production, along with natural gas liquids production, rising by 2030, (the assumption was that the bulk of the increase would accrue to Mexico, and not Chile). With tight oil reserves – i.e., as an extension of the Eagle Ford – now adding to conventional reserves, there is uncertainty regarding both the level and future mix of crude oil production in Mexico. For the purposes of the current study, EnSys chose to keep roughly the same crude production mix as today, in its projections.

2.3.2 Demand by Major Product

EnSys analyzed recent Mexico demand data and then projected demand by major product, consistent with the total demand derived from the IEO (EIA 2015). The next step was to break down into further detail the demand within the "other products" group. The final step was to disaggregate the marine fuels sales in Mexico.

EnSys reviewed both PEMEX and EIA data on historical demand. PEMEX data corresponded to refined product production, imports and exports. The net of these should, in principle, equate to consumption. However, comparison with EIA data (EIA 2015) resulted in an inferred demand, based on PEMEX data,

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[6] See EERA 2012, Tables 6, 7 and 8.

that was somewhat lower than direct demand in the EIA data – i.e., around 1.9 mbd for 2011-2012-2013 (PEMEX), versus around 2.14 mbd from EIA. On the basis that the PEMEX data could have had certain exclusions, EnSys employed the higher EIA data. These were also more consistent with the EIA's IEO data.

The demand projections for each product category were then adjusted to reflect a realistic level of growth over time, given regional trends; which matched, when summed together, the EIA total. In this respect, EnSys applied one specific modification. Based on guidance from PEMEX regarding potential reduced inland residual fuel demand in the future, and on examination of data and reports on growing gas imports from the United States into Mexico, EnSys reduced the total residual fuel demand from around 0.24 mbd in 2012 to just over 0.05 mbd by 2020 and 0.04 mbd by 2030.[7]

Table 8 and Figure 2 summarize this base demand projection. As stated, the projected displacement of residual fuel by natural gas leads to a large negative growth rate for residual fuel inland demand between 2012 and 2030. Conversely, the distillates—inland diesel/gasoil and jet/kerosene—are projected (based on internal WORLD Model data) as having the highest growth rates, followed by gasoline and, at lower levels, LPGs and other products.

Table 8. EIA-Based Projection for Mexico Product Demand

Major product categories (pre-adjustment) in million bpd									**Growth rates**
	2009	2010	2011	2012	2015	2020	2025	**2030**	2010-2030
Liquified Petroleum Gases	0.42	0.421	0.42	0.41	0.44	0.47	0.49	0.51	1.00%
Motor Gasoline	0.78	0.784	0.78	0.79	0.83	0.92	1.00	1.08	1.61%
Kerosene + Jet Fuel	0.05	0.055	0.06	0.06	0.06	0.07	0.08	0.09	2.17%
Distillate Fuel Oil	0.41	0.424	0.44	0.46	0.49	0.55	0.60	0.64	2.06%
Residual Fuel Oil	0.24	0.215	0.23	0.24	0.14	0.05	0.04	0.04	-8.06%
Other Products Total	0.18	0.182	0.19	0.19	0.19	0.20	0.21	0.22	1.05%
Total Petroleum Consumption	2.07	2.080	2.11	2.14	2.17	2.26	2.42	2.58	1.08%

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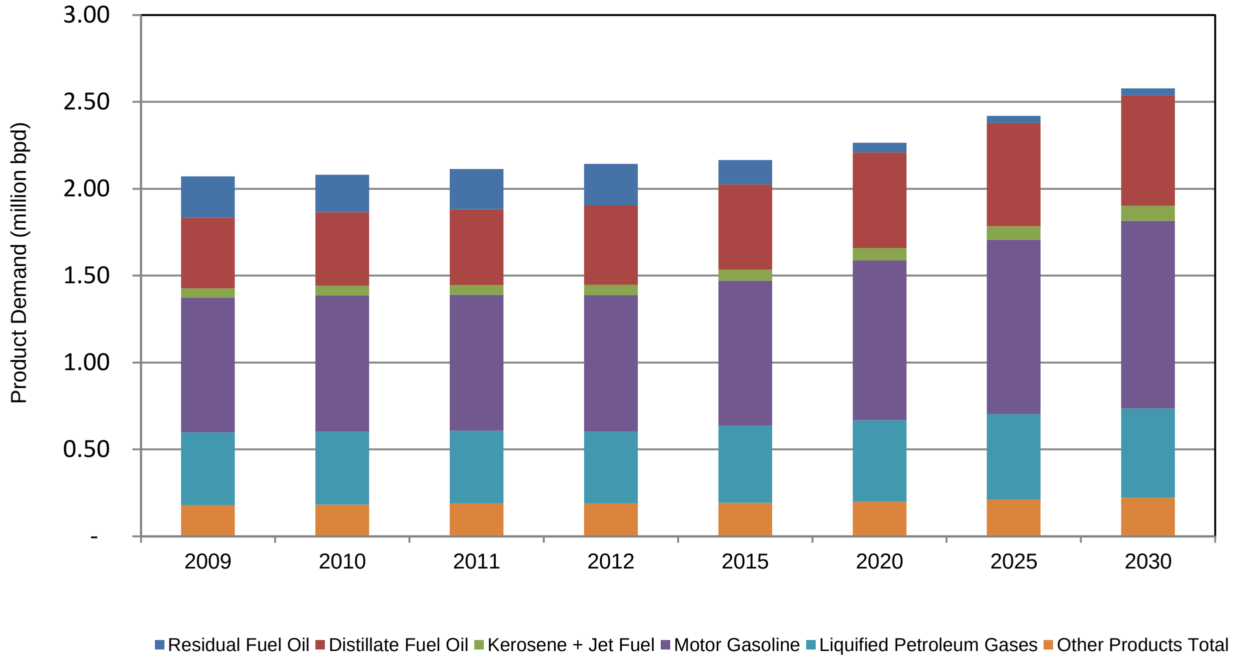
[7] Reports on cross-border natural gas pipeline projects indicate the potential for nearly 1 million bfoed (barrels of fuel oil equivalent per day) capacity by 2020. This compares to actual imports, according to PEMEX data, of less than 0.1 million bfoed in 2010 and 1.3 million bfoed in 2013. EnSys' rationale was that this gas would find a range of uses, including meeting demand growth, but would displace much of the current residual fuel demand, including potentially some of the internal refinery consumption by 2030 or sooner. EnSys did not attempt to assess the impacts of rising gas imports on demand for other liquid fuels.

Figure 2. EIA-Based Projection for Mexico Product Demand (pre-adjustments)



2.3.3 Breakdown and Adjustments for Minor Products

The EIA “Other Products” category is an aggregation of several minor products including, in general, naphtha, aromatics and propylene as petrochemical feedstocks, special naphthas and solvents, lubricating oils, waxes and asphalt together with petroleum coke and elemental sulfur, which are produced mainly as refinery by-products. Data from PEMEX and EIA were used to break down the “Other Products” total and to apply growth rates that varied and were considered realistic by individual product – e.g., higher for elemental sulfur – while respecting the overall projection for the “Other Products” total.

2.3.4 Marine Fuels Sales

Marine fuels are clearly the focal point in this study. The Mexican sales data that were assessed are summarized in Table 9.[8] In summary, these comprise three categories:

1. Marine diesel (500 ppm), sales of 6,000-8,000 bpd, 2011-2013, data from PEMEX;[9]
2. IFO 180, sales of about 1,000-2,000 bpd, 2011-2013, data from PEMEX;[10]

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[8] Note: for marine fuels, there is a distinction between sales and consumption by region, whereas for inland fuels, sales and consumption within a region are effectively the same. Marine fuels sold at ports in Mexico are not consumed within Mexico, but rather either within Mexico territorial waters (e.g., in supporting offshore oil production or fishing), or on the high seas in transit to other world regions. For this reason, reference to marine fuels “demand” in this report corresponds to assessed sales by region.

[9] Pemex Refinación, Información para estudio “Fuel Analysis” pp. 7-20. Received 18 March 2014.

[10] Pemex, residual fueloil (“Combustóleo”) data and information received from Gustavo Sánchez Gutiérrez via email 19 June 2014.

3. IFO 380, sales of about 6,000 bpd, 2013-2014, data from the *Asociación Mexicana de Industriales de Servicio a Buques* (AMISBAC).[11]

PEMEX provided sales data for marine diesel and for Intermediate Fuel Oil (IFO). These were taken as volumes to be subtracted from the total demand volumes for diesel and residual fuel, respectively.

A meeting with AMISBAC, the association of bunker fuel blenders in Mexico, along with data it provided, highlighted the fact that the PEMEX sales data do not cover one hundred percent of the marine fuels actually sold in Mexico. AMISBAC reported that it buys Combustóleo (residual fuel with maximum 4% sulfur) from PEMEX, as well as "cutter" stock (assumed to be diesel fuel) to blend and then sell the resulting product as IFO 380 (3.5%). AMISBAC provided data for 2013 and the first part of 2014. Volumes for the 2014 year were estimated based on the January to April data provided. EnSys' understanding is that the volumes sold to AMISBAC are listed in PEMEX oil statistics under exports, not demand.[12] Thus, these AMISBAC volumes were added on to the base (EIA) data for Mexican petroleum product demand.

In summary, the combined PEMEX and AMISBAC data indicate a total of around 14,000 bpd of marine fuel sales for 2014, of which approximately half is marine diesel, with the rest IFO 180 or 380.

Table 9. Mexico Marine Fuel Sales – Detail

Data from PEMEX							
2007	**2008**	**2009**	**2010**	**2011**	**2012**	**2013**	**2014**
Sales of marine diesel to distributors							
6,822	8,534	6,805	6,994	7,686	7,053	6,134	n.a
Sales of IFO 180 to direct clients							
1,222	990	688	809	646	158	35	n.a
Sales of IFO 180 to the *Comisión Federal de Electricidad*)							
1,679	1,467	1,307	1,254	867	223	1,253	n.a
Sales of IFO 180 to PEMEX *Exploración y Producción*							
338	419	355	371	363	392	348	n.a
Sales of IFO 180 Total							
3,238	2,876	2,350	2,433	1,876	773	1,636	n.a
Data from AMISBAC							
2007	**2008**	**2009**	**2010**	**2011**	**2012**	**2013**	**2014**
IFO 380 sold							
n.a	n.a	n.a	n.a	n.a	n.a	3,838	6,645
Combustóleo purchased from PEMEX (and listed under exports)							
n.a	n.a	n.a	n.a	n.a	n.a	3,133	5,009
Implied diesel cutter stock purchased from PEMEX (and listed under exports)							

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[11] AMISBAC, Seguimiento Proyecto MARPOL – Datos, information about IFO 380 received from Leonor Mondragón via email 17 June 2014.

[12] This situation is part of a much broader issue relating to the under-reporting of marine fuel consumption. The July, 2014 Third IMO GHG Study went to great lengths to compare top down IEA data with bottom up IMO data and concluded that the difference is likely accounted for by product being listed as exports when in fact it is sold (as marine bunker fuel) in the country of origin. The eventual consumption is likely to take place on the high seas but, with marine bunker fuel, the key issue is to identify total volumes sold and the sales locations.

n.a	n.a	n.a	n.a	n.a	n.a	705	1,636
Cutter stock as percent of IFO 380 sold						*18.4%*	*24.6%*

Note: AMISBAC 2014 sales estimated from part year data provided.
Units in barrels per day.

2.3.5 Product Quality

The fact that Mexico has a partially implemented "clean fuels" program was taken into account; however, more importantly for this study, it was assumed by EnSys that this program would be fully implemented by 2030. Based on supplied PEMEX information, certain metropolitan zones in Mexico already have gasoline that is sold at a specification of 30/80 ppm sulfur (with the rest at a maximum of 1,000 ppm. In addition, current industrial and marine diesel is supplied to a 500 ppm standard with a growing proportion, (currently at or close to 100,000 bpd), of 15 ppm ultra-low sulfur "UBA (*ultra bajo en azufre*)" diesel being supplied. For 2030, and again drawing on PEMEX information, gasoline was assumed to be 20 ppm nominal nationwide and all inland diesel and marine gasoil (domestic use) at 15 ppm nominal by 2030. Residual fuel sold for inland use was assumed to remain at today's 4% sulfur standard. However, as discussed in Section 3.3, EnSys assumed that inland residual fuel demand would largely disappear by 2030.

2.4 Refinery Capacity and Projects

2.4.1 Mexico Base Refinery Capacity

Base capacity data by refinery by major unit as of January 2015 were assessed for Mexico using several sources. These included PEMEX statistical data for capacities as of 2012, the Oil & Gas Journal Refinery Survey from December 2014,[13] and an October 2012 report for the International Council on Clean Transportation (ICCT) on refining in Mexico and three other countries (ICCT 2012). Web research was also undertaken. The results of EnSys' assessment are presented in Table 10. Again, this represents base capacity to which the WORLD Model was applied in order to project the situation in 2030.

PEMEX's recent capacity utilization data show that its refineries have been averaging around 80% of calendar day nameplate capacity. In this analysis, a gradual increase in maximum effective utilization was assumed.

2.4.2 Mexican Refinery Projects

PEMEX provided data for planned "clean fuels" refinery projects centered mainly on renovated and new diesel desulfurization units. In addition, Oil & Gas Journal and other sources list additional planned projects. However, in an announcement in March 2015 PEMEX stated that all refinery projects, including those for clean fuels, had been deferred because of the drop in crude oil prices and the resulting reduction in PEMEX revenues (Argus 2015, Martínez 2015, Iliff 2015).

EnSys' approach in undertaking studies using the WORLD model is to consider as confirmed (and thus, adding to the base capacity) only those projects which are actually under construction or which are otherwise at an advanced stage and almost certain to go ahead. Because of the deferral announcement (which was one of a growing number that have emerged in the aftermath of the crude price drop) EnSys

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[13] Oil & Gas Journal. 2014, US Refining Survey, 2 December 2014.

did not consider any currently identified Mexican refinery projects as confirmed and therefore, did not add them to the projected future base capacity. However, certain capacity additions and investments were allowed for, as follows:

1. To reflect the projected growth in the demand for light products including gasoline (and the country’s expressed desire to limit imports of gasoline and the projected large displacement of residual fuel by natural gas), EnSys did add, for 2030, a minimum of approximately 100,000 bpd each of catalytic cracking (FCC) and coking capacity additions.

2. In addition, the option was open for Mexico, as for other regions, to add new capacity based on the model’s selection of what would be needed and most economical in 2030. As discussed later, certain additions were projected as occurring by 2030.

Table 10. Summary of Mexico’s Refinery Base Capacities in January, 2015

	Cadereyta	**Madero**	**Minatitlan**	**Salamanca**	**Salina Cruz**	**Tula**	**Total**	**PEMEX data**
Crude distillation	275.0	190.0	335.0	245.0	330.0	315.0	1690.0	1690.0
Vacuum distillation	124.0	101.0	155.0	143.0	165.0	144.0	832.0	832.0
Coking	50.0	50.0	56.0	0.0	0.0	0.0	156.0	156.0
Visbreaking	0.0	0.0	0.0	0.0	50.0	41.0	91.0	91.0
Cracking	90.0	60.5	72.0	40.0	80.0	80.0	422.5	423.0
- FCC / RFCC (1)	*90.0*	*60.5*	*72.0*	*40.0*	*80.0*	*43.0*	*385.5*	
- HCR (resid) (2)						*37.0*	*37.0*	
Catalytic reforming	46.0	30.0	49.0	39.3	50.0	65.0	279.3	279.0
Alkylation and Isomerization	29.7	22.1	29.0	17.4	27.7	29.1	155.0	155.0
- Alkylation	17.7	12.1	14.0	5.4	12.7	14.1	76.0	
- Isomerization	12.0	12.0	15.0	12.0	15.0	15.0	81.0	
MTBE	2.7	4.8	0.0	1.1	2.3	4.6	15.5	
Aromatics			17.0					
Lubes				16.6			16.6	
Asphalt	20.0	18.0	0.0	15.0	0.0	5.0	58.0	
Hydrodesulfurization (HDS) - total	208	156	192	150	153	214	1073	1067
- Naphtha HDS	48	49	51	41	53	68	310	
- FCC gasoline deep HDS (3)							0	
- Distillate conventional HDS	89	75	57	69	100	100	490	
- Distillate deep HDS (4)	31	0	34	22	0	25	112	
- FCC feed HDS	40	32	50	0	0	21	143	
- Lubes HDS				18			18	
- Resid HDS							0	

Hydrogen plant million SCFD (5)	*25*	*14*	*25*	41	0	*250*	*355*	
Sulfur plant tpd (6)	600	600	210	240	240	1000	2890	

Notes: Units are in thousand barrels per calendar day unless otherwise noted, c.f. 2012

1. Reports from the Cadereyta RFCC unit; but it also notes that the Madero sum of coking plus FCC is greater than VCU capacity, also indicating at least partial RFCC operation.
2. Hydraulic Oil unit reported at Tula. Following completion of the EnSys study, PEMEX advised that Salamanca has a hydrocracker which typically operates at 15,000 bpd. This capacity information was not in the data supplied by PEMEX prior to EnSys' execution of model cases.
3. The project in 2007 reported a ULSG FCC gasoline unit, but it appears that it never went ahead.
4. Distillate DHT (diesel hydrotreatment) capacity was estimated from 2013 PEMEX refinery production data.
5. Estimated hydrogen plant capacities , with the exception of the Salamanca and Salina Cruz plants.
6. Sulfur plant data from 2007 PEMEX data, as well as information on the Minatitlán project.

tpd = tonnes per day.

3 Analytical Results

As previously discussed, the 2030 Base Case projections employed the EIA 2014 International Energy Outlook Reference case adjusted to incorporate EnSys' IMO-based projection for global marine fuels demand, as well as EERA's assessment of Mexican ECA demand – all supplemented by multiple bottom-up, detailed EnSys data and premises embodied within the WORLD Model. The 2030 Base Case incorporated the 0.5% sulfur global marine fuel standard which, to be conservative, was assumed to be met predominantly by switching high sulfur IFO fuel to 0.5% sulfur marine distillate (at DMB standard). The ECA Case then switched some 2.98 million bpd (150.6 million tpa) of global 0.5% sulfur (DMB) fuel to 0.1% sulfur ECA fuel (at DMA standard). The focus in the analysis was on the impacts of the switch on refining investments and activity and, especially, on product supply costs.[14]

3.1 Refining Investments and Capacity Additions

Shifting 2.98 mbd of 0.5% sulfur global DMB fuel to 0.1% sulfur ECA DMA fuel has the effect of raising refining investments at a global scale. This is to be expected, given the way the analysis was run, since the ECA (DMA) fuel has (a) a lower sulfur content and (b) somewhat tighter specifications for density, viscosity and pour point than does the DMB standard 0.5% sulfur global fuel. Table 11 summarizes the projected 2030 refining investments over and above base capacity, plus the confirmed projects for the Base and ECA Cases. Table 12 summarizes the capacity additions in each case that generate the investments in Table 11.

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[14] EnSys uses the term "product supply cost" to relate to the projected cost of producing and supplying a given product to a major regional distribution point. The cost thus *includes* the aggregate costs of crude oil purchase, transport and refining plus delivery to a major distribution point or market center. The cost *excludes* the costs of final distribution to points of sale. Taxes are also excluded. Broadly, EnSys considers supply cost for a product at a major market location used in the WORLD Model, e.g., US Gulf Coast, Northwest Europe or Singapore, as equating to the open market spot price at that location for the product. EnSys also uses the term supply cost to relate to the cost per barrel for a product multiplied by the volume consumed in that region.

Table 11. Investments by 2030, Over and Above Base Capacity and Confirmed Projects

	Global	**US & Canada**	**Mexico**	**Rest of World**	**Global**	**US & Canada**	**Mexico**	**Rest of World**	**Global**	**US & Can.**	**Mex.**	**Rest of World**
Refining	**Base Case**				**ECA Case**				**Change**			
Renovated	6.98	0.93	0.55	5.50	6.76	0.90	0.55	5.32	(0.22)	(0.03)	0.00	(0.18)
Debottle-necking	1.03	0.29	0.02	0.72	0.99	0.30	0.02	0.67	(0.04)	0.01	-	(0.05)
Major new units	373.75	24.37	7.81	341.57	380.44	24.76	7.84	347.84	6.68	0.39	0.03	6.26
Total refining	381.76	25.59	8.38	347.79	388.19	25.95	8.41	353.83	6.43	0.36	0.03	6.03

Note: Units are in billion 2012 US$

Table 12. Secondary Processing Capacity Additions by 2030 – Major New Units and Debottlenecking (millions of barrels per day)

Nameplate Capacity	**Global**	**US & Canada**	**Mexico**	**Rest of World**	**Global**	**US & Canada**	**Mexico**	**Rest of World**	**Global**	**US & Canada**	**Mexico**	**Rest of World**
	Base Case				**ECA Case**				**Change**			
Vacuum Distillation	4.45	0.007	-	4.444	4.51	0.007	-	4.508	0.06	-	-	0.064
Coking	1.91	0.197	0.101	1.616	1.86	0.204	0.101	1.557	(0.05)	0.007	-	(0.059)
Catalytic Cracking	1.32	-	0.103	1.213	1.47	-	0.103	1.364	0.15	-	-	1.151
Hydro-cracking	3.56	0.024	0.045	3.488	3.63	0.016	0.049	3.567	0.08	(0.007)	0.004	0.079
Catalytic Reforming - New	0.63	-	-	0.633	0.63	-	-	0.633	-	-	-	-
Desulphurization (Total)	18.69	1.229	0.583	16.878	18.97	1.247	0.581	17.143	0.28	0.019	(0.002)	0.266
- Gasoline - ULS	0.58	-	0.158	0.426	0.64	-	0.160	0.479	0.05	-	0.001	0.053
- Distillate ULS New	9.24	0.587	0.162	8.486	9.26	0.636	0.155	8.470	0.03	0.049	(0.007)	(0.017)
- Distillate (ULS) Revamp	3.83	0.435	0.174	3.226	3.67	0.379	0.174	3.121	(0.16)	(0.056)	-	(0.105)
- Distillate CONV/LS	2.45	0.196	0.044	2.213	2.77	0.224	0.048	2.496	0.31	0.028	0.004	0.283
- VGO/RESID	2.58	0.010	0.045	2.527	2.63	0.009	0.045	2.578	0.05	(0.002)	(0.001)	0.051
Hydrogen (MMBFOED)	1.34	0.233	0.010	1.101	1.37	0.236	0.010	1.124	0.03	0.003	0.000	0.022
Sulphur Plant (TPD)	67,130	2,220	1,080	63,830	69,630	2,800	1,030	65,800	2,500	580	(50)	1,970

Note: Units are in million bpcd

* Millions of barriles de petróleo equivalentes diarios (mbped)

** Tonnes per day (tpd)

As can be seen, the effect of the 2.98 million bpd switch is to raise global investments by around US$6.4 billion (US$2012). Only a very small amount of the total investment is projected to occur in Mexico, because the volume of marine fuel sold there is projected to be small (around 28,000 bpd in 2030, from around 14,000 bpd in 2014). The United States would be impacted as it is a major maritime trading partner with Mexico and is assumed to be an important source of bunker for that trade. The bulk of the incremental investment is projected to occur in other world regions beyond both Mexico and the United States. This is because the EERA-calculated volume of switched fuel used was so substantial at 2.98 million bpd that the switched volumes necessarily had to be spread across multiple world regions, including Asia. To reiterate, (a) the projected 2.98 million bpd of ECA fuel is, in EnSys' view, high; the real volume associated with a Mexican ECA would be lower, bringing total costs down from those assessed in this study; and (b) the assessed costs are spread across multiple world regions. Since only a small proportion of total Mexican bunker fuel is sold in Mexico, the establishment of a Mexican ECA would, as stated, impact primarily the United States and other regions.

The capacity additions and the differences between the Base and ECA Cases summarized in Table 12 illustrate that the world-wide industry (based on the premise that it could "see" the ECA shift coming sufficiently in advance to appropriately adapt) would undertake a range of changes in capacity added with some reductions and some increases. Overall, the changes focus on (a) a net increase in upgrading capacity (coking, FCC and hydro-cracking) supported by incremental vacuum distillation capacity, plus (b) a net increase in desulfurization capacity centering on distillate capacity, but also involving incremental gasoline and VGO/residuum capacity as part of the refining system's adjustment, and (c) incremental supporting capacity for hydrogen and sulfur plants. These changes and additions reflect, as previously discussed, that the assumed ECA DMA fuel is both lower in sulfur and slightly lighter than the assumed DMB global fuel, leading to the combination of incremental desulfurization and upgrading.

Table 13 summarizes the corresponding impacts projected for refinery CO_2 emissions. These increase moderately because of the increases in upgrading, desulfurization and supporting processing duties.

Table 13. Global Refinery CO_2 Emissions, 2030

	Global	**US & Canada**	**Mexico**	**Rest of World**	**Global**	**US & Canada**	**Mexico**	**Rest of World**	**Global**	**US & Canada**	**Mexico**	**Rest of World**
	Base Case				**ECA Case**				**Change**			
CO_2 (10^6 Tonnes) EX H_2 Plant	329	38	2	289	332	38	2	292	3	0	0	3
CO_2 (10^6 Tonnes) EX RFO	703	107	9	587	705	107	9	588	2	0	(0)	2
CO_2 (10^6 Tonnes) EX Flare Loss	52	10	1	41	52	10	1	41	(0)	0	-	(0)
CO_2 (10^6 Tonnes) EX SUL Tail Gas	4	1	0	3	4	1	0	3	0	0	-	0
CO_2 (10^6 Tonnes) EX FCC Coke	141	39	4	99	143	38	4	101	1	(1)	(0)	2
TOTAL	1,229	194	16	1,019	1,236	193	16	1,026	7	(0)	(0)	7

Note: Units are in million tonnes per year.

3.2 Global Product Supply Costs

Table 14 illustrates changes projected by the WORLD model in open market product prices and supply costs in four major locations. The changes reflect the refining rebalancing that would occur, consistent with having 2.98 million bpd of marine distillate 0.1% sulfur assumed DMA ECA standard in the ECA Case, versus the 0.5% sulfur assumed DMB standard in the Base Case. As previously noted, the industry has to incur an incremental upgrading in the quality of fuel, in order to produce the slightly lighter DMA fuel in place of DMB; however, this entails parallel increases in supply of other, quality streams of gasoline, naphtha, and LPG. Consequently, prices for these products generally drop moderately. As would be expected, the prices for marine 0.1% DMA rise and those for global 0.5% DMB fall because of the switch from the latter to the former. However, the required improvement in overall middle distillate quality raises prices and supply costs in all other distillate fuels, including inland diesel and jet/kerosene. Impacts on residual fuel are mixed and vary depending on the region.

Table 14. Regional Product Price Changes Resulting from the Establishment of an ECA

	US Gulf Coast	US West Coast	Northwest Europe	Singapore
LPG	0.09	(0.23)	(0.54)	(0.23)
PETCHEM Naphtha	(0.30)	0.10	(0.30)	0.08
Gasoline (ULS) Premium	0.08	(0.02)	(0.36)	(0.29)
Gasoline (ULS) Regular	0.11	(0.09)	(0.28)	(0.27)
KERO/JET JTA/A1	0.16	0.15	0.14	0.18
DSL NO_2 ULSD (50 - 10 PPM)	0.15	0.27	0.12	0.17
RESID .3-1.0%	0.03	(0.31)	(0.09)	0.24
MGO (DMA)	0.41	0.09	0.10	0.01
MDO 0.5% Global Fuel (DMB)	0.80	0.40	1.51	1.25
MGO 0.1% ECA Fuel (DMA)	0.08	(0.21)	(0.72)	(1.20)
IFO380 HS	0.14	(0.16)	(0.25)	(0.35)

Note: Units in US$/barrel (2012 US$)

Table 15 presents the impacts on global supply costs by major product category. These values are obtained by multiplying the prices generated for each product in each model region by the corresponding demand volume for that product in that region; then adding the totals for all regions. As is evident, the 2.98 million bpd fuel switch raises the costs of marine fuels by a projected US$3.29 billion per year, but also raises the supply costs for other light and middle distillates (jet/kero and diesel/gasoil) by a combined US$2.97 billion per year – i.e., by nearly as much as the increase in marine fuel supply costs. However, as noted, these increases are partially offset by reductions in global supply costs for LPG, naphtha and gasoline, leading to a projected net increase in global supply cost across all fuels of just over US$4 billion per year because of the 2.98 million bpd marine distillate global-to-ECA quality shift. Assessing this global supply cost net increase against the 2.98 mbd of fuel shifted equates to a cost of around US$3.70/barrel, or US$27/tonne. In terms of scale, this assessed cost is similar in magnitude to those that have been assessed for other fuel quality measures.[15] From another perspective, the assessed costs are much lower than the US$150–US$400/tonne price differentials for IFO and marine distillate that have been applied in the market recently.[16] Again, as assessed in this analysis, a lower cost is to be expected since the shift in quality was limited, compared to a shift from IFO to distillate.

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[15] Studies undertaken of the costs of a range of diesel and gasoline quality initiatives have often resulted in assessed costs in the order of US$1–US$3 per barrel; but most of these studies were undertaken during periods with far lower crude oil prices than applied in the scenario used here. Had higher crude prices applied, the assessed costs would also have been higher.

[16] The lower end of the range is more reflective of crude oil prices at around US$50/barrel, recorded in the second half of 2014, while the upper end is more reflective of the differential from when crude prices were around US$100/barrel.

Table 15. Cost of Total Global Oil Product Supply in 2030, Excluding Internal Costs of Refinery Fuel Consumption

Product	US$ million /day			US$ billion / year
	Base	ECA	Change	Change
LPG and Naphtha	1,803	1,802	(0.96)	(0.35)
Gasoline	3,188	3,183	(5.40)	(1.97)
Light Distilates (Jet/Kero)	1,182	1,184	1.23	0.45
Middle Distillates (excluding bunker fuels)	4,653	4,660	6.89	2.52
Residual Fuels (excluding bunker fuels)	396	397	0.14	0.05
Other Products	643	643	0.12	0.05
Marine Bunker Fuels	1,037	1,046	9.01	3.29
Total	12,903	12,914	11.04	4.03

Note: Amounts indicated are in US$ (2012).

The above results need to be considered within the specific context and premises of the analysis undertaken. There are several factors which could have resulted in the assessed incremental product supply cost being higher or lower. These include:

1. If the assumption in the model had been that the 0.5% sulfur global fuel was DMA, requiring a shift only from DMA at 0.5% sulfur to DMA at 0.1% sulfur (versus the shift from DMB at 0.5% sulfur to DMA at 0.1% sulfur that was assumed) the assessed costs would have been lower.

2. Conversely, assuming that the global fuel would be some combination of the newer fuel formulations being brought onto the market as a result of the 2015 ECA 0.1% sulfur standard, formulations that are generally either a form of intermediate/hybrid or vacuum gasoil fuel (such as the ExxonMobil HDME 50), or a form of low sulfur IFO (often at around 80 to 200 centistokes), would have arguably raised the cost of conversion to ECA standard from that assessed.[17] The extent of the cost increase would have depended greatly on whether the 0.5% sulfur fuels could have been directly converted via (additional) desulfurization to meet the 0.1% standard, while retaining their other quality characteristics, or whether it would have proved necessary to replace them with (effectively upgrade them to) 0.1% DMA type distillate fuel. Such an assessment was beyond the scope of this analysis. Also, while several newer fuel formulations are on the market, driven by the new ECA standard, at this stage it is questionable whether they could be offered in adequate volumes as to become the generally used global or ECA fuel formulations. In other words, assuming marine distillates for both the global and ECA fuels appears to be a realistic, conservative premise for this study.

3. Equally, the timing of the entry into effect of the Mexican ECA would have a significant effect on the associated fuel supply costs. Given that this analysis is based on projections for 2030, it was assumed that in the Base Case the global industry would have already converted to the 0.5%

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[17] Past studies of the supply of global 0.5% sulfur standard fuel have assumed compliance via use of marine distillate (either DMA or DMB), together with some proportion of on-board scrubbers and high sulfur fuel. The 0.1% ECA fuel standard of 2015 has led to the introduction of some volumes of 0.1% sulfur IFO fuel together with new intermediate or “hybrid” fuels. These appear to be produced primarily from the vacuum gas oil fraction of crude, with boiling points in the range between those of marine distillate and IFO. There is, therefore, the potential for such formulations to also provide 0.5% sulfur level marine fuels under the global 0.5% sulfur standard.

> sulfur standard – i.e., that it would already have done the “heavy lifting” to convert the majority of today’s high sulfur IFO to lower sulfur (0.5%) marine distillate. An evaluation focused on pre-2020 (or pre-2025, if the global standard were deferred to that year) would have necessarily assessed the cost of a shift from today’s fuel mix (with 3.5% maximum sulfur on IFO) to 0.1% sulfur ECA distillate fuel. As noted above, the differentials that have applied in the market, of US$150–US$400/tonne, are more reflective of what the likely assessed cost would have been under those circumstances.

It should be noted that the use of the very high volume of fuel for the Mexican ECA (2.98 mbd, or 150.7 million tpa for 2030), as projected by EERA, clearly raised the assessed impact of the global product supply cost. Using a smaller figure would have correspondingly reduced the cost by billions of US dollars per year. However, the view of EnSys is that while the cost in terms of US$/barrel or tonne of fuel converted would have been reduced this effect would have been limited since the same kinds of refinery processing changes would have been needed.

3.3 Product Supply Costs in Mexico

Table 16 highlights the assessed impacts of the product supply cost on Mexico. The impacts on Mexico are driven more by the broad global consequences of the 2.98 mbd shift to the ECA standard than by the volumes of marine fuel sold in Mexico *per se*, since these were projected to still be minor in 2030 (about 28,000 bpd versus around 14,000 bpd in 2014, and about half already marine gasoil).

The assessed net impact is around US$0.27 million per day (US$2012) which equates to US$0.1 billion per year and to just over US$0.10 per barrel of total Mexico product demand (excluding refinery fuel).

Table 16. Total Product Supply Cost (Excluding Refinery Fuel)

Total Cost	2030 Base	2030 ECA	Change
million US$/day			
Gasoline	131.0	131.1	0.06
Distillates (Jet/Kerosene, Gasoil/Diesel)	104.6	104.8	0.18
Residual Fuels	4.0	4.0	-
Other Products	49.3	49.3	0.03
Total	288.9	289.1	0.27
Portion of the total corresponding to marine fuels	3.6	3.7	0.07
billion US$/year			
Gasoline	47.8	47.9	0.02
Distillates (Jet/Kerosene, Gasoil/Diesel)	38.2	38.2	0.06
Residual Fuels	1.5	1.5	-
Other Products	18.0	18.0	0.01
Total	105.4	105.5	0.10
Portion of the total corresponding to marine fuels	1.32	1.34	0.03

4 Conclusions

EnSys employed its WORLD Model to assess the total global impacts of a shift in the fuel that would be consumed in 2030 in a 200 nautical mile Mexican ECA zone to a 0.1% sulfur fuel (i.e., the required ECA standard). The analysis comprised a Base Case and an ECA Case. In the 2030 Base Case, the 0.5% IMO global marine fuel sulfur standard was taken as being in effect. Since there remains significant uncertainty as to whether any fuel formulations other than marine distillates can fulfill the need, at scale, to meet the 0.5% sulfur standard, and to be conservative with regard to future scrubber potential, the Base Case marine fuel mix assumed that the 0.5% standard would be met predominantly by use of 0.5% sulfur marine distillate fuel. It was further assumed, in part to be conservative and in part to mark a contrast between the global and ECA fuels, that the global 0.5% sulfur fuel would be DMB standard, and the 0.1% sulfur ECA fuel would be the DMA standard.

2030 global marine fuel consumption was projected by applying data from the July 2014 IMO 3rd GHG Study, specifically by using the average of the IMO's four "BAU" scenarios as the basis for the 2030 demand. This led to a projection for total global marine fuel demand of 7.86 million bpd (versus an IMO base level of 5.5 million bpd in 2011/2012). To maintain consistency with the parallel air modeling study by the MCE2, the estimate for 2030 Mexican ECA fuel volume that they had used was also applied in this Fuels Analysis study. The projection was taken from work by Energy and Environmental Research Associates (EERA) and equated to 2.98 million bpd. This figure EnSys considered to be very high but we applied it by spreading the ECA conversion volume across most world regions (in effect reflecting a scenario more akin to a situation where several ECA's were to come into effect).

Refining, supply, demand, quality and transport premises were applied to be consistent with the above marine fuel demand figures within the framework of the EIA 2014 International Energy Outlook Reference case for 2030. Particular attention was focused on Mexico, including its refining system, crude production, product demand and marine fuel sales. Marine fuel sales at ports in Mexico were found to be relatively minor, a total in 2014 of approximately 14,000 bpd made up of sales (of mainly marine diesel) listed in PEMEX statistics plus sales listed under exports that were in fact blends sold by local distributors as IFO.

The results of the analysis corresponded to switching 2.98 million bpd of 0.5% sulfur global fuel (assumed DMB quality) to 0.1% sulfur ECA fuel (assumed DMA quality). This switch was projected to increase global refining investments by US$6.4 billion (US$2012) versus the Base Case. The associated capacity additions related to increases in desulfurization and supporting hydrogen and sulfur plant capacity, but also upgrading capacity (this since DMA is a somewhat lighter product than DMB). Capacity changes were assessed as being needed on a global scale, since the shift to ECA fuel was necessarily spread across the world's regions. Impacts on Mexico's refining system were minor, which was to be expected as the marine fuel volume sold there was assessed as small. The projected adjustments to the refining system corresponded to increased marine fuels prices (global 0.5% marine fuel price dropping, and ECA 0.1% fuel price rising because of the volume switch – with an overall net increase); but also raising the prices of other distillate products, namely inland diesel/gasoil and jet/kerosene. These increases were partially offset by reductions in prices for the lighter products,—LPGs, naphtha, gasoline—but the net impact was assessed to be an increase in total global supply costs (all regions, all products) of just over US$4 billion (2012 US$) per year.

Clearly this assessment is sensitive to assumptions. Assuming a narrower quality gap between the global and ECA fuel quality level (e.g., both at DMB or DMA versus the assumed global at DMB and ECA at DMA) would have reduced the incremental supply cost associated with the fuel switch. Conversely, assuming some mix in the Base Case of other formulations such as low sulfur IFO or intermediate (vacuum gasoil) fuel would have raised the costs of conversion. Assuming a switched volume lower than the 2.98 million bpd taken from the EERA analysis would have lowered the total associated annual dollar costs roughly proportionately but may have reduced costs per barrel or tonne only moderately since the same mix of refinery processing changes would have been called for. Assessed impacts on 2030 product supply costs in Mexico were projected to be small, in line with the limited volume of marine fuel sold in the country.

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