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Economic Analysis of IMO 2020

The Benefits to the U.S. Economy of Full Participation and Compliance

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Disclaimer

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1. Summary

IMO 2020, a regulation developed by the International Maritime Organization (IMO) to significantly reduce sulfur emissions from the global shipping sector, will come into effect on January 1, 2020. The regulation will require a large reduction in the sulfur content of marine fuels consumed by most ships around the world. The resulting shift in fuel demand, from higher sulfur fuels to IMO 2020 compliant fuels, will be supported by a well-prepared global refining sector. The U.S. refiners are particularly well prepared for the shift as a result of significant investments to develop complex refineries.

While marine fuels represent only about 4% of global fuel consumption, the move to compliant marine fuels may have some impact on broader refined product prices. The U.S. Energy Information Administration (EIA) has forecast minimal fuel price impacts of IMO 2020. Still, consternation around IMO 2020 remains among several large fuel consuming sectors. There has been some political pressure for the U.S. to somehow support and encourage non-compliance with IMO 2020 (by ships) through non-enforcement (by countries).

While it is well reported that non-enforcement by the U.S. and other countries faces legal, political and regulatory hurdles, the economic implications of a U.S.-led “defection” from IMO 2020 have not been directly studied. This study evaluates the fuel price and macroeconomic impacts of a move to less global IMO 2020 compliance. An advanced suite of models, including CRA’s EMR-IMO macroeconomic model and Baker & O’Brien’s PRISM refinery model, were employed in this analysis.

The key findings related to a shift to less IMO 2020 compliance include:

- Gasoline prices see no discernable change. IMO 2020 has minor impacts in both directions on gasoline prices.
- Diesel prices may change by about $0.04/gallon – less than the average monthly change in diesel prices over the past four years. EIA estimated that diesel prices could increase by 5% on average from 2019 to 2020, though remain below 2018 levels. With less IMO 2020 compliance, the increase could be 3% instead.
- U.S. refiners, which are well positioned to see margin benefit from IMO 2020 since they produce the fuels that will increase in demand, would be expected to see a decrease in margin from less IMO 2020 compliance.
- Of the non-energy sectors in the U.S., only the relatively small marine transportation sector sees an economic output change greater than 0.02% in either direction.
- The impact on U.S. GDP growth is not detectable at the one-hundredth of a percent level (i.e., GDP grows at 2.16% regardless of IMO 2020 compliance levels, based on EIA’s baseline GDP estimate and CRA’s modeling of a partial compliance scenario).

As IMO 2020 implementation approaches, there is greater clarity into how the shipping and refining sectors will respond, and it appears the industries are driving toward a transition with minimal price disruption or fuel availability issues. The U.S. is in a unique position, based on its low sulfur crude production and the significant investments made by refiners, to support the global shift in marine fuel demand.

A U.S.-led defection from IMO 2020 compliance, which is clearly a difficult, if not impossible, proposition to execute, does not drive material benefit for the U.S. economy, with any benefits likely accruing to other global economies instead.

2. Introduction

2.1. Background

On January 1, 2020, a regulation developed by the International Maritime Organization (IMO) to limit sulfur in marine fuels ("IMO 2020") will come into effect. The regulation was announced in 2008 and has been set for implementation since 2016. It will significantly decrease sulfur emissions from international shipping, leading to benefits for human health and the environment.[1] It will also lead to several forms of economic benefits for countries, such as the U.S., that are best suited to support global compliance.

IMO 2020 will require a large reduction in the sulfur content of fuels consumed by most ships around the world. This shift will be facilitated by changes in fuel production and refining, industries that have been preparing for years to supply more low sulfur fuels to the shipping sector while meeting all other fuel demands. Refiners in the U.S. are particularly well situated to provide lower sulfur fuels and the crude oil produced in the U.S. is naturally lower in sulfur and therefore will see increased demand around the world.

The pending fuel demand shifts have led to some consternation within fuel-consuming sectors, particularly around the impacts on fuel prices in 2020. This topic has been analyzed, both directly and indirectly, in a variety of studies, including by the U.S. Department of Energy's Energy Information Administration (EIA). While some price movements are expected, the EIA does not forecast major disruptions or significant price movements. Our review suggests the fuel production and refining sectors are expected to find economical solutions. This conclusion is supported by the forward fuel prices at the time of this report.

Despite these assurances, there has been some political pressure for the U.S. to somehow support and encourage non-compliance with IMO 2020 (by ships) through non-enforcement (by countries). Non-compliance involves ships continuing to use High Sulfur Fuel Oil ("HSFO") while not scrubbing the exhaust gas to remove sulfur oxides. While it is well reported that non-enforcement by the U.S. and other countries faces legal, political and regulatory hurdles, the economic implications have not been directly studied.

Other studies to-date have focused on full implementation (with minimal non-compliance) compared to a scenario with no implementation of IMO 2020. Such a comparison at this point is no longer realistic since IMO 2020 will be implemented in January 2020. Therefore, a more reasonable comparison is between full implementation and a partial implementation that involves additional non-compliance driven by U.S.-coordinated non-enforcement.

2.2. Analyzing Impacts

This study evaluates the economic implications in 2020 of the U.S. driving less global enforcement of IMO 2020, thus leading to lower overall compliance. It does so by comparing two scenarios:

1) Baseline IMO 2020 (or "Full IMO 2020") Scenario - Full implementation is assumed to include 15% non-compliance globally,[2] similar to non-compliance estimates in many

[1] "Health Impacts Associated with Delay of MARPOL Global Sulphur Standards" presented by Finland to IMO, August 2016.

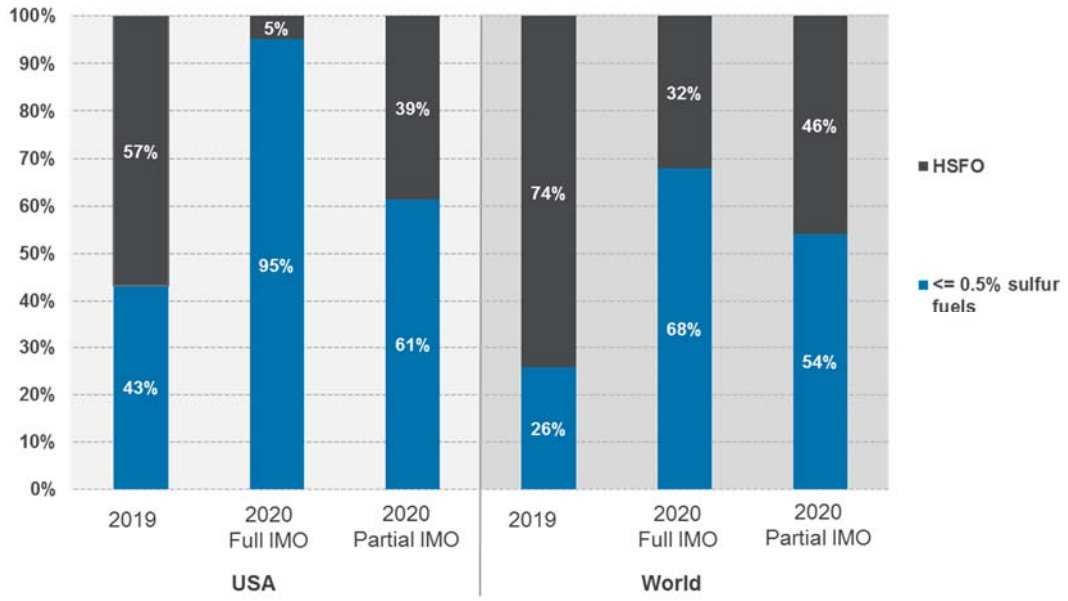
[2] Percentage non-compliance = (total HSFO consumed by ships not running scrubbers) / (total marine fuels consumed)

IMO 2020 studies, such as the April 2016 study by the International Energy Agency (IEA).[3]

2) Partial IMO 2020 - Partial implementation assumes cumulative global non-compliance of 30% of marine shipping fuels, allowing for greater use of HSFO. This level of non-compliance is not a prediction of likely achievable levels, but rather an indicative level based on one possible result of U.S.-led defections from IMO 2020 enforcement.

The following chart shows the percentages of marine shipping fuels consumed in the two scenarios in 2019 and 2020, for both the U.S. and globally. The IMO 2020 compliant fuels (blue) are any fuels with a sulfur content of no greater than 0.5%. The HSFO share (gray) includes both compliant use (pre-IMO 2020 or in ships with scrubbers) and non-compliant use (in ships without scrubbers in 2020). At the global level, in both scenarios about 15% of total fuel use will be HSFO used in a compliant manner.

Figure 1: IMO 2020 compliant fuels as shares of marine transport fuels, 2019 to 2020



The analysis involved two advanced energy and economic models. Charles River Associates ("CRA") utilized a global macroeconomic model ("EMR-IMO") to evaluate fuel price responses to changes in compliance levels and to determine sector-level and economy-wide impacts. Baker & O'Brien, Inc, ("Baker & O'Brien") used its PRISM model to evaluate responses by U.S. refiners. The PRISM model determined refinery output of various products, as well as the refining sector's economic outcomes in the scenarios.

Both models were calibrated to the EIA's recently published forecasts of prices and quantities in 2020 under full IMO 2020 implementation. To estimate the impacts of moving to partial implementation, we modeled an increase in demand for higher sulfur fuels in the marine shipping sector (and the associated decrease in lower sulfur fuels). The EMR-IMO model

[3] International Energy Agency, "Oil Market Report", April 2019

determined the macroeconomic response, and the PRISM model determined the response by U.S. refiners.

2.3. Key Findings

Assuming it is even possible, a move to partial IMO 2020 implementation would have competing impacts on the U.S. economy. There would be some reduction in refined product prices, which are mostly found in diesel and marine fuels. This has a slight, positive impact on a few sectors of the economy for which those fuels are a significant share of production costs. No modeled non-energy sector of the economy would see a benefit greater than 0.02% of its economic output. There would also be a loss of productivity and economic value added in the refining and oil production sectors. The overall impact on the U.S. economy is **not detectable** at the hundredth of a percent level of the GDP growth rate.

Petroleum product prices are far more sensitive to changes in crude market developments than to changes in IMO 2020 implementation levels. For example, without IMO 2020 in effect, diesel prices dropped nearly 19.8% from January 2018 ($1.85/gal) to January 2019 ($1.48/gal), mostly driven by a nearly identical (19.3%) drop in WTI crude price. The price changes between 2019 and 2020 are forecasted to be much more modest. In the Baseline IMO 2020 scenario, which is calibrated to EIA forecasts, average diesel prices increase 5% from 2019 to 2020. In the Partial IMO 2020 scenario, average diesel prices increase 3% from 2019 to 2020. In both cases, average diesel prices remain under 2018 levels.

The following charts show the refined product price impacts of reducing compliance with IMO 2020. The prices are presented as “refiner prices,” which is the average price received by refiners, excluding taxes. These prices are highly dependent on crude oil prices, which in this study were calibrated to EIA’s STEO April 2019 forecast for the Baseline IMO 2020 scenario.[4] In addition to the diesel price changes discussed above, the chart below shows that gasoline prices see no discernable benefit from reduced global compliance with IMO 2020.

[4] The STEO April 2019 estimates for 2020 prices were: Brent $62/barrel, WTI $58/barrel. If crude prices are higher, we would expect both scenarios’ refined product prices to rise at about the same rate. Crude oil prices in the Partial IMO 2020 scenario are determined by the EMR IMO model and do not change materially from the Baseline IMO 2020 scenario.

Figure 2: Fuel prices, refiner prices (cents/gallon), 2018 to 2020

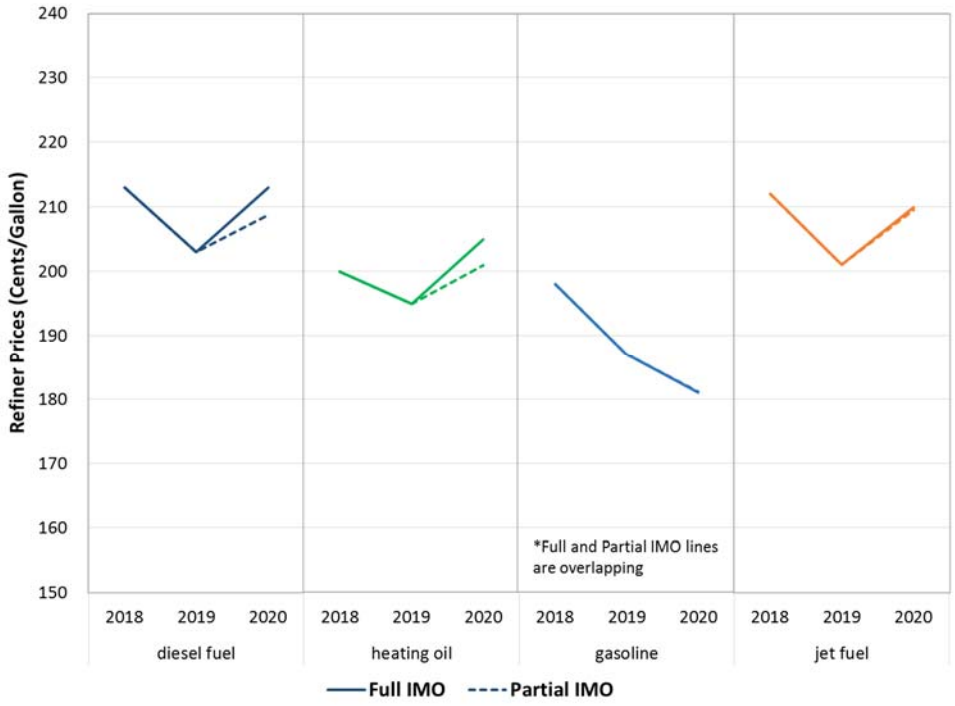
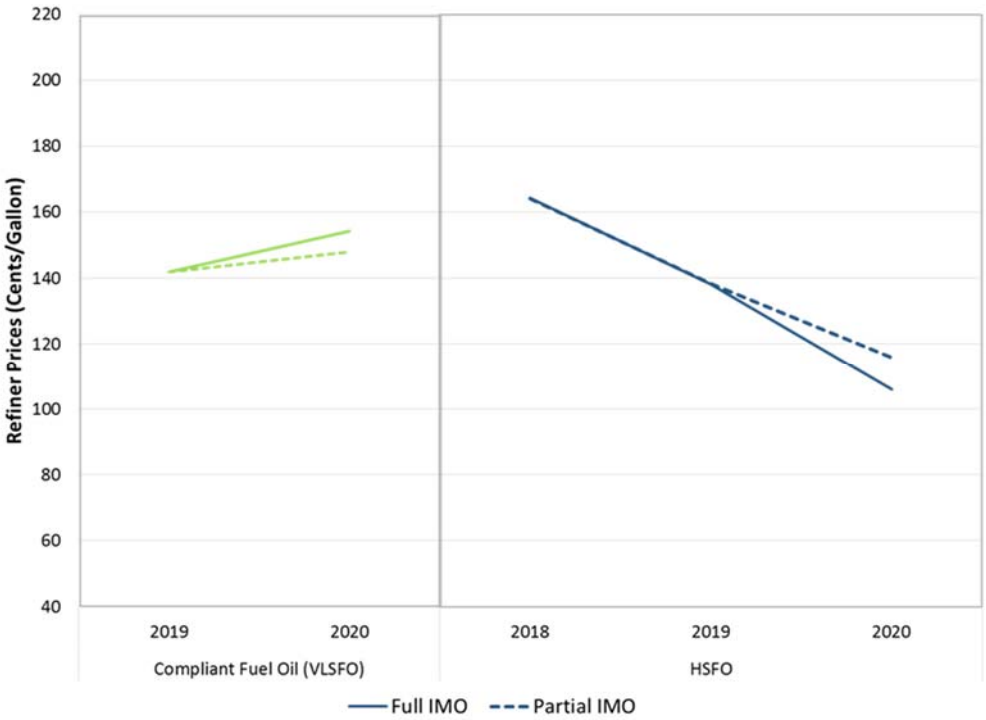


Figure 3: Fuel oil prices, refiner prices (cents/gallon), 2018 to 2020



U.S. refineries are well positioned to provide the types of fuels most needed in an IMO 2020 future. They currently provide over 10% of marine fuels consumed in the world, and that share is expected to increase. Along with increased volume, refiners can expect to see their refining margins improve with IMO 2020, though remaining within their historical range. This is borne out in our analysis. Following the introduction of the new IMO 2020 regulations, we see average U.S. oil refining margins in 2020 outperforming the recent past. In the Partial IMO 2020 scenario, we see a minor reduction in product prices eroding refining margins, compared to the Baseline IMO 2020 scenario.

Due to the option of using more of the lower-cost HSFO, the global marine transport sector would see the greatest benefit of less compliance with IMO 2020. However, that benefit would be mostly isolated to the trade routes for which the additional non-compliance occurs. These benefits would be moderated by rising HSFO prices and would mostly accrue to shipowners, as shipping rates would still largely be set by compliant vessels and the compliant fuels that do not change significantly in price on the whole.

The overall impact on the economy is minimal. For example, under the baseline, GDP grows 2.16% from 2019 to 2020 (an EIA estimate). Under the Partial IMO 2020 scenario, GDP also grows 2.16%. The difference is in the thousandths of a percent, which is well within the error of the assumptions and modeling.

2.4. Report Outline

Section 3 provides an overview of the economics of IMO 2020. The overview includes insights into both marine shipping sector and refinery sector responses to the regulation, as well as commentary on fuel market impacts. Section 4 presents the two scenarios of IMO 2020 compliance. Section 5 describes the modeling at a high level. Section 6 presents the results of our study.

3. Overview of IMO 2020 Economics

This report section provides an overview of IMO 2020 economics. It describes how the shipping and refining sectors are likely to respond to the upcoming regulation. It also provides high-level insight into how the global fuel markets will respond. These insights support our assumptions used in modeling an increase in IMO 2020 non-compliance.

3.1. Marine Shipping Sector Response

Under the IMO 2020 regulation, ships must use fuel with no greater than 0.5% mass by mass (m/m) sulfur content, which is an 86% reduction from the current maximum sulfur content of 3.5% m/m in most open waters. There is an exception for ships with exhaust gas cleaning systems, or “scrubbers,” that would allow them to continue to use fuel with up to 3.5% m/m sulfur content. Therefore, ships have three main options for responding to IMO: 1) use lower sulfur fuels that comply with IMO 2020 (“compliant fuels”), 2) install and use a scrubber, or 3) not comply and face potential consequences.

There are many factors that drive the decisions for each shipowner, some at the fleet level and some at the vessel level. These factors include home or “flagged” states, trade routes, and vessel features (age, size, tank segregation, etc.). While this study is focused on macroeconomic impacts and fuel markets, we present a high level discussion of the marine shipping sector’s response options because they impact the demand for various fuels, which drives the impacts of IMO 2020 and the impacts of variable levels of non-compliance.

3.1.1. Using Compliant Fuels

Ships that plan to comply through using compliant fuels have many decisions to make in preparation for implementation of IMO 2020. The main decision is which compliant fuels to use. They will have several fuel types to choose between:

- Marine gasoil ("MGO") – Marine gasoil is similar to diesel fuel, but may have a higher density, viscosity, or cold properties. It consists of distillates, which are evaporated from crude oil then condensed into liquid. Unlike heavy fuel oil (the main bunker fuel), most marine gasoils typically do not require heating during storage. It also produces less particulate matter and soot when burned. While marine gasoil can have variable sulfur contents, the most common form has sulfur content below 0.1% m/m to comply with Emissions Control Areas ("ECA"s) in several regions around the world. However, it can have sulfur content up to 1.5% m/m.

  Marine gasoil has historically been more expensive than heavy fuel oil, principally due to its similarity to diesel fuel and lower sulfur content. Because of this lower sulfur content, marine gasoil has been primarily used for ECA compliance and for shipping on inland waterways. Large ships can run on heavy fuel oil, marine gasoil and blends.

- Compliant fuel oils – There is inconsistent terminology used for describing fuel oils with lower sulfur content than HSFO. The most common is the following:

  - Low Sulfur Fuel Oil ("LSFO") has sulfur content of 1% or less.[5]
  - Very Low Sulfur Fuel Oil ("VLSFO") has sulfur content of 0.5% or less.
  - Ultra Low Sulfur Fuel Oil ("ULSFO") has sulfur content of 0.1% or less.

  VLSFO and ULSFO are considered compliant fuels for IMO 2020. VLSFO may have different formulas from different producers. ULSFO is also compliant in ECAs, however it is very rare as it contains such a high percentage of distillate that it is essentially MGO.

The decision to use either of these fuels will be based on relative prices, fuel availability at ports, and technical aspects specific to each ship.

There are mechanical and other technical challenges to switching from HSFO to either MGO or lower sulfur fuel oils. For ships converting to alternative fuels (e.g., HSFO to VLSFO), there is a required tank cleanout process that cannot be carried out while the ship is in operation. The cleanout process takes about a week, and is necessary to ensure fuel-burning compliance and to keep the equipment running efficiently.[6] Due to a need to stagger cleanouts, it is expected that a significant number of vessels will commence using compliant fuels in late 2019.

3.1.2. Using Scrubbers

Ships can avoid buying compliant fuel if they have exhaust gas cleaning systems, or "scrubbers," installed. The decision to install a scrubber on a ship is mostly based on two key variables: 1) the cost of the scrubber, and 2) expectations for the price spread between compliant fuels and HSFO. Lower scrubber costs and higher price spreads reduce the

[5] Many sources use the term LSFO for IMO 2020 compliant fuels. The distinction is important in this report due to the modeling approach discussed later. LSFO in the traditional definition is mostly used in the power sector.

[6] "IBIA offers practical advice on tank cleaning to IMO 2020 planning meeting," IBIA, June 2018.

payback periods for investments in scrubbers. The cost of scrubbers are lower for new build ships. Cost estimates for retrofitting existing vessels vary widely, ranging from $2 million to $10 million. The price spread between compliant fuel and HSFO is discussed later. One recent public analysis shows that a $200/MT price spread can lead to about $1 million in fuel savings per year for ships with scrubbers.[7]

In addition to those key variables, owners evaluating the installation of scrubbers must consider other factors. Factors supporting scrubbers include fuel diversification to hedge price risk. Factors challenging scrubbers include concerns about the likely availability of HSFO, which will be a secondary bunker fuel in many ports, and a rising opposition to discharge from open-loop scrubbers in certain regions.

The amount of HSFO consumed by ships with scrubbers in 2020 is an important variable in determining the impact of various levels of IMO 2020 compliance. To estimate the volume of HSFO, most studies begin with estimating the number of scrubbers that will be installed across the over 90,000 ships expected to be operational in 2020. The 2019 IEA oil report estimated that 2,500 ships will have scrubbers by the end of 2019, 4,000 by the end of 2020, and 5,200 by the end of 2024.[8] While the longer term installation estimates seem to line up with other industry estimates, the IEA seems to be more pessimistic than others regarding installations prior to 2020. DNV GL reports that the total number of ships in operation and on order with scrubbers fitted through 2019 is 2,859.[9]

The ships that will be fitted with scrubbers are generally much larger than average sized vessels and have trading routes that involve more time at sea. DNB Markets estimates that the top 5% of fuel-consuming ships (which translates to under 4,500 vessels) consume 38% of marine shipping fuel.[10] The 2019 IEA oil report estimates that the 2,500 ships with scrubbers (plus the additional ships adding scrubbers throughout 2020) will consume 700 kbpd of HSFO, which represents about 16% of global marine fuel consumption.[11] Using IEA's estimates, an additional 500 scrubbers could lead to the marine sector having 10% greater HSFO demand and 7% lower MGO demand than IEA's current estimate.

3.1.3. Converting to LNG

Another option for ship owners is to convert their existing vessels or purchase new vessels that run on liquefied natural gas ("LNG"). Burning LNG emits only trace amounts of sulfur, thus qualifying LNG as an IMO 2020 compliant fuel. The capital costs are much more substantial than installing scrubbers and LNG is much more limited in availability. Each of those factors is changing, and the economics could improve depending on the relative prices of marine fuel oils, MGO and LNG. The likely impact of LNG as a bunker fuel will be gradual, with most impact expected after 2020. As this analysis is focused on the year 2020, LNG is not a modeled IMO 2020 compliant fuel and is not discussed further in this report.

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[7] Scorpio Tankers, "Company Presentation," May 2019.

[8] International Energy Agency, Oil 2019 Analysis and forecast to 2024

[9] DNV GL, Alternative Fuels Insight, https://afi.dnvgl.com/

[10] "DNB: Scrubbers are a good investment", Splash247, September 17, 2018.

[11] International Energy Agency, Oil 2019 Analysis and forecast to 2024

3.1.4. Not Complying

Shipowners also have an option of not complying with the IMO 2020 regulation by continuing the use of HSFO without using scrubbers (either not installing them or not using installed scrubbers). With this option comes a variety of potential consequences that can vary significantly and are highly uncertain as IMO 2020 implementation approaches.

The first uncertainty is related to the likelihood of getting caught for not complying. Enforcement is mostly driven by Port States (countries that ships visit, to load/unload cargo, to dry dock for repairs, or to take on bunker fuel). Most Port States will force compliance by simply not providing HSFO to ships without scrubbers. Many Port States have shared plans to support enforcement both directly, by monitoring/testing emissions and fuels, and indirectly, through evaluating bunker logs. Enforcement is expected to vary by Port State and region.

The second uncertainty is related to the many penalties and other costs of getting caught. Port and Flag States are charged with determining direct penalties for non-compliance. A likely Port State enforcement mechanism will be demanding the costly and time-consuming process of unloading non-compliant fuels and re-bunkering with compliant fuel before the ship may leave the port. There can also be more extreme direct penalties such as significant fines or jail. Indirectly, ship owners may face reputation risk and could face loss of insurance. For example, the largest insurance broker in the world published a report discussing the likelihood of denied insurance claims for ships not complying with IMO 2020.[12]

The topic of enforcement by Port and Flag States is discussed further in Section 4.2.1.

3.2. Refining Sector Response

While the marine shipping sector's responses to IMO 2020 will determine the changes in fuel demand, the refining sector's responses will determine the changes in fuel supply. How refiners respond to changes in demand for lower sulfur fuels in the marine shipping sector will drive prices and fuel availability in 2020 and beyond. Refiners, particularly U.S.-based refiners, have proven adaptable many times in the past.

Over the past 30 years, road transport fuel quality regulations, particularly in OECD markets, have been tightened with a focus on reducing sulfur content (and associated sulfur oxide related exhaust emissions). Global oil refiners have invested in their facilities to meet this challenge primarily by installing process units to remove and recover sulfur. IMO 2020 extends onshore "clean fuels" programs into the marine sector. However, while shippers can comply with IMO 2020 by installing scrubbers that allow for continued use of high sulfur fuel oil, regulations for ultra clean diesel and gasoline land transportation fuels did not allow for the continued consumption of higher sulfur fuels. Rather, the land fuel regulations required that all vehicles use lower sulfur fuels. Also, unlike some other regulations, refiners have seen the introduction of IMO 2020 on the horizon for many years and have been able to factor it into their long term plans.

As IMO 2020 implementation approaches, there is more clarity into how the sector will respond, and it appears the industry is driving toward a transition with minimal price disruption or fuel availability issues. This section addresses several key issues and topics that will frame the refining sector response.

[12] "Emissions Regulations: Concerns for the Marine Industry," Marsh, Q1 2018.

3.2.1. Economics of Refinery Response

The global refining sector is highly complex, competitive and diverse, with significant variations in capabilities between regions and refinery technologies. While the industry does not explicitly operate in a coordinated manner, it adjusts to short and long-term changes in fuel markets in a manner that may seem coordinated since it is generally guided by economics (short-term) and regulations (long-term). When there are small demand changes, a combination of price signals and expectations lead to operational adjustments seen in refinery utilization levels and product yields. Refineries can respond similarly to changes in crude oil prices and availability.

Oil refineries generally benefit from inherent production flexibilities associated with their complexity; in addition to adjusting the volume of crude oil processed, i.e. adjusting the utilization rate, refineries generally can also, to a certain degree, adjust their product yields by changing the type of crude oil they process and by modifying their plant operations. This enables refiners to respond to minor/modest changes in their downstream markets (e.g., refined product pricing and/or demand changes) and upstream markets (e.g., crude oil pricing and supply).

For larger industry changes (such as a step-change in fuel quality specifications), adjusting existing operations, realigning infrastructure and changing crude inputs may not be sufficient. However, many of the constraints can be resolved with price responses and adequate time. Higher prices can incentivize increased production of certain products and/or demand shifts to other products. Lower prices can have the opposite impacts. However, the potential impacts of these price changes can often be anticipated, and the industry can respond by relieving potential constraints.

The industry players consider strategic competitive positioning but the overall response is motivated by regulatory compliance and by the refiners' evaluation of returns from making investments to increase production of the fuels that are in demand and would therefore receive higher prices. Paradoxically, the refiner response of increased production often leads to a muting of price impacts. However, this is not guaranteed given the lack of perfect foresight, particularly around aggregate refiner response. The question is therefore whether refiners in the aggregate will make the adjustments to operations and infrastructure necessary to mute a price change.

3.2.2. IMO 2020 Compliant Fuel Production

As discussed in Section 2.1.1, shipowners will have three main fuel options in 2020: 1) HSFO, used either in a compliant or non-compliant manner, 2) very lower sulfur fuel oil (VLSFO) with sulfur content of 0.5% m/m or lower, or 3) marine gasoil and diesel fuel oils. As discussed, the decisions by shipowners will be based on ship or fleet-specific factors (e.g., technology, operations, and intended compliance levels), combined with expectations for fuel prices and fuel availability. Actual fuel prices and availability in 2020 will be determined by the global refining sector's ability to increase output of marine gasoil and VLSFO while maintaining production of other fuels.

- Producing more marine gasoil – Marine gasoil is produced as a middle distillate in the refining process, which places it in-between lighter distillates (such as gasoline) and heavy distillates/residuals (such as residual fuel oils and solids). Middle distillates (from lightest to heaviest) include jet fuel, heating kerosene, diesel/heating oil, and marine gasoil. The IEA estimates 2019 global production of 36.8 mbpd of these

products combined.[13] In the same report, the IEA estimates that the IMO 2020 regulation will lead to an additional 1.1 mbpd increase in demand for marine gasoil, or a 3% increase in total distillate demand.

To meet such an increase in middle distillate demand, refiners can either increase overall throughput using existing refinery setups, maximize middle distillate production or, over a longer time period, they can increasingly employ technologies, such as hydrocrackers, for more significant yield shift. Both approaches are likely as IMO 2020 implementation approaches.

- Producing compliant fuel oil – Refiners have already begun to test and produce compliant fuel oils, or VLSFOs. The VLSFOs available in the market will be a range of residual fuels that have been desulfurized through the refining process (generally starting with lower sulfur crude) or blends of higher sulfur fuel oils with distillates. More technically speaking, the VLSFOs will originate from "sweet crudes, de-sulphurised fractions, cracked fractions, heavy and lighter hydrotreated fractions and residual fuels blended down with distillates to meet the sulphur limit..."[14] Therefore, the main ways refiners will commence and then increase production of VLSFO will be to increase the use of certain refining technologies, adjust crude inputs, and increase distillate production (as discussed above).

Given these approaches to providing the marine shipping sector with compliant fuels, the options for refiners fall into five main categories, as listed below.

1) Increasing overall throughput – This option could have the most impact on other refined product markets beyond compliant fuels, with price impacts in both directions. It can increase supply of other refined products, which would tend to decrease their prices. However, there is an upward pressure on crude prices given the increased overall demand.

   The extent to which increased throughput is an available option for each refinery depends on the pre-2020 utilization and the total capacity. Total capacity by refinery has proven to be an imprecise estimate of potential. Many refineries can run above their rated capacities for limited periods of time. In fact, in the U.S., entire PADDs have had multiple weeks of utilization over 100% since 2014 (7 weeks in PADD 2 and 2 weeks in PADD 4).[15] Over the longer term, even in the absence of substantial investment in new capacity, the U.S. refining sector continues to debottleneck facilities resulting in small increases in capacity (known as capacity creep).

   Another possible constraint is the potential over-production of high sulfur fuel oils without adequate disposal options. A significant portion of HSFO that will no longer be used in the shipping sector is expected to be absorbed in the global power sector, or used in carbon black or asphalt production. Additional HSFO production can also be used as an input in refineries, particularly by refineries that may use these fuels as an alternative to heavy sour crudes, like Venezuelan crude, that has been in short supply.

[13] IEA Oil Market Report 2019

[14] "Detailed information on preparation and operation on fuels with maximum 0.50% sulphur", MAN Energy Solutions, March 2019.

[15] "Refinery Operable Capacity Percent Utilization," U.S. EIA, May 8, 2019.

2) Changing operations while using existing infrastructure – The refining sector has repeatedly proven creative and resourceful in adapting to demand and fuel quality changes in the industry. There is significant market uncertainty as to the extent operational and other small changes can alter product yields. As discussed, there are multiple degrees of freedom for refiners to adjust operations and change yields. With the industry anticipating demand for compliant fuels, operational changes are already underway. Many changes associated with improving their operating flexibilities (such as additional tankage to segregate crude oil and fuel oil products) will be made during maintenance activities throughout 2019.

3) Utilizing certain refineries more – It is commonly understood that the refinery-level impacts of the IMO 2020 regulation will vary depending on refinery type. Generally, more complex refineries with more heavy fuel oil upgrading technology (such as cokers) are likely to benefit and target increasing production. These refiners are able to process and upgrade heavy sour crudes into refined products (gasoline and distillates), while producing minimal fuel oil products. They are also able to upgrade high sulfur oil produced by other refineries. Therefore, they are likely to benefit from improved distillate margins/prices and heavy sour crude oil price discounts, and lower prices for high sulfur fuel oil. The U.S. has a higher concentration of these refineries, often referred to as "deep conversion" refineries, than the rest of the world.[16]

   Conversely, "simple" refineries that have limited heavy fuel oil upgrading capacity generally produce more fuel oil for sale, and as a result are more exposed to high sulfur fuel oil price changes, and potentially may be forced to switch to light sweet crudes. These refineries are more likely to cut rates either to reduce high sulfur fuel oil production or accommodate an alternative light-sweet crude oil. The refineries most likely to see negative impacts are these "simple" refineries, particularly those processing higher sulfur crudes and unable to adjust crude inputs or to make the more in-demand fuels. These types of refineries are more common in Europe and Asia.

4) Adding conversion and treating technologies to change yields – Refiners have known about IMO 2020 for many years. They have had a decent amount of certainty of its implementation for at least four years. In that time period, many refineries have added desulfurization, coking or hydrocracking capacity that would reduce the amount of HSFO they produce and/or increase volumes of the fuels needed for IMO 2020 compliance.

5) Altering crude inputs – Many refineries can alter the type of crudes they process based on price spreads and availability of the various crude types. There will likely be economic incentive for many simpler refineries to shift to sweeter crude oil (such as U.S.-produced crude oil, see Section 3.3.2), thus improving the production of compliant fuels and/or distillates that will see higher demand. With the curtailing of the marine bunker fuels market as an outlet for heavy, high sulfur residues, intra-refinery trade of these intermediates – from simpler to complex refineries – is likely to increase. For U.S. refineries this provides potentially an alternative feedstock to sanctioned Venezuelan heavy oil for maximizing the utilization of their heavy oil upgrading units, such as cokers.

Each of the refinery options are interrelated, and all are likely responses to IMO 2020 in varying degrees. There are many indications that refinery responses are already underway. This is indicated by many announcements by refiners that they are already testing and will be

[16] IEA, "Oil Refineries," Energy Technology Systems Analysis Programme, April 2014.

prepared to offer compliant fuels well before IMO 2020 implementation on January 1, 2020. =For example, the following refiners, among others, have made such public announcements: Shell,[17] Exxon Mobil,[18] Chevron,[19] Marathon,[20] and BP.[21]

In sum, oil refiners in the U.S. and elsewhere have successfully met previous clean fuel regulatory tightening with a smooth and coordinated transition. They have seen IMO 2020 on the horizon and have a multitude of operation and investment "levers" at their disposal to respond to its implementation before the end of this year. As a result of significant investments to develop complex refineries, the U.S. refiners are particularly well prepared and set to benefit.

3.3. Fuel Market Impacts

Given the expected responses by the shipping and refining sectors, the EIA and others have forecasted minimal fuel market impacts of IMO 2020 (as discussed later). This conclusion is supported by expectations that fuel price changes will lead to shipowner and refiner responses that will mute any possible impacts. In this section, several significant fuel market topics are discussed in relation to IMO 2020 response.

3.3.1. Regarding Short-term Price Impacts

Short-term price impacts are generally driven by unexpected shifts in demand (or supply) in an environment in which either supply (or demand) is inflexible, constrained, or highly sensitive to small changes. Such price impacts are particularly acute when the change is not predictable and occurs too fast to allow responses by the market. The IMO 2020 regulation is not such a change. It has been expected for years and, even though implementation begins on a set date, the market will begin responding well before January 2020.

There are both supply-related and demand-related reasons to expect that price increases during IMO 2020 implementation will be muted. On the supply side, there is a significant amount of fuel storage available in and near ports across the world that could begin accepting compliant fuels months in advance of January 2020. There are also options to expand storage opportunistically. Storage of VLSFO has already begun at the time of this report, including off-shore storage in large vessels near ports in Singapore and Malta. [22] Many global ports have increased fuel storage capacity and segregation capabilities in anticipation of IMO 2020 implementation.

On the demand side, shipowners have no choice but to begin to take on compliant fuels prior to January 1, 2020. Most ships switching fuels will require tank cleanouts which, due to port availability and trip schedules, requires staggering for months prior to IMO 2020. Even without extensive cleanouts, ships will likely begin using compliant fuels early to avoid holding non-compliant fuels as of January 1, 2020.

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[17] Shell: https://www.shell.com/business-customers/marine/imo-2020.html

[18] ExxonMobil: https://www.exxonmobil.com/en/marine/technicalresource/press-releases/2020-compliant-fuels

[19] Chevron: https://www.reuters.com/article/us-chevron-shipping-idUSKCN1T61G7

[20] Marathon Pertroleum: https://www.marathonpetroleum.com/content/documents/Responsibility/MPC-ClimateReport-2018.pdf

[21] BP: https://www.bp.com/content/dam/bp/business-sites/en/global/bp-global-energy-trading/documents/what-we-do/marine/marpol-technical-guide-oct-2018.pdf

[22] Cheong and Cang, "A Fleet of Tankers Is Hoarding Oil for a Gathering Storm," Bloomberg, April 29, 2019.

In addition to the EIA, and with the exception of a few studies, the market seems to agree that significant refined product price increases before or during January 2020 are unlikely, as well as in the months following January 2020 (though trade volume is extremely low that far in the future). This can be inferred by reviewing commodity futures prices for refined petroleum products. Diesel and gasoline are the refined products with the highest product consumption and futures trade volumes. Most other refined products, such as heating oil, jet fuel and bunker fuels, are not traded forward at a high volume, and instead they can be hedged through diesel and gasoline futures, or through crude futures or forward contracts. While there are also compliant bunker fuel futures contracts available, they are not yet traded at a volume to be informative.

The following chart shows futures prices for diesel (New York Harbor Ultra-Low Sulfur Diesel) and gasoline from July 2020 through the end of 2020.

Figure 4: Diesel and gasoline futures prices (cents/gallon), July 2019 to Dec 2020

Source: Bloomberg

Diesel prices see a gradual price increase prior to IMO 2020 implementation, but the price increase is only $0.04/gallon (<2%) over six months. For reference, the average absolute change in diesel prices ***per month*** from 2015 to June 2019 was nearly $0.10/gallon.[23] Also, the increase in futures prices follows a general expectation that New York Harbor diesel prices increase in the winter due to Northeast U.S. heating demand.

Gasoline futures prices show even less of an expected impact. As discussed later, there are aspects of IMO 2020 response that could push gasoline prices in either direction, and the futures show no significant upward or downward price movement near January 2020. Rather, there is a consistent downward trend that reflects crude price expectations.

There have been a series of articles suggesting that these futures prices are not yet capturing expectations for price impacts of IMO 2020. Such an assertion runs counter to the fundamental theories of efficient markets and the economics of futures prices. Simple logic

[23] Analysis of AEO 2019 historical monthly data.

can explain why – if fuel consumers (or speculators) believe there is a likelihood of a spike, it would make sense to secure future pricing at the low current futures prices, at the very least as a hedge. As such purchases are made, the price would increase in response to the demand. Eventually, an equilibrium price would be found at the market's collective view of the most likely price at the future delivery date (with minor adjustments for risk and asymmetric information). Any significant deviation would be an arbitrage opportunity in a liquid market. If the market believed the studies that estimate price impacts of 20% or more, the futures prices would certainly reflect that by now.

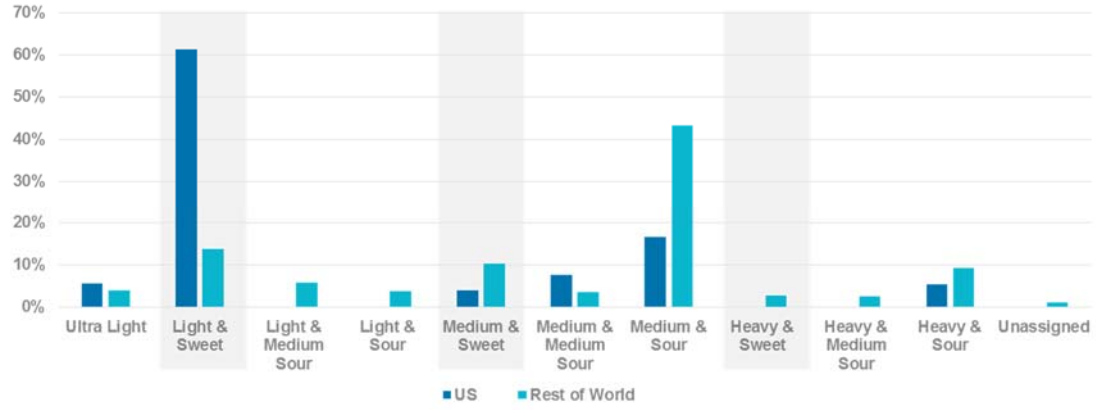
3.3.2. Crude Oil Price and Production Response

Crude oils are generally defined and differentiated by two properties: sulfur content and relative density. Crude oil sulfur content ranges from sweet (low sulfur) to sour (high sulfur), with a gradient in between. Crude oil relative density , measured in API Gravity, ranges from light (high API gravity) to heavy (low API gravity), with a gradient in between. The combination of these properties, along with a few other physical characteristics, generally drive the value of each crude type. In general, sulfur content is considered undesirable, and therefore sweeter crudes are more valuable for simple refineries. Lighter crudes have a higher percentage of light hydrocarbons that can be recovered by simple refineries.

The price spreads between different crudes are driven by a complex interaction between supply and demand dynamics for each crude and each refined product. These dynamics are influenced by exploration and production economics, refining technologies and economics, and market demand for fuels. The most important consideration for evaluating the impact of IMO 2020 (or a reduction in compliance with IMO 2020) is that a shift toward lower sulfur bunker fuels will result in more demand for sweeter crudes. It is commonly accepted that IMO 2020 will increase the value of light sweet crude and decrease the value of heavy sour crude.

The following chart shows the share of crude production in the U.S. and the world excluding the U.S. for each major crude type. Sweet crudes are highlighted with gray boxes. The U.S. light sweet crude share was over 60% in 2017. Only about 5% of U.S. production was heavy sour crude.

Figure 5: Share of Crude Production by Type, U.S. and Rest of World (2017) [24]



Source: eni

[24] "World Oil Review 2018," eni, 2018.

The IMO 2020 regulation will benefit countries that produce light sweet crudes, such as the U.S., and will negatively impact producers of heavy sour crudes (such as Saudi Arabia, Russia, Iraq, Iran, Venezuela, and Canada). Therefore, the opposite can be said of a move to Partial IMO, as the higher demand for HSFO and lower value of low sulfur fuels lead to a decrease in the value of U.S. crude oil.

The global fuels markets are already experiencing a "lightening" and "sweetening" of crude oil. This is mostly driven by the expansion of U.S. production. More recently, there have been significant production cuts by several countries with more sour crudes, such as Iran and Venezuela.[25] Interestingly, this has the impact of making HSFO scarcer since there is less residuum from processing heavy sour crudes. This will likely decrease impacts of IMO 2020 since it represents a crude-driven reduction in the spreads between HSFO and other marine fuels.[26]

4. Defining the Compliance Scenarios

This study evaluates the economic implications in 2020 of a U.S.-led defection from full global implementation of the IMO 2020 regulation. This required a comparison of two scenarios that differ only in the level of compliance. The first scenario is the "baseline" scenario that assumes full implementation of IMO and compliance at the rates commonly estimated by studies of IMO 2020. The second scenario is almost identical, except the U.S. leads increased non-compliance. The differences in economic outcomes between the scenarios is the economic impact of additional non-compliance. In both scenarios the IMO 2020 regulation will begin implementation on January 1, 2020.

4.1. Baseline Scenario ("Baseline IMO 2020")

The Baseline IMO 2020 scenario includes a certain level of non-compliance that reflects the most common views for various forms of non-compliance. Some non-compliance is expected in certain international shipping routes between ports and countries with low expectations of enforcement and on vessels flagged in countries with low likelihood of enforcement. Non-compliance within the IMO 2020 framework is also expected for ships fueling at ports with issues related to compliant fuel quality and availability. While this particular form of "non-compliance" may be excused under IMO 2020, it is included as part of the baseline non-compliance since it may result in additional HSFO use by ships without scrubbers. More of this form of non-compliance is expected in the earlier part of 2020 as certain ports convert their fuel offerings.

The EIA discusses non-compliance in its stand-alone report on IMO 2020.[27] While they do not cite a specific assumption about non-compliance, the majority of analyses to date include estimates between 10-20% of total shipping fuel consumed in 2020. For example, in April 2019 the IEA estimated baseline non-compliance in 2020 of 16%.[28] Consist with these studies, the Baseline IMO 2020 scenario assumes that non-compliance represents 15% of total marine fuels.

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[25] Xu. Conglin. "Crude quality imbalances," Oil and Gas Journal, March 26, 2019.

[26] "How the bottom of the barrel became the top of refining margins," International Shipping News, May 6, 2019.

[27] "The Effects of Changes to Marine Fuel Sulfur Limits in 2020 on Energy Markets," EIA, March 2019.

[28] International Energy Agency, Oil 2019 Analysis and forecast to 2024

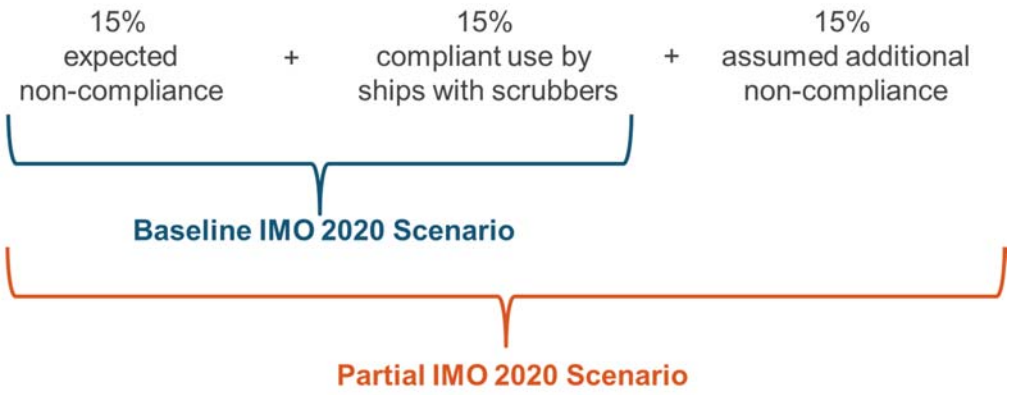
4.2. Partial Compliance Scenario ("Partial IMO 2020")

Despite the health, environmental and certain economic benefits expected from IMO 2020, there have been policy discussions in the U.S. about trying to delay implementation. The delay proposals are mostly based on concerns of fuel price impacts of IMO 2020. Such proposals have failed at the international level, most recently in 2018 when the IMO rejected a delay proposal and confirmed explicit enforcement measures. It is therefore assumed that any reduction in compliance led by the U.S. would involve deliberate non-enforcement in certain regions, between certain ports, and/or on ships flagged in certain countries.

This study is not designed to critique the legality or practicality of the U.S. coordinating significant levels of IMO 2020 non-compliance. Nevertheless, to evaluate a "partial compliance" scenario, it was necessary to formulate a view on the possible pattern and extent of non-compliance that could be driven by the U.S. Given the complexities of a single country attempting to materially influence global compliance rates, it was difficult to envision a scenario with significantly less compliance.

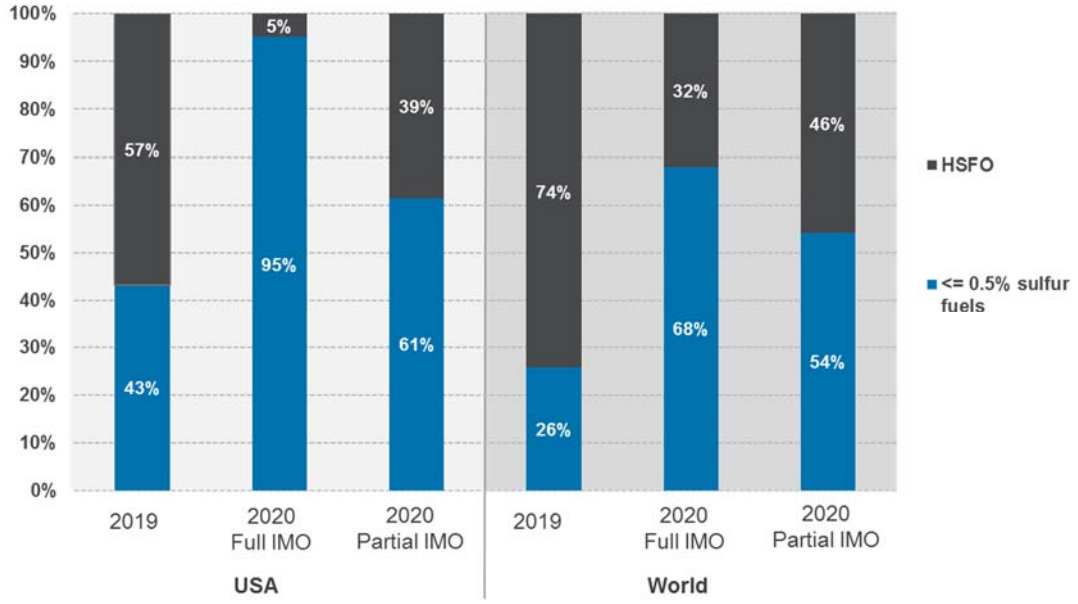
The Partial IMO 2020 scenario is considered to be at the high end of possible levels of global non-compliance with IMO 2020 that could be driven by the U.S. The scenario assumes an additional 15% global non-compliance, leading to total HSFO consumption of about 45% of marine fuels, up from 30% in the Baseline IMO 2020 scenario. The Baseline IMO 2020 scenario assumed 15% total non-compliance and 15% of marine fuels consumed as HSFO by ships with scrubbers in a compliant manner. The figure below shows the global share of marine fuels consumed as HSFO in the two scenarios.

Figure 6: Global Share of Marine Fuels Consumed as HSFO in the Scenarios (2020)



In the Partial IMO 2020 scenario, U.S. consumption of HSFO is allowed to significantly increase. It is only constrained by the mostly fixed demand for lower sulfur fuels consumed by ships requiring compliant fuels (for reasons such as complying with Flag State requirements or heading to destinations in Port States that enforce IMO 2020 compliance). In the Partial IMO 2020 scenario, HSFO consumption in the U.S. reaches 40% of marine fuel sales, compared to only 5% of bunker sales in the Baseline IMO 2020 scenario. This includes HSFO sales to both scrubber-less ships (non-compliant) and ships with scrubbers (possibly compliant). The global and U.S. shares of marine fuel volumes are shown in the figure below.

Figure 7: Shares of Marine Fuels, U.S. and Global, 2019-2020 (% of total)



The following sub-section describes the analysis supporting the definition of the Partial IMO 2020 scenario.

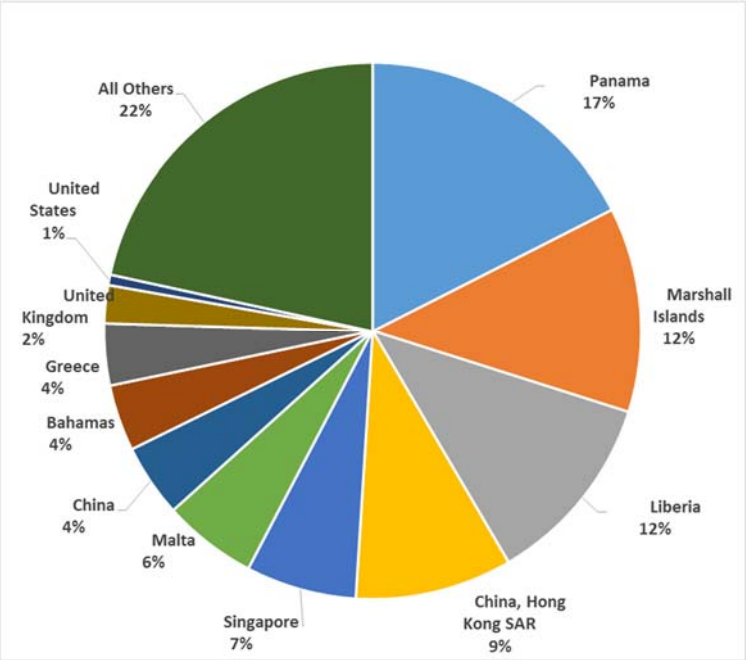
4.2.1. Additional Discussion of Partial Compliance Scenario

Under IMO regulations, compliance is enforced by Flag States and/or Port States. A U.S.-led defection would likely require coordination of non-enforcement among many different Member States with either significant numbers of flagged vessels or active bunkering ports. Neither would be straight-forward:

Flag States – The U.S. itself is not a significant Flag State for merchant ships. U.S.-flagged merchant ships represent about 1% of total global merchant shipping volume capacity (by deadweight tonnage, or "DWT"). The following chart shows the share of shipping capacity for ships flagged in the U.S. and in the 10 countries with greater than 2% of global capacity.[29] Of note, the five countries that proposed an "experience building phase" in October 2018 (Bahamas, Liberia, Panama, the Marshall Islands and the U.S.) represent 46.1% of capacity.

[29] UNCTADSTAT, "Merchant fleet by flag of registration and by type of ship, annual, 1980-2018." United Nations Conference on Trade and Development.

Figure 1: Merchant Fleet by Flag Country, 2018 (by DWT)



Flag States could encourage non-compliance either by refusing to fine vessels or, more likely, by staying somewhat compliant with IMO 2020 by levying extremely low fines. However, Flag States' control over compliance is limited since Port States can enforce compliance on any ship entering their ports and waterways. It is therefore highly unlikely that significant levels of non-compliance would be driven by Flag State non-enforcement.

Port States – Driving non-compliance through Port States would require a more blatant disregard for the IMO 2020 rules, particularly after March 2020. As of March 1, 2020, ships without scrubbers are not permitted to carry non-compliant fuels, meaning that Port States allowing fuel suppliers to sell HSFO to ships without scrubbers would be directly disregarding the MARPOL regulation.[30] Assuming the Port States were to comply with that regulation, their only option for encouraging non-compliance would be offering lax or non-existent monitoring of ships entering their ports and waterways. This could allow both scrubber-less ships to arrive with non-compliant fuels and ships with scrubbers to arrive without proof of having used their scrubbers.

Even if the U.S. was willing to violate its IMO 2020 obligations as a Port State and allow ships without scrubbers to bunker with HSFO, it would still need to coordinate with other Port States that would commit to not enforcing IMO 2020 regulations on incoming vessels. Even then, such an arrangement alone would only have a minor impact on global non-compliance given the U.S. position in global bunker fuel sales and the high percentage of ships leaving the U.S. for countries that would not be willing partners in a non-compliance scheme.

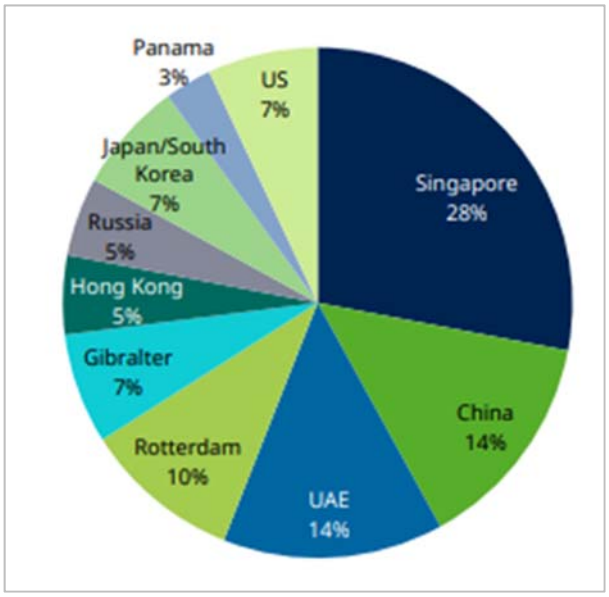
According to the IEA, the U.S. is responsible for about 7% of global bunker fuel sales. This is shown in the chart below, which was provided in a report by asset manager Shroders.[31] The

[30] "Implementation of sulphur 2020 limit - carriage ban adopted," IMO, October 26, 2018.

[31] Odey and Lacey, "IMO 2020 – Short-term implications for the oil market," Schroders, August 2018.

OECD estimates that the "OECD Americas" region, which includes the U.S., will represent just 12% of global bunker fuel demand in 2020.

Figure 8: Country shares of global bunker fuels (IEA, Shroder)



Source: IEA, Shroder

Of the Port States with significant shares of global bunker sales, most have already committed to enforcement of IMO 2020. For example, Singapore (28%) has threatened prison sentences of up to 2 years for captains of ships that violate the regulation. The Port of Rotterdam (10%), the largest port in Europe, directly lobbied for IMO 2020.[32]

Even countries that may not have been expected to enforce IMO 2020 have signaled intent to enforce compliance. For example, the UAE (14%) is not a member of MARPOL, yet its globally significant port, the Port of Fujairah, stated publicly "*Ships will have to use compliant fuel once the IMO 2020 sulphur cap comes into force*."[33]

There are a few port countries in the above chart that would not be expected to enforce IMO 2020 rigorously. For example, Russia (6%) directly challenged the IMO decision on not allowing vessels without scrubbers to bunker with non-compliant fuels. However, even in these port countries with potentially lax enforcement, a significant share of bunker sales will likely be compliant fuels, since ships heading to ports with enforcement will demand such fuels.

Regardless of any decisions by individual or multiple port countries to reduce enforcement, there are other forces that could drive compliance:

- Carriers and shippers - A large number of carriers have announced plans to comply and would likely still choose compliance even when given the opportunity to not comply. Additionally, there are many large shippers that may require their contracted carriers to comply to meet sustainability goals and avoid negative customer perceptions.

[32] "Alternative Fuels," Port of Rotterdam website: https://www.portofrotterdam.com/en/doing-business/port-of-the-future/energy-transition/alternative-fuels

[33] Port of Fujairah Notice to Mariners No.252 dated January 22, 2019.

- Insurance companies driving compliance – Several insurance companies have signaled that they may require insured vessels to comply to receive coverage.[34]
- Bunker suppliers - Bunker suppliers may be reluctant to sell HSFO to non-scrubber ships in fear of damaging relationships with Port States that require compliance.
- Logistics – Ships without scrubbers would likely need to decide whether they will wholly comply or wholly not comply, since switching between high and low sulfur fuels presents significant challenges.

Given all of these factors, the 15% additional global non-compliance is fairly aggressive, but it was selected to show economic impacts if a U.S.-coordinated non-compliance campaign succeeds.

4.2.2. U.S. Partial Compliance

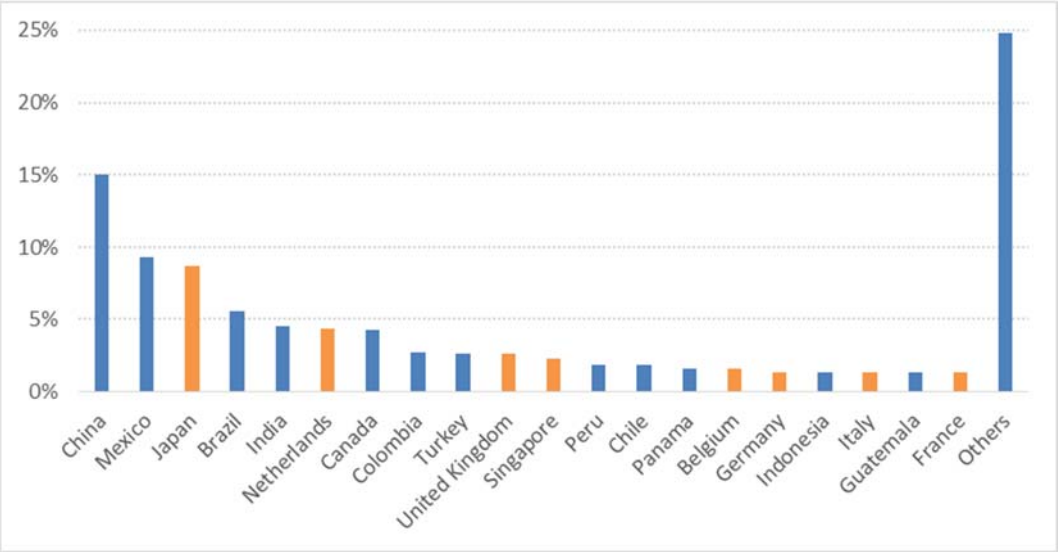
An additional assumption for the Partial IMO 2020 scenario is the amount of HSFO that would be sold as marine fuel at U.S. ports. Given that IMO 2020 will reduce HSFO prices significantly (discussed later), there will be material demand for maintaining HSFO bunker sales at U.S. ports if non-compliance is an option (i.e., the U.S. announces that it will not enforce IMO 2020 and will allow sales of HSFO to ships without scrubbers even after March 2020). However, that amount will still be constrained by the same factors that drive compliance on the global level, as described in the previous section.

The amount of HSFO sold at U.S. ports will be significantly determined by global shipping patterns, specifically the destinations of ships that bunker at U.S. ports. While some shipping routes may change based on IMO 2020 implementation, the routes from the U.S. would likely not change materially. Therefore, reviewing recent historical shipping patterns can be informative. The following chart shows the country destination shares of U.S. shipped goods in 2017, according to the U.S. Army Corps of Engineers.[35] The shares are based on deadweight tonnage (DWT), which is a reasonable approximation for bunker fuel consumption by shipping route. The countries that have publicly announced intention for full compliance are colored orange, and they cumulatively represent over 30% of the Top 20 countries' volume.

[34] https://www.marsh.com/content/dam/marsh/Documents/PDF/UK-en/the-sulphur-conumdrum.pdf

[35] U.S. Army Corps of Engineers. https://publibrary.planusace.us/#/series/Waterborne%20Foreign%20Cargo

Figure 9: Destination for U.S. Exports via Shipping, 2017 (% of DWT)



It is clear that the U.S. would need to work with a large number of countries to form a coalition of IMO 2020 non-compliance trade partners in order to greatly increase HSFO sales from the Baseline IMO 2020 scenario. The EIA estimates the HSFO share of U.S. bunker fuel sales will drop from 57% in 2019 to 2% in 2020. Given updates in scrubber uptake, we assume HSFO only drops to 5% in 2020 in the Baseline IMO 2020 scenario. Under the Partial IMO 2020 scenario, we assume it rises again to 40% of bunker sales, representing a fairly aggressive view on the number of countries with which the U.S. would coordinate non-compliance. For context, 40% of U.S. bunker fuel sales represents only about 4% of global bunker fuel sales.

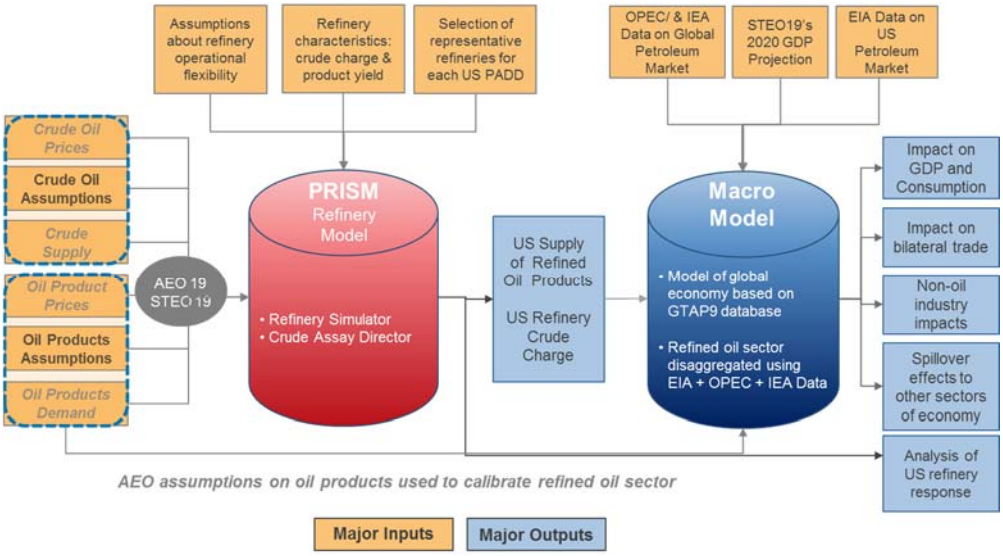
5. Modeling Methodology

The modeling framework for this study was designed to capture a variety of impacts of changing global IMO 2020 compliance levels. The impacts of a significant change in sulfur content in marine fuels will be mostly driven by the complex responses in the marine shipping and fuel refining sectors. If those sectoral responses cause shifts in fuel and shipping prices, the overall impacts can flow throughout the global economy. Therefore, to capture IMO 2020 compliance impacts, a modeling framework must include global and U.S. macroeconomic impacts by sector, with adequate representation of the most directly impacted sectors.

To capture the range of impacts, this analysis involved two advanced energy and economic models. CRA utilized a global macroeconomic model (“EMR-IMO”) to evaluate fuel price responses to changes in compliance levels and to determine sector-level and economy-wide impacts. Of all sectors of the economy, the most important to understand in evaluating IMO 2020 impacts is the refining sector. In coordination with CRA, Baker & O’Brien used its PRISM model to evaluate responses by U.S. refiners, based on fuel price changes determined in EMR-IMO. The PRISM model determined refinery margins and output of various products, which greatly informed the assessment of refinery sector impacts of the scenario.

Both models were calibrated to the EIA's recently published forecasts of prices and quantities in 2020 under full IMO 2020 implementation.[36] To estimate the impacts of moving to partial implementation, we modeled an increase in demand for higher sulfur fuels in the marine shipping sector (and the associated decrease in lower sulfur fuels). The EMR-IMO model determined the macroeconomic response, and the PRISM model determined the response by U.S. refiners. The following chart shows the modeling framework:

Figure 10: Modeling Framework Diagram



5.1. Initial Calibrations to EIA Forecasts

The EIA publishes a variety of periodic energy market forecasts for multiple regions and forward time periods. The two most relevant to this study are the Annual Energy Outlook ("AEO") and the Short-Term Energy Outlook ("STEO"). The AEO 2019 and STEO April 2019 were relied on by both models for key inputs that would determine the state of the economy and energy markets under the Baseline IMO 2020 scenario. In addition, the EIA produces topic-focused studies and an International Energy Outlook ("IEO"), each of which were also used in model calibration.

- AEO - The AEO provides "modeled projections of domestic energy markets through 2050."[37] The most recent version of the AEO was published in January 2019 ("AEO 2019"). The AEO 2019 includes IMO 2020 implementation in its modeled outlook, and thus provides a useful baseline for many of the inputs to the models used in this study.
- STEO - The STEO "produces monthly projections of energy supply, demand, trade, and prices over a 13-24 month period. Every January, the forecast horizon is extended through December of the following year."[38] The STEO published in January

[36] As mentioned previously in this report, "full" implementation includes an assumed baseline level of non-compliance.

[37] https://www.eia.gov/outlooks/aeo/

[38] https://www.eia.gov/analysis/pdfpages/coal_powersectorfuelcostsindex.php

2019 (“STEO January 2019”) was the first STEO that included months within the year 2020, and thus explicitly included IMO 2020 implementation. The most recent version of the STEO at the time of the modeling for this study was April 2019 (“STEO April 2019”).

- IEO – The IEO “focuses on how different drivers of macroeconomic growth may affect international energy markets in three heavily populated and high economic growth regions of the world: China, India, and Africa.” The latest version, IEO 2018, was published in July 2018 and did not explicitly model IMO 2020. It was only used for the global model calibration.
- IMO 2020 special report – In March 2019, EIA released a special report “The Effects of Changes to Marine Fuel Sulfur Limits in 2020 on Energy Markets.” This report was mostly based on the AEO 2019 modeling, but it included some additional information relevant to understanding EIA’s view of domestic marine fuel consumption.

It is important to note that these studies informed the Baseline IMO 2020 scenario, but the models were used to determine the results in the Partial IMO 2020 scenario. The results can be reasonably applied in an environment with small changes in EIA’s 2020 forecasts since most of the model results are initially calculated as percentage changes from the baseline.

5.2. EMR-IMO

Numerous studies aim to quantify the first-order impacts of the IMO 2020 regulation on the global refining and marine transport sectors. These studies generally include isolated modeling of either or both sectors, often basing future changes on past price and demand statistical relationships without multi-sector equilibrium. Such constructs can lead to extreme results, such as balancing the diesel fuel market by forcing expected diesel prices to levels considered necessary to “destroy” demand in other sectors in response to additional demand in the marine transport sector. In addition, these studies do not incorporate the many different sectors of the economy that form integrated and complex responses to changes, such as IMO 2020 implementation.

It is therefore preferable to review the potential change in compliance with IMO 2020 using a computable general equilibrium (CGE) model of the global economy. CRA’s Energy and Macroeconomic Response (EMR) is a static CGE model generally used for evaluating policy and other changes in energy markets. For the purpose of this study, CRA has developed EMR-IMO, a version of EMR with detailed representations of the petroleum products and marine transport sectors. EMR-IMO uses the Global Trade Analysis Project (GTAP) database as its core data and calibrates the base year’s (2019) benchmark data to EIA’s STEO April 2019 and AEO 2019. The state of the economy in the year 2020, including GDP growth and prices (and demand) of petroleum goods under the IMO regulation, is also calibrated to EIA’s STEO April 2019 and AEO 2019 reports.

5.3. PRISM

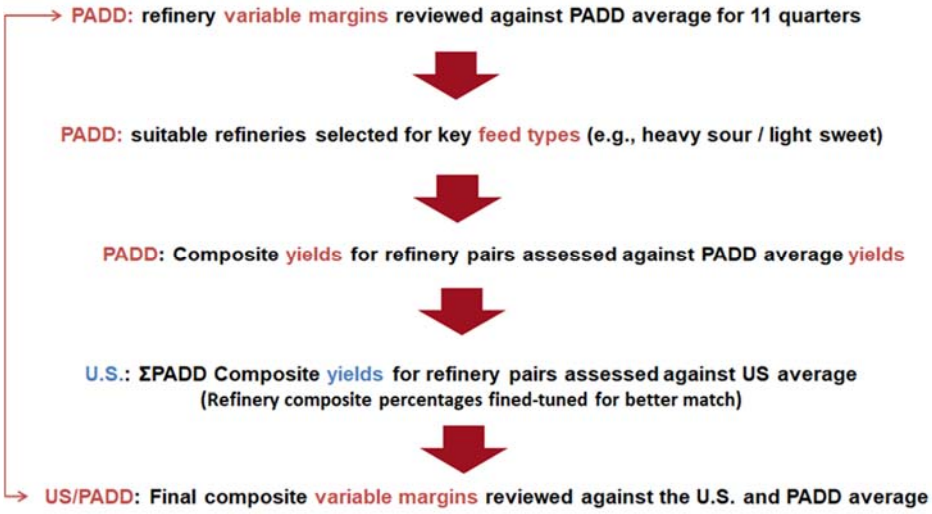
Baker & O’Brien applied their *PRISM*™ (“PRISM”) refining and marketing supply chain modelling system for a more in-depth analysis of the impact of IMO 2020 compliance changes on U.S. refineries. PRISM is widely used in the refining industry and by government agencies. The database includes models of all U.S. refineries. Each calendar quarter, Baker & O’Brien collates industry data, and then performs a detailed analysis of each refinery, estimating its crude slate, product yields, and fixed and variable operating costs. The end result is that each quarter Baker & O’Brien produces an estimate of the financial performance of each U.S. oil refinery. PRISM is an established and proven refinery modelling platform that is grounded in industry data. Therefore, it provides a reliable and strong platform for studies of this nature.

Baker & O'Brien has been completing its U.S. quarterly refinery assessment since the late 1990s. Consequently, this legacy, coupled with the direct refinery industry experience of the Baker & O'Brien consulting team, provides Baker & O'Brien with a detailed understanding of the U.S. refinery system.

The standard PRISM refining and marketing supply chain database contains quarterly models for over 120 refineries. Analyzing each individual U.S. refinery is beyond the scope of this study. Therefore, Baker & O'Brien selected nine representative refineries that are representative of the U.S. PADDs and the U.S. as a whole. This allowed analysis of responses by different types of refineries in different regions, and the ability to aggregate results to determine industry-level outcomes.

The Baker & O'Brien methodology focused on selecting a representative pair of refineries for each PADD. The weighting between the refineries was adjusted to best match key parameters – such as variable margins or product yields – for the PADD and the U.S. overall. The following diagram illustrates the overall methodology for using PRISM in this study:

Figure 11: Overall PRISM-related Methodology



As mentioned previously, the model was calibrated to STEO April 2019. U.S. refined petroleum product production data is not explicitly available in the STEO and was therefore calculated by Baker & O'Brien from the STEO, Table 4a (U.S. Petroleum and Other Liquids Supply, Consumption, and Inventories). The target yield profile for the Baseline IMO 2020 scenario was obtained by applying the STEO U.S. refined product yield shifts (from 2018 to 2020) to the yield profile for PRISM's baseline 2018 scenario for the nine representative refineries.

To assess each of the scenarios with PRISM, a detailed crude oil and petroleum product price set is required. For the Baseline IMO 2020 scenario, the underlying spine of the price-set, in terms of marker crude oil prices (such as Brent) and U.S. refined product prices, originates from STEO April 2019 and includes a variety of assumptions made by Baker & O'Brien. For the Partial IMO 2020 scenario, changes in price sets were determined by EMR-IMO modeling

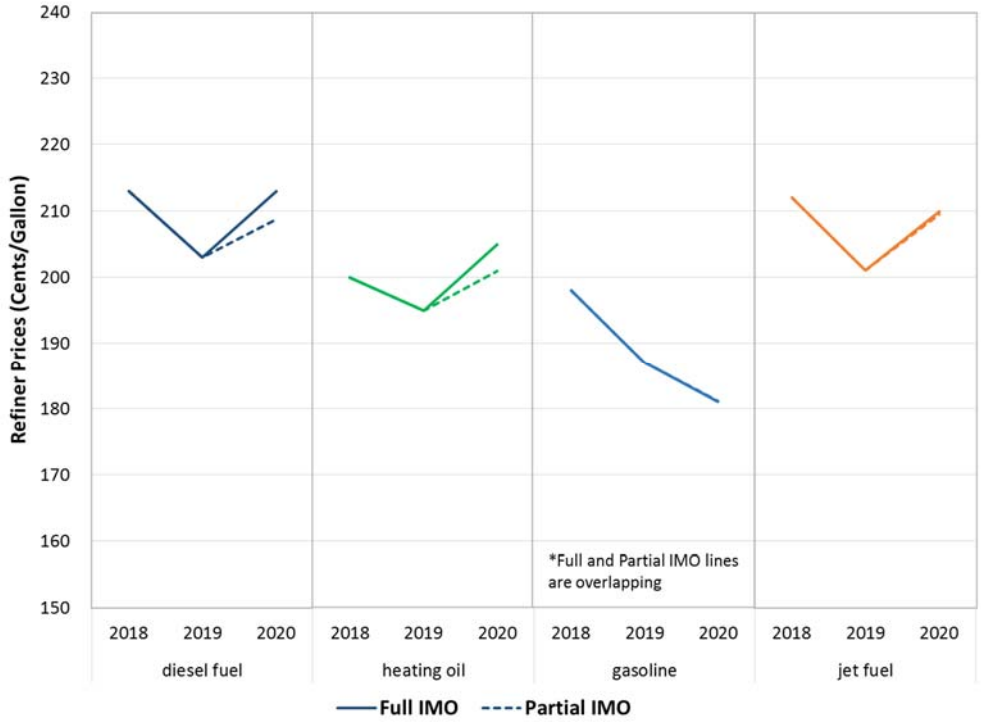
6. Results

This section highlights key results of the EMR-IMO and PRISM modeling.

6.1. Price Impacts of Lower IMO 2020 Compliance

The most direct impact of altering compliance levels with IMO 2020 can be seen in fuel prices, particularly for marine shipping fuels. The following chart shows the 2018, 2019 and 2020 refiner prices for the modeled fuels used primarily outside of the marine transportation sector (diesel, heating oil, gasoline, and jet fuel). These prices are highly dependent on crude oil prices, which in this study were calibrated to EIA's STEO April 2019 forecast for the Baseline IMO 2020 scenario.[39]

Figure 12: Fuel prices, refiner prices (cents/gallon), 2018 to 2020 [40]



Diesel prices – Diesel includes marine fuels, but the majority is used in other sectors (over 94% in other sectors globally, over 96% in the U.S.). In the Baseline IMO 2020 scenario, which is calibrated to EIA forecasts, average diesel prices increase 5% from 2019 ($2.03/gallon) to 2020 ($2.13/gallon). In the Partial IMO 2020 scenario, average diesel prices increase 3% from 2019 ($2.03/gallon) to 2020 ($2.09/gallon). Neither of these increases is

[39] The STEO April 2019 estimates for 2020 prices were: Brent $62/barrel, WTI $58/barrel. If crude prices are higher, we would expect both scenarios' refined product prices to rise at about the same rate. Crude oil prices in the Partial IMO 2020 scenario are determined by the EMR IMO model and do not change materially from the Baseline IMO 2020 scenario.

[40] Refiner prices, as defined by EIA = Total revenue derived from the sale of product during the time period divided by the total volume sold; also known as the weighted average price. Total revenue should exclude all taxes but include transportation costs that were paid as part of the purchase price.

significant relative to historical changes in annual diesel prices. For example, between 2017 and 2018 the average price increased over 25%. In both scenarios, average diesel prices in 2020 remain under 2018 levels. This story is mirrored in heating oil prices, which are almost perfectly correlated with diesel prices.

The 5% diesel price increase in the Baseline IMO 2020 scenario is also not entirely caused by IMO 2020 implementation. There are two primary drivers of diesel price increases unrelated to IMO 2020. The first, as mentioned, is crude oil prices. For example, the previous annual EIA forecast, AEO 2018, did not model IMO 2020 implementation, yet it estimated a 14.2% increase in diesel prices from 2019 to 2020. This larger increase was mostly driven by AEO 2018's estimate of a 26% increase in crude price.[41] The second, related driver of higher diesel prices is increased demand due to economic growth.

Gasoline prices - Motor gasoline prices would be expected to see almost no benefit to reduced IMO 2020 compliance. This appears to be the result of: 1) a balance between competing impacts of IMO 2020, and 2) a gasoline market large enough to absorb small changes without material price disruptions. The competing price impacts in response to less IMO 2020 compliance include:

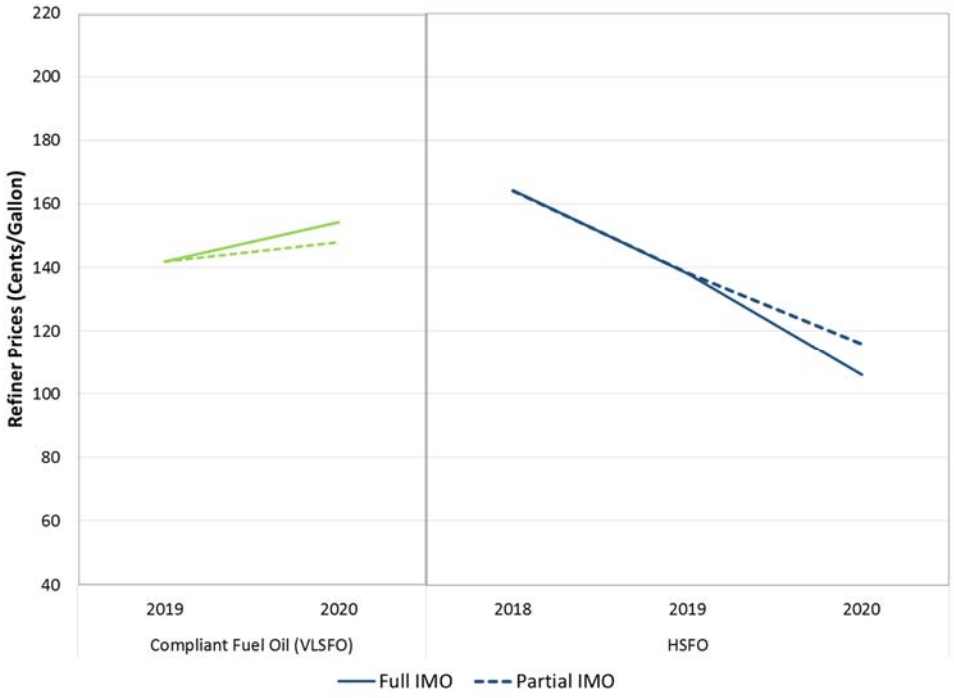
- Upward price pressure – As discussed in Section 3.2.2, an expected refining sector response to IMO 2020 is increased overall throughput to produce more middle distillates. This additional crude processing will lead to increased gasoline production. Therefore, one impact of a decrease in IMO 2020 compliance would be slightly lower gasoline supply, and therefore an upward pressure on gasoline price.
- Downward price pressures – With less demand for diesel products, refinery economics would slightly shift back to supporting more production of gasoline. In addition, some intermediates, such as vacuum gasoils (VGOs) which are generally often converted into gasoline blendstocks, would see less demand for contributing to IMO 2020 compliant fuel production.

These gasoline price drivers were not explicitly modeled and are not expected to have a material impact on overall prices.

[41] AEO 2018

The following chart shows the 2018, 2019 and 2020 refiner prices for the modeled fuel oils.

Figure 13: Fuel oil prices, refiner prices (cents/gallon), 2018 to 2020



The Partial IMO 2020 scenario leads to a shift in marine shipping demand from lower sulfur fuels (including VLSFO) to HSFO. This leads to lower VLSFO prices and higher HSFO prices than in the Baseline IMO 2020 scenario. The main beneficiaries of lower VLSFO prices will be shippers and consumers in regions of the world that remain in full compliance with IMO 2020. In the Partial IMO 2020 scenario, nearly 40% of marine fuels sold in the U.S. would be HSFO, thus the HSFO price increase may dampen some of the economic benefit of non-compliance.

Petroleum product prices are far more sensitive to changes in crude market developments than to changes in IMO 2020 implementation levels. For example, without IMO 2020 in effect, diesel prices dropped nearly 19.8% from January 2018 ($1.85/gal) to January 2019 ($1.48/gal), mostly driven by a nearly identical (19.3%) drop in WTI crude price.

6.2. Overall U.S. Economy Impacts

As shown in the previous section, the Partial IMO 2020 scenario has a minor downward pull on several fuel prices, and a small upward push on others. The way these fuel price changes filter through the U.S. economy is extremely complex. The EMR-IMO model is designed to capture the impacts of the fuel price changes throughout the U.S. economy (in addition to determining the price changes).

The modeling of the two scenarios shows that, with the exception of fuel sectors and the water transportation sector, the U.S. leading a defection from IMO 2020 compliance does not increase any modeled sector's output by even 0.1%. Moreover, lower IMO 2020 compliance has no discernable benefit to the U.S. overall GDP at the hundredth of a percent level of the

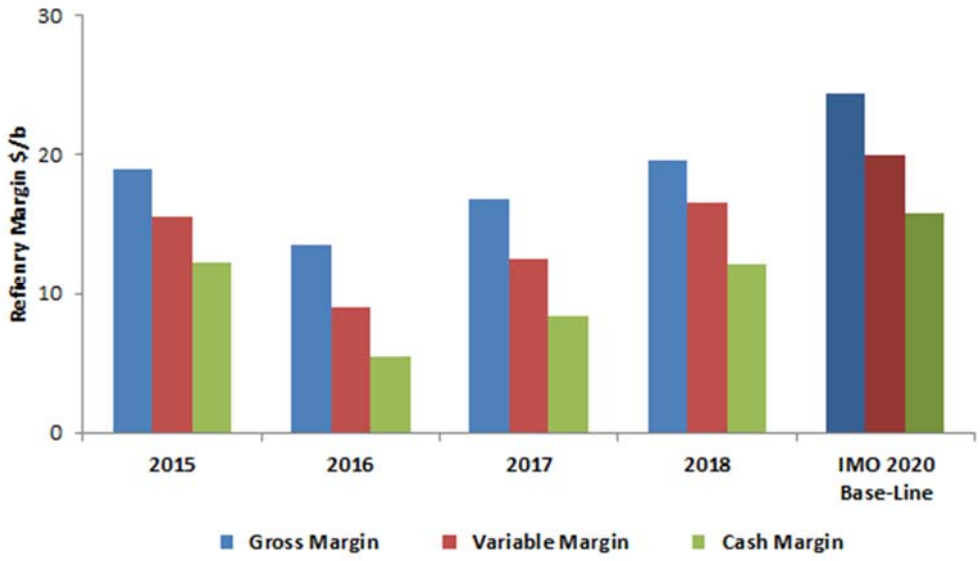
GDP growth rate. More specifically, the U.S. GDP grows at 2.16% from 2019 to 2020 in both scenarios.[42]

6.3. Refining Sector Impacts

This study is not focused on the impacts of the IMO 2020 regulation on the U.S. economy. (Rather, it is focused on a hypothetical change in compliance level.) However, it is helpful to understand certain IMO 2020 impacts as they can provide insight into the importance of IMO 2020 to key sectors of the economy. As highlighted throughout the report, the largest direct impact of IMO 2020 on the U.S. economy is in the refining sector. This is not true in every country in the world, particularly those without refineries or with substantial interests in international shipping. In the U.S., there are over 120 operating refineries producing over $500 billion in total refined products. These refineries stand to benefit significantly from IMO 2020 given their product yields and overall position in the global refining sector.

The first step to understanding the benefit of IMO 2020 to the refining sector is considering the refining margins. Refining margins on a per-barrel of crude basis were outputs from the PRISM model. The average U.S. variable refinery margin for the Baseline IMO 2020 scenario is $20/bbl. As shown in Figure 16, refinery margins in 2020 under the Baseline IMO 2020 scenario are expected to substantially exceed recent historical levels.

Figure 14: U.S. Refining Margins



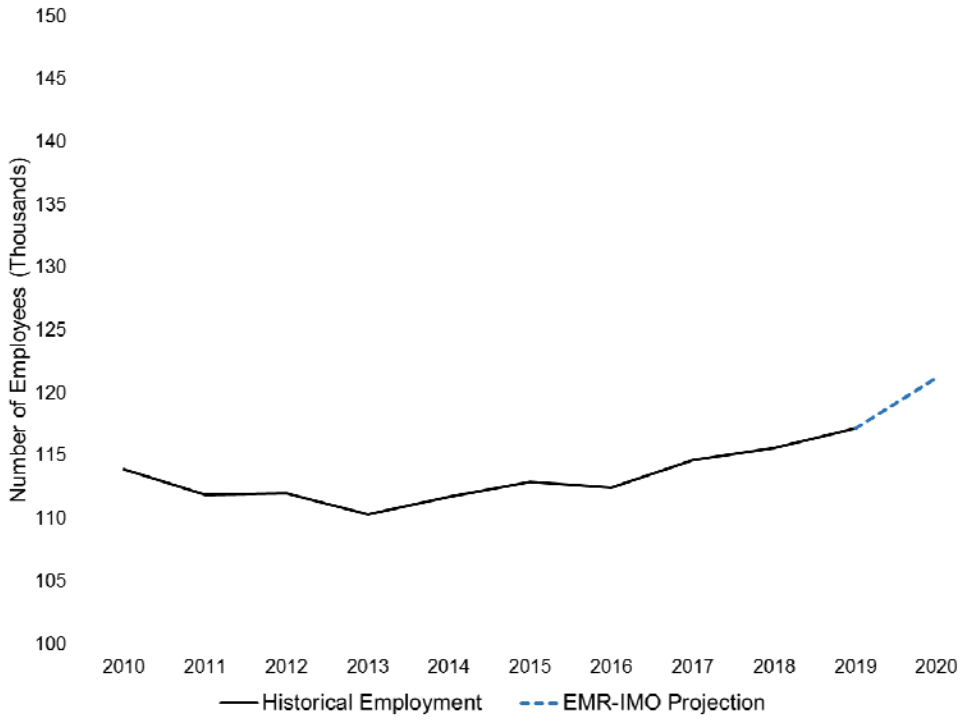
Increased refining margins are not only beneficial to refining companies, they are also indicative of a healthy industry that contributes to the economy in many ways. In particular, the EMR-IMO modeling sees labor employment in the fuel manufacturing sectors experience substantial growth in the Baseline IMO 2020 scenario. This is important since the industry provides significant employment at relatively high wages. According to the U.S. Bureau of Labor Statistics (BLS), in 2018 employment in petroleum refineries and other lubricating oil manufacturing sectors amounted to over 80,700 jobs. These are high wage jobs, with an

[42] This GDP growth level is calibrated in the Baseline IMO 2020 scenario to the STEO April 2019 GDP estimates.

average annual wage of nearly $134,200. As a point of reference, the BLS reported a 2018 national annual mean wage of about $57,200.[43]

According to extractions from BLS figures, employment in the refining sector grows by 1.33% from 2018 to 2019.[44] EMR-IMO results indicate that, under the Baseline IMO 2020 scenario, growth in employment increases significantly to 3.46% between 2019 and 2020. Some of this growth is attributed to GDP growth. However, considering the STEO April 2019 projected higher GDP growth between 2018 and 2019 (2.44%) than between 2019 and 2020 (2.16%), it is reasonable to consider the IMO 2020 regulation as a reason the refining sector employment growth outpaces overall economic growth. The figure below shows historical and forecasted employment in the refining sector.[45]

Figure 15: Employment in Petroleum Manufacturing Sectors in the Baseline IMO 2020 Scenario



[43] Bureau of Labor Statistics data in this paragraph sourced from the May 2018 Occupational Employment Statistics database. Data for NAICS industry codes 324110 (petroleum refineries) and 324191 (petroleum lubricating oil and grease manufacturing).

[44] Bureau of Labor Statistics, Current Employment Statistics survey.

[45] The figures in this chart also include all jobs associated with NAICS 324, "petroleum and coal products manufacturing." Historical data was not available for petroleum refineries only, and that definition is also too narrow to capture refining employment impacts associated with IMO 2020.

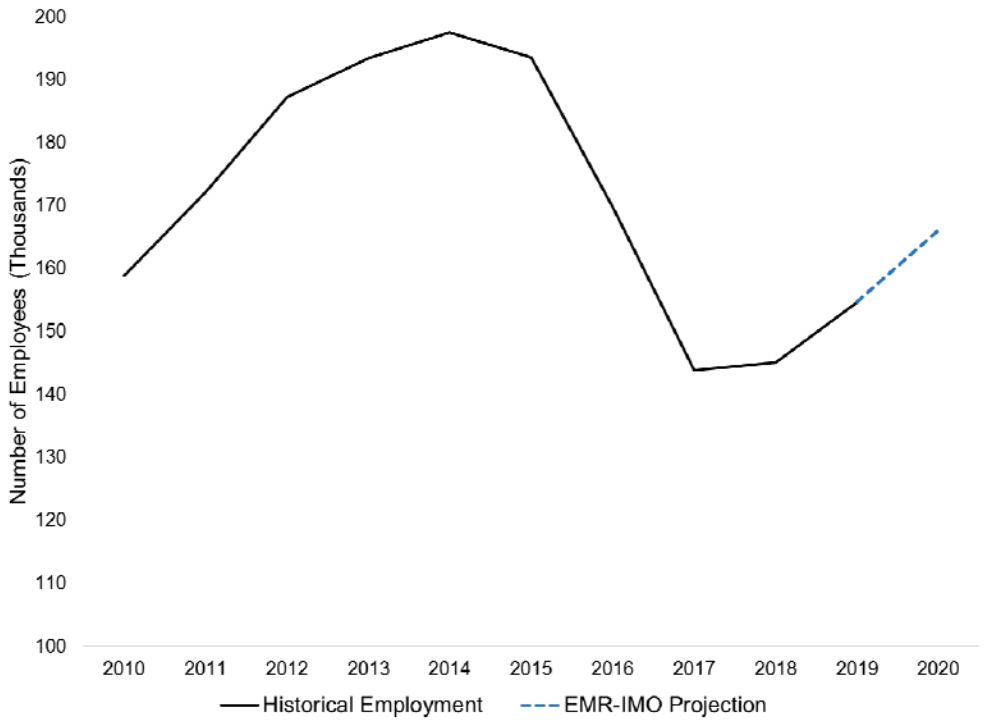
6.4. Exploration and Production (Crude) Sector Impacts

The BLS reports that total employment in the extraction sectors in March of 2019 amounted to over 471,000 jobs. This industry is responsive to crude economics. In 2018, the annual mean wage in the oil and gas extraction sectors[46] were reported to have been $115,018. This wage rate is more than double the national average.[47]

As discussed elsewhere in the report, the IMO 2020 regulation has two positive impacts on crude oil production in the U.S. The first is the general increase in crude demand due to higher refinery throughput. The second is an additional increase in demand for light, sweet crudes, which are the type most produced in the U.S.

As in the refining sector, the extraction sectors' benefits of moving to IMO 2020 can be seen in terms of employment. According to extrapolations from BLS figures, employment in the extraction sectors grows by 6.64% between 2018 and 2019.[48] According to EMR-IMO modeling, this growth increases further to 7.4% between 2019 and 2020 (from a higher beginning employment level), which can be attributed to the 5% increase in output in the crude oil sectors.

Figure 16: Employment in Oil and Gas Extraction Sectors in the Baseline IMO 2020 Scenario



[46] NAICS industry codes 211 (oil and gas extraction), 213111 (drilling oil and gas wells) and 213112 (support activities for oil and gas operations) are considered in the oil and gas extraction sectors.

[47] Bureau of Labor Statistics data in this paragraph sourced from the May 2018 Occupational Employment Statistics database.

[48] Bureau of Labor Statistics, Current Employment Statistics survey.

7. Conclusion

This report showed that a U.S.-led defection from IMO 2020 compliance would be a difficult, if not impossible, proposition. The U.S. is not a significant flag state for ships and non-enforcement at U.S. ports, which sell 10% or less of global bunker fuels, is limited in effectiveness since most ships would demand IMO 2020 compliant fuels regardless of U.S. enforcement prospects. A significant decrease in IMO 2020 compliance would therefore require significant coordination with other countries, though most countries and major ports have committed to enforcement.

This study determined that such an effort, even if successful in reducing global IMO 2020 compliance, would bring the U.S. no discernable fuel price or macroeconomic benefit. The most significant impact would be on the cost of marine fuels for ships that would no longer comply with IMO 2020, but that benefit is not concentrated in the U.S. The impact on diesel prices is less than the average historical monthly fluctuation in diesel prices.

The U.S. is well positioned to support the global shift to lower sulfur marine fuels, both at the refinery and crude production levels. Global refiners and shippers have had many years to prepare, and it appears the industries are driving toward a transition with minimal price disruption or fuel availability issues. The results of this economic analysis, which do not even include the expected environmental and health benefits, support U.S. compliance with IMO 2020.