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Inclusion of Marine Bunker Fuels in a National LCFS Scheme

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Discussion Draft

National Low Carbon Fuel Standard Study

National Low Carbon Fuel Standard Study

The document examines the feasibility of regulatin the carbon content of marine bunker fuels by including domestic and international shipping in a National Low Carbon Fuel Standard framework

About the National LCFS Study

The National LCFS Study has two objectives: 1) compare an LCFS with other policy instruments that have the potential to significantly reduce transportation GHG emissions from fuel use; and (2) design an effective and implementable national LCFS. The study is a collaboration project between researchers from the following institutions: Institute of Transportation Studies, University of California, Davis; Department of Agricultural and Consumer Economics/Energy Biosciences Institute, University of Illinois, Urbana-Champaign; Margaret Chase Smith Policy Center, and School of Economics, University of Maine; Environmental Sciences Division, Oak Ridge National Laboratory; Green Design Institute of Carnegie Mellon University; and the International Food Policy Research Institute.

In a series of white papers, we discuss specific analyses conducted over the past year, each addressing one or several key LCFS design and implementation issues or impact assessment of a national LCFS. These topics include:

- Economic Costs and Benefits of a National Low Carbon Fuel Standard and Implications for Greenhouse Gas Emissions
- Energy Security and a National LCFS
- Analysis of iLUC Impacts under a National LCFS
  Indirect Land Use Change (ILUC) in National LCFS: Treatment, Policy Options, and Policy Design Issues
- Costs and Credit Trading of a National LCFS
- Incorporating Uncertainty in Life-Cycle Carbon Intensity into a National LCFS
- Electricity and National LCFS Analysis and Policy Design Considerations

Our goal is to propose the design of a robust national LCFS policy that balances environmental, political, and economic goals and is readily implementable and enforceable in terms of data availability, simplicity, etc. The specific design recommendations will be summarized in a forthcoming Policy Design Report (PDR). The results of the above white papers will also be summarized in a forthcoming Technical Analysis Report (TAR).

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EXECUTIVE SUMMARY

The document examines the feasibility of regulating the carbon content of bunker fuels used for shipping by including the industry in a national LCFS framework. Our review suggests that, as generally expected, the structure of bunkering industry could potentially result in leakage in face of regulation and thus precludes the inclusion of shipping fuels as regulated fuels in a national LCFS scheme. Bunker suppliers can provide bunkering services in international waters to avoid regional or national regulatory constraints; while ship operators, especially those involved in international trade, have considerable flexibility in deciding bunkering location and supplier.

However, the shipping industry is likely to witness significant changes in fuel uses and increases in operating costs as a result of MARPOL Annex VI regulation of sulphur and NOx emissions, forcing the industry to transition from inexpensive but dirty residual oil-dominated bunkers to cleaner and low sulphur distillate-dominated bunker by 2020 / 2025. This could have two impacts: (1) The transition could raise bunker costs by 50-150% (based on current price differentials) and overall ship operating costs by 10-90%; (2) ships may be incentivized to adopt natural gas which can reduce greenhouse gas (GHG) emissions by around 15%.

If LCFS is applied to the shipping industry and assuming no leakage, which is highly unlikely, we estimate the total abatement costs will be US$ 0.7 – 4 billion to reduce the well-to-wheel (WTW) CO_2e intensity of bunkers sold in the US by 10%. This is roughly US$33-330/tonne CO_2e for 19 million tonne GHG reduction. The expected increase in fuel price under MARPOL Annex VI regulation will make the substitution of low-carbon biofuel less costly, and even potentially economical. If the cost of carbon reduction is lower than the LCFS credit prices, which has been estimated at around US$ 70/tonne CO_2e (Khanna, et al. forthcoming), then there is a potential for bunker fuel providers opting into the LCFS program and earning credits by providing lower carbon bunker. The option is also attractive as it reduces the need for large investments for refineries in adding processes like hydrocracking that increase yields of distillates and reduce production of residual oil. Instead, they can blend in BTL into a wide range of products depending on the market prices and profit margins of the products.

The table below summarizes our key observations.

Table ES1: Key observations and implications

#	Observations	Implications for inclusion on shipping in a National LCFS
1	Estimates of GHG emissions from shipping	
	Global shipping contributes significantly	GHG emission from shipping is currently

	to anthropogenic GHG emissions and emissions are expected to grow in absence of appropriate policies. The “fair share” of the U.S. is 12-27% of global shipping emissions depending on the methodology, and range from 1.4 to 3.8% of total domestic emissions (7,200 million tonnes of CO_2-e in 2007).	small at about 3 % of the global and US emissions. The ratio could increase if other sectors are included in future GHG emission regulations.
2	Need for regional regulation of shipping GHG emissions	
	It may take a decade, if not more, to establish a global policy / framework to regulate shipping GHG emissions under the aegis of International Maritime Organization (IMO).	Similar to the experience with EU regulation on aviation GHG emissions and threat to regulate shipping emissions, regional and national policy initiatives may be considered in the absence of international action
3	Dynamics of bunkering industry	
	The shipping industry is likely to witness significant change in fuel use and increases in operating costs as a result of MARPOL Annex VI regulation of sulphur emissions. The regulation will force the industry to transition from inexpensive but dirty residual oil-dominated bunkers to cleaner and low sulphur distillate-dominated bunker by 2020/2025. The transition could raise bunker costs by 50-150% (based on current price differentials) and overall ship operating costs by 10-90%.	Even in absence of GHG regulation, fuel costs are likely to increase sharply in future and provide strong incentives to reduce fuel consumption.
	The structure of the bunker industry precludes the potential to regulate the refinery or bunker supplier. Existing regulations to regulate emissions and fuel quality, as well as most of the proposed market-based regulations to regulate GHG emissions have focused on the ship as the regulated entity.	Since the LCFS framework regulates the fuel suppliers, further research is required on potential of leakage/shuffling and options for mitigation.
4	GHG Reduction potential	
	Opportunities exist to reduce 35% to 45% of emissions relative to BAU in 2020 in a cost effective way; i.e. at negative marginal abatement costs. Most of these opportunities pertain to ship design and	Natural gas offers opportunity to reduce emissions of GHG and local pollutants, and historical costs have been similar to residual oil. In the post-MARPOL Annex VI scenario, LNG could witness significant

	operational measures.	penetration provided bunkering infrastructure is established and existing tonnage could be economically retrofitted.
		Potential to reduce emissions by using low carbon biofuels is deemed limited in existing literature due to technical and economic barriers; and potential supply constraints.
5	Blending BTL – Potential costs and opportunities	
	Blending renewable biodiesel or biomass-to-liquid (BTL) from agricultural and forest residue, and energy crops like miscanthus to fossil fuel based marine bunker will reduce the WTW lifecycle emissions of marine bunker at an estimated CO2-e abatement cost (per tonne of CO2-e abated) of US$ 200-330/tonne for IFO and US$ 30-230/tonne for distillates based on historical low, medium and high prices of marine bunkers. In post MARPOL Annex VI scenario, total abatement cost will be around US$ 0.7-3 billion to reduce GHG intensity by 10% for fuels sold in the US bunker market (15% of global marine bunker volume assuming no leakage) and require around 7.5 billion liters of BTL.	More research is required to understand potential role of renewable diesel or BTL diesel whose chemical composition could be close to existing bunkers.

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LIST OF ABBREVIATIONS

BAU	Business-as-usual
BTL	Biomass-to-liquids (Fischer-Tropsch diesel)
CNG	Compressed natural gas
ECA	Emission control area
GHG	Greenhouse gases
IFO	Intermediate fuel oil
IMO	International Maritime Organization
LNG	Liquid natural gas
MDO	Marine diesel oil
MGO	Marine gas oil
NG	Natural gas
RO	Residual oil
WTW	Well-to-wheel

1. ESTIMATES OF GHG EMISSIONS FROM SHIPPING

Global shipping contributes to anthropogenic GHG emissions and emissions are expected to grow in absence of appropriate policies. The "fair share" of the U.S. is significant.

1.1: The global shipping industry contributed to 3.3% of anthropogenic GHG emissions in 2007 or 1,046 million tonnes measured on a tank-to-wheel or TTW basis (Buhaug, Corbett et al. 2009)[1]. The share of international shipping, i.e. shipping between ports of different countries, is around 84%. Business-as-usual (BAU) emissions are expected to grow by a factor between 2.4 to 3 by 2050 representing annualized growth of 1.9 – 2.7%.

1.2: International shipping emissions have been excluded from national emission inventories and targets. Since bunkers (marine fuels) may be purchased and GHG emitted internationally during a ship's voyages between countries, no consensual approach has been reached to allocate emissions to different countries. A number of approaches may be adopted to calculate a country's "fair share" to decide on the need for local or regional policies to regulate shipping emissions in absence of international ones (UK-EAC 2009; Faber, Markowska et al. 2010). Some of these approaches as suggested in literature are discussed in the table below:

Table 1: US' fair share of GHG emissions from shipping

Approach	**Explanation**	**Potential uncertainty**	**Calculated US "fair share"**
Bunker sales	Allocation to a country is based on share of total bunker sales	International fuel statistics reported by IEA and EIA are underreported to the extent of about 30% (IMO 2009)	15% (Corbett and Winebrake 2008)
Route based allocation	Emissions of ships on routes that end in US are allocated to US. This approach has been adopted for inclusion of aviation in EU ETS.	Current estimates are uncertain due to data availability. Container ships, which account for 21% of total fuel consumption, dock and load/discharge cargo in several countries in a single journey. This increases uncertainty of route based allocation	~ 12% (Faber, Markowska et al. 2009)
Share of global GDP		GDP is strongly correlated with trade, but not maritime trade or tonne-miles. Proportion of air freight and service-related trade may differ between countries	~27%

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[1] On a Well-to-Wheel basis, total marine CO2-e emissions are around 1,200 million tonnes.

Based on the above table, the share of global shipping emissions attributable to the US would range from 1.4 to 3.8% of total domestic emissions (around 7,200 million tonnes of CO2-e in 2007).

2. NEED FOR REGIONAL REGULATION OF SHIPPING GHG EMISSIONS

It may take a decade, if not more, to establish a global policy / framework to regulate shipping GHG emissions under the aegis of IMO. Similar to the experience with EU regulation on aviation GHG emissions, regional and national policy initiatives may be considered in the absence of international action.

2.1: International standards aimed at improving safety and security of shipping operations and reducing marine pollution are adopted under the aegis of International Maritime Organization (IMO), which is a specialized agency of the United Nations. These standards pertain to the areas of design, construction and equipment of ships, crew training and manning, and marine fuels. Ships have to also comply with the regional and national regulations when plying within the areas of jurisdiction of coastal states.

2.2: IMO adopts regulations and conventions using a philosophy of international consensus (not majority) and in a four-step process that may take years to produce effective results. Draft conventions are introduced by interested nation(s), which are then debated, possibly modified and then adopted. Subsequently, various member countries sign the convention and then introduce it in their domestic legislation so that it becomes part of the law of the country (ratify). The convention comes into force only after a certain number of countries have ratified it. The following case study about MARPOL Annex VI, which regulates, inter alia, SOx emissions and sulphur content of fuels, highlights the time consuming nature of international conventions adopted through IMO.

2.3: MARPOL Annex VI was adopted in 1997 following years of discussions and came into force in 2005. As of January 2011, 62 member nations representing 85% of global shipping tonnage have ratified the convention. Further, the convention adopted a global sulphur limit of marine fuels of 4.5% - well above the current observed average of around 2.7%. IMO's report on GHG emissions from shipping (Buhaug, Corbett et al. 2009) acknowledges that sulphur content exceeding 4.5% was very rarely found in fuels before this regulation came into force. The cap will be progressively reduced to 0.5% by 2020 or 2025. This has led to local, national and regional regulators to preempt IMO and adopt their own regulations including those pertaining to criteria air pollutants. Examples include European Commission's directive capping sulphur content to 0.1% while at berth or if operating in EU inland waterways; and California Air Resources Board cap of 0.1%.

2.4: GHG emissions from international shipping are excluded from UNFCC and proposed to be regulated through IMO. This has presented numerous challenges largely because of the fundamental differences between UNFCC's "common but differentiated" philosophy and IMO's philosophy of treating all ships equal. IMO has made progress in a number of areas pertaining to GHG reduction including a voluntary design index for new ships and an operating index for existing ships. However, more effective market based regulation in form of global bunker taxes or global cap and trade program; or mandatory performance standards for ship design and/or operations are likely to take years to adopt. After the recent addition of international aviation to ETS, the European Union plans to regulate GHG emissions from ships arriving at or departing from EU ports if no firm international policies are adopted through IMO by 2013 (European Commission 2010). Such emissions will account for around 30% of global shipping emissions (Faber, Markowska et al. 2009).

3. DYNAMICS OF THE BUNKER INDUSTRY

The shipping industry is likely to witness significant increases in operating costs as a result of MARPOL Annex VI regulation of sulphur emissions. The regulation will force the industry to transition from inexpensive but dirty residual oil-dominated bunkers to cleaner and low sulphur distillate-dominated bunker by 2020 / 2025. The impacts on costs due to the regulation is highly uncertain (EIA 2009), though we estimate that the transition could raise bunker costs by 50-150% (based on current price differentials) and overall ship operating costs by 10-90%.

Table 2: Fuel grades, properties and historical prices of bunker

Fuel type	Fuel grade	Ratio of distillate in the fuel grade (a)	Sulphur content (b)	Estimated volume in million tonnes in 2007 (c)	Long term price premium relative to IFO (d)	"Long run average" Prices in $/tonne (low, high)(e)
Intermediate fuel oil (IFO)	IFO380	2% distillate. Remaining residual oil	Average: 2.4%. Can be as high as 4%	192 (58%)		$500 ($200, $700)
	IFO180	12% distillate	As above	64 (19%)		
	Low Sulphur LS380 and LS180	As above	0.5% to 1%	Not available	10-30%	
Marine Diesel Oil (MDO	DMB and DMC	Trace of residual oil	0.55% to 0.75%.	48 (14%)	50-150%	$800 ($500, $1,200)
Marine Gas Oil (MGO)	DMA	100% distillate	0.35%.	28 (8%)	50-150%	

(a) Source: Rogozen and Lin (2008); (b) Source: Corbett and Winebrake (2008); (c) Based on (Corbett and Winebrake 2008; Buhaug, Corbett et al. 2009); (d) Sources: (Kalli, Karvonen et al. 2009; EMSA 2010) (e) Source: (Kalli, Karvonen et al. 2009; Notteboom, Delhay et al. 2010). The low prices were experienced in beginning 2009 and the high prices in mid-2008

3.1: Residual oil (RO), the primary fuel used by the shipping industry, is the viscous residue left after lighter hydrocarbons - gases like propane, gasoline and distillates like diesel and kerosene - are extracted from crude oil through distillation and cracking in a refinery. Most of the contaminants in the crude oil like sulphur, ash and metals like vanadium and nickel get concentrated in the residue. Consequently the level of contaminants will depend upon the crude oil being processed – heavy sour crude will leave more contaminants in the residue. Further, as refinery processes have improved to maximize extraction of lighter and more valuable hydrocarbons, proportion of RO produced has decreased while level of contaminants in the RO has increased (Corbett and Winebrake 2008; Tetra Tech Inc. and UltraSystems 2008). Residual oil may be mixed with varying proportions of distillates to produce different grades of oil as summarized in the table.

3.2: To reduce operating expenses, marine engines have been designed to burn the least costly of petroleum products – fuel grades with high proportion of residual oil. Higher grade and more expensive fuels are used primarily for environmental compliance – large vessels while at or close to ports, inland shipping, harbor vessels like tugs and port crafts, and recreational vessels. Globally, shipping accounts for more than 6% of anthropogenic sulphur emissions (Corbett and Winebrake 2008; Buhaug, Corbett et al. 2009).

3.3: MARPOL Annex VI establishes two sets of emission and fuel quality requirements: one applicable at a global level and the other more stringent requirement applicable in Emission Control Areas (ECA). The global standard, as described in 2.3 above, mandates a maximum sulphur level of 0.5% by 2020 (or 2025). For ECAs, the maximum sulphur levels are mandated at 0.1% by 2015. At least two ECAs are already in force in Europe. In North America, an ECA covering the entire Pacific and Atlantic / Gulf coastline of United States and Canada and extending up to 200 nautical miles from shore (the so-called North American ECA) will most likely be enforced by 2012 (EPA 2010)[2].

3.4: As a result of MARPOL Annex VI and other more stringent local regulations, ships have to migrate from residual oils to marine distillates raising fuel prices by 50 to 150%. Since fuel costs accounts for 20-60% of vessel operating costs (Corbett and Winebrake 2008), the later could potentially rise by 10-90%. Alternatives to transition to expensive distillates are either limited or impractical. Availability of low sulphur residual oil is limited (European Commission 2009) either due to technical (Kalli, Karvonen et al. 2009) and economic (Notteboom, Delhay et al. 2010) challenges to desulphurize residual oil, or because of limited availability of sweet crude oil from which low sulphur residual oils can be produced economically [3]. An alternative to using low sulphur fuels is to use scrubbers to trap SOx in

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[2] EPA (2010) estimates the societal cost of the ECA at US$3.1 billion and monetized health-benefits at US$110 billion in 2020.

[3] In addition to increase in ship operating costs, massive investments are expected in the refinery sector. Purvin and Gertz (2009) expect need for US$30 billion of investments by European refineries to add processes like hydrocracking that increase yields of distillates and reduce production of residual oil. Similar conclusion is also noted in the U.S. analysis (EIA, 2009).

the exhaust gas to meet the regulatory mandates. However, outstanding issues especially disposal of waste streams from scrubbers will limit wide spread adoption of this option (Notteboom, Delhay et al. 2010). Transition to natural gas, which significantly reduces emissions of local pollutants, is another option and will be analyzed in next section.

The structure of the bunker industry precludes the potential to regulate the refinery or bunker supplier. Existing regulations to regulate emissions and fuel quality, as well as most of the proposed market-based regulations to regulate GHG emissions have focused on the ship as the regulated entity.

3.5: The bunker industry is highly cost competitive[4] and ship operators choose their bunker source on the basis of small price differentials. An often quoted example is that of introduction and subsequent repealing of sales tax on bunkers sold at the Port of Long Beach / LA in California (Michaelis 1997). Before the introduction of the tax in 1992, around the LA/LB bunker market had a monthly turnover of 4.5 million barrels. After introduction of an 8.5% sales tax, bunker sales dropped below one million barrels and shifted largely to Panama, which is en-route for many ships calling ports of LA/LB. As a result, the tax was rescinded within one year. None of the major bunker markets – Houston, Singapore, Rotterdam and LA/LB impose any taxes on bunkers sold to international shipping.

3.6: The competitiveness has been increased as a result of rise of offshore bunkering, which may happen in international waters outside the jurisdiction of any nation. Such practice has developed largely to avoid paying port fees or being constrained by loading limits in ports. Michaelis (1997) reports that the cost of bringing fuel from a port in Africa or the Middle East to northern Europe, or from Latin America to North America, is of the order of $10-15/tonne - less than 3% the current price of RO and 1.8% the price of distillates. A large proportion of residual oil sold in the United States is imported from South America (Fearnley Consultants 2003) and supplied by dealers independent of the large oil companies / refineries (Michaelis 1997) – hence any regulation that increases price of bunker sold from the US bunker markets will increase share of offshore bunkering and neighboring bunker markets.

4. GHG MITIGATION POTENTIAL

Opportunities exist to reduce 35% to 45% of emissions relative to BAU in 2020 in a cost effective way; i.e. at negative marginal abatement costs. Most of these opportunities pertain to ship design and operational measures. Potential to reduce emissions by using low carbon fuels is deemed limited in existing literature due to technical and economic barriers; and potential supply constraints.

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[4] In other words, high price elasticity of demand for bunkers in any given regional market.

4.1: Opportunities exist to reduce 25% to 45% of emissions relative to BAU in 2020 in a cost effective way; i.e. at negative marginal abatement costs (Buhaug, Corbett et al. 2009; Faber, Markowska et al. 2009; IMarEST 2010). Technical measures like optimization of hull design, improved hull coating, capitalizing wind and solar power, and lightweight construction account for around half of the above savings. Operational measures primarily speed reduction, accounts for the other half (IMarEST 2010)[5]. Potential for GHG reduction below BAU by adopting low carbon fuels such as liquefied natural gas (LNG), biofuels, and hydrogen is considered limited in existing literature. There are significant challenges in terms of fuel availability, need for modifications to ships and operating practices to store and use alternative fuels, and cost considerations.

Natural gas offers opportunity to reduce emissions of GHG and local pollutants, and historical costs have been similar to residual oil. In the post-MARPOL Annex VI scenario, LNG could witness significant penetration provided bunkering infrastructure is established and existing tonnage could be economically retrofitted. Further research is necessary to understand the potential and feasibility of biofuels.

4.2: Natural gas (NG), whether in liquid (LNG) or compressed (CNG) form, offers a number of advantages over residual oil and distillates. They have no emissions of SOx, significantly lower emissions of PM and NOx, and a 15% reduction in TTW CO2-equivalent after accounting for methane-slip (Buhaug, Corbett et al. 2009; IMarEST 2010). Based on current prices, natural gas is equal to the price of IFO on energy basis and significantly lower than MDO or MGO. A number of ships using LNG are already operating or being built (IMO 2009). Ship engine manufacturers like MAN and Wartsila have developed dual-fuel engines, which can run on NG and can be easily switched between NG and other fuels including distillates and RO (MAN 2010). However, there are significant challenges to widespread deployment of natural gas. Because of lower energy density, NG tanks will eat into cargo / passenger space. Additionally, ships have to be retrofitted to store and use NG, bunkering facilities need to be established, and crew and shore officials have to be trained to handle natural gas. IMO's (Buhaug, Corbett et al. 2009) future GHG emission estimates accounts for LNG penetration of 5-10% in coastwise shipping and 0-5% of tank ships by 2020 from negligible levels in 2007. The penetration of LNG will increase to 25-50% and 10-20% by 2050 for coastwise and tank ships respectively. Coastwise shipping, as opposed to ocean-going shipping represents coastal or regionally-bound shipping and other non-cargo carrying vessels like tugs, fishing vessels, dredgers, supply vessels, and port crafts and consumed around 40% of total fuel in 2007. A higher penetration of LNG in such ships will be facilitated by more predictable bunkering locations and timing; and driven by the more stringent emissions norms close to coastline of most countries.

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[5] However, both the marginal abatement cost, and the fuel use reduction potential of reduced speeds is uncertain due to variations in bunker price and need to add capacity as a result of slow steaming (Corbett 2009)

4.3: The overall low levels of penetration of NG forecasted by IMO are due to its assumption that LNG is relevant only for new buildings and not for retrofits. However, strong economic incentives resulting from MARPOL Annex VI may lead to ship operators retrofitting existing vessels as has been observed in Norway, where taxes on NOx emissions as well as stringent SOx emission norms has motivated conversion of a product tanker to run on LNG (LNG World News 2010). It is possible that certain categories like container shipping which have more predictable routes and hence bunkering patterns, and where bunkers can constitute a large portion of total costs, LNG penetration could be larger than IMO forecasts.

4.4: Research is limited on the technical, economical and institutional feasibility of using biofuels. A few ship operators are experimenting with biodiesel or FAME (fatty acid methyl ester), although technical challenges exist in form of stability during storage, plugging of filters, increased engine deposits and microbial growth (Buhaug, Corbett et al. 2009). No information is available on experience in renewable diesel (biomass-to-liquid or BTL) whose chemical composition is completely fungible with petroleum diesel and hence unlikely to pose many of the technical challenges mentioned before for biodiesel. The latest ISO standards on marine fuels (ISO 8217:2010), which is the primary international standard (Chevron 2007), excludes biofuels implying that marine fuels with biofuels will not comply with the current ISO standards.

5. BTL BLENDING – POTENTIAL COSTS & OPORTUNITIES

Blending renewable biodiesel (BTL) from agricultural and forest residue, and energy crops like miscanthus to fossil fuel based marine bunker will reduce the well-to-wheel (WTW) lifecycle emissions of marine bunker at an estimated CO_2-e abatement cost of around US$ 200-330/tonne CO_2e for IFO and US$ 30-230/tonne CO_2e for distillates based on "long run average" prices.

5.1: The cost of producing renewable diesel, as estimated by the economic analysis of the national LCFS study (Khanna et al. forthcoming) to be $1/liter by 2020, is 3X and 1.6X times the long run average prices of IFO and distillates, respectively. BTL from agricultural residue like wheat straw, forest residue, and energy crops like miscanthus and switchgrass with low WTW CO_2-e emissions could potentially be blended with distillates and IFO as discussed above. Blending of BTL to reduce WTW emissions by 10% will increase price of distillates by 7% and of IFO by 20%. This is equivalent to a CO_2-e abatement cost of between US$150-250/tonne CO_2e. Around 7.5 billion liters of BTL will be required and total abatement costs will be US$ 4.3 billion. Post MARPOL Annex VI in 2020, when distillates will be the primary bunker fuel, total abatement costs to reduce WTW CO_2 emissions of bunker sold in the US markets (assuming zero leakage) will be around US$ 3 billion.

5.2: We considered two alternate price scenarios – low price and high price scenarios. The low price scenario corresponds to prices witnessed during beginning 2009; while the high price scenario corresponds to prices seen during mid-2008. A high price scenario may result not only from high crude prices, but also if supply constraints fail to meet increased distillate demand due to MARPOL VI (EMSA 2010). Total abatement costs will be around US$0.7 billion in such a scenario.

Table 3: Abatement costs

			Avg. Price Scenario (a)		Low Price Scenario (b)		High Price Scenario (c)	
	US Bunker Market million tonnes (2007)	BTL volume required (million liters) (d)	Abatement Cost ($ / tonne CO2)	Total Abatement Cost (US$ million) (e)	Abatement Cost ($ / tonne CO2)	Total Abatement Cost (US$ million) (e)	Abatement Cost ($ / tonne CO2)	Total Abatement Cost (US$ million) (e)
Current Bunker sales								
- Distillates	12	1,541	148	631	234	999	33	139
- IFO	39	5,767	252	3,592	332	4,826	199	2,884
- Total	**51**	**7,308**		**4223 (15%)**		**5825 (43%)**		**3023 (7%)**
Post MARPOL Annex VI								
- Distillates	55	7,404	148	3,030	234	4,801	33	669
- IFO	-			-		-		-
- Total	**55**	**7,404**		**3030 (11%)**		**4801 (17%)**		**669 (1%)**

(a) Prices assumed are US$800 and US$500 for distillates and IFO respectively, (b) Corresponding values in low price scenario are US$500 and US$200, (c) US$1200 and US$700, (d) Volume required for blending with distillates and IFO to reduce WTW CO_2-e intensity by 10%, and assuming BTL from residue and energy crops, (e) Total abatement cost for 10% reduction in WTW CO_2-e intensity of bunkers sold in the US bunker markets assuming zero leakage

5.3: The above estimates translate into $33-330/tonne CO_2e for around 19 million tonne GHG reduction. The expected increase in fuel price under MARPOL Annex VI regulation will make the substitution of low-carbon biofuel less costly, and even potentially economical. If the cost of carbon reduction is lower than the LCFS credit prices, which we estimate to be around US$70/tonne CO2e (Khanna, et al. forthcoming), then there is a potential for bunker fuel providers opting into the LCFS program and earning credits by providing lower carbon bunker. The option is also attractive as it reduces the need for large investments for refineries in adding processes like hydrocracking that increase yields of distillates and reduce production of residual oil. Instead, they can blend in BTL into a wide range of products depending on the market prices and profit margins of the products.

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