GHG Emission Intensity of Crude Oil and Condensate Production

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Submitted by ICF

Contact:
Harry Vidas
(703) 218-2745
Harry.Vidas@icf.com

ICF

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Executive Summary

ES.1. Purpose and Scope

The National Ocean Industries Association (NOIA) commissioned ICF to perform this analysis to address the narrow technical question of how the GHG emission intensity of US oil production compares to those of oils produced around the world. This report does not address the various legal and policy questions related to whether such consideration of relative GHG emissions are required by law, what authority agencies have to conduct or mandate inquiries into GHG emissions, whether GHG emissions outside of the US can or should be considered, what mitigation measures can or should imposed by the agencies on project developers, how the GHG emissions once defined and estimated can or should be folded into an agency's decision-making processes, etc.

The report is intended to be general in nature and does not address any specific federal or state agency or action that might cause a change in US crude supplies. However, the calculations presented in the report focus on the US Gulf of Mexico (GoM). This region is the focus because it is the region of greatest interest to NOIA's members and because oil production there is mostly under federal authority and so decisions made by federal agencies can be expected to have large impacts.

ES.2. Methodology

The methodology employed in this study to evaluate the GHG emission intensity from the crude oil production in the US and internationally involved the following four steps:

1. **Set Up a Framework for Analysis of US Oil Production**: Production data for crude oil and condensates in the US in 2020 was compiled into approximately 3,600 categories of wells.
2. **Set Up a Framework for Analysis of International Oil Production:** A similar process was untaken to organize data for 2020 crude oil and condensates production outside of the US for 8,100 fields in 103 countries.
3. **Estimate of GHG Emissions from Oil Production**: Data for each category of wells or individual field were processed through a consistent series of algorithms that computed several emission components that were added up to a total CO_2e metric tons per year for each well category or field. The algorithms were developed by ICF but rely on relationships developed in previous studies using OPGEE and other models. Where possible, the Base Case parameters for the US were calibrated to GHG inventory and energy consumption estimates made by EPA, DOE and other federal agencies. For other countries, similar statistics estimated by the International Energy Agency, the World Bank and other international organizations were used to calibrate the Base Case parameters and also the alternative assumptions used for sensitivity analyses.
4. **Allocate GHG Emissions from Production by Hydrocarbon:** The total of production-related emissions for each well category or field were then allocated between oil and wet

natural gas based on the Btu content of production in that individual well category or field.

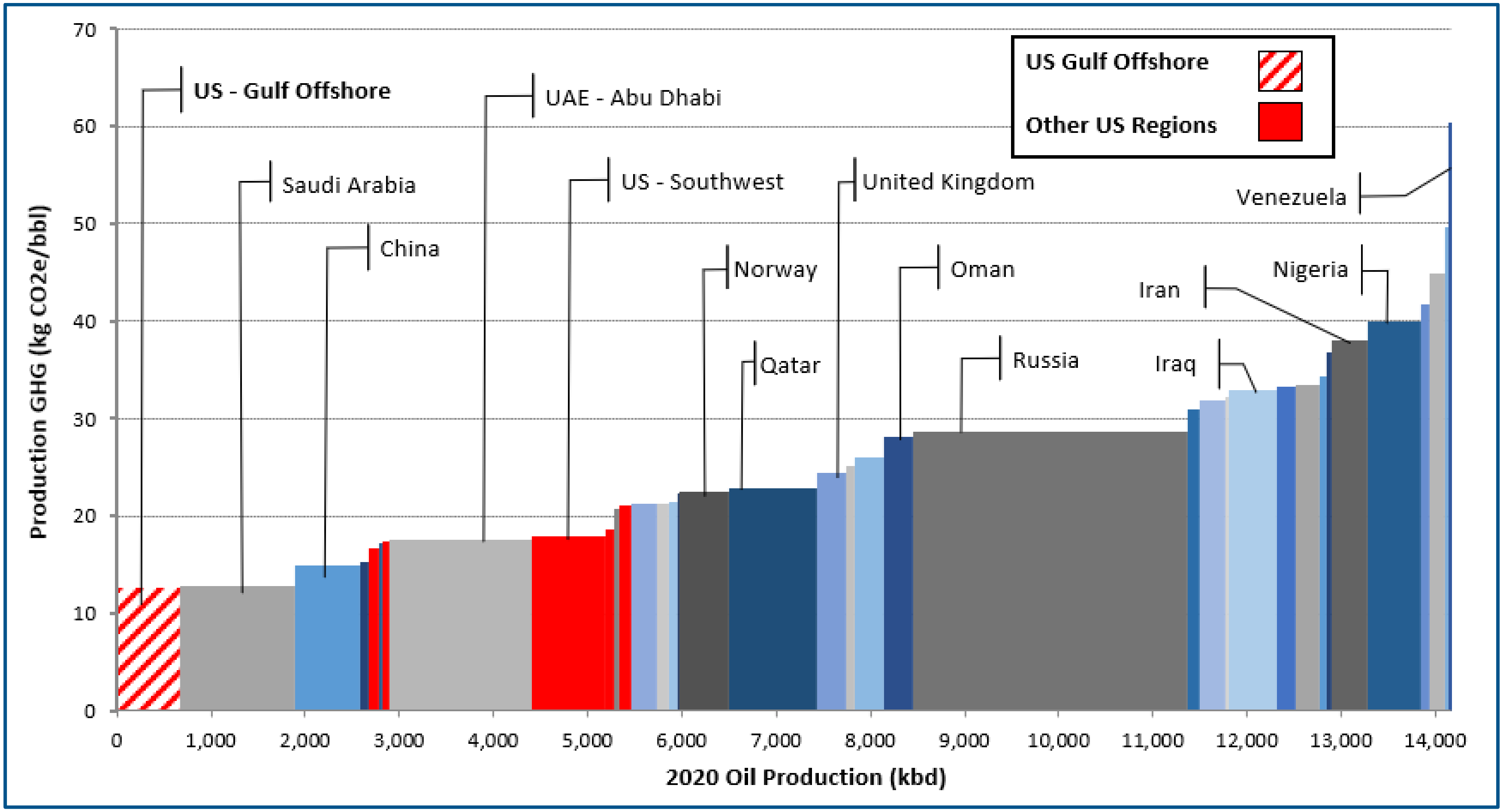
It is important to note that this study is based on 2020 data and practices and as such does not account for changes that are expected to occur in the future in how oil and gas are produced. Most noteworthy is the fact that methane emissions as reported in EPA GHG Inventory have historically been falling on a per-unit of production basis. As the focus on methane emissions in this sector continues and detection and mitigation technologies improve and are more widely adopted, reductions in per-unit methane emissions are expected to continue in the future.

ES.3. Conclusions

This study concludes that, when a consistent set of data and algorithms are applied to estimate GHG emission intensity of crude oil and condensate production, US oil in general and GoM oil in particular are shown to have emissions that are lower than much of the remaining world. Some additional and more specific conclusions presented in the report include:

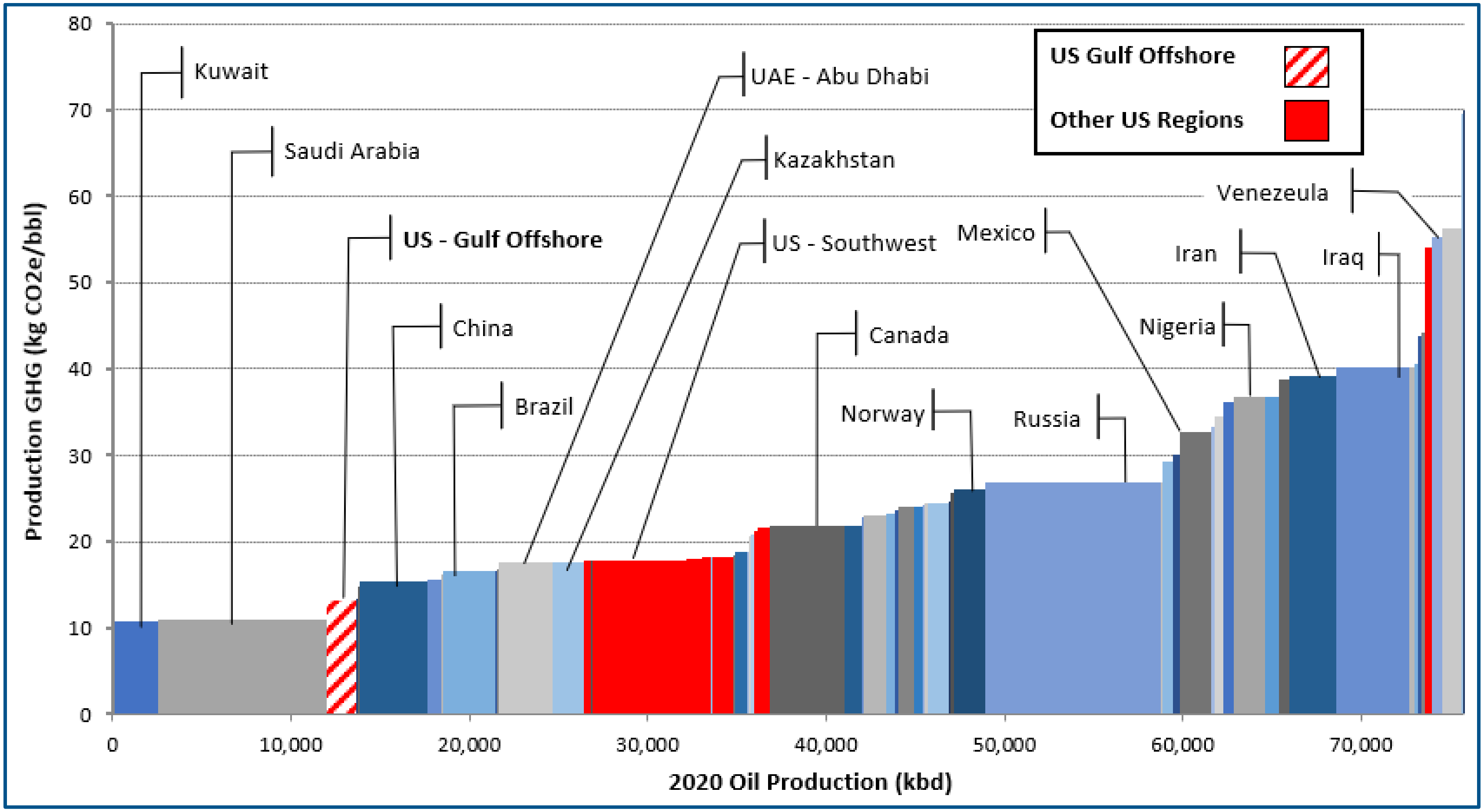
- A comparison of GHG emission intensity for production for various crudes in the API gravity 37.5° category (the largest portion for GoM production) is shown in Exhibit 1. Lower GHG emission intensity for Gulf of Mexico oil production as compared to the US as a whole is due to higher well productivity and less energy used per unit of production.
- Exhibit 2 provides a similar comparison of GHG emission intensity for production for various crudes but includes volumes across all API gravity categories. Gulf of Mexico oil production is again one of the lowest emitting crude oils and the lowest for any US region.
- The greatest source of differences in the results of this study and other published studies is this study's use of the EPA GHG Inventory values for (a) methane emission volumes expressed in metric tons of methane and (b) a global warming potential of 25 to convert from tons of methane to tons of carbon dioxide equivalent. A series of sensitivity analyses were performed to test how the use of methane emission tonnage estimated by the International Energy Agency and a GWP of 34 (used by IEA and others) would affect the relative standing of the GoM. As shown below in Exhibit 3, under these alternative methane assumptions the methane emissions of all regions increase, but the GoM's relative standing improves from being 13.4 CO_2e kg/bbl below the world average GHG emission intensity in the Base Case to being 14.2 to 26.4 CO_2e kg/bbl below in the sensitivities.

Exhibit 1: Comparison of Production Volumes and Production GHG Emission Intensity for Gulf of Mexico and Other US Regions and Other Countries Crude Oil in API 37.5º Category



Source: ICF analysis of GHG emission intensity from the production stage only (that is exclusive of crude transport, refining, petroleum product transport, petroleum product distribution & dispensing and petroleum production utilization). The quantity of oil in the API 37.5º category for each US region and foreign country is indicated by the width of each rectangle. Worldwide production of this category of crude is 14.2 million barrels per day. The gray and blue rectangles are individual foreign countries. More detailed information for each country appears in Appendix A.

Exhibit 2: Comparison of Production Volumes and Production GHG Emission Intensity for Gulf of Mexico and Other US Regions and Other Countries Crude Oil across all API gravity categories



Source: ICF analysis of GHG emission intensity from the production stage only (that is exclusive of crude transport, refining, petroleum product transport, petroleum product distribution & dispensing and petroleum production utilization). The quantity of oil for each US region and foreign country is indicated by the width of each rectangle. Worldwide production of this category of crude is 75.6 million barrels per day. The gray and blue rectangles are individual foreign countries. More detailed information for each country appears in Appendix A.

Exhibit 3: Sensitivity Analyses of Methane Emissions and Methane GWP

	All GHG in Kilograms CO2e per Barrel of Oil (Year 2020)			
Region	Base Case (GWP=25)	Base Case CH4 Volumes but GWP=34	IEA CH4 Volume Multipliers for All Countries (GWP=25)	IEA CH4 Vol. Multipliers + GWP=34
US GOM	13.1	15.0	18.5	22.4
US Total	18.7	20.6	23.9	27.6
Canada	77.2	81.3	84.0	90.6
Rest of World	24.4	27.3	41.1	49.9
World Average	26.5	29.2	40.9	48.8
Gap Between GoM and World Average	**-13.4**	**-14.2**	**-22.4**	**-26.4**
Notes: Production only. Excludes crude transportation, petroleum refining, petroleum product distribution, dispensing and use.				

1. Background

1.1 Purpose and Scope

The National Ocean Industries Association commissioned ICF to perform this analysis of the greenhouse gases (GHG) emitted during the production of crude oil and condensate from supply regions throughout the world. The GHG emissions are quantified from all infrastructure and related equipment to produce crude oil and condensate at the wellhead. Particular attention is given to emissions from crude oil produced from the US Gulf of Mexico (GoM). This region is in focus in this report as it is of greatest interest to NOIA's members.

This report addresses the narrow technical question of how GHG emission intensity vary for oil production across world energy markets. This report does not address the various legal and policy questions related to whether such consideration of GHG emissions are required by law, what authority agencies have to conduct or mandate inquiries into GHG emissions, whether GHG emissions outside of the US can or should be considered, what mitigation measures can or should imposed by the agencies on project developers, how the GHG emissions once defined and estimated can or should be folded into an agency's decision-making processes, etc.

1.2 Considerations

Estimating GHG emission intensities for the production of crude oils and condensates is difficult due to the wide variety of oils produced in the world; the complex processes used to produce the oils; the lack of reliable, up-to-date public data for all portions of the supply chain; and conceptual issues related to which GHGs are relevant and how they should be estimated, allocated among coproducts and aggregated into a single measure (typically kilograms of carbon dioxide equivalent per barrel or per million Btu).

1.2.1 Crude Characteristics

Crude oil is a complex mix of hydrocarbons that must be refined to produce usable consumer products. Refineries first process crude in atmospheric distillation units in which liquids and vapors are separated into petroleum components called "fractions" or "cuts." The lightest fractions with the lowest boiling points, including gasoline components and liquefiable refinery gases, vaporize and rise to the top of the distillation tower, where they condense back to liquids. Medium weight liquids, including kerosene and distillates, are drawn off in the middle portion of the distillation tower. Heavier vaporized liquids, called gas oils, are separated near the bottom of distillation tower. The heaviest components (called atmosphere residue or atmospheric residuum) are not vaporized and remain at the bottom of the atmospheric tower. These are sent into a vacuum distillation unit which can draw more vapors out of the oil due to its lower pressure. The lightest vaporized portion produced in the vacuum tower is condensed into light vacuum gas oil (LVGO) and the remainder is heavy vacuum gas oil (HVGO). The components that remain at the bottom of the vacuum distillation tower are called vacuum residue or vacuum residuum (VR).

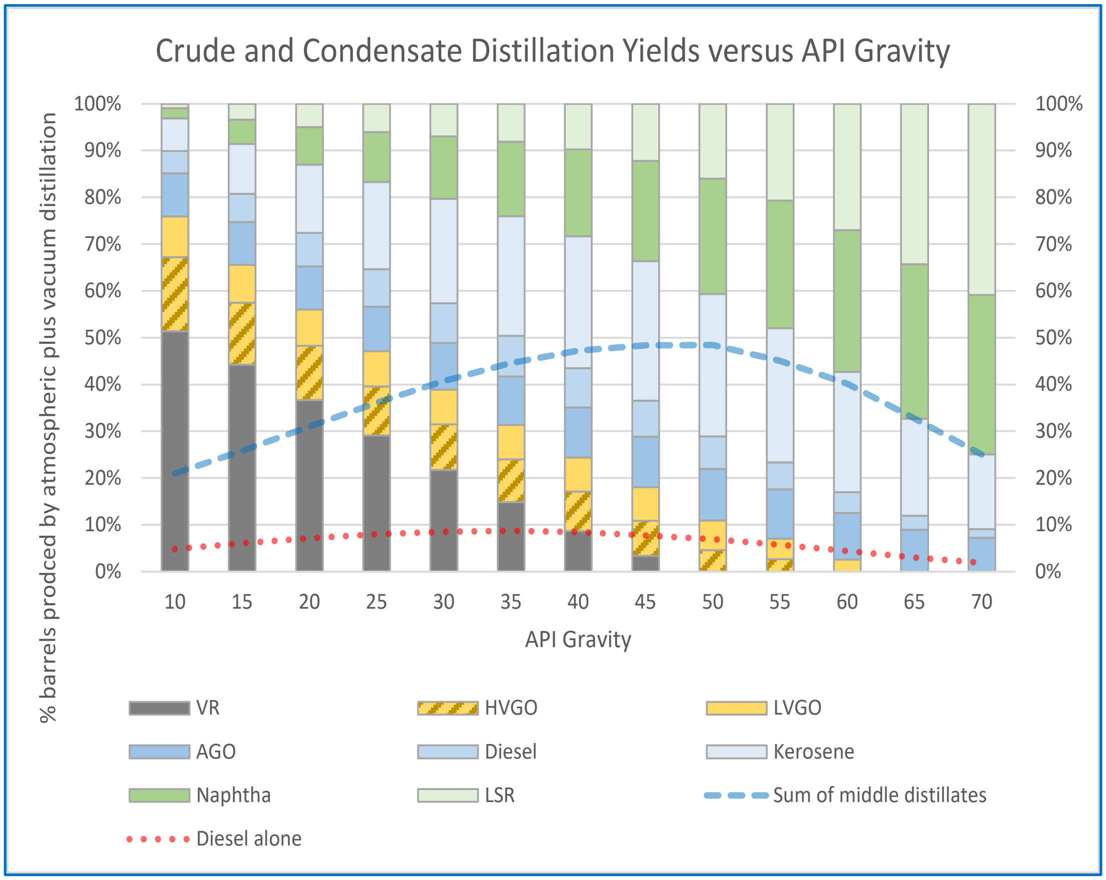
A crude oil “assay” conducted at petroleum testing laboratories describes the volume and characteristics of the gases and liquids that are separated by atmospheric and vacuum distillation. Since no two crude oil reservoirs produce crudes that are identical in all respects, the assay provides important information that can help determine the crude’s market value and where and how it can best be refined into final petroleum products. One important characteristic described in the assay is the crude density or gravity, often measured in units of kilograms per cubic meter of volume or degrees API gravity. Density can be converted to degrees API gravity using the following conversion equation:

API gravity = 141.5/(Density/1,000) – 131.5
where density is in units of kilograms per cubic meter

The middle distillates made up of atmospheric gas oil, diesel (or distillate) and kerosene represent the most valuable parts of distilled crude oil and condensates because they can be used to produce high valued products (distillate fuel oil, diesel fuel and jet fuel) with relatively little processing. The fraction of the assay volumes made up by all these middle distillates is shown as a blue dashed line in Exhibit 4 and the portion made up by the diesel cut alone (which is the most valuable cut amongst the middle distillates) is shown as a dashed red line. The portion of assay made up by the diesel cut peaks on the chart at API gravities of 35^o and the portion made up of all middle distillates peaks around 40^o to 45^o API gravity.

Exhibit 4 shows that heavy crudes (API gravities of 10^o, 15^o and 20^o in the exhibit) have larger portions of high-boiling-point cuts (vacuum residue, heavy vacuum gas oil and light vacuum gas oil) which make up the atmospheric residue and together represent over 50% of the assay volumes. These cuts have relatively low value because they require significant processing to be made into high-value products: vacuum gas oils must be processed in gas oil crackers to produce final products and vacuum residue must either be sold as low-value residual oil/bunker fuel; be made into asphalt; or undergo “deep conversion” such as delayed coking. Crude oils with special characteristics have atmospheric and vacuum gas oils that can be processed to make high-value lubricating oils and waxes.

Exhibit 4: Typical Distillation Yields versus API Gravity of Crude and Condensates



Source: ICF analysis of sample crude oil assays in PRELIM model databases. These represent averaged or smoothed values. Actual distillation yields for an individual crude will vary around these values based on that crude's compositions. The charts acronyms refer to vacuum residuum=VR, heavy vacuum gasoil=HVGO, light vacuum gasoil=LVGO, atmospheric gasoil=AGO and light straight run=LSR (that is, refinery gases and light naphtha). Note that VR+HVGO+LVGO=atmospheric residue.

1.3 Overall Methodology

This study tries to address the quantification of production in a transparent and consistent manner that will allow for a reasonable comparison of the GHG emission intensities of various crudes and condensates. The methodology for evaluating the GHG emission intensities from crude oil production is as follows:

1. **Setting Up a Framework for Analysis of US Oil Production**: Production data for crude oil and condensates in the US in 2020 was combined into approximately 3,600 analytic categories that varied by region, well type (oil versus gas), onshore versus offshore, drilling depth, well design (horizontal versus vertical), production method, and API gravity of the crude or condensate produced. This included approximately 409,000 oil wells and 528,000 gas wells.
2. **Setting Up a Framework for Analysis of International Oil Production**: Production data for crude oil and condensates outside of the US in 2020 was compiled by individual fields categorized by country, field type (oil versus gas), onshore versus offshore, drilling

depth, production method, and API gravity of the crude or condensate produced. This included approximately 8,100 fields in 103 countries.

3. **Estimation of GHG emission intensity from Oil Production**: Production-related GHG emission intensity for each category of wells or individual field were computed using the characteristics (e.g., drilling depth, fluid types, etc.) noted above as processed through a series of algorithms that computed several emission components that were added up to a total CO_2e metric tons per year for each well category or field. These emissions included the so called "embodied" emissions related to the construction of the oil and gas wells and production facilities.
4. **Allocation of GHG Emissions from Production by Hydrocarbon**: The total of production-related emissions for each well category or field were then allocated between oil and wet natural gas based on the Btu content of production in that individual well category or field. The amount allocated to crude and condensate is reported in units of CO_2e kg/bbl.

The next chapter (Chapter 2) includes a description of the methodology used to estimate the production-related components and Chapter 3 presents a summary and breakdown of all results.

1.4 Methodology Uses Historical Data and Does Not Account for Future Changes

This study is based on 2020 data and practices and as such does not account for changes that are expected to occur in the future in how oil and gas are produced. Methane emissions have historically been falling on a per-unit of production basis. As the focus on methane emissions in this sector continues and detection and mitigation technologies improve and are more widely adopted, per-unit methane emissions are expected to continue decreasing in the future. The driving forces for voluntary measures will be more effective and cheaper methane leak detection equipment and emission controls, the turnover of older higher-emitting equipment as it reaches the end of Its useful life, and the change in stockholder and consumer attitudes that place increasing value on companies that demonstrate that they produce products and services in an environmentally responsible manner.

In addition to these voluntary factors, there are also several legislative and regulatory actions currently in consideration which target reducing methane emissions from oil and gas operations. At the time of this report, EPA has proposed regulatory actions which strengthen guidelines to control emissions from both new and existing oil and natural gas emission sources.[1] According to the EPA, the implementation of both actions of the proposed regulation (New Source Performance Standards OOOOb and Emissions Guidelines OOOOc) will result in a reduction of 810 million metric tons CO_2e of methane for the period from 2023 to 2035.[2] Of these amounts, approximately 625 million metric tons could be classified as production related with the remainder coming from the gas processing and transmission supply chain segments. On an

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[1] https://www.federalregister.gov/documents/2022/12/06/2022-24675/standards-of-performance-for-new-reconstructed-and-modified-sources-and-emissions-guidelines-for
[2] https://www.epa.gov/system/files/documents/2022-12/Supplemental-proposal-ria-oil-and-gas-nsps-eg-climate-review-updated.pdf

annual basis, the projected reductions in production-related methane is 48 million metric tons CO_2e or about 38% of the 2020 emissions estimated in the EPA Inventory.

These regulations also coincide with the enaction of the Inflation Reduction Act of 2022 (IRA) which contains a methane emissions reduction program (MERP). One mechanism is fees on emissions from regulated facilities which exceed certain thresholds (i.e., facilities that emit 25,000 metric tons CO_2e or more per year). The thresholds are specific to the type of facility, with penalties applied to emissions which exceed the limit beginning at $900 per metric methane in 2024. The fee then escalates over time, increasing to $1,200 and $1,500 per metric ton by 2025 and 2026, respectively. The fee would then remain constant at $1,500 per metric ton in subsequent years. Another mechanism in the MERP is a provision for $1.55 billion in grants as positive incentives for producers to reduce methane emissions.

2. Methodology for GHG Emission Intensity of Production of Crude Oil and Lease Condensate

2.1 Overview of Estimating GHG from Production

This chapter explains how the GHG emission intensity associated with crude oil and condensate production were estimated for this study. The process consisted of developing algorithms to estimate various intermediate parameters (including most importantly energy use and the emissions related to venting, flaring and fugitive releases of methane and process carbon dioxide) and then using those parameters to estimate 2020 GHG emission intensity. These emissions are calculated in units of (a) metric tons per year for groups of wells or individual oil or gas fields and (b) kilograms per barrel produced.

The emissions include the so called “embodied emissions” which relate to the GHG emissions from the construction of the oil and gas wells and production facilities. The term “embodied emissions” also encompasses GHG emissions associated with the production and transportation of raw materials used in the construction of these facilities.

For the US, the GHG emission estimates were made for approximately 3,600 groupings of wells sorted and binned by region, well type (oil versus gas), onshore versus offshore, drilling depth, well design (horizontal versus vertical), production method, and API gravity of the crude or condensate produced. Outside of the US, GHG emission estimates were made for approximately 8,100 individual fields characterized by country, field type (oil versus gas), onshore versus offshore, drilling depth, production method, and API gravity of the crude or condensate produced.

The characteristics (e.g., drilling depth, fluid types, etc.) of each grouping of wells or field were processed through a series of algorithms to estimate intermediate parameters and GHG emission for several emission components. The total of production-related emissions were summed across all components for each well category or field and were then allocated between oil and wet natural gas based on the Btu content of production in that individual well grouping or field. However, the oil-related emissions that occur away from the producing property (that is, crude oil transportation, petroleum refining, petroleum product transportation and dispensing) are borne solely by “oil.” Likewise natural gas processing; dry gas transportation, storage and distribution; hydrocarbon gas liquids (HGL) pipeline; and HGL storage and distribution are borne solely by “wet gas.”

The components of GHG emission intensity reported here by geographic region and type of crude or condensate include the following eight production-related components:

- Drilling and Completing Wells and Construction of Production Facilities
- Flaring & Wellhead Venting
- Lease Compression of Natural Gas
- Oil Stabilization/Treating
- Storage Tank Fugitives
- Methane Leaks & Non-wellhead Venting
- Electricity & Natural Gas for Oil, Water and CO_2 Pumps

- Electricity & Natural Gas for Steam Floods

When emissions of methane are converted to CO_2e, a global warming potential of 25 is used. This convention makes the numbers that appear in this report consistent with EPA's National GHG Inventory, from which various factors and control totals were taken.

The algorithms were developed by ICF but rely on relationships developed in previous studies using OPGEE and other models. Where possible the results were calibrated to GHG inventory and energy consumption estimates made by EPA, DOE and other federal agencies for the US. For other countries, similar statistics estimated by the International Energy Agency, the World Bank and other international organizations were used to determine parameters and set up sensitivity analyses.

In summary, the most important features of this study which distinguish it from many other published analyses are:

1. The world's entire crude and condensate production for 2020 is included in the study.
2. The analysis is built up from highly disaggregated (field-level or groupings of individual wells) data that characterizes where and how the oil is produced.
3. The same set of algorithms and conventions are used to estimate GHGs for all oil production, so that the results are truly "apples to apples."
4. Where possible, the results are checked and calibrated to national and international inventory data.
5. Published results are split out into eight GHG subcategories to facilitate comparisons among sources of oil.
6. Sensitivity analyses are performed on methane emission parameters and the methane global warming potential.

2.2 Methodology for Estimating GHGs from each Component of Production

The methodology and data for estimating each of the eight main components of GHG related to the production of crude oil and condensates is discussed below.

2.2.1 Drilling and Completing Wells and Construction of Production Facilities

One large part of the GHG's associated with the construction of oil and gas wells come from the energy (traditionally almost entirely from diesel fuel with growing use of natural gas and electricity) used to drill and complete the wells and to move materials to and from the well sites. Another large portion is associated with manufacturing of the equipment and materials used in the well's construction including oil country tubular goods, cement, sand, gravel, onshore production equipment, and offshore production platforms. For onshore wells, another component are the land disturbances related to clearing the areas needed for drilling pads, roads and gathering line rights of way. As shown in Exhibit 5, for onshore horizontal hydraulically fractured wells, these emissions add up to about 3,000 metric tons of CO_2e or 200 kg per measured foot of well depth. Offshore deepwater wells consume much more energy and require considerably more material. The GHG emission related to their construction is about

9,700 tons or about 600 kg per foot of measured depth. As will be shown later, these higher GHG values for offshore well construction are offset by the higher well productivity for offshore wells and so the construction-related emissions per unit of production are typically lower for offshore wells as compared to onshore wells.

Exhibit 5: Examples of Estimated GHG Emissions Related to Well Construction

	US Horizontal Fracked Wells	Offshore Deepwater
True Vertical Depth (ft.)	7,500	14,000
Lateral Length or Deviation (ft)	8,000	2,000
Total depth (ft)	15,500	16,000
GHG in metric tons CO_2e		
Diesel use	1,648	4,923
Land disturbances	383	-
Production of well equipment and materials	980	4,814
Sum tons CO_2e / well	3,011	9,737
Sum kg CO_2e / foot	194	609

Source: ICF estimates for materials and fuel use. Average depths are approximations based on historical drilling statistics collected by state and federal regulatory agencies and compiled into a database of oil and gas wells at Enverus.com. Estimation of emissions in this study is based on actual depths for each field or grouping of wells.

The emission factors used to model US and international well construction and production facilities were estimated by ICF and are 150 CO_2e kg/foot for onshore wells that are not hydraulically fractured, 200 CO_2e kg/foot for onshore fractured wells and 600 CO_2e kg/foot for offshore wells. Onshore wells that are not hydraulically fractured require less materials (frack sand and water) and use less energy in their completion as compared to fracked wells and so their construction related emissions are modeled as 150 CO_2e kg/foot compared to 200 CO_2e kg/foot for fracked wells. Additionally, 100 metric tons of GHG emissions are assigned per well to the construction of lease equipment and gathering systems for handling produced fluids. On average for the US, construction of wells and production facilities adds up to 2.60 kilograms of CO_2e per barrel of oil produced. Of this amount, 2.40 CO_2e kg/bbl is for the wells and 0.20 CO_2e kg/bbl is for the production facilities.

Outside of the US, well and production facilities construction contribute 0.34 kg/bbl of oil production. This is a lower number than the US average because the international fields are larger with higher per-well recoveries.

2.2.2 Flaring & Wellhead Venting (not related to storage tanks)

The overall estimates of the amount of methane and CO_2e released in the production of oil and gas are taken from EPA's National Inventory of GHGs.[3] For the subcategory of vented associated gas production and flared natural gas (other than related to storage tanks) the EPA Inventory shows 15.86 million metric tons in units of CO_2e of which 14.1 million metric tons is from flare combustion and 1.76 million tons is from un-combusted flared gas or intentionally

[3] https://www.epa.gov/ghgemissions/inventory-us-greenhouse-gas-emissions-and-sinks

vented methane from associated gas wells at the wellhead.[4] These volumes were allocated among the 3,600 US well groupings based on the volume of gas reported by EIA to have been flared in each state (overwhelmingly associated-dissolved gas from oil wells) and an assumption of a 98% flare combustion efficiency. In total for the US, wellhead venting and flaring that is not related to storage tanks contributes 2.56 CO_2e/bbl of crude oil and condensate that is produced.

Outside of the US, venting of produced associate gas and gas flaring that is not related to storage tanks is estimated by ICF to contribute 11.78 CO_2e kg/bbl on average across all countries. This is a much higher number than for the US due to the prevalence in many countries of widespread and inefficient flaring. The amount of flaring in each field was taken from published studies if available (largely from the Oil Climate Index) or assumed to be equal to each country's average flaring factor (measured in cubic feet of flared gas per barrel of oil produced) as reported in the World Bank's Global Flaring Tracker Report.[5] The international flared volumes were converted to CO_2e assuming a 93% combustion efficiency and a GWP for methane of 25.[6]

While country-specific values for flaring from the World Bank were available for use in this analysis, there is a lack of reliable data on associated gas production venting outside the US. Therefore, the Base Case rate of wellhead venting (as a percent of gas production) was assumed to be the same as in the US. However, this assumption for wellhead venting was scaled up for sensitivity analyses that were conducted to approximate the overall oil and gas sector methane emissions for each country as estimated by IEA. (See Appendix B Section 5.2)

2.2.3 Lease Compression of Natural Gas

Natural gas is used on oil and gas leases for several purposes including the compression of natural gas; the heating of produced oil and other fluids for separation/ stabilization/ treatment/ dehydration; to power various fluid (mostly for oil and water) pumps; and to make steam used for enhanced thermal recovery. Based on the total amount of natural gas reported by EIA in the Natural Gas Annual to be consumed by all such lease uses, ICF has estimated that – after accounting for all other uses such as oil stabilization and gas-fired pumps – approximately 2.36% of gas produced is consumed to compress natural gas.[7] This compression is used for

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[4] The specific 2020 EPA Inventory categories used for these estimates are Oil Systems Production Associated Gas Flaring CO_2 (13,041 kt), Oil Systems Production Associated Gas Flaring Methane (41.9 kt), Oil Systems Production Associated Gas Venting Methane (23.5 kt), Natural Gas Systems Production Miscellaneous Flaring CO_2 (1,060 kt) and Natural Gas Systems Production Miscellaneous Flaring Methane (4.9 kt). Converting the methane values to CO_2e and adding up these categories yields a total of 15,857 kt of CO_2e.

[5] Global Gas Flaring Tracker Report (worldbank.org)

[6] Regarding the efficiency of production flares, IEA says "With current global operations and maintenance practices and regulations, we estimate the average global combustion efficiency (including both normally operating and extinguished flares) to be around 92%." Flaring Emissions – Analysis - IEA If the US flare efficiency were changed from 98% to the assumed non-US value of 93%, the average US emissions from associated gas production venting and non-tank production flares would increase from 2.56 to 2.98 CO_2e kg/bbl. while the GoM average would go from 0.57 to 0.66 CO_2e kg/bbl.

[7] In the Natural Gas Annual (Natural Gas Annual 2021 (NGA) - Energy Information Administration - With Data for 2021 (eia.gov)) EIA reports 2020 lease consumption of natural gas to be 1,291 billion cubic. The ICF estimates for uses of lease gas uses other than compression add up to 334 bcf leaving 957 bcf as

pressure maintenance in oil fields, gas lift of oil in oil wells and pressurizing gas in gathering systems. This same 2.36% factor is used for estimating GHG emissions for international oil and gas fields.

Gas compression contributes 2.56 CO_2e kg/bbl for US oil production and 1.55 CO_2e kg/bbl for fields outside of the US. The lower number for the international fields reflects lower average gas-to-oil production ratios.[8] The GHG emissions for gas compression for each field or well grouping were estimated as the annual production rate times the 2.36% compressor fuel use factor times an emission factor based on the estimated raw (unprocessed) gas composition.

2.2.4 Oil Stabilization

As stated above a certain amount of natural gas is consumed on leases to heat the produced oil for the purposes of separating the oil from water and gas and thereby stabilizing the oil so that it can be efficiently and safely transported while not harming the environment by releasing dissolved volatile organic compounds (VOCs). Based on analysis of OPGEE case studies, ICF estimates that approximately 52,000 Btus of natural gas are used per barrel of oil produced for oil stabilization with lighter oils requiring less energy (because they separate from other fluids more easily) and oil produced at high gas-to-oil ratio needing more (because they are likely to contain high amounts of dissolved gases). Oil stabilization contributes an average of 1.91 CO_2e kg/bbl to US oil production and an average of 2.40 CO_2e kg/bbl to the 8,100 international fields modelled for this study. The GHG emissions for stabilization for each field or well grouping were estimated as the annual production rate times the Btu/bbl fuel use factor times an emission factor based on the estimated raw (unprocessed) gas composition.

2.2.5 Storage Tank Fugitives

Storage tanks temporarily hold produced oil on the lease until it can be removed to market by truck or pipeline. During this time, some amounts of methane and other dissolved gases likely will be released from the oil and collect at the top of the tank where they then could be:

- Released directly into the atmosphere (believed to be 2% of such tank fugitive volumes in the US per the EPA National GHG Inventory)
- Captured and burned in a flare (per the EPA Inventory, believed to be 70% of US volumes which are combusted with 98% efficiency)
- Captured and put into a vapor recovery unit (VRU) where 95% of the gases will be recovered for lease use or sold (per the EPA Inventory, believed to be 28% of US volumes).

Using the splits among control technologies and the control effectiveness shown above from the EPA inventory, ICF estimates that storage tank fugitives contribute 1.26 CO_2e kg/bbl to the GHG emission intensity of US oils. For the calculation for the international fields, ICF assumed

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consumption in compressors. This compressor use is 2.36% of the 40.6 Tcf of gross natural gas withdrawals in 2020.

[8] The ratio of gross natural gas produced to oil produced in the US is 9,840 cubic feet per barrel. The corresponding ratio outside the US would be about 5,359 cubic feet per barrel. International - U.S. Energy Information Administration (EIA)

that a smaller fraction of tank fugitives would be sent to VRUs (14% versus 28% for the US), more would be directly release (16% versus 2% in the US) and the same fraction would be flared (70%). The higher levels of control assumed for the US versus other countries can be justified by the fact that US tanks built or modified since 2011 have been subject to EPA regulations NSPS OOOO or NSPS OOOOa. These national regulations require flares or VRUs for “affected facilities” which are defined to include oil storage tanks with potential volatile organic compounds (VOC) emissions equal to or greater than six tons per year. Another difference is that the flaring efficiency for storage tanks in the international fields was assumed to be lower (93% versus 98% in the US) in keeping with similar assumptions for production flares. With these assumptions, ICF estimates that storage tank fugitives contribute 2.71 CO_2e kg/bbl to the GHG emission intensity of the 8,100 international fields modelled for this study.

2.2.6 Other Methane Emissions

Gas vented at the wellhead and portions of flared gas volumes and the storage tank fugitive volumes discussed above would occur in the form of un-combusted methane entering the atmosphere. For the Base Case GHG emission tables and chart shown in this report, these methane releases have been converted to carbon dioxide equivalent using a global warming potential of 25.

In addition to methane released through wellhead venting, production flares and storage tank vents and flares, methane can be released on oil and gas leases through several other pathways including leaky valves, flanges and meters; pneumatic devices that bleed methane into the atmosphere when actuated; faulty compressor seals; un-combusted compressor and other engine fuel; certain kinds of liquid unloading procedures; and the venting of well tubing and boreholes, pipelines and other equipment during repair and maintenance activities.

The main source of data for methane emission for oil and gas production in the US is the EPA GHG Inventory. As shown in Exhibit 6, the EPA Inventory estimates methane emissions through the gas processing step to be 5,526,000 metric tons for the year 2020. Of this amount, 232,000 metric tons is attributed to offshore oil and gas production. The breakout of methane emissions by specific onshore sources is different for “Gas Systems,” which has ten subcategories, as opposed to “Petroleum Systems,” which lists eight subcategories. The EPA Inventory does not publish data for subcategories of GHG emissions associated with offshore oil and gas production but more detailed data is available from the source data (described in the next paragraph) from which EPA derives its offshore estimates.

Exhibit 6: 2020 EPA GHG Inventory for Methane Emissions from Oil and Gas Production and Gas Processing

Gas Systems Metric Tons CH4		Petroleum System Metric Tons CH4		GS+OS Metric Tons CH4	As % of Onshore
Exploration	**8,000**	**Exploration**	**12,000**	**20,000**	0.42%
Production	**3,455,000**	**Production**	**1,557,000**	**5,012,000**	
Pneumatic Controllers	952,000	Pneumatic Controllers	854,000	1,806,000	37.63%
G&B Station Sources	1,500,000	Equipment Leaks	95,000	1,595,000	33.23%
Gas Engines	228,000	Gas Engines	89,000	317,000	6.60%
Produced Water	140,000	Produced Water	89,000	229,000	4.77%
Small Tanks w/o Flares	13,613			13,613	0.28%
		Chemical Injection Pumps	76,000	76,000	1.58%
Miscellaneous Onshore Flaring	4,894	Assoc Gas Flaring	42,000	46,894	0.98%
Gathering Pipeline Leaks	128,000			128,000	2.67%
Gathering Pipeline Blowdowns	8,000			8,000	0.17%
Other Sources	441,000	Other Sources	120,000	561,000	11.69%
Offshore Production	39,000	Offshore Production	193,000	232,000	
Processing	**494,000**			**494,000**	
Sum	**3,957,000**	**Sum**	**1,569,000**	**5,526,000**	

EPA uses the Gulfwide Offshore Activities Data System (GOADS) in estimating the GHG emissions from offshore areas.[9] The data are adjusted for the reporting year and scaled up to include offshore areas outside of the Gulf of Mexico. The GOADS methane data for 2017, the last available year is shown below in Exhibit 7 (without adjustment for year or geographic scope). The source categories reported in GOADS are different from those used in the EPA Inventory. However, to provide a means for an approximate comparison, ICF has reclassified

[9] https://www.boem.gov/environment/environmental-studies/ocs-emissions-inventories

each of the GOADS categories into the closest EPA category. (See last column in Exhibit 7 below).

Exhibit 7: 2017 Methane Emissions from Oil and Gas Activity in the Gulf of Mexico

	Oil & Gas Only		
Equipment and Source Category	**CH4 Emissions (metric tons per year)**	**CH4 Emissions as %**	*Reclassification into EPA Inventory Categories*
Cold vents	71,200	37.5%	*Other Sources*
Fugitive sources	54,787	28.9%	*Equipment Leaks*
Pneumatic pumps	28,847	15.2%	*Pneumatic Controllers*
Pneumatic controllers	15,626	8.2%	*Pneumatic Controllers*
Natural gas engines	10,519	5.5%	*Gas Engines*
Losses from flashing	4,074	2.1%	*Other Sources*
Combustion flares	3,216	1.7%	*Flaring*
Glycol dehydrators	563	0.3%	*Produced Water*
Storage tanks	557	0.3%	*Small Tanks w/o Flares*
NG, diesel, & dual fuel turbines	301	0.2%	*Gas Engines*
Mud degassing	87	0.0%	*Other Sources*
Support vessels	9	0.0%	*Other Sources*
Diesel engines	6	0.0%	*Gas Engines*
Boilers, heaters, and burners	5	0.0%	*Other Sources*
Amine units	3	0.0%	*Other Sources*
Drilling rigs	3	0.0%	*Exploration*
Support helicopters	1	0.0%	*Other Sources*
Survey vessels	1	0.0%	*Exploration*
Drilling equipment	1	0.0%	*Exploration*
Total Emissions	**189,807**	**100.0%**	

Note: This listing does not include methane sources (e.g., commercial fishing vessels, recreational vessels) unrelated to oil and gas exploration and development activity. Reclassification into categories used for EPA Inventory are approximate.

Exhibit 8 shows the breakout of 2020 methane emission by onshore versus offshore in units of tons and kg CO_2e/barrel of oil equivalent. Also shown are methane emissions in CO_2e kg/BOE. The methane emissions exclude gas processing and are from the 2020 EPA GHG Inventory. Oil and gas production data are from EIA. Overall methane emissions for the offshore (7.21 CO_2e kg/BOE) are one-third lower as compared to the onshore (10.82 CO_2e kg/BOE).

Exhibit 8: 2020 US Methane Emissions per Unit of Production

	Sum methane CH4 metric tons	Oil Production (kbpd)	Gas Production (MMcf/day)	All Production (kboe/day)	CH4 kg/BOE	CH4 CO_2e kg/BOE
Onshore	4,800,000	9,631	108,088	30,381	0.43	10.82
Offshore	232,000	1,703	2,270	2,204	0.29	7.21
All	5,032,000	11,334	110,358	32,585	0.42	10.58

Source: Methane emissions exclude gas processing and are from 2020 EPA GHG Inventory. Oil and gas production data are from EIA. GWP=25 for methane. Note that the 2020 EPA Inventory value for offshore methane (232,000 metric tons per year) is used for this table and not the 2017 GOADS value (189,807 metric tons per year).

Exhibit 9 shows the breakout of 2020 methane emission by the categories used for the EPA Inventory. Although an accurate apples-to-apples comparison cannot be made due to differences in categorization by EPA versus in GOADS, it appears that the offshore has lower emissions per unit of production in all categories except for the "other sources" category. This is the category into which the GOADS values for "cold vents" and "losses from flashing" were reclassified. It is possible that such emissions could be reallocated to other EPA categories so that the differences between onshore/offshore for each category would be reduced. However, the total emissions for the offshore would remain one-third lower as compared to the onshore.

Exhibit 9: 2020 US Methane Emissions Approximated by Categories

Category	Onshore Percent	Onshore CO_2e kg/BOE	Approximate Offshore Percent	Offshore CO_2e kg/BOE
Exploration	0.40%	0.05	0.00%	0.00
Pneumatic Controllers	37.60%	4.07	23.40%	1.69
Equipment Leaks	33.20%	3.60	37.50%	2.70
Gas Engines	6.60%	0.71	5.70%	0.41
Produced Water	4.80%	0.52	0.30%	0.02
Small Tanks w/o Flares	0.30%	0.03	0.30%	0.02
Chemical Injection Pumps	1.60%	0.17	0.00%	0.00

Category	Onshore Percent	Onshore CO_2e kg/BOE	Approximate Offshore Percent	Offshore CO_2e kg/BOE
Flaring	1.00%	0.11	1.70%	0.12
Gathering Pipeline Leaks	2.70%	0.29	0.00%	0.00
Gathering Pipeline Blowdowns	0.20%	0.02	0.00%	0.00
Other Sources	11.70%	1.26	31.10%	2.24
Sum	**100.00%**	**10.82**	**100.00%**	**7.21**

Note: Reclassification of offshore emissions into categories used for EPA Inventory are approximate.

The lower per-unit rate of methane emission for offshore production as compared to onshore can be attributed to several factors:

- The offshore wells have much higher average well productivity (658 BOE/day) compared to onshore wells (33 BOE/day) and so there is a lower count of wells, valves, separators, etc. per unit of production. Since emissions are partly a function of equipment count, this tends to reduce the volume of methane emission per unit of production.
- Methane leaks create a safety issue on offshore facilities because of the fire/explosion risk of gas leaks in confined space. For this reason, operators deploy gas detectors and monitor any flares to track and prevent this risk. The monitoring is done using optical and thermal devices that detect when a flame is present and sound an alarm if none is detected.
- The economics of offshore production usually prevents lower productivity wells from continuing to produce decade after decade as can be the case in onshore areas. This means that offshore facilities are often newer and in better operating condition.

Sensitivity Analysis Using IEA Methane Assumptions

For the Base Case, ICF assumed that international fields would exhibit the same methane emissions patterns as indicated in the EPA GHG Inventory for onshore and offshore regions (except for the portion of methane related to flaring for which country-specific data were employed). Given the uncertainty on methane emissions for the US and for regions outside of the US,[10] ICF performed three sensitivity analyses using IEA assumptions for the expected

[10] This issues regarding the levels of methane emissions related to oil and gas production have been fueled, in part, by studies that have used satellites and other remote sensing technologies to measure the concentration of methane in the air above oil and gas producing areas or the size and methane concentrations of plumes of gases emanating for oil and gas infrastructures. There are considerable uncertainties about the accuracy of these measuring methods and how they can be used to isolate and estimate emission factors from oil and gas infrastructure. Only a few studies have been done to understand emission measurement challenges for the US offshore and there are even fewer international offshore remote sensing studies to provide comparative statistics for other countries. Some recent work includes: Tara I. Yacovitch, Conner Daube, and Scott C. Herndon, 2021, Methane Emissions from Offshore Oil and Gas Platforms in the Gulf of Mexico | Environmental Science & Technology (acs.org);

emissions from crude oil production from US and international fields and a different GWP for methane. IEA publishes scaling factors which are meant to represent differences in emissions due to the age of the infrastructure, types of operators in each country, etc.[11] The three sensitivity case shown in Appendix B were constructed by (1) adjusting the GWP to 34 in the first sensitivity case, (2) adjusting the methane emission factor expressed in physical units to match IEA value in the second sensitivity case and (3) applying both changes in the third sensitivity case.

2.2.7 Electricity & Natural Gas for Oil, Water and CO_2 Pumps and Compressors

There are several kinds of pumps that are operated on an oil and gas lease. The largest of these are pumps that help lift oil and produced water from the bottom of the wells to the surface. If the field is undergoing secondary and tertiary recovery, there will also be pumps (and possibly compressors) to move pressurized fluids (that is, water, water mixed with chemicals, steam, CO_2, or miscible gases like methane or propane) down injection wells into the producing reservoir. Such pumps and compressors can be powered by gas-fired prime movers or electric motors. If electric motors are used, they can draw power from the electric grid or be served by onsite power generation.

Based on standard engineering calculations and assumptions for typical fluid characteristics, friction losses and pump efficiencies, ICF estimates that the energy used to lift oil and water out of a well undergoing artificial lift is about 0.14 kWh per 1,000 feet of reservoir depth. Since water must be lifted along with the oil, the ratio of produced water to oil is an important parameter in determining energy used per barrel of oil produced. The average water-to-oil ratio for US oil wells is about 5.1 barrels of water per barrel of oil according to the EPA National GHG Inventory and that ratio differs substantially among oil fields. It is common for mature fields that are undergoing secondary recovery using water floods to operate with water-to-oil ratios above 10.

Additional electricity is needed for tertiary recovery, especially CO_2 floods which typically require 107 kWh of electricity to compress each ton of CO_2 that is produced with the oil and then reinjected back into the reservoir. Given that 0.52 metric tons of CO_2 are injected per barrel of oil produced, this means 56.17 kWh are needed per barrel produced from CO_2 floods – more than 10 times the amount typically used for artificial lift.

In total ICF estimates US oil and gas fields consume 49,745 MWh of electricity-equivalent each day for pumping and miscellaneous uses. This comes to an installed equipment capacity of slightly more than 2,000 MW. For the onshore US, ICF has assumed that 30% of this energy comes from grid electricity and that the rest comes from onsite use of self-produced fuels (mostly natural gas used in either direct drive configurations or as electric motors fed by

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Alan M. Gorchov Negron, Eric A. Kort, Stephen A. Conley, and Mackenzie L. Smith, 2020, Airborne Assessment of Methane Emissions from Offshore Platforms in the U.S. Gulf of Mexico | Environmental Science & Technology (acs.org); Alana K Ayasse, et al, 2002, Methane remote sensing and emission quantification of offshore shallow water oil and gas platforms in the Gulf of Mexico (iop.org)

[11] https://www.iea.org/reports/global-methane-tracker-2022

electricity generated onsite).[12] For the rest of the world, grid electricity is assumed to supply 15% of onshore oil and gas field pumping and miscellaneous electricity use. In all countries, offshore energy is assumed to be supplied by self-produced natural gas or oil.

The GHG emissions from using grid electricity varies by region based on what fuel sources are used to generate electricity. Exhibit 10 shows the GHG emission intensity associated with electricity in each state of the US and Exhibit 11 shows the same information for various oil producing countries. The value used for this analysis are those in the “LCA” column which includes both the direct emissions from fuel combustion at the power plants (the value in the adjacent “Reported” column) plus the emissions associate with producing and delivering the fuel to the power plant, plus the emissions associated with building the power plant, plus the non-fuel emissions associate with plant operations. By way of comparison to these tables showing the GHG emission intensity of grid electricity, the use of a wet associated gas (1,280 Btu/scf) from a lease separator to make onsite electricity at a heat rate of 10,000 Btu per kWh, comes to a GHG intensity of roughly 570 CO_2e kg/MWh on a combustion-only basis.

For the US on average, GHG emissions related to pumping and miscellaneous energy uses contributes 1.78 CO_2e kg/bbl of oil production. For the 8,100 international fields analyzed in this study, the same statistic is 1.82 CO_2e kg/bbl.

Exhibit 10: GHG Emission for Electricity Generation by State

State	kg/MWh All Generation as Reported	kg/MWh All Generation with LCA Adders
AK	438	518
AL	327	384
AR	431	494
AZ	334	396
CA	206	262
CO	553	620
CT	240	299
DC	363	421
DE	342	427
FL	382	460
GA	328	390
HI	692	835
IA	279	322
ID	97	126
IL	252	296
IN	703	786
KS	365	409
KY	764	848

State	kg/MWh All Generation as Reported	kg/MWh All Generation with LCA Adders
MT	414	458
NC	294	351
ND	630	692
NE	545	603
NH	112	147
NJ	223	280
NM	571	643
NV	325	399
NY	189	234
OH	568	646
OK	321	380
OR	155	190
PA	316	379
PR	730	866
RI	375	458
SC	233	280
SD	154	181
TN	259	304

[12] The authors of this report are not aware on any compiled public data showing the mix of prime movers that power oilfield pumps or where electric motors are used, how much of the electricity comes from the grid versus onsite generation. The use of internal combustion engines to directly drive pumps has been trending downward for some time and that trend has accelerated with the advent of horizontal multistage hydraulically fracture oil wells that will typically employ electric submersible pumps (ESP) rather than the old-style rod pumps systems. (The rod pump systems are still used in hundreds of thousands of older oil wells in the US and elsewhere.) Based on few geographically limited studies we have conducted; we believe that nearly all newer onshore US oil wells use electric pumps for artificial lift and to power instrument air control systems and that self-generated electricity is the dominant source of electricity. However, this pattern is also changing as environmental concerns are causing producers to increasingly connect new well pads to the grid.

State	kg/MWh All Generation as Reported	kg/MWh All Generation with LCA Adders
LA	346	421
MA	399	472
MD	293	346
ME	104	128
MI	425	489
MN	349	402
MO	734	813
MS	406	485

State	kg/MWh All Generation as Reported	kg/MWh All Generation with LCA Adders
TX	389	456
UT	710	794
VA	292	357
VT	14	25
WA	97	119
WI	541	612
WV	873	961
WY	903	982
All States	**373**	**435**

Source: The reported values are from EPA's eGrid2020. ICF added lifecycle analysis components for the production and delivery of fuels to the power plant and for the construction and operation of the power plant.

Exhibit 11: GHG emission intensity for Electricity Generation for Major Crude Producing Countries

Country	kg/MWh All Generation as Reported	kg/MWh All Generation with LCA Adders
Argentina	353	412
Australia	594	674
Brazil	101	137
Canada	119	157
China	577	656
Colombia	215	261
Ecuador	172	215
India	654	740
Indonesia	655	741
Iran	486	558
Italy	320	376
Mexico	425	490
Norway	26	56
Russia	361	421
Thailand	488	559
United Kingdom	213	260

Source: The reported values are from the International Energy Agency for 2020. ICF added lifecycle analysis components for the production and delivery of fuels to the power plant and for the construction and operation of the power plant.

2.2.8 Natural Gas for Steam

The final component of GHG emission intensity from oil and gas production comes from the use of steam to improve recovery of heavy oils. In the US this occurs primarily in shallow oil reservoirs in California where approximately three barrels of steam are injected to produce one barrel of oil. The net energy used to make steam is about 437,000 Btu per barrel of steam or 1.3 MMBtu per barrel of oil produced. Steam is also used extensively in Canada in situ oil sands production. (Discussed below.) Steam is also employed in few oil fields outside of the US and Canada, most notably in Venezuela and Indonesia.

For the US on average, GHG emissions related to making steam contributes 1.28 CO_2e kg/bbl of oil production. As can be seen in the tables in Appendix A, the GHG emissions associated with steam floods are concentrated in the West Coast Region, where they add over 37 CO_2e kg/bbl. to the heavy oil categories. Outside of the US and Canada, steam floods contribute 0.28 CO_2e kg/bbl. to average oil GHG emission intensity.

2.2.9 Summary of Algorithms and Data Sources

Exhibit 12 contains a summary of the algorithms used to estimate GHG for each of the eight modelled components of production and the data sources used to develop energy use/emission factors and calibration targets. GHG for conventional oil in Canada is estimated the same way as in the US while GHG for Canadian oil sands is estimated using a procedure described below. Any difference between how estimates are prepared in countries outside of the US and Canada are shown in the right-hand portion of the exhibit.

Exhibit 12: Summary of GHG Algorithms and Data Sources

Component of Upstream GHG	Algorithm to Estimate GHGs	Data Sources for US	US Base Case Average (CO2e kg/bbl)	Estimates outside US/Canada	Non-US, Non-Can. Base Case Avr. (CO2e kg/bbl)
Drilling and Completing Wells and Construction of Production Facilities	**For wells:** #_of_wells * feet/well * GHGFactor_in_kg/foot. **For production facilities:** BOE_per_day_capacity * GHGFactor_in_kg/BOE_per_day	Well construction GHG factors range from 150 to 600 kg/foot and were estimated by ICF using material balances for example cases that varied by location (onshore versus offshore), completion method (fracked or not) and types of produced fluids. GHG per BOE of production is computed by dividing construction GHGs by estimated ultimate recovery (EUR or lifetime BOE produced).	2.60	Same as US	0.34
Flaring & Venting at Wellhead	**For flaring:** oil_production_in_barrels_per_year * flaring_ratio_in_cf/barrel * MMBtu/cf * GHGFactor_in_kg/MMBtu. **For wellhead venting:** gas_production_in_MMBtu/year * WH_venting% * GHGFactor_in_kg/MMBtu	Flaring by state was taken from EIA Natural Gas Annual, but adjusted to match EPA Inventory totals for the base case. Sensitivity case used higher values. Wellhead venting percent (~0.01%) was computed from EPA Inventory and EIA statistics.	2.56	Same algorithm but flaring factors are from World Bank Global Flaring Tracker Report. Wellhead venting percent assumed to be same as US for base case. Sensitivity case used methane release factors from IEA.	11.78
Lease Compression of Natural Gas	gas_production_in_MMBtu/year * lease_compression% * GHGFactor_in_kg/MMBtu	Percent of gas used for lease compression is 2.36% and was computed from EIA lease gas use minus amounts of lease gas estimated to be used for other use such as stabilization and gas-fired pumps. GHG factor was based on estimated gas composition for each field or group of wells.	2.65	Same as US	1.55
Oil Stabilization/Treating	oil_production_in_barrels_per_year * fuel_use_in_Btu/barrel *GHGFactor_in_kg/MMBtu	Fuel use was a function of oil characteristics (gravity & GOR) as fit from case studies performed in OPGEE model. GHG factors average about 52,000 Btu/bbl of crude and are based on estimated gas composition for each field or group of wells.	1.91	Same as US	2.40
Storage Tank Fugitives	**For each kind of storage tank system:** oil_production_in_barrels_per_year * VRU_or_Release_or_Flare% * VRU_or_Release_or_Flare_GHGFactor_in_kg/bbl	Algorithm is calibrated to EPA Inventory to match how much oil is stored in each kind of system and the CO2 and methane released by each kind of system. System types are vapor recovery units, direct release to atmosphere or flaring of tank vapors.	1.26	For the international fields, fraction of fugitives sent to VRUs is assumed to be 14% (versus 28% for the US), direct release is 16% (versus 2% in the US) and flaring is 70% (same as US). Flaring efficiency for the international fields was assumed to be 93% (versus 98% in the US) per IEA estimates.	2.71
Methane Leaks & Non-wellhead Venting	gas_production_in_MMBtu/year * leak_&_nonWH_venting% * GHGFactor_in_kg/MMBtu	Algorithm is calibrated to EPA Inventory. Percent of gas from leaks and non-wellhead venting ranges from 0.72% to 1.87% of production.	4.70	Leaks and non-wellhead venting percent assumed to be same as US for base case. Sensitivity case used country-specific methane release factors from IEA.	3.55
Electricity & Natural Gas for Oil, Water, and CO2 Pumps	artificial_lift_oil_production_in_barrels_per_year * (1+WOR) * fuel_use_in_Btu/barrel *GHGFactor_in_kg/MMBtu (for CO2 floods, 107kWh/ton of CO2 is added)	Each barrel of water or oil requires 0.14 kWh (478 Btu) per 1,000 feet of reservoir depth. Average US water-to-oil ratio is 5.1 with range of 0 to 10+.	1.78	Same algorithm but non-US factors assume 15% of onshore energy is grid electricity versus 30% in US.	1.82
Electricity & Natural Gas for Steam Floods	steam_assisted_oil_production_in_barrels_per_year * fuel_use_in_Btu/barrel *GHGFactor_in_kg/MMBtu	The net energy used to make steam is about 437,000 Btu per barrel of steam or 1.3 MMBtu per barrel of oil produced.	1.28	Same as US. Significant only in Venezuela and Indonesia.	0.28
Sum of All Production Components			**18.75**		**24.44**

2.3 Allocation of GHG Emissions by Type of Hydrocarbon

Wells that produce crude oil and lease condensate very often also produce wet natural gas that goes through a gas processing plant to be separated into dry natural gas and natural gas plant liquids (ethane, propane, butane, and pentanes plus). Therefore, the common convention is to apportion the GHGs from the production phase among all the hydrocarbons that are produced by a field or group of wells. This apportionment is done in this study into one category called "oil" (that is, crude oil and lease condensate) and another called "wet gas" which includes dry gas and extracted natural gas plant liquids.

This apportionment is shown at a national level in Exhibit 13 for the US. The totals of production-related emissions are first calculated for each of the 3,600 well categories. The sum for all oil well categories was 88.9 million metric tons and the sum for all gas well categories was 177.6 million metric tons. The GHG amounts for each well grouping then were allocated between "oil" and "wet gas" based on the Btu content of production for each individual well category. When summed by hydrocarbon type this yields 77.5 million metric tons for "oil" and 189.0 million metric tons for "wet gas." After dividing by the 4.1 billion barrels produced in 2020, the amount allocated to crude and condensate can be reported as 18.75 of CO_2e kg/bbl.

Exhibit 13: US Production-related GHG Emissions First Calculated by Type of Well and Then Allocated by Hydrocarbons Produced

	First Calculated by Well Type			Then Allocated by Hydrocarbon Type		
	All wells	Oil wells	Gas wells	All Oil & Gas	Crude & Condensate	Wet Gas
Construction CO_2e metric tons/year	30,968,128	13,196,203	17,771,925	30,968,128	10,771,575	20,196,553
Vented & Flare CO_2e metric tons/year	15,838,925	14,856,493	982,432	15,838,925	10,583,979	5,254,946
Compression CO_2e metric tons/year	59,489,320	10,728,610	48,760,711	59,489,320	10,960,693	48,528,627
Stabilizer CO_2e metric tons/year	12,325,358	10,542,039	1,783,319	12,325,358	7,909,078	4,416,280
Tank fugitives CO_2e metric tons/year	8,172,009	6,928,518	1,243,492	8,172,009	5,205,075	2,966,934
Methane Leaks CO_2e metric tons/year	123,969,966	17,471,247	106,498,719	123,969,966	19,442,026	104,527,939
Elec. & pumps CO_2e metric tons/year	10,035,928	9,481,193	554,736	10,035,928	7,370,822	2,665,106
Energy for steam CO_2e metric tons/year	5,701,976	5,701,976	-	5,701,976	5,304,584	397,392
Sum Production CO_2e tons/year	**266,501,610**	**88,906,278**	**177,595,332**	**266,501,610**	**77,547,833**	**188,953,777**

Note: The convention ICF adopted for this study was to allocate all emissions related to production to both oil and gas based on their relative rates of production within each well grouping or field. Other LCA methods might apportion some or all compression to wet gas only since the compression occurs after the produced fluids are split into stream (e.g., oil, water, wet gas) at lease separators. Such a convention would reduce the average GHG emission rate of US oil by up to 14%.

2.4 GHG Emission Intensity of Canadian Oil Sands

Because of their unique characteristics, the GHG emission intensity from the production of Canadian oil sands was estimated using a separate process that is explained here.

Oil sands refer to underground deposits which can be extracted as raw bitumen and processed into various petroleum products. Formations which include oil sand reserves are found in Alberta, Canada and Venezuela (Orinoco Belt). Extraction can occur via surface mining or through in-situ methods such as steam assisted gravity drainage (SAGD) or cyclic steam stimulation (CSS). The extraction technology is dictated by the depth at which the oil sands are located, where mining is utilized when reserves are located close to the surface. For deeper reserves, in-situ methods are used for extraction.

After extraction, the raw bitumen is very viscous and must be diluted, heated, or otherwise further processed before transportation to a refinery. Diluent, often pentanes plus or naphtha, is blended with raw bitumen to allow for transportation via pipeline or rail primarily to US refineries. Volumes with diluent added are referred to as "dilbit" or "railbit" based on the transportation mode. Raw or diluted bitumen can also be upgraded to synthetic crude oil (SCO) through additional processing at an upgrader. Product SCO can then be transported to refineries for further processing similar to traditional crude oil volumes.

ICF developed carbon intensities for two general oil sands pathways which are shown in Exhibit 14:

- Mining + Synthetic Crude Oil (SCO): oil sands produced through surface mining, where bitumen volumes are transported to upgraders before conversion to SCO.
- In situ + Dilbit: oil sands produced through in situ techniques (SAGD or CSS), where diluent is added to raw bitumen volumes before transportation directly to the refinery consumer.

The intensity factors shown here include several components of a life-cycle assessment (LCA):

- Direct emissions – fugitives, venting, flaring, and onsite combustion of fuels from the operations of equipment producing the oil.
- Indirect emissions – emissions from the production and transportation of fuels such as natural gas or electricity to support onsite processes.
- Embodied emissions – emissions that occur during the construction of the facility, as well as production, processing, and transportation of construction materials to the oil field location.

The direct emissions quantified in Exhibit 14 are consistent with data reported by Environment Canada in the National Inventory Report (NIR). Indirect emissions shown were calculated by combining purchased energy requirements and GREET emission factors. Embodied emissions are based on a combination of assumptions related to the construction material CO_2e factors and capital expenditures. The in-situ + dilbit direct emission results shown include blended diluent volumes. A portion of emissions are also allocated to additional co-products such as surplus electricity from cogeneration and upgrader petcoke production.

Exhibit 14: Carbon Intensities for Two Oil Sand Extraction Pathways

Parameter	Mining + SCO	In-situ + Dilbit	Source
Denominator CI	SCO to Refinery	Raw Bitumen + Diluent to Refinery	-
Direct Emissions*	98.2	48.1	Environment Canada
Indirect Emissions	16.3	31.1	AER, IHS, CERI
Land Use Change Emissions	11.9	2.9	OPGEE
Embodied Emissions	4.3	1.6	AER
Emissions Allocated to Coproducts	-3.7	-1.4	AER
Carbon Intensity Total (kg CO2e/ bbl)	126.9	82.3	-

Sources: Environment Canada National Inventory Report (NIR), Alberta Energy Regulator (AER), IHS statistics, Canada Energy Research Institute (CERI), Oil Production Greenhouse Gas Emissions Estimator (OPGEE)
**In-situ result includes diluent volume*

3. Summary and Comparison of GHG Emission Intensities from Oil Production

This section of the report shows summary tables of GHG emission intensity estimated for crude oil and condensates by region and API gravity. Exhibit 15 presents the GHG estimates in units of CO_2e kg/bbl for the ten regions modelled by EIA for its Annual Energy Outlook (AEO) and used as the basis for the US production estimates contained in International Energy Outlook (IEO). The table displays the volume of oil produced in each region in 2020 and the production related GHG emissions for each of the eight components discussed above and for their sum.

Exhibit 15: GHG Emission Intensities for US Crude and Condensates by Region

				Kilograms CO2e per barrel of crude and condensate (LCA basis)								
	API Gravity Classification	2020 Oil Production (kbpd)	Fraction of Oil Production	Prod. well construction (CO2e kg/bbl)	Prod. vented & flared (CO2e kg/bbl)	Prod. lease compression (CO2e kg/bbl)	Prod. oil stabilization (CO2e kg/bbl)	Prod. storage fugitives (CO2e kg/bbl	Prod. methane leaks (CO2e kg/bbl)	Prod. electricity & pumps (CO2e kg/bbl	Prod. steam (CO2e kg/bbl)	Production GHG (CO2e kg/bbl)
Alaska	Total	449	100%	3.59	0.94	3.56	1.53	0.97	6.54	0.61	-	17.75
East	Total	154	100%	2.22	0.45	5.14	0.70	0.47	11.17	1.02	-	21.18
Gulf Coast	Total	707	100%	3.38	3.65	2.38	2.01	1.34	3.93	4.85	-	21.52
Gulf Offshore	Total	1,690	100%	1.40	0.57	1.48	2.44	1.59	5.16	0.42	-	13.07
Midcontinent	Total	567	100%	2.78	1.09	3.23	1.64	1.09	5.72	2.57	-	18.12
Northern Great Plains	Total	1,243	100%	2.66	5.32	2.43	2.00	1.33	3.51	1.03	-	18.28
Pacific Offshore	Total	13	100%	1.37	1.88	0.85	2.65	1.79	2.75	1.02	-	12.32
Rocky Mountain	Total	881	100%	2.90	0.81	3.41	1.56	1.03	5.79	2.40	-	17.91
Southwest	Total	5,232	100%	2.61	3.10	2.93	1.80	1.18	4.59	1.66	-	17.87
West Coast	Total	398	100%	4.18	1.97	0.68	2.79	1.80	0.87	5.16	36.53	53.98
US	Total	11,334	100%	2.60	2.56	2.65	1.91	1.26	4.70	1.78	1.28	18.75

The GHG emission estimates for the US were made by applying the algorithms described in the last chapter to approximately 3,600 groupings of wells sorted and binned by region, well type (oil versus gas), onshore versus offshore, drilling depth, well design (horizontal versus vertical), production method, and API gravity of the crude or condensate produced. The regional values shown above are the averages (weighted by production volumes) for the well groupings found in each region.

The differences in intensity values among regions or among crude types within a region stem from each well grouping's unique characteristics in terms of well counts, liquids-to-gas production ratios, drilling depths, drive mechanism, fluid characteristics, etc. Even when a common algorithm is used for all wells, the unique characteristics of each grouping will result in different emission values when some of those characteristics are variables in the algorithms. For example, GHG emissions related to electricity use and pumps is largely a function of drive mechanism, water-to-oil ratios, oil gravity, reservoir depth and the GHG emission intensity of state grid electricity. Even when national-level averages are used for items such as methane leak rates (other than from flaring and associated gas production venting), the contribution to the GHG intensity will vary among well groupings (measured in CO_2e kg/bbl of oil) based on each grouping's gas-to-oil production ratio and its average gas composition (that is, what percent of the leaked gas is methane).

The same data are displayed in Exhibit 16 for all US regions broken out by API gravity. There is no simple observable pattern for how total production-related emissions change with API gravity because components can sometimes be positively correlated to API gravity, negatively correlated to API gravity, or not related to API gravity at all.

Exhibit 16: GHG Emission Intensity for US Crude and Condensates by API Gravity

			Kilograms CO2e per barrel of crude and condensate (LCA basis)								
API Gravity Classification	2020 Oil Production (kbpd)	Fraction of Oil Production	Prod. well construction (CO2e kg/bbl)	Prod. vented & flared (CO2e kg/bbl)	Prod. lease compression (CO2e kg/bbl)	Prod. oil stabilization (CO2e kg/bbl)	Prod. storage fugitives (CO2e kg/bbl)	Prod. methane leaks (CO2e kg/bbl)	Prod. electricity & pumps (CO2e kg/bbl)	Prod. steam (CO2e kg/bbl)	Production GHG (CO2e kg/bbl)
17.5: Heavy	100	1%	4.32	2.01	0.56	2.89	1.79	0.63	5.28	37.40	54.87
22.5: Heavy	236	2%	2.77	1.86	1.52	2.49	1.56	3.15	2.68	5.36	21.38
27.5: Medium	1,166	10%	2.59	1.27	1.39	2.51	1.61	3.31	1.81	7.43	21.92
32.5: Medium	1,511	13%	2.65	2.98	2.09	2.21	1.43	3.59	2.12	0.26	17.34
37.5: Light	1,856	16%	2.36	2.51	1.96	2.23	1.47	3.81	1.80	0.21	16.34
42.5: Light	2,658	23%	2.80	3.57	2.39	2.03	1.35	3.45	2.23	0.03	17.83
47.5: Light	2,730	24%	2.63	2.91	3.18	1.65	1.11	5.38	1.56	-	18.43
52.5: Light	534	5%	2.30	0.30	5.75	0.49	0.34	11.36	0.22	-	20.76
62.5: Light	543	5%	2.19	0.25	5.69	0.42	0.29	11.36	0.15	-	20.35
Grand Total	**11,334**	**100%**	**2.60**	**2.56**	**2.65**	**1.91**	**1.26**	**4.70**	**1.78**	**1.28**	**18.75**

Exhibit 17 has the same column headings as the prior two exhibits but differs in that it shows the results for just one crude oil category (API gravity 37.5°), which is the largest category of production in the Gulf of Mexico. This table indicates that controlling for the type of crude produced, the Gulf of Mexico at 12.66 CO_2e kg/bbl has near the lowest GHG emission intensity among US supply regions.

Exhibit 17: GHG Emission Intensity for API Gravity 37.5° Crudes by US Region

				Kilograms CO2e per barrel of crude and condensate (LCA basis)								
	API Gravity Classification	2020 Oil Production (kbpd)	Fraction of Oil Production	Prod. well construction (CO2e kg/bbl)	Prod. vented & flared (CO2e kg/bbl)	Prod. lease compression (CO2e kg/bbl)	Prod. oil stabilization (CO2e kg/bbl)	Prod. storage fugitives (CO2e kg/bbl)	Prod. methane leaks (CO2e kg/bbl)	Prod. electricity & pumps (CO2e kg/bbl)	Prod. steam (CO2e kg/bbl)	Production GHG (CO2e kg/bbl)
Alaska	37.5: Light	3	1%	3.42	1.49	1.85	2.27	1.50	2.52	0.93	-	13.97
East	37.5: Light	4	3%	3.38	1.65	1.51	2.40	1.61	2.12	5.20	-	17.87
Gulf Coast	37.5: Light	121	17%	3.37	4.36	1.64	2.35	1.56	2.22	5.59	-	21.09
Gulf Offshore	37.5: Light	675	40%	1.37	0.58	1.42	2.43	1.62	4.81	0.43	-	12.66
Midcontinent	37.5: Light	71	13%	3.17	1.64	1.63	2.36	1.57	2.33	4.66	-	17.36
Northern Great Plains	37.5: Light	94	8%	2.79	5.54	2.26	2.12	1.38	3.20	1.25	-	18.54
Pacific Offshore	37.5: Light	2	14%	1.38	1.89	0.82	2.67	1.80	2.60	1.03	-	12.20
Rocky Mountain	37.5: Light	107	12%	3.06	1.10	2.37	2.07	1.35	3.44	3.34	-	16.73
Southwest	37.5: Light	769	15%	2.80	3.85	2.44	2.05	1.33	3.50	1.93	-	17.90
West Coast	37.5: Light	11	3%	3.96	2.00	0.55	2.77	1.90	0.62	5.24	37.17	54.21

Exhibit 18 shows GHG emission intensity data for countries other than the US and Canada aggregated into the regions used for EIA's International Energy Outlook. (More detailed data by country is contained in Appendix A.) Exhibit 19 covers the same crude and condensate volumes but reports statistics for all countries aggregated by API gravity.

Exhibit 18: GHG Emission Intensity for World Crudes and Condensates by Region (exc. US & Can.)

		Kilograms CO2e per barrel of crude and condensate (LCA basis)								
IEO Model Region	2020 Oil Production (kbpd)	Prod. well construction (CO2e kg/bbl)	Prod. vented & flared (CO2e kg/bbl)	Prod. lease compression (CO2e kg/bbl)	Prod. oil stabilization (CO2e kg/bbl)	Prod. storage fugitives (CO2e kg/bbl)	Prod. methane leaks (CO2e kg/bbl)	Prod. electricity & pumps (CO2e kg/bbl)	Prod. steam (CO2e kg/bbl)	Production GHG (CO2e kg/bbl)
OPEC Middle East	21,820	0.04	9.99	1.56	2.40	2.72	2.84	1.27	-	20.82
OPEC North Africa	1,531	0.08	37.86	1.84	2.20	2.59	2.85	3.00	-	50.41
OPEC Central and West Africa	3,636	0.20	17.70	1.88	2.26	2.58	6.16	1.48	-	32.27
OPEC South America	527	0.15	30.12	1.84	2.34	2.50	2.73	2.88	12.65	55.20
Mexico	1,710	0.09	20.70	1.23	2.57	2.81	3.44	1.86	-	32.71
Other OECD Americas	783	0.20	5.31	1.75	2.33	2.57	2.71	0.81	-	15.69
OECD Europe	3,031	0.35	6.20	2.27	2.10	2.39	9.08	2.01	-	24.40
Australia and New Zealand	361	0.30	16.98	1.52	2.38	2.71	5.22	0.69	-	29.82
Other OECD Asia	-									
Russia	9,865	0.88	15.19	1.02	2.60	2.92	1.46	2.72	-	26.79
Caspian Area	2,651	0.41	7.43	1.83	2.27	2.62	3.92	1.40	-	19.88
Other non-OECD Europe and	191	1.63	6.44	1.51	2.42	2.71	2.58	1.69	-	18.98
China	3,889	0.63	4.56	0.94	2.65	2.95	1.87	1.83	-	15.42
India	627	0.42	10.89	2.92	1.84	2.16	9.49	1.46	-	29.18
Other non-OECD Asia	1,902	0.54	11.80	2.34	2.06	2.38	7.93	1.26	5.37	33.68
Oman	949	0.22	12.01	1.28	2.49	2.80	1.88	1.09	-	21.77
Other Middle East	1,557	0.10	7.36	2.56	2.00	2.32	6.29	4.10	-	24.74
Non-OPEC Africa	1,288	0.62	22.08	1.77	2.32	2.61	5.63	1.50	-	36.52
Brazil	2,940	0.39	2.93	1.19	2.58	2.83	3.63	2.99	-	16.54
Other non-OECD Americas	1,223	0.83	11.81	1.59	2.42	2.66	3.12	1.06	-	23.48
World Sum (ex. US & Can.)	**60,482**	**0.34**	**11.78**	**1.55**	**2.40**	**2.71**	**3.55**	**1.82**	**0.28**	**24.43**

Exhibit 19: GHG Emission Intensity for World Crude and Condensates by API Gravity (exc. US & Can.)

		Kilograms CO2e per barrel of crude and condensate (LCA basis)								
API Gravity Classification	2020 Oil Production (kbpd)	Prod. well construction (CO2e kg/bbl)	Prod. vented & flared (CO2e kg/bbl)	Prod. lease compression (CO2e kg/bbl)	Prod. oil stabilization (CO2e kg/bbl)	Prod. storage fugitives (CO2e kg/bbl)	Prod. methane leaks (CO2e kg/bbl)	Prod. electricity & pumps (CO2e kg/bbl)	Prod. steam (CO2e kg/bbl)	Production GHG (CO2e kg/bbl)
05.5: Extra Heavy	81	0.04	30.59	0.87	2.78	2.68	1.05	1.67	-	39.68
12.5: Heavy	401	0.38	7.81	0.61	2.87	2.86	0.81	2.52	16.61	34.46
17.5: Heavy	1,077	0.53	6.71	1.02	2.69	2.80	3.60	1.27	9.48	28.11
22.5: Heavy	6,050	0.33	13.96	0.89	2.72	2.91	2.10	1.69	-	24.60
27.5: Medium	8,523	0.33	14.64	0.97	2.66	2.92	2.24	1.65	-	25.41
32.5: Medium	20,861	0.29	9.49	1.29	2.51	2.83	2.56	1.80	-	20.76
37.5: Light	12,544	0.43	11.46	2.02	2.20	2.55	4.66	2.16	-	25.47
42.5: Light	7,050	0.31	13.74	2.35	2.03	2.41	6.10	1.85	-	28.79
47.5: Light	2,902	0.29	14.17	2.45	1.96	2.37	6.04	1.45	-	28.72
52.5: Light	711	0.48	13.06	2.11	2.06	2.50	5.33	1.76	-	27.30
57.5: Light	102	0.35	14.22	3.11	1.61	2.02	7.96	0.60	-	29.87
62.5: Light	4	0.24	6.25	4.35	1.00	1.31	7.74	0.31	-	21.21
67.5: Light	177	0.04	2.02	4.84	0.76	1.02	8.61	1.13	-	18.42
World Sum (ex. US & Can.)	**60,482**	**0.34**	**11.78**	**1.55**	**2.40**	**2.71**	**3.55**	**1.82**	**0.28**	**24.43**

The difference between the world GHG emission intensity averages and the US GHG emission intensity averages are shown in Exhibit 20 by API gravity classification. The results for the heaviest crude classification (less than 17.5°) and those of the lightest category (greater than 57.5°) are distorted somewhat by the fact that API gravity is reported by EIA within a limited number of broad classes, while the international data used for this analysis contains API gravity for each field. Caution should also be exercised in comparing the bottom-line average across all gravities because the weighted average gravity for the US crudes and condensates (40.7°) is higher than those of the world outside of the US and Canada (34.1°).

Allowing for these issues that make a pure apples-to-apples comparison difficult, one can see in Exhibit 20 some notable differences that are not simply due to a different mix of crude being produced:

- The US has lower GHG emission intensity from production flaring and venting of associated gas production (-9.23 CO_2e kg/bbl) and storage tanks (-1.45 CO_2e kg/bbl). This is the main reason US oil production has a lower GHG emission intensity compared to much of the rest of the world.
- The US has a greater contribution from well construction (+2.27 CO_2e kg/bbl) than the world comparison. This is due to the fact that US oil fields are drilled more intensely and oil production per well is lower. This reduces the advantage for US production.
- Another set of reductions in the GHG emission intensity advantage from US production comes from the US tending to produce more natural gas with its oil (+1.10 CO_2e kg/bbl for lease compression and +1.15 CO_2e kg/bbl for methane leaks) and using more electricity and steam for enhanced oil recovery (+1.0 CO_2e kg/bbl for EOR steam).
- This is offset somewhat by the US using less energy for stabilization (-0.49 CO_2e kg/bbl).

The approximate “real” difference that one might expect from increasing the production and use of an average US crude or condensate to replace an average crude from outside of the US might be about -5.7 CO_2e kg/bbl or about a 23% reduction of the 24.4 CO_2e kg/bbl international average shown in Exhibit 19. This adds together all of the production related GHG emission intensity differences but excludes refining and combustion factors, which are driven by the mix of API gravity and would disappear if like crudes were substituted for each other. It also excludes product transportation since the simple substitution of one crude for each another is unlikely to change the distance over which products travel from refineries to consumers.

Using the same sort of reasoning one can estimate that increasing production and use of Gulf of Mexico’s largest crude category (API gravity 37.5°) in place of the average of similar crudes from outside of the US and Canada might be expected to change GHG emission intensities by about -12.8 CO_2e kg/bbl or about a 50% reduction from the 25.5 CO_2e kg/bbl international average shown in Exhibit 19. The increased positive impact of Gulf of Mexico oil production as compared to the US as a whole is due to the factors discussed above: higher well productivity, less energy used per unit of production, and relatively lower methane emissions. This favorable ranking of Gulf of Mexico oil production relative to other regions of the world also holds true over the range of sensitivities (on methane release rates and the global warming potentials factor for methane) that are shown in Appendix B.

Exhibit 20: Difference in GHG Emission Intensity for US versus World by API Gravity (exc. Can.)

	US Average minus World (Non-US, Non-Can.) Averages by API Gravity (kg/bbl. LCA basis)								
	Prod. well construction (CO2e kg/bbl)	Prod. vented & flared (CO2e kg/bbl)	Prod. lease compression (CO2e kg/bbl)	Prod. oil stabilization (CO2e kg/bbl)	Prod. storage fugitives (CO2e kg/bbl)	Prod. methane leaks (CO2e kg/bbl)	Prod. electricity & pumps (CO2e kg/bbl)	Prod. steam (CO2e kg/bbl)	Production GHG (CO2e kg/bbl)
<=17.5: Heavy	3.79	(4.70)	(0.47)	0.20	(1.01)	(2.98)	4.01	27.92	26.76
22.5: Heavy	2.45	(12.10)	0.63	(0.24)	(1.35)	1.05	0.98	5.36	(3.22)
27.5: Medium	2.26	(13.37)	0.42	(0.15)	(1.31)	1.07	0.16	7.43	(3.49)
32.5: Medium	2.35	(6.51)	0.80	(0.30)	(1.40)	1.04	0.32	0.26	(3.43)
37.5: Light	1.93	(8.94)	(0.06)	0.03	(1.08)	(0.85)	(0.36)	0.21	(9.12)
42.5: Light	2.48	(10.17)	0.04	(0.01)	(1.07)	(2.65)	0.38	0.03	(10.96)
47.5: Light	2.34	(11.26)	0.74	(0.31)	(1.26)	(0.65)	0.12	-	(10.29)
52.5: Light	1.82	(12.76)	3.64	(1.57)	(2.16)	6.03	(1.54)	-	(6.54)
>=57.5: Light	2.04	(6.21)	1.48	(0.65)	(1.09)	2.99	(0.78)	-	(2.22)
Grand Total	**2.27**	**(9.23)**	**1.10**	**(0.49)**	**(1.45)**	**1.15**	**(0.04)**	**1.00**	**(5.68)**

Source: ICF analysis. Negative values indicate US crudes and condensates have lower GHG emission intensity per barrel compared to crude and condensate produced outside of the US and Canada. Since US crudes have a higher weighted average gravity (40.7°) as compared to those of the world outside of the US and Canada (34.1°) the "Grand Total" row should be interpreted with caution.

3.1 Conclusions

Estimation of GHG

- The estimation of the production related GHG for various crude oils and condensates is a complex process that is hindered by lack of public, up-to-date, and high-quality data.
- Around the world and even in the US, there is considerable controversy regarding certain critical data including quantity of gas flared, operational flare efficiencies, and the volumes of methane releases along oil and gas supply chains.
- Analysis and reconciliation of published reports on GHG emission intensity of the oil supply chain is hindered by wide differences in geographic scope, analysis boundaries (both in the sense of which oil supply chain components are included and if terms of conventions for LCA boundaries[13]), methodology, tools, data, and assumptions. Insufficient documentation in some published studies also makes comparisons difficult.
- This study was able to address many of the common shortcomings of similar studies by looking at virtually all of the world's oil production with a consistent scope and analytic method. However, this study could not overcome the absence of universal, reliable, up-to-date, and public field-level data for such items as production rates, water-to-gas ratios, production methods and energy use.
- This study also could not resolve the uncertainties mentioned above regarding flaring and methane releases. For the US, the study adopted the data from the EPA GHG

[13] The differences most often encountered are whether or not the GHG emissions related to facilities construction is included in the LCA analysis. For this study, these so called "embodied emissions" were included.

Inventory regarding methane releases and for the rest of the world relied on UN flaring data and IEA's 2020 Methane Tracker for estimates for methane and N_2O releases associated with each primary energy source.

- Sensitivity analyses were also performed under which higher methane releases as estimated by the IEA in its Methane Tracker and a higher methane GWP of 34 were used. These are summarized in Exhibit 21 and shown in more detail in Appendix B.

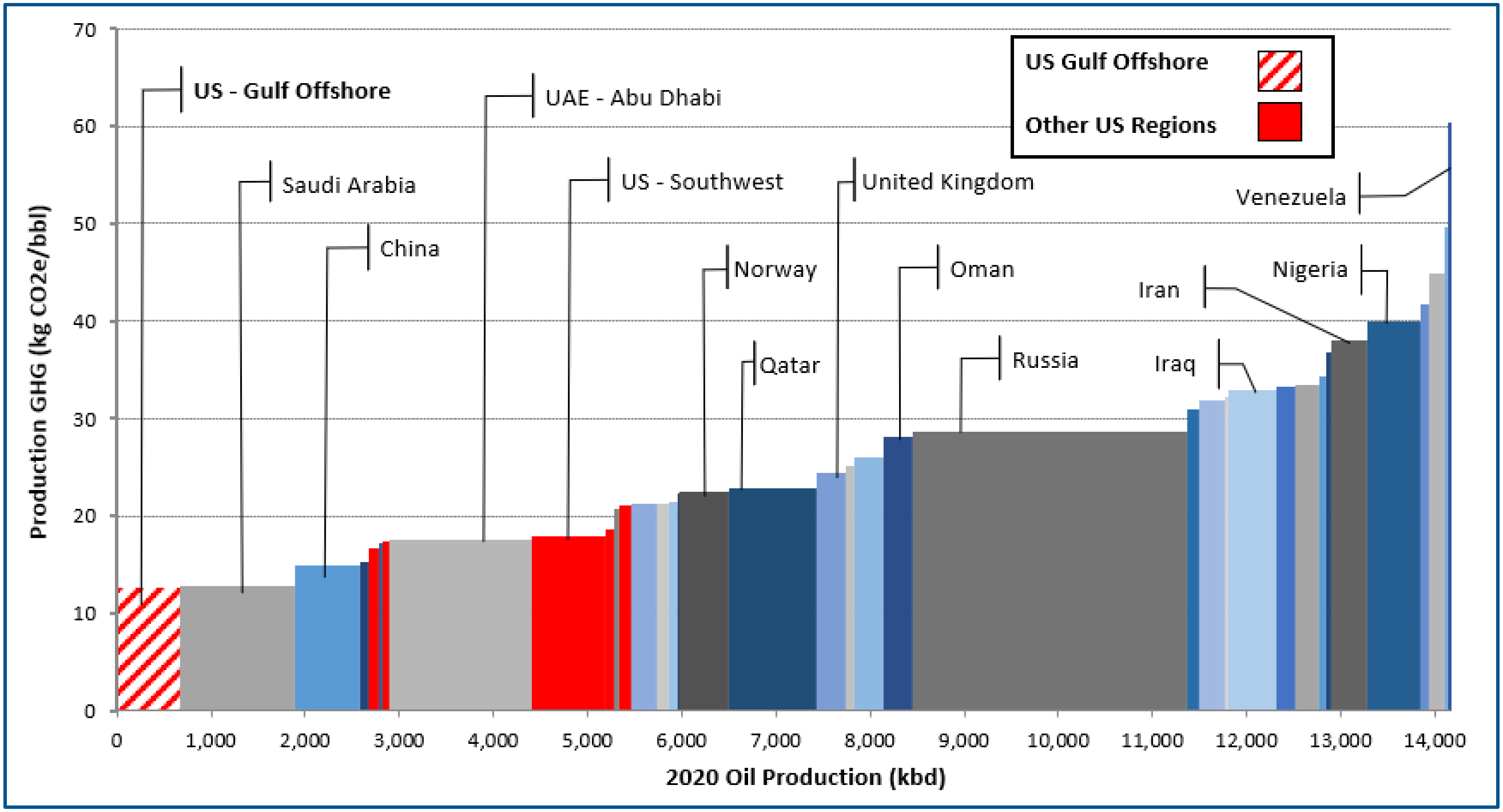
Comparison of GHG of GoM and All US Oils with World Supplies

- A comparison of GHG for production for various crudes in the API gravity 37.5° category (the largest portion for GoM production) is shown in Exhibit 22. Increasing production and use of GoM API gravity 37.5° crude in place of the average of similar crudes from outside of the US might be expected to change GHG emission intensities by about -12.8 CO_2e kg/bbl or about -50%. The increased positive impact of Gulf of Mexico oil production as compared to the US as a whole is due to higher well productivity and less energy used per unit of production.
- Similarly, Exhibit 23 provides a comparison of GHG for production for various crudes as shown in Exhibit 22, but includes volumes across all API gravity categories. Gulf of Mexico oil production is again one of the lowest emitting crude oils, and the lowest for any US region.
- ❖ These charts are based on applying US emission factors for methane (except for methane emissions related to flaring) and a GWP for methane of 25. Three sensitivity analyses were performed to test how the use of methane emission tonnage estimated by the International Energy Agency and a GWP of 34 (used by IEA and others) would affect the relative standing of the GoM. As shown below in Exhibit 21, under these alternative methane assumptions the GHG emissions intensities of all regions increase, but the GoM's relative standing improves. GoM oil production is 13.4 CO_2e kg/bbl below the world average in the Base Case and that difference increase to between 14.2 to 26.4 CO_2e kg/bbl in the sensitivities.

Exhibit 21: Sensitivity Analyses of Methane Emissions and Methane GWP

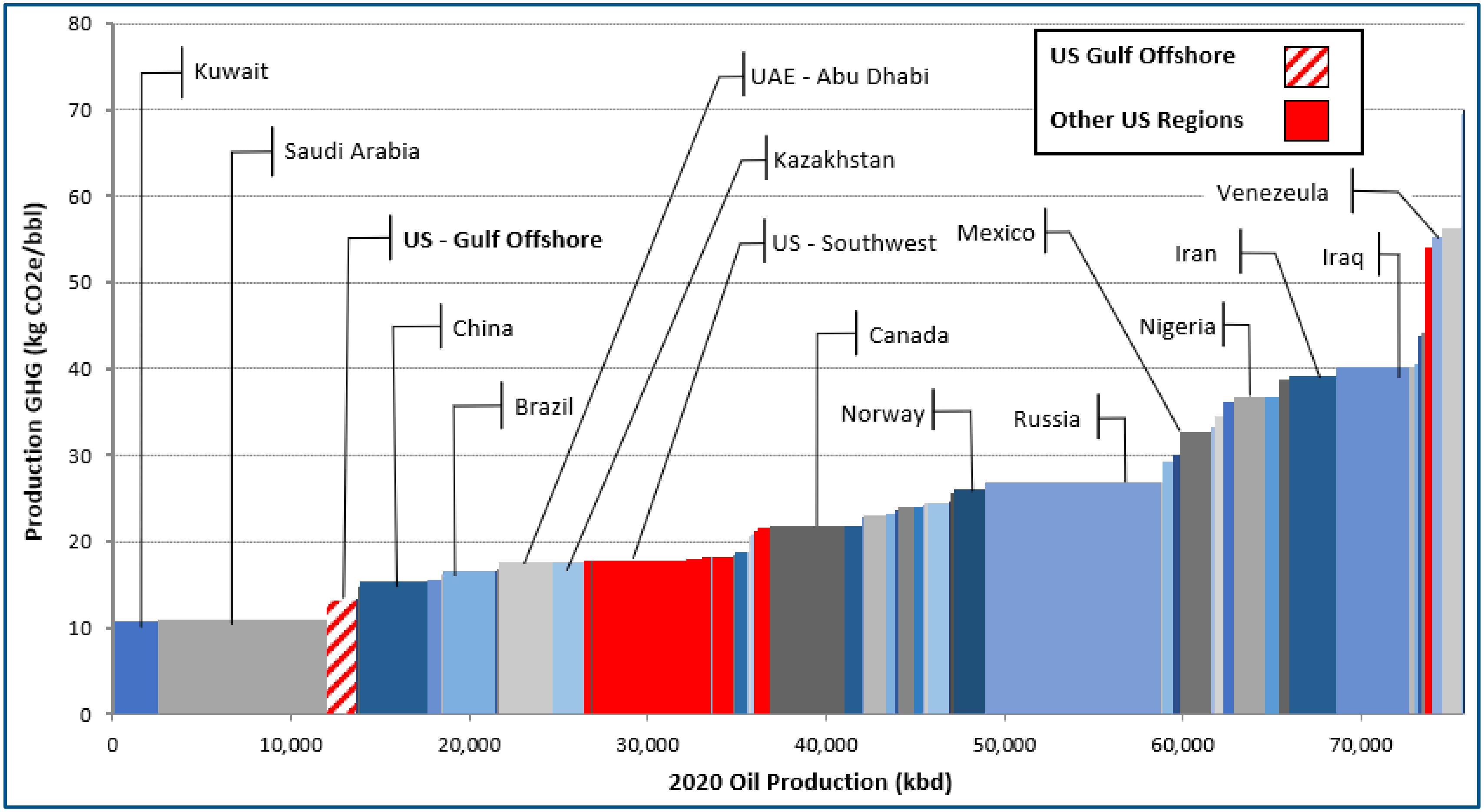
	All GHG in Kilograms CO2e per Barrel of Oil (Year 2020)			
Region	Base Case (GWP=25)	Base Case CH4 Volumes but GWP=34	IEA CH4 Volume Multipliers for All Countries (GWP=25)	IEA CH4 Vol. Multipliers + GWP=34
US GOM	13.1	15.0	18.5	22.4
US Total	18.7	20.6	23.9	27.6
Canada	77.2	81.3	84.0	90.6
Rest of World	24.4	27.3	41.1	49.9
World Average	26.5	29.2	40.9	48.8
Gap Between GoM and World Average	**-13.4**	**-14.2**	**-22.4**	**-26.4**
Notes: Production only. Excludes crude transportation, petroleum refining, petroleum product distribution, dispensing and use.				

Exhibit 22: Comparison of Production Volumes and Production GHG emission intensity for Gulf of Mexico and Other US Regions and Other Countries Crude Oil in API 37.5° Category



Source: ICF analysis of GHG emission intensity from the production stage only (that is exclusive of crude transport, refining, petroleum product transport, petroleum product distribution & dispensing and petroleum production utilization). The quantity of oil in the API 37.5° category for each US region and foreign country is indicated by the width of each rectangle. Worldwide production of this category of crude is 15.8 million barrels per day. The gray and blue rectangles are individual foreign countries. More detailed information for each country appears in Appendix A.

Exhibit 23: Comparison of Production Volumes and Production GHG emission intensity for Gulf of Mexico and Other US Regions and Other Countries Crude Oil across all API gravity categories



Source: ICF analysis of GHG emission intensity from the production stage only (that is exclusive of crude transport, refining, petroleum product transport, petroleum product distribution & dispensing and petroleum production utilization). The quantity of oil for each US region and foreign country is indicated by the width of each rectangle. Worldwide production of this category of crude is 75.6 million barrels per day. The gray and blue rectangles are individual foreign countries. More detailed information for each country appears in Appendix A.

3.2 Caveats

The authors of this report wish to highlight these caveats on data quality and other issues that can affect the estimates presented here:

- Data related to US oil and gas production are generally up-to-date and accurate but certain data are out of date or are lacking altogether and have to be estimated. For example, the Oil and Gas Journal Survey of EOR which was used to help identify where and how much EOR occurs in the US was last published in 2014. There is no comprehensive survey of electricity and machine drive use in oil and gas fields and one of the key variables for estimating it (water to oil production ratios) is not reported in some states (including Texas).
- Data on international oil and gas field productions is reported inconsistently so this report had to rely on field production values that were often several years old. Production by country was scaled to actual 2020 production so the total production by country and NEMS region is accurate. But the mix by basin, field, and API gravity could be inaccurate. Also, the identification of international EOR projects suffers from the same reliance on the O&GJ EOR survey of 2014.
- The uncertainties related to the estimation methane releases in the EPA GHG Inventory (to which this report has calibrated its numbers) has been raised earlier in this report. The US Inventory values for methane releases are usually based on EPA's equipment-specific emission factors that are often several years old. The testing and improvement methods to measure methane emission using remote sensing technologies is being pursued aggressively by governments and private companies. Studies based on these emerging techniques often suggest that the EPA GHG Inventory methane release values are understated. However, it is not clear how the eventual improvements that new technologies will bring to the estimation/measurement of methane releases will affect the relative ranking of different crudes and other fuels in the US and around the world since the same estimation problems affect the methane release values which are incorporated into the LCAs for natural gas and coal. See Appendix B for more discussion on these topics.

4. Appendix A: Detailed Results for the Oil Supply Chain (Base Case)

				Kilograms CO2e per barrel of crude and condensate (LCA basis)								
NEMS Region	API Gravity Classification	2020 Oil Production (kbpd)	Fraction of Oil Production	Prod. well construction (CO2e kg/bbl)	Prod. vented & flared (CO2e kg/bbl)	Prod. lease compression (CO2e kg/bbl)	Prod. oil stabilization (CO2e kg/bbl)	Prod. storage fugitives (CO2e kg/bbl)	Prod. methane leaks (CO2e kg/bbl)	Prod. electricity & pumps (CO2e kg/bbl)	Prod. steam (CO2e kg/bbl)	Production GHG (CO2e kg/bbl)
Alaska	22.5: Heavy	11	2%	3.65	1.51	1.87	2.35	1.46	2.56	0.95	-	14.36
Alaska	27.5: Medium	250	56%	3.58	1.50	1.87	2.33	1.47	2.55	0.94	-	14.24
Alaska	32.5: Medium	8	2%	3.50	1.49	1.86	2.30	1.49	2.53	0.94	-	14.11
Alaska	37.5: Light	3	1%	3.42	1.49	1.85	2.27	1.50	2.52	0.93	-	13.97
Alaska	42.5: Light	1	0%	3.34	1.48	1.84	2.24	1.50	2.51	0.93	-	13.83
Alaska	47.5: Light	58	13%	3.73	0.07	6.37	0.27	0.19	13.13	0.09	-	23.85
Alaska	52.5: Light	58	13%	3.64	0.07	6.23	0.27	0.19	12.84	0.09	-	23.33
Alaska	62.5: Light	58	13%	3.50	0.07	6.03	0.26	0.18	12.41	0.09	-	22.54
Alaska	Total	449	100%	3.59	0.94	3.56	1.53	0.97	6.54	0.61	-	17.75
East	22.5: Heavy	9	6%	3.37	1.36	2.65	2.05	1.28	4.01	2.68	-	17.39
East	27.5: Medium	9	6%	3.30	1.35	2.62	2.03	1.29	3.97	2.67	-	17.23
East	32.5: Medium	4	3%	3.46	1.66	1.52	2.42	1.59	2.13	5.21	-	18.01
East	37.5: Light	4	3%	3.38	1.65	1.51	2.40	1.61	2.12	5.20	-	17.87
East	42.5: Light	5	3%	3.38	1.76	1.14	2.51	1.72	1.50	6.06	-	18.07
East	47.5: Light	5	3%	3.26	1.71	1.29	2.42	1.68	1.87	5.88	-	18.12
East	52.5: Light	54	35%	2.02	0.26	5.80	0.43	0.30	12.73	0.19	-	21.73
East	62.5: Light	65	42%	1.77	0.03	6.29	0.10	0.07	14.34	0.02	-	22.62
East	Total	154	100%	2.22	0.45	5.14	0.70	0.47	11.17	1.02	-	21.18
Gulf Coast	22.5: Heavy	23	3%	3.44	3.61	1.23	2.60	1.63	1.61	4.93	-	19.05
Gulf Coast	27.5: Medium	23	3%	3.37	3.59	1.23	2.57	1.65	1.61	4.91	-	18.94
Gulf Coast	32.5: Medium	121	17%	3.44	4.38	1.65	2.38	1.55	2.23	5.61	-	21.25
Gulf Coast	37.5: Light	121	17%	3.37	4.36	1.64	2.35	1.56	2.22	5.59	-	21.09
Gulf Coast	42.5: Light	163	23%	3.31	4.37	1.70	2.29	1.55	2.32	5.72	-	21.27
Gulf Coast	47.5: Light	189	27%	3.33	3.31	2.90	1.75	1.20	5.12	4.75	-	22.36
Gulf Coast	52.5: Light	34	5%	3.61	0.33	5.89	0.42	0.29	12.02	0.51	-	23.08
Gulf Coast	62.5: Light	34	5%	3.48	0.25	5.89	0.32	0.23	12.02	0.30	-	22.49
Gulf Coast	Total	707	100%	3.38	3.65	2.38	2.01	1.34	3.93	4.85	-	21.52

				Kilograms CO2e per barrel of crude and condensate (LCA basis)								
NEMS Region	API Gravity Classification	2020 Oil Production (kbpd)	Fraction of Oil Production	Prod. well construction (CO2e kg/bbl)	Prod. vented & flared (CO2e kg/bbl)	Prod. lease compression (CO2e kg/bbl)	Prod. oil stabilization (CO2e kg/bbl)	Prod. storage fugitives (CO2e kg/bbl)	Prod. methane leaks (CO2e kg/bbl)	Prod. electricity & pumps (CO2e kg/bbl)	Prod. steam (CO2e kg/bbl)	Production GHG (CO2e kg/bbl)
Gulf Offshore	22.5: Heavy	84	5%	1.47	0.58	1.43	2.52	1.57	4.87	0.43	-	12.88
Gulf Offshore	27.5: Medium	576	34%	1.44	0.58	1.43	2.49	1.59	4.85	0.43	-	12.81
Gulf Offshore	32.5: Medium	324	19%	1.41	0.58	1.42	2.46	1.61	4.83	0.43	-	12.74
Gulf Offshore	37.5: Light	675	40%	1.37	0.58	1.42	2.43	1.62	4.81	0.43	-	12.66
Gulf Offshore	42.5: Light	10	1%	1.34	0.57	1.41	2.40	1.63	4.79	0.42	-	12.57
Gulf Offshore	47.5: Light	19	1%	1.32	0.04	6.10	0.41	0.28	30.97	0.06	-	39.17
Gulf Offshore	52.5: Light	2	0%	1.28	0.04	5.97	0.40	0.28	30.33	0.06	-	38.36
Gulf Offshore	62.5: Light	1	0%	1.24	0.04	5.78	0.39	0.27	29.37	0.06	-	37.14
Gulf Offshore	Total	1,690	100%	1.40	0.57	1.48	2.44	1.59	5.16	0.42	-	13.07
Midcontinent	22.5: Heavy	21	4%	3.45	1.76	1.32	2.56	1.62	1.87	5.66	-	18.23
Midcontinent	27.5: Medium	21	4%	3.38	1.76	1.31	2.53	1.64	1.86	5.65	-	18.13
Midcontinent	32.5: Medium	71	13%	3.24	1.64	1.64	2.38	1.56	2.35	4.67	-	17.49
Midcontinent	37.5: Light	71	13%	3.17	1.64	1.63	2.36	1.57	2.33	4.66	-	17.36
Midcontinent	42.5: Light	144	25%	2.92	1.40	2.32	2.06	1.37	3.35	2.35	-	15.76
Midcontinent	47.5: Light	144	25%	2.45	0.63	4.61	1.03	0.71	8.72	1.18	-	19.34
Midcontinent	52.5: Light	48	8%	2.19	0.23	5.69	0.51	0.36	11.33	0.73	-	21.05
Midcontinent	62.5: Light	48	8%	2.14	0.14	5.77	0.38	0.27	11.59	0.35	-	20.64
Midcontinent	Total	567	100%	2.78	1.09	3.23	1.64	1.09	5.72	2.57	-	18.12
Northern Great Plains	22.5: Heavy	5	0%	3.02	5.42	2.09	2.27	1.41	2.94	1.51	-	18.66
Northern Great Plains	27.5: Medium	5	0%	2.95	5.39	2.08	2.25	1.42	2.92	1.50	-	18.52
Northern Great Plains	32.5: Medium	94	8%	2.86	5.58	2.27	2.15	1.38	3.22	1.26	-	18.71
Northern Great Plains	37.5: Light	94	8%	2.79	5.54	2.26	2.12	1.38	3.20	1.25	-	18.54
Northern Great Plains	42.5: Light	514	41%	2.70	5.49	2.36	2.04	1.35	3.38	1.01	-	18.33
Northern Great Plains	47.5: Light	514	41%	2.58	5.16	2.51	1.94	1.31	3.67	0.96	-	18.12
Northern Great Plains	52.5: Light	8	1%	1.99	2.25	3.88	1.32	0.90	6.45	0.81	-	17.61
Northern Great Plains	62.5: Light	8	1%	1.92	2.15	3.85	1.27	0.88	6.43	0.76	-	17.25
Northern Great Plains	Total	1,243	100%	2.66	5.32	2.43	2.00	1.33	3.51	1.03	-	18.28

				Kilograms CO2e per barrel of crude and condensate (LCA basis)								
NEMS Region	API Gravity Classification	2020 Oil Production (kbpd)	Fraction of Oil Production	Prod. well construction (CO2e kg/bbl)	Prod. vented & flared (CO2e kg/bbl)	Prod. lease compression (CO2e kg/bbl)	Prod. oil stabilization (CO2e kg/bbl)	Prod. storage fugitives (CO2e kg/bbl)	Prod. methane leaks (CO2e kg/bbl)	Prod. electricity & pumps (CO2e kg/bbl)	Prod. steam (CO2e kg/bbl)	Production GHG (CO2e kg/bbl)
Pacific Offshore	22.5: Heavy	2	13%	1.47	1.91	0.83	2.75	1.74	2.62	1.04	-	12.36
Pacific Offshore	27.5: Medium	2	13%	1.44	1.90	0.83	2.72	1.77	2.61	1.04	-	12.31
Pacific Offshore	32.5: Medium	2	14%	1.41	1.90	0.83	2.69	1.79	2.61	1.03	-	12.26
Pacific Offshore	37.5: Light	2	14%	1.38	1.89	0.82	2.67	1.80	2.60	1.03	-	12.20
Pacific Offshore	42.5: Light	2	20%	1.35	1.89	0.82	2.64	1.82	2.59	1.03	-	12.13
Pacific Offshore	47.5: Light	2	20%	1.32	1.89	0.82	2.61	1.83	2.59	1.02	-	12.06
Pacific Offshore	Total	13	100%	1.37	1.88	0.85	2.65	1.79	2.75	1.02	-	12.32
Rocky Mountain	22.5: Heavy	17	2%	3.38	1.61	1.79	2.38	1.48	2.45	5.85	-	18.95
Rocky Mountain	27.5: Medium	17	2%	3.31	1.60	1.78	2.36	1.50	2.44	5.83	-	18.83
Rocky Mountain	32.5: Medium	107	12%	3.13	1.10	2.39	2.09	1.35	3.47	3.35	-	16.89
Rocky Mountain	37.5: Light	107	12%	3.06	1.10	2.37	2.07	1.35	3.44	3.34	-	16.73
Rocky Mountain	42.5: Light	193	22%	3.00	1.11	2.47	2.00	1.32	3.61	3.34	-	16.86
Rocky Mountain	47.5: Light	203	23%	3.06	0.89	3.17	1.66	1.12	5.32	2.55	-	17.76
Rocky Mountain	52.5: Light	119	13%	2.50	0.12	5.61	0.56	0.38	10.69	0.18	-	20.06
Rocky Mountain	62.5: Light	118	13%	2.40	0.11	5.47	0.53	0.37	10.43	0.17	-	19.47
Rocky Mountain	Total	881	100%	2.90	0.81	3.41	1.56	1.03	5.79	2.40	-	17.91
Southwest	22.5: Heavy	31	1%	2.99	3.70	2.53	2.10	1.29	3.65	1.45	-	17.71
Southwest	27.5: Medium	31	1%	2.92	3.68	2.52	2.08	1.31	3.63	1.44	-	17.57
Southwest	32.5: Medium	769	15%	2.87	3.87	2.46	2.08	1.33	3.53	1.94	-	18.07
Southwest	37.5: Light	769	15%	2.80	3.85	2.44	2.05	1.33	3.50	1.93	-	17.90
Southwest	42.5: Light	1,624	31%	2.75	3.40	2.48	1.99	1.32	3.58	2.12	-	17.63
Southwest	47.5: Light	1,588	30%	2.49	2.75	3.15	1.67	1.12	5.07	1.36	-	17.61
Southwest	52.5: Light	210	4%	1.73	0.40	5.75	0.50	0.35	10.93	0.10	-	19.75
Southwest	62.5: Light	210	4%	1.67	0.39	5.57	0.49	0.34	10.59	0.09	-	19.14
Southwest	Total	5,232	100%	2.61	3.10	2.93	1.80	1.18	4.59	1.66	-	17.87

NEMS Region	API Gravity Classification	2020 Oil Production (kbpd)	Fraction of Oil Production	Kilograms CO2e per barrel of crude and condensate (LCA basis)								
				Prod. well construction (CO2e kg/bbl)	Prod. vented & flared (CO2e kg/bbl)	Prod. lease compression (CO2e kg/bbl)	Prod. oil stabilization (CO2e kg/bbl)	Prod. storage fugitives (CO2e kg/bbl)	Prod. methane leaks (CO2e kg/bbl)	Prod. electricity & pumps (CO2e kg/bbl)	Prod. steam (CO2e kg/bbl)	Production GHG (CO2e kg/bbl)
West Coast	17.5: Heavy	100	25%	4.32	2.01	0.56	2.89	1.79	0.63	5.28	37.40	54.87
West Coast	22.5: Heavy	34	9%	4.23	2.01	0.56	2.86	1.83	0.62	5.27	37.35	54.72
West Coast	27.5: Medium	232	58%	4.14	2.01	0.55	2.83	1.86	0.62	5.26	37.29	54.56
West Coast	32.5: Medium	11	3%	4.05	2.00	0.55	2.80	1.88	0.62	5.25	37.23	54.39
West Coast	37.5: Light	11	3%	3.96	2.00	0.55	2.77	1.90	0.62	5.24	37.17	54.21
West Coast	42.5: Light	2	0%	3.87	2.00	0.55	2.75	1.91	0.62	5.23	37.13	54.06
West Coast	47.5: Light	8	2%	3.79	0.10	6.23	0.34	0.24	12.41	0.30	-	23.41
West Coast	Total	398	100%	4.18	1.97	0.68	2.79	1.80	0.87	5.16	36.53	53.98
US	Total	11,334	100%	2.60	2.56	2.65	1.91	1.26	4.70	1.78	1.28	18.75

				Kilograms CO2e per barrel of crude and condensate (LCA basis)								
Canadian Source	Average API Gravity	2020 Oil Production (kbpd)	Fraction of Oil Production	Prod. well construction (CO2e kg/bbl)	Prod. vented & flared (CO2e kg/bbl)	Prod. lease compression (CO2e kg/bbl)	Prod. oil stabilization (CO2e kg/bbl)	Prod. storage fugitives (CO2e kg/bbl)	Prod. methane leaks (CO2e kg/bbl)	Prod. electricity & pumps (CO2e kg/bbl)	Prod. steam (CO2e kg/bbl)	Production GHG (CO2e kg/bbl)
Canadian Oil Sands Mining + SCO:	33.0	1,376	32.9%									126.90
Canadian Oil Sands In-situ + Dilbit:	21.0	1,471	35.2%									82.30
Western Light	38.0	502	12.0%	3.26	1.17	2.53	2.20	1.44	3.66	3.55	0.00	17.82
Western Heavy	21.0	257	6.1%	4.25	2.02	2.25	3.00	1.86	3.08	7.36	0.00	23.84
Condensate	50.0	345	8.3%	2.47	0.12	5.55	0.56	0.38	10.58	0.18	0.00	19.85
Eastern	34.6	229	5.5%	0.16	1.11	2.90	1.83	2.13	11.50	2.10	0.00	21.73
Total	30.1	4,180	100.0%									77.17

				Kilograms CO2e per barrel of crude and condensate (LCA basis)								
Country	API Gravity Classification	2020 Oil Production (kbpd)	Fraction of Oil Production	Prod. well construction (CO2e kg/bbl)	Prod. vented & flared (CO2e kg/bbl)	Prod. lease compression (CO2e kg/bbl)	Prod. oil stabilization (CO2e kg/bbl)	Prod. storage fugitives (CO2e kg/bbl)	Prod. methane leaks (CO2e kg/bbl)	Prod. electricity & pumps (CO2e kg/bbl)	Prod. steam (CO2e kg/bbl)	Production GHG (CO2e kg/bbl)
Albania	12.5: Heavy	11	62%	3.24	7.74	1.40	2.57	2.62	1.82	2.05	-	21.43
Albania	17.5: Heavy	2	14%	2.08	8.40	0.87	2.77	2.84	1.04	1.63	-	19.63
Albania	22.5: Heavy	2	9%	5.46	6.47	2.41	2.14	2.37	3.51	0.76	-	23.13
Albania	47.5: Light	3	15%	0.76	-	1.47	2.36	2.81	1.93	4.39	-	13.72
Albania	**Total**	**17**	**100%**	**2.90**	**6.55**	**1.42**	**2.53**	**2.65**	**1.87**	**2.23**	**-**	**20.16**
Algeria	37.5: Light	8	1%	0.10	28.60	2.76	1.92	2.27	4.06	0.79	-	40.49
Algeria	42.5: Light	570	51%	0.08	49.30	1.43	2.40	2.81	1.93	3.09	-	61.03
Algeria	47.5: Light	302	27%	0.12	55.92	1.46	2.34	2.81	1.97	4.65	-	69.27
Algeria	52.5: Light	58	5%	0.10	43.19	1.41	2.34	2.82	1.92	3.66	-	55.44
Algeria	57.5: Light	12	1%	0.05	40.84	2.86	1.74	2.17	4.26	1.23	-	53.16
Algeria	67.5: Light	173	15%	0.03	2.05	4.82	0.77	1.03	8.56	1.16	-	18.43
Algeria	**Total**	**1,122**	**100%**	**0.08**	**43.25**	**1.98**	**2.12**	**2.53**	**3.00**	**3.21**	**-**	**56.17**
Angola	22.5: Heavy	186	15%	0.10	12.58	0.64	2.82	2.99	1.92	2.61	-	23.66
Angola	27.5: Medium	273	22%	0.11	14.59	0.41	2.88	3.11	1.18	3.28	-	25.56
Angola	32.5: Medium	395	31%	0.23	8.70	1.28	2.52	2.84	4.30	1.93	-	21.79
Angola	37.5: Light	296	24%	0.36	10.82	1.77	2.30	2.66	6.25	1.83	-	25.99
Angola	42.5: Light	42	3%	0.33	11.37	1.81	2.25	2.66	6.45	2.76	-	27.63
Angola	47.5: Light	64	5%	0.26	8.48	3.10	1.72	2.10	12.17	2.40	-	30.24
Angola	**Total**	**1,257**	**100%**	**0.22**	**11.13**	**1.22**	**2.54**	**2.83**	**4.20**	**2.35**	**-**	**24.50**
Argentina	17.5: Heavy	26	5%	1.28	8.61	1.07	2.67	2.79	1.56	1.18	-	19.16
Argentina	22.5: Heavy	85	18%	1.91	11.56	1.51	2.48	2.68	2.27	1.44	-	23.84
Argentina	27.5: Medium	108	23%	1.82	11.34	1.66	2.40	2.65	2.46	1.63	-	23.96
Argentina	32.5: Medium	109	23%	1.55	11.96	1.84	2.29	2.59	3.22	1.67	-	25.14
Argentina	37.5: Light	96	20%	1.05	12.14	2.11	2.15	2.49	3.65	1.52	-	25.11
Argentina	42.5: Light	41	9%	0.67	10.90	2.58	1.94	2.29	4.33	1.13	-	23.83
Argentina	47.5: Light	8	2%	1.05	4.54	4.30	1.16	1.43	8.32	1.14	-	21.95
Argentina	52.5: Light	5	1%	0.28	0.70	5.98	0.37	0.52	12.01	0.15	-	20.01
Argentina	57.5: Light	1	0%	0.76	6.21	4.28	1.12	1.45	15.19	0.58	-	29.59
Argentina	**Total**	**480**	**100%**	**1.46**	**11.26**	**1.90**	**2.27**	**2.54**	**3.17**	**1.49**	**-**	**24.10**

				Kilograms CO2e per barrel of crude and condensate (LCA basis)								
Country	API Gravity Classification	2020 Oil Production (kbpd)	Fraction of Oil Production	Prod. well construction (CO2e kg/bbl)	Prod. vented & flared (CO2e kg/bbl)	Prod. lease compression (CO2e kg/bbl)	Prod. oil stabilization (CO2e kg/bbl)	Prod. storage fugitives (CO2e kg/bbl)	Prod. methane leaks (CO2e kg/bbl)	Prod. electricity & pumps (CO2e kg/bbl)	Prod. steam (CO2e kg/bbl)	Production GHG (CO2e kg/bbl)
Australia	17.5: Heavy	17	5%	0.22	22.78	1.55	2.49	2.63	5.62	0.89	-	36.19
Australia	22.5: Heavy	112	32%	0.09	27.15	0.88	2.74	2.91	2.77	1.30	-	37.83
Australia	27.5: Medium	1	0%	0.55	21.58	2.16	2.21	2.50	7.85	1.27	-	38.13
Australia	32.5: Medium	8	2%	0.61	2.52	0.05	2.98	3.28	0.14	0.42	-	10.00
Australia	37.5: Light	5	1%	0.97	22.56	0.69	2.71	3.08	1.43	2.53	-	33.97
Australia	42.5: Light	64	18%	0.64	12.57	1.03	2.55	2.96	3.21	0.48	-	23.43
Australia	47.5: Light	72	20%	0.37	3.80	2.67	1.88	2.28	9.57	0.19	-	20.76
Australia	52.5: Light	59	17%	0.20	18.83	2.40	1.95	2.39	8.90	0.28	-	34.94
Australia	57.5: Light	13	4%	0.31	21.04	0.48	2.68	3.23	1.29	0.39	-	29.42
Australia	**Total**	**351**	**100%**	**0.31**	**17.25**	**1.53**	**2.38**	**2.71**	**5.28**	**0.70**	**-**	**30.15**
Austria	17.5: Heavy	1	5%	2.01	7.71	1.39	2.56	2.72	1.79	1.34	-	19.52
Austria	22.5: Heavy	9	84%	1.36	5.10	3.51	1.70	1.96	5.43	1.22	-	20.30
Austria	27.5: Medium	0	4%	2.67	4.01	3.82	1.54	1.81	6.25	0.52	-	20.61
Austria	32.5: Medium	0	0%	2.43	4.50	3.88	1.44	1.62	8.57	0.18	-	22.63
Austria	37.5: Light	1	6%	1.45	6.70	2.08	2.19	2.54	3.00	1.88	-	19.84
Austria	**Total**	**11**	**100%**	**1.46**	**5.29**	**3.33**	**1.77**	**2.03**	**5.14**	**1.24**	**-**	**20.25**
Azerbaijan	17.5: Heavy	3	0%	1.83	7.97	1.07	2.68	2.81	1.33	1.41	-	19.10
Azerbaijan	22.5: Heavy	19	3%	4.40	8.09	1.10	2.65	2.82	3.19	1.29	-	23.53
Azerbaijan	27.5: Medium	20	3%	3.15	6.76	2.08	2.22	2.45	7.79	1.91	-	26.37
Azerbaijan	32.5: Medium	617	89%	0.19	1.51	2.12	2.18	2.52	7.78	1.78	-	18.10
Azerbaijan	37.5: Light	28	4%	1.17	5.63	2.89	1.85	2.20	7.10	1.45	-	22.29
Azerbaijan	42.5: Light	6	1%	2.37	5.06	3.27	1.68	2.01	7.63	2.11	-	24.13
Azerbaijan	52.5: Light	2	0%	4.18	2.73	4.89	0.92	1.20	21.98	0.97	-	36.86
Azerbaijan	**Total**	**695**	**100%**	**0.47**	**2.07**	**2.14**	**2.17**	**2.51**	**7.65**	**1.76**	**-**	**18.77**
Bahrain	32.5: Medium	171	100%	0.13	-	6.48	0.45	0.61	12.57	0.49	-	20.74
Bahrain	**Total**	**171**	**100%**	**0.13**	**-**	**6.48**	**0.45**	**0.61**	**12.57**	**0.49**	**-**	**20.74**
Bangladesh	32.5: Medium	3	100%	0.10	-	6.77	0.29	0.41	13.83	0.04	-	21.44
Bangladesh	**Total**	**3**	**100%**	**0.10**	**-**	**6.77**	**0.29**	**0.41**	**13.83**	**0.04**	**-**	**21.44**
Barbados	27.5: Medium	1	54%	1.42	6.68	2.15	2.22	2.50	3.01	0.29	-	18.28
Barbados	32.5: Medium	0	42%	3.78	5.48	3.06	1.83	2.15	4.58	1.69	-	22.58
Barbados	37.5: Light	0	3%	4.48	5.60	2.94	1.87	2.20	4.37	0.25	-	21.71
Barbados	**Total**	**1**	**100%**	**2.53**	**6.14**	**2.56**	**2.04**	**2.34**	**3.72**	**0.89**	**-**	**20.22**

				Kilograms CO2e per barrel of crude and condensate (LCA basis)								
Country	API Gravity Classification	2020 Oil Production (kbpd)	Fraction of Oil Production	Prod. well construction (CO2e kg/bbl)	Prod. vented & flared (CO2e kg/bbl)	Prod. lease compression (CO2e kg/bbl)	Prod. oil stabilization (CO2e kg/bbl)	Prod. storage fugitives (CO2e kg/bbl)	Prod. methane leaks (CO2e kg/bbl)	Prod. electricity & pumps (CO2e kg/bbl)	Prod. steam (CO2e kg/bbl)	Production GHG (CO2e kg/bbl)
Belarus	27.5: Medium	5	13%	1.29	8.51	0.74	2.75	3.01	0.87	3.45	-	20.63
Belarus	32.5: Medium	13	38%	1.83	8.47	0.72	2.73	3.04	0.85	3.76	-	21.42
Belarus	37.5: Light	11	33%	1.60	7.90	1.16	2.54	2.91	1.47	3.58	-	21.15
Belarus	42.5: Light	4	12%	2.56	6.74	1.98	2.17	2.60	2.73	2.93	-	21.71
Belarus	47.5: Light	1	4%	3.29	6.89	1.84	2.21	2.65	2.52	4.16	-	23.55
Belarus	52.5: Light	0	0%	13.83	5.74	2.64	1.86	2.29	3.86	3.69	-	33.90
Belarus	**Total**	**34**	**100%**	**1.86**	**8.01**	**1.07**	**2.58**	**2.92**	**1.36**	**3.58**	**-**	**21.38**
Belize	32.5: Medium	1	100%	0.08	7.57	1.42	2.46	2.79	1.85	0.33	-	16.51
Belize	**Total**	**1**	**100%**	**0.08**	**7.57**	**1.42**	**2.46**	**2.79**	**1.85**	**0.33**	**-**	**16.51**
Bolivia	27.5: Medium	0	1%	0.90	9.03	0.35	2.90	3.14	0.38	0.39	-	17.09
Bolivia	32.5: Medium	1	2%	1.92	7.04	1.83	2.29	2.63	2.55	0.31	-	18.57
Bolivia	37.5: Light	1	4%	1.11	5.99	2.58	1.97	2.34	3.75	0.26	-	18.01
Bolivia	42.5: Light	10	30%	0.47	7.12	1.71	2.27	2.68	2.56	0.35	-	17.16
Bolivia	47.5: Light	16	50%	1.03	0.51	4.16	1.24	1.55	7.35	0.27	-	16.11
Bolivia	52.5: Light	4	11%	0.46	0.67	5.97	0.39	0.55	11.81	0.17	-	20.01
Bolivia	57.5: Light	1	2%	1.36	1.83	5.42	0.62	0.84	9.93	0.43	-	20.43
Bolivia	**Total**	**32**	**100%**	**0.82**	**2.94**	**3.52**	**1.51**	**1.82**	**6.17**	**0.29**	**-**	**17.07**
Brazil	12.5: Heavy	9	0%	0.55	3.20	0.78	2.81	2.82	2.35	0.39	-	12.90
Brazil	17.5: Heavy	56	2%	0.99	2.08	1.11	2.66	2.78	3.71	1.00	-	14.32
Brazil	22.5: Heavy	1,305	44%	0.33	3.14	0.89	2.72	2.92	2.76	3.18	-	15.94
Brazil	27.5: Medium	910	31%	0.39	2.96	1.24	2.56	2.83	4.14	3.01	-	17.13
Brazil	32.5: Medium	464	16%	0.33	2.95	1.22	2.55	2.85	3.91	3.53	-	17.34
Brazil	37.5: Light	99	3%	1.00	1.88	1.84	2.25	2.60	4.28	1.42	-	15.26
Brazil	42.5: Light	45	2%	0.78	2.13	2.83	1.85	2.21	8.45	0.64	-	18.89
Brazil	47.5: Light	52	2%	0.21	0.41	4.93	0.92	1.20	9.07	0.86	-	17.59
Brazil	**Total**	**2,940**	**100%**	**0.39**	**2.93**	**1.19**	**2.58**	**2.83**	**3.63**	**2.99**	**-**	**16.54**
Brunei	22.5: Heavy	34	34%	0.39	5.70	3.03	1.90	2.15	11.77	1.21	-	26.15
Brunei	37.5: Light	40	39%	0.37	0.16	5.19	0.91	1.16	23.67	0.80	-	32.26
Brunei	42.5: Light	18	17%	0.26	7.43	1.47	2.37	2.81	3.13	1.06	-	18.51
Brunei	47.5: Light	10	9%	0.35	4.53	3.61	1.50	1.86	10.22	0.20	-	22.26
Brunei	**Total**	**100**	**100%**	**0.35**	**3.70**	**3.66**	**1.55**	**1.85**	**14.81**	**0.93**	**-**	**26.86**

				Kilograms CO2e per barrel of crude and condensate (LCA basis)								
Country	API Gravity Classification	2020 Oil Production (kbpd)	Fraction of Oil Production	Prod. well construction (CO2e kg/bbl)	Prod. vented & flared (CO2e kg/bbl)	Prod. lease compression (CO2e kg/bbl)	Prod. oil stabilization (CO2e kg/bbl)	Prod. storage fugitives (CO2e kg/bbl)	Prod. methane leaks (CO2e kg/bbl)	Prod. electricity & pumps (CO2e kg/bbl)	Prod. steam (CO2e kg/bbl)	Production GHG (CO2e kg/bbl)
Bulgaria	32.5: Medium	0	20%	4.26	7.51	0.15	2.94	3.25	0.16	1.71	-	19.98
Bulgaria	37.5: Light	0	36%	5.90	6.07	2.53	2.00	2.36	3.66	2.40	-	24.92
Bulgaria	42.5: Light	0	44%	6.47	7.07	1.76	2.27	2.67	2.51	1.46	-	24.21
Bulgaria	**Total**	**1**	**100%**	**5.82**	**6.81**	**1.71**	**2.31**	**2.68**	**2.44**	**1.84**	**-**	**23.60**
Cameroon	17.5: Heavy	4	6%	0.35	47.20	0.91	2.74	2.86	2.88	1.18	-	58.12
Cameroon	27.5: Medium	6	9%	0.56	58.50	1.56	2.43	2.72	5.53	0.71	-	72.02
Cameroon	32.5: Medium	30	44%	0.38	69.00	1.99	2.23	2.57	7.27	1.27	-	84.72
Cameroon	37.5: Light	22	33%	0.50	43.42	1.30	2.48	2.84	4.71	1.97	-	57.21
Cameroon	42.5: Light	5	8%	0.42	25.04	1.68	2.29	2.67	6.95	1.28	-	40.33
Cameroon	**Total**	**67**	**100%**	**0.44**	**54.90**	**1.64**	**2.37**	**2.70**	**6.00**	**1.44**	**-**	**69.49**
Chad	17.5: Heavy	50	43%	0.20	7.90	0.16	3.02	3.10	0.17	2.50	-	17.04
Chad	22.5: Heavy	66	57%	0.20	9.02	0.37	2.92	3.09	0.41	0.39	-	16.39
Chad	**Total**	**116**	**100%**	**0.20**	**8.54**	**0.28**	**2.96**	**3.09**	**0.31**	**1.30**	**-**	**16.67**
Chile	32.5: Medium	0	7%	1.39	1.55	6.23	0.51	0.65	13.01	0.21	-	23.54
Chile	37.5: Light	1	66%	3.47	4.63	3.70	1.53	1.82	10.20	0.27	-	25.62
Chile	42.5: Light	0	23%	3.97	4.62	3.62	1.50	1.82	8.46	0.25	-	24.24
Chile	47.5: Light	0	5%	0.27	0.00	6.70	0.05	0.09	15.94	0.01	-	23.06
Chile	**Total**	**2**	**100%**	**3.28**	**4.20**	**4.00**	**1.39**	**1.66**	**10.27**	**0.25**	**-**	**25.05**
China	12.5: Heavy	11	0%	1.29	5.16	0.31	2.99	2.94	0.34	2.97	-	16.01
China	17.5: Heavy	192	5%	0.93	4.42	3.34	1.81	1.97	14.14	0.68	-	27.28
China	22.5: Heavy	270	7%	0.51	4.95	0.54	2.86	3.01	0.90	1.26	-	14.04
China	27.5: Medium	211	5%	0.56	3.84	0.52	2.83	3.08	0.81	1.51	-	13.15
China	32.5: Medium	2,194	56%	0.50	4.61	0.84	2.69	2.99	1.15	2.12	-	14.91
China	37.5: Light	693	18%	0.80	4.62	0.84	2.66	3.01	1.43	1.66	-	15.02
China	42.5: Light	178	5%	0.83	4.55	1.33	2.44	2.84	2.33	1.33	-	15.64
China	47.5: Light	52	1%	1.22	2.19	0.77	2.61	3.07	1.67	2.07	-	13.60
China	52.5: Light	84	2%	1.68	4.90	0.62	2.65	3.16	1.16	1.63	-	15.79
China	57.5: Light	3	0%	0.51	1.90	4.26	1.12	1.44	7.07	1.66	-	17.96
China	**Total**	**3,889**	**100%**	**0.63**	**4.56**	**0.94**	**2.65**	**2.95**	**1.87**	**1.83**	**-**	**15.42**

				Kilograms CO2e per barrel of crude and condensate (LCA basis)								
Country	API Gravity Classification	2020 Oil Production (kbpd)	Fraction of Oil Production	Prod. well construction (CO2e kg/bbl)	Prod. vented & flared (CO2e kg/bbl)	Prod. lease compression (CO2e kg/bbl)	Prod. oil stabilization (CO2e kg/bbl)	Prod. storage fugitives (CO2e kg/bbl)	Prod. methane leaks (CO2e kg/bbl)	Prod. electricity & pumps (CO2e kg/bbl)	Prod. steam (CO2e kg/bbl)	Production GHG (CO2e kg/bbl)
Colombia	12.5: Heavy	84	11%	0.20	6.75	0.34	2.97	2.96	0.39	0.74	-	14.36
Colombia	17.5: Heavy	46	6%	0.31	5.03	0.48	2.90	2.97	0.59	0.36	-	12.65
Colombia	22.5: Heavy	79	10%	0.36	7.47	1.04	2.67	2.85	1.37	0.95	-	16.71
Colombia	27.5: Medium	213	27%	0.18	6.83	1.07	2.62	2.88	1.53	0.61	-	15.71
Colombia	32.5: Medium	128	16%	0.23	7.12	0.76	2.71	3.02	0.98	0.55	-	15.39
Colombia	37.5: Light	32	4%	0.32	5.61	2.63	1.95	2.30	4.06	0.29	-	17.16
Colombia	42.5: Light	195	25%	0.05	0.99	4.18	1.28	1.60	6.89	1.37	-	16.37
Colombia	47.5: Light	4	1%	1.02	6.32	2.26	2.04	2.47	3.25	1.26	-	18.61
Colombia	**Total**	**781**	**100%**	**0.20**	**5.31**	**1.75**	**2.33**	**2.57**	**2.70**	**0.81**	**-**	**15.67**
Congo	17.5: Heavy	9	3%	0.46	5.03	0.10	3.03	3.12	0.29	2.04	-	14.07
Congo	22.5: Heavy	40	14%	0.22	17.61	0.35	2.92	3.10	1.01	1.63	-	26.84
Congo	27.5: Medium	69	24%	0.24	20.61	0.70	2.77	3.01	2.41	1.45	-	31.19
Congo	32.5: Medium	43	15%	0.39	28.87	0.61	2.77	3.08	1.87	1.53	-	39.13
Congo	37.5: Light	47	16%	0.37	37.11	0.93	2.62	2.99	3.07	2.55	-	49.64
Congo	42.5: Light	75	26%	0.30	35.17	2.80	1.87	2.24	8.79	2.27	-	53.42
Congo	**Total**	**283**	**100%**	**0.31**	**27.52**	**1.21**	**2.53**	**2.83**	**3.87**	**1.90**	**-**	**40.18**
Cote d'Ivoire	22.5: Heavy	14	39%	0.22	8.74	0.59	2.84	3.00	1.75	3.02	-	20.17
Cote d'Ivoire	32.5: Medium	21	58%	0.49	6.38	2.36	2.11	2.43	8.73	2.14	-	24.65
Cote d'Ivoire	37.5: Light	1	4%	1.19	6.28	2.40	2.07	2.42	8.92	0.28	-	23.56
Cote d'Ivoire	**Total**	**37**	**100%**	**0.42**	**7.28**	**1.68**	**2.39**	**2.65**	**6.05**	**2.41**	**-**	**22.88**
Croatia	27.5: Medium	1	11%	0.81	8.39	0.83	2.71	2.98	1.01	1.34	-	18.09
Croatia	32.5: Medium	2	17%	2.40	8.22	0.94	2.65	2.96	1.18	1.85	-	20.20
Croatia	37.5: Light	6	52%	1.30	7.23	1.55	2.39	2.75	2.15	1.66	-	19.03
Croatia	42.5: Light	1	11%	1.30	8.07	1.05	2.56	2.94	1.40	1.23	-	18.55
Croatia	47.5: Light	1	9%	0.56	7.34	1.49	2.33	2.80	1.96	2.35	-	18.83
Croatia	**Total**	**12**	**100%**	**1.37**	**7.62**	**1.31**	**2.48**	**2.83**	**1.77**	**1.67**	**-**	**19.06**
Cuba	12.5: Heavy	19	52%	0.31	8.99	0.41	2.96	2.94	0.45	2.11	-	18.15
Cuba	17.5: Heavy	12	34%	0.35	9.17	0.23	2.99	3.08	0.38	0.41	-	16.62
Cuba	22.5: Heavy	0	0%	1.20	8.75	0.55	2.84	3.04	0.70	0.38	-	17.46
Cuba	27.5: Medium	3	7%	1.18	9.21	0.19	2.95	3.21	0.21	0.41	-	17.36
Cuba	32.5: Medium	2	7%	0.54	9.18	0.21	2.92	3.23	0.24	0.40	-	16.72
Cuba	**Total**	**36**	**100%**	**0.43**	**9.08**	**0.32**	**2.96**	**3.02**	**0.40**	**1.29**	**-**	**17.50**

				Kilograms CO2e per barrel of crude and condensate (LCA basis)								
Country	API Gravity Classification	2020 Oil Production (kbpd)	Fraction of Oil Production	Prod. well construction (CO2e kg/bbl)	Prod. vented & flared (CO2e kg/bbl)	Prod. lease compression (CO2e kg/bbl)	Prod. oil stabilization (CO2e kg/bbl)	Prod. storage fugitives (CO2e kg/bbl)	Prod. methane leaks (CO2e kg/bbl)	Prod. electricity & pumps (CO2e kg/bbl)	Prod. steam (CO2e kg/bbl)	Production GHG (CO2e kg/bbl)
Czech Republic	22.5: Heavy	0	16%	0.56	6.71	2.18	2.23	2.46	3.19	1.77	-	19.10
Czech Republic	27.5: Medium	0	16%	4.18	3.51	4.74	1.17	1.42	8.21	0.37	-	23.60
Czech Republic	32.5: Medium	0	21%	1.08	7.14	1.79	2.31	2.63	2.64	1.83	-	19.41
Czech Republic	37.5: Light	1	47%	0.66	7.66	1.35	2.45	2.80	2.12	1.90	-	18.95
Czech Republic	**Total**	**2**	**100%**	**1.29**	**6.74**	**2.11**	**2.18**	**2.49**	**3.36**	**1.63**	**-**	**19.80**
Dem. Rep. of Congo	32.5: Medium	20	86%	0.79	31.61	1.97	2.25	2.56	6.59	1.64	-	47.40
Dem. Rep. of Congo	37.5: Light	3	13%	1.12	30.36	2.88	1.86	2.17	11.16	1.75	-	51.31
Dem. Rep. of Congo	**Total**	**23**	**100%**	**0.85**	**31.28**	**2.11**	**2.19**	**2.50**	**7.33**	**1.65**	**-**	**47.90**
Denmark	27.5: Medium	5	7%	0.24	8.35	0.86	2.70	2.97	2.70	2.02	-	19.83
Denmark	32.5: Medium	23	32%	0.34	6.72	2.10	2.21	2.51	8.02	1.96	-	23.87
Denmark	37.5: Light	14	19%	0.28	6.98	1.87	2.27	2.62	6.83	1.50	-	22.36
Denmark	42.5: Light	5	7%	0.36	5.95	2.60	1.96	2.33	9.85	2.57	-	25.62
Denmark	47.5: Light	25	35%	0.15	5.18	3.09	1.70	2.09	12.16	1.79	-	26.17
Denmark	**Total**	**71**	**100%**	**0.26**	**6.29**	**2.36**	**2.06**	**2.40**	**9.02**	**1.86**	**-**	**24.24**
Ecuador	12.5: Heavy	17	4%	0.34	10.68	0.24	3.01	3.01	0.27	0.37	-	17.92
Ecuador	17.5: Heavy	51	11%	0.29	11.61	0.34	2.95	3.04	0.39	0.36	-	18.98
Ecuador	22.5: Heavy	300	63%	0.20	15.47	1.19	2.61	2.82	1.53	0.90	-	24.73
Ecuador	27.5: Medium	55	11%	0.22	13.88	1.04	2.64	2.90	1.34	0.33	-	22.35
Ecuador	32.5: Medium	55	12%	0.19	12.48	0.94	2.64	2.95	1.26	1.49	-	21.95
Ecuador	37.5: Light	1	0%	4.26	12.97	1.89	2.25	2.62	2.61	0.28	-	26.88
Ecuador	**Total**	**479**	**100%**	**0.23**	**14.36**	**1.02**	**2.67**	**2.87**	**1.32**	**0.83**	**-**	**23.29**
Egypt	12.5: Heavy	1	0%	0.40	9.38	0.18	3.03	3.01	0.21	1.35	-	17.56
Egypt	17.5: Heavy	4	1%	0.71	8.45	0.17	3.01	3.11	0.26	0.40	-	16.10
Egypt	22.5: Heavy	57	10%	0.32	11.30	0.70	2.79	2.96	2.33	1.93	-	22.32
Egypt	27.5: Medium	150	26%	0.33	28.28	0.75	2.74	3.01	2.32	2.83	-	40.26
Egypt	32.5: Medium	242	41%	0.36	26.43	1.13	2.57	2.89	3.41	2.47	-	39.26
Egypt	37.5: Light	63	11%	0.43	21.85	2.00	2.20	2.55	4.34	0.91	-	34.28
Egypt	42.5: Light	52	9%	0.49	16.95	1.40	2.41	2.80	2.55	2.33	-	28.93
Egypt	47.5: Light	18	3%	0.61	26.72	1.41	2.36	2.82	3.05	0.86	-	37.83
Egypt	**Total**	**587**	**100%**	**0.38**	**23.96**	**1.11**	**2.58**	**2.88**	**3.02**	**2.26**	**-**	**36.19**

				Kilograms CO2e per barrel of crude and condensate (LCA basis)								
Country	API Gravity Classification	2020 Oil Production (kbpd)	Fraction of Oil Production	Prod. well construction (CO2e kg/bbl)	Prod. vented & flared (CO2e kg/bbl)	Prod. lease compression (CO2e kg/bbl)	Prod. oil stabilization (CO2e kg/bbl)	Prod. storage fugitives (CO2e kg/bbl)	Prod. methane leaks (CO2e kg/bbl)	Prod. electricity & pumps (CO2e kg/bbl)	Prod. steam (CO2e kg/bbl)	Production GHG (CO2e kg/bbl)
Equatorial Guinea	27.5: Medium	19	13%	0.47	8.42	0.80	2.72	3.00	2.48	3.08	-	20.97
Equatorial Guinea	32.5: Medium	26	17%	0.17	7.50	1.47	2.43	2.79	4.99	1.77	-	21.11
Equatorial Guinea	37.5: Light	-	0%									
Equatorial Guinea	42.5: Light	103	70%	0.06	7.78	1.21	2.47	2.91	3.98	2.12	-	20.54
Equatorial Guinea	**Total**	**148**	**100%**	**0.13**	**7.82**	**1.20**	**2.50**	**2.90**	**3.96**	**2.19**	**-**	**20.69**
France	22.5: Heavy	0	2%	1.62	-	-	3.06	3.18	-	2.47	-	10.33
France	27.5: Medium	2	17%	1.34	5.89	2.77	1.95	2.19	4.69	1.48	-	20.31
France	32.5: Medium	6	49%	1.13	7.16	1.05	2.60	2.93	1.35	1.80	-	18.02
France	37.5: Light	3	27%	1.87	7.53	1.45	2.43	2.79	1.96	2.11	-	20.14
France	42.5: Light	1	5%	0.56	5.82	2.69	1.91	2.29	3.97	1.95	-	19.18
France	**Total**	**13**	**100%**	**1.35**	**6.82**	**1.51**	**2.42**	**2.74**	**2.19**	**1.85**	**-**	**18.88**
Gabon	22.5: Heavy	4	2%	0.99	25.08	0.49	2.88	3.04	1.44	0.40	-	34.31
Gabon	27.5: Medium	24	14%	0.66	28.27	0.55	2.83	3.06	1.57	0.96	-	37.90
Gabon	32.5: Medium	87	50%	0.31	35.49	0.76	2.72	3.03	1.20	1.54	-	45.05
Gabon	37.5: Light	53	31%	0.29	28.08	0.58	2.76	3.11	1.23	0.74	-	36.80
Gabon	42.5: Light	0	0%	0.69	36.27	0.71	2.67	3.10	2.14	0.38	-	45.96
Gabon	47.5: Light	5	3%	0.31	11.83	0.23	2.84	3.30	0.36	0.40	-	19.27
Gabon	**Total**	**174**	**100%**	**0.38**	**31.30**	**0.66**	**2.75**	**3.07**	**1.25**	**1.15**	**-**	**40.56**
Germany	17.5: Heavy	0	0%	3.00	8.41	0.84	2.76	2.90	1.00	0.35	-	19.27
Germany	22.5: Heavy	26	69%	0.14	6.66	0.21	2.96	3.16	0.25	3.36	-	16.74
Germany	27.5: Medium	1	3%	1.50	7.93	0.38	2.89	3.13	0.42	1.57	-	17.83
Germany	32.5: Medium	8	21%	0.84	7.43	0.89	2.67	2.97	1.18	1.45	-	17.43
Germany	37.5: Light	2	5%	1.48	1.46	1.81	2.27	2.66	2.47	3.58	-	15.72
Germany	42.5: Light	1	2%	0.54	7.73	1.26	2.46	2.88	1.64	1.17	-	17.68
Germany	**Total**	**37**	**100%**	**0.40**	**6.61**	**0.46**	**2.86**	**3.09**	**0.59**	**2.88**	**-**	**16.88**
Ghana	37.5: Light	199	100%	2.36	3.40	4.64	1.14	1.43	20.19	0.15	-	33.31
Ghana	**Total**	**199**	**100%**	**2.36**	**3.40**	**4.64**	**1.14**	**1.43**	**20.19**	**0.15**	**-**	**33.31**
Greece	27.5: Medium	2	100%	1.32	6.24	2.50	2.08	2.37	9.34	2.50	-	26.35
Greece	**Total**	**2**	**100%**	**1.32**	**6.24**	**2.50**	**2.08**	**2.37**	**9.34**	**2.50**	**-**	**26.35**
Guatemala	17.5: Heavy	7	88%	0.19	-	-	3.07	3.13	-	3.37	-	9.77
Guatemala	22.5: Heavy	1	7%	0.80	8.36	0.87	2.73	2.92	1.05	0.36	-	17.09
Guatemala	27.5: Medium	0	4%	0.61	8.44	0.80	2.74	2.98	0.95	0.83	-	17.34
Guatemala	**Total**	**8**	**100%**	**0.27**	**0.96**	**0.10**	**3.03**	**3.11**	**0.12**	**3.04**	**-**	**10.64**

				Kilograms CO2e per barrel of crude and condensate (LCA basis)								
Country	API Gravity Classification	2020 Oil Production (kbpd)	Fraction of Oil Production	Prod. well construction (CO2e kg/bbl)	Prod. vented & flared (CO2e kg/bbl)	Prod. lease compression (CO2e kg/bbl)	Prod. oil stabilization (CO2e kg/bbl)	Prod. storage fugitives (CO2e kg/bbl)	Prod. methane leaks (CO2e kg/bbl)	Prod. electricity & pumps (CO2e kg/bbl)	Prod. steam (CO2e kg/bbl)	Production GHG (CO2e kg/bbl)
Guyana	32.5: Medium	74	100%	0.43	16.35	2.41	2.10	2.41	8.97	0.29	-	32.96
Guyana	**Total**	**74**	**100%**	**0.43**	**16.35**	**2.41**	**2.10**	**2.41**	**8.97**	**0.29**	**-**	**32.96**
Hungary	17.5: Heavy	2	11%	2.77	8.09	1.08	2.67	2.82	1.35	3.54	-	22.33
Hungary	22.5: Heavy	1	4%	0.61	8.84	0.51	2.88	3.02	0.59	0.36	-	16.82
Hungary	27.5: Medium	1	7%	1.78	7.05	1.89	2.31	2.59	2.70	0.44	-	18.77
Hungary	32.5: Medium	1	8%	1.09	7.31	1.40	2.46	2.74	2.44	0.36	-	17.80
Hungary	37.5: Light	8	46%	0.99	0.47	4.86	1.04	1.31	8.35	1.22	-	18.24
Hungary	42.5: Light	0	3%	5.63	4.74	3.49	1.57	1.88	6.13	0.76	-	24.20
Hungary	47.5: Light	1	8%	1.93	4.87	3.31	1.59	1.92	5.91	0.85	-	20.38
Hungary	52.5: Light	2	12%	1.38	4.86	3.15	1.61	1.99	5.42	1.04	-	19.46
Hungary	**Total**	**16**	**100%**	**1.49**	**3.74**	**3.37**	**1.64**	**1.92**	**5.70**	**1.26**	**-**	**19.12**
India	17.5: Heavy	14	2%	0.71	8.63	0.17	3.02	3.07	0.19	1.94	-	17.73
India	22.5: Heavy	56	9%	0.62	15.17	1.70	2.43	2.62	2.35	2.25	-	27.14
India	27.5: Medium	50	8%	0.56	12.52	2.67	2.01	2.29	3.97	1.38	-	25.40
India	32.5: Medium	42	7%	0.68	14.27	1.98	2.25	2.55	2.89	1.66	-	26.29
India	37.5: Light	262	42%	0.29	8.29	3.79	1.49	1.80	14.89	1.37	-	31.92
India	42.5: Light	84	13%	0.39	13.53	2.14	2.12	2.52	7.16	1.57	-	29.44
India	47.5: Light	118	19%	0.44	11.13	2.90	1.79	2.17	8.36	1.11	-	27.91
India	**Total**	**627**	**100%**	**0.42**	**10.89**	**2.92**	**1.84**	**2.16**	**9.49**	**1.46**	**-**	**29.18**
Indonesia	17.5: Heavy	139	20%	0.35	4.59	0.18	3.00	3.10	0.36	0.90	73.22	85.69
Indonesia	22.5: Heavy	12	2%	0.76	15.72	1.29	2.57	2.77	2.56	0.45	-	26.12
Indonesia	27.5: Medium	28	4%	0.48	4.71	1.05	2.61	2.86	2.44	1.73	-	15.87
Indonesia	32.5: Medium	220	31%	0.51	9.89	1.57	2.39	2.71	3.38	1.54	-	22.00
Indonesia	37.5: Light	133	19%	0.32	10.54	1.54	2.38	2.73	3.12	0.72	-	21.35
Indonesia	42.5: Light	53	7%	0.48	10.85	3.71	1.47	1.78	12.33	0.51	-	31.13
Indonesia	47.5: Light	79	11%	0.43	10.07	4.13	1.28	1.59	16.03	0.19	-	33.72
Indonesia	52.5: Light	11	2%	0.21	8.39	4.37	1.09	1.39	13.89	0.18	-	29.52
Indonesia	57.5: Light	26	4%	0.40	9.14	4.22	1.13	1.46	18.29	0.16	-	34.80
Indonesia	62.5: Light	3	0%	0.33	9.92	3.93	1.20	1.54	6.93	0.17	-	24.02
Indonesia	67.5: Light	4	1%	0.11	-	5.60	0.38	0.55	10.86	0.05	-	17.55
Indonesia	**Total**	**708**	**100%**	**0.42**	**8.85**	**1.88**	**2.25**	**2.52**	**5.52**	**0.94**	**14.42**	**36.80**

				Kilograms CO2e per barrel of crude and condensate (LCA basis)								
Country	API Gravity Classification	2020 Oil Production (kbpd)	Fraction of Oil Production	Prod. well construction (CO2e kg/bbl)	Prod. vented & flared (CO2e kg/bbl)	Prod. lease compression (CO2e kg/bbl)	Prod. oil stabilization (CO2e kg/bbl)	Prod. storage fugitives (CO2e kg/bbl)	Prod. methane leaks (CO2e kg/bbl)	Prod. electricity & pumps (CO2e kg/bbl)	Prod. steam (CO2e kg/bbl)	Production GHG (CO2e kg/bbl)
Iran	17.5: Heavy	3	0%	0.03	10.36	0.20	3.00	3.07	0.23	0.40	-	17.30
Iran	22.5: Heavy	108	4%	0.09	26.85	1.02	2.68	2.84	3.58	0.37	-	37.43
Iran	27.5: Medium	254	10%	0.05	26.22	1.42	2.49	2.75	3.99	0.28	-	37.21
Iran	32.5: Medium	1,461	55%	0.04	27.41	1.59	2.40	2.73	2.74	3.22	-	40.12
Iran	37.5: Light	384	15%	0.03	26.02	2.22	2.13	2.48	3.49	1.61	-	37.98
Iran	42.5: Light	433	16%	0.01	27.16	2.32	2.06	2.45	3.64	0.62	-	38.26
Iran	47.5: Light	1	0%	0.02	15.73	4.44	1.16	1.47	7.37	0.15	-	30.34
Iran	**Total**	**2,644**	**100%**	**0.04**	**27.01**	**1.76**	**2.32**	**2.65**	**3.15**	**2.16**	**-**	**39.09**
Iraq	17.5: Heavy	2	0%	0.01	9.08	0.18	3.01	3.10	0.20	0.40	-	15.97
Iraq	22.5: Heavy	862	21%	0.02	23.30	1.21	2.61	2.80	1.54	0.23	-	31.72
Iraq	27.5: Medium	1,975	48%	0.03	31.13	1.00	2.64	2.93	1.24	1.85	-	40.81
Iraq	32.5: Medium	513	13%	0.03	51.69	1.73	2.35	2.67	2.34	1.43	-	62.25
Iraq	37.5: Light	519	13%	0.01	20.39	3.26	1.73	2.06	4.97	0.40	-	32.83
Iraq	42.5: Light	67	2%	0.04	26.26	2.07	2.15	2.56	2.88	0.29	-	36.25
Iraq	47.5: Light	150	4%	0.01	19.65	3.30	1.65	2.01	5.05	0.22	-	31.90
Iraq	**Total**	**4,088**	**100%**	**0.03**	**30.18**	**1.53**	**2.44**	**2.72**	**2.08**	**1.18**	**-**	**40.16**
Italy	)5.5: Extra Heav	-	0%									
Italy	12.5: Heavy	66	66%	0.37	3.77	0.07	3.08	3.00	0.08	0.39	-	10.76
Italy	17.5: Heavy	-	0%									
Italy	22.5: Heavy	19	19%	1.08	9.05	0.33	2.93	3.09	0.37	0.38	-	17.24
Italy	27.5: Medium	-	0%									
Italy	32.5: Medium	15	15%	0.53	2.60	5.44	0.87	1.11	9.56	0.11	-	20.23
Italy	37.5: Light	-	0%									
Italy	**Total**	**101**	**100%**	**0.53**	**4.61**	**0.92**	**2.72**	**2.74**	**1.55**	**0.35**	**-**	**13.42**
Kazakhstan	12.5: Heavy	5	0%	0.79	9.54	0.19	3.02	3.03	0.21	1.33	-	18.12
Kazakhstan	17.5: Heavy	64	4%	0.49	4.95	0.10	3.03	3.12	0.13	1.40	-	13.22
Kazakhstan	22.5: Heavy	229	13%	0.68	11.41	1.17	2.62	2.82	1.52	1.11	-	21.32
Kazakhstan	27.5: Medium	25	1%	0.94	10.77	0.87	2.70	2.96	1.10	0.78	-	20.12
Kazakhstan	32.5: Medium	243	14%	0.65	11.75	0.74	2.72	3.04	0.89	1.61	-	21.39
Kazakhstan	37.5: Light	270	15%	0.72	8.74	2.35	2.07	2.41	3.54	1.47	-	21.31
Kazakhstan	42.5: Light	243	14%	0.25	11.34	0.85	2.63	3.03	1.39	1.86	-	21.36
Kazakhstan	47.5: Light	676	38%	0.04	2.03	2.03	2.13	2.57	2.82	0.84	-	12.47
Kazakhstan	**Total**	**1,757**	**100%**	**0.37**	**7.18**	**1.53**	**2.38**	**2.73**	**2.17**	**1.24**	**-**	**17.60**

				Kilograms CO2e per barrel of crude and condensate (LCA basis)								
Country	API Gravity Classification	2020 Oil Production (kbpd)	Fraction of Oil Production	Prod. well construction (CO2e kg/bbl)	Prod. vented & flared (CO2e kg/bbl)	Prod. lease compression (CO2e kg/bbl)	Prod. oil stabilization (CO2e kg/bbl)	Prod. storage fugitives (CO2e kg/bbl)	Prod. methane leaks (CO2e kg/bbl)	Prod. electricity & pumps (CO2e kg/bbl)	Prod. steam (CO2e kg/bbl)	Production GHG (CO2e kg/bbl)
Kuwait	27.5: Medium	116	5%	0.03	7.86	1.25	2.56	2.82	1.67	1.41	-	17.60
Kuwait	32.5: Medium	2,400	94%	0.02	1.84	0.90	2.68	2.97	1.09	0.81	-	10.29
Kuwait	37.5: Light	-	0%									
Kuwait	42.5: Light	29	1%	0.03	7.89	1.14	2.51	2.93	1.43	3.34	-	19.27
Kuwait	**Total**	**2,545**	**100%**	**0.02**	**2.18**	**0.92**	**2.67**	**2.96**	**1.12**	**0.86**	**-**	**10.73**
Kyrgyzstan	27.5: Medium	0	6%	0.05	8.95	0.42	2.89	3.09	0.47	0.39	-	16.26
Kyrgyzstan	32.5: Medium	1	83%	3.17	5.47	2.18	2.19	2.49	3.20	1.49	-	20.18
Kyrgyzstan	42.5: Light	0	1%	0.86	5.77	2.73	1.90	2.27	4.01	0.25	-	17.81
Kyrgyzstan	47.5: Light	0	11%	3.06	3.46	4.42	1.16	1.47	7.34	0.15	-	21.05
Kyrgyzstan	**Total**	**1**	**100%**	**2.96**	**5.46**	**2.32**	**2.11**	**2.41**	**3.49**	**1.27**	**-**	**20.03**
Libya	27.5: Medium	13	3%	0.11	16.83	4.40	1.33	1.59	18.95	0.18	-	43.40
Libya	32.5: Medium	37	9%	0.11	26.49	0.62	2.77	3.07	0.75	1.80	-	35.62
Libya	37.5: Light	256	63%	0.06	21.95	1.44	2.43	2.78	2.05	2.78	-	33.49
Libya	42.5: Light	93	23%	0.08	25.27	1.22	2.48	2.89	1.67	2.11	-	35.71
Libya	47.5: Light	4	1%	0.18	29.12	2.18	2.06	2.49	3.18	0.59	-	39.79
Libya	52.5: Light	3	1%	0.14	19.45	3.59	1.48	1.83	5.71	1.54	-	33.75
Libya	**Total**	**408**	**100%**	**0.07**	**23.01**	**1.43**	**2.42**	**2.78**	**2.44**	**2.42**	**-**	**34.59**
Lithuania	37.5: Light	0	37%	0.78	9.03	0.32	2.85	3.22	0.36	1.81	-	18.38
Lithuania	42.5: Light	0	63%	0.89	8.91	0.42	2.79	3.20	0.48	1.56	-	18.27
Lithuania	**Total**	**1**	**100%**	**0.85**	**8.96**	**0.38**	**2.81**	**3.21**	**0.44**	**1.65**	**-**	**18.31**
Malaysia	22.5: Heavy	-	0%									
Malaysia	27.5: Medium	21	4%	0.24	25.13	2.33	2.16	2.43	8.59	0.29	-	41.17
Malaysia	32.5: Medium	70	13%	0.24	23.28	2.13	2.19	2.52	7.86	0.51	-	38.72
Malaysia	37.5: Light	78	14%	0.31	25.90	2.07	2.18	2.55	7.61	1.12	-	41.73
Malaysia	42.5: Light	262	47%	0.10	22.80	2.43	2.00	2.39	9.31	1.57	-	40.60
Malaysia	47.5: Light	124	22%	0.19	9.67	3.53	1.53	1.89	14.52	1.28	-	32.61
Malaysia	52.5: Light	-	0%									
Malaysia	**Total**	**556**	**100%**	**0.17**	**20.44**	**2.58**	**1.95**	**2.32**	**10.02**	**1.26**	**-**	**38.76**

				Kilograms CO2e per barrel of crude and condensate (LCA basis)								
Country	API Gravity Classification	2020 Oil Production (kbpd)	Fraction of Oil Production	Prod. well construction (CO2e kg/bbl)	Prod. vented & flared (CO2e kg/bbl)	Prod. lease compression (CO2e kg/bbl)	Prod. oil stabilization (CO2e kg/bbl)	Prod. storage fugitives (CO2e kg/bbl)	Prod. methane leaks (CO2e kg/bbl)	Prod. electricity & pumps (CO2e kg/bbl)	Prod. steam (CO2e kg/bbl)	Production GHG (CO2e kg/bbl)
Mexico	12.5: Heavy	-	0%									
Mexico	17.5: Heavy	3	0%	1.77	19.79	1.67	2.45	2.62	2.23	2.11	-	32.64
Mexico	22.5: Heavy	1,253	73%	0.06	22.54	0.85	2.73	2.94	2.64	1.93	-	33.68
Mexico	27.5: Medium	100	6%	0.21	17.66	2.24	2.18	2.47	6.26	1.23	-	32.24
Mexico	32.5: Medium	184	11%	0.16	13.77	2.14	2.19	2.51	5.44	2.40	-	28.62
Mexico	37.5: Light	140	8%	0.14	16.77	2.43	2.05	2.41	5.85	1.24	-	30.89
Mexico	42.5: Light	31	2%	0.15	15.18	2.83	1.86	2.23	4.18	0.71	-	27.15
Mexico	**Total**	**1,710**	**100%**	**0.09**	**20.70**	**1.23**	**2.57**	**2.81**	**3.44**	**1.86**	**-**	**32.71**
Mongolia	27.5: Medium	4	20%	13.35	8.41	0.82	2.72	2.99	0.97	0.69	-	29.94
Mongolia	32.5: Medium	-	0%									
Mongolia	37.5: Light	14	80%	0.49	6.71	0.13	2.93	3.28	0.15	0.40	-	14.10
Mongolia	**Total**	**18**	**100%**	**3.06**	**7.05**	**0.27**	**2.89**	**3.22**	**0.31**	**0.46**	**-**	**17.27**
Myanmar	17.5: Heavy	1	14%	1.27	6.52	2.36	2.17	2.38	3.36	0.29	-	18.36
Myanmar	22.5: Heavy	0	0%	2.85	8.39	0.84	2.73	2.95	1.00	0.36	-	19.13
Myanmar	27.5: Medium	2	22%	2.11	4.05	4.29	1.35	1.62	7.16	0.18	-	20.77
Myanmar	32.5: Medium	2	21%	0.85	6.23	2.47	2.07	2.39	3.55	0.95	-	18.51
Myanmar	37.5: Light	3	40%	4.91	6.51	2.21	2.13	2.49	3.15	1.74	-	23.15
Myanmar	42.5: Light	0	3%	0.88	1.03	6.38	0.35	0.49	12.71	0.13	-	21.98
Myanmar	47.5: Light	-	0%									
Myanmar	**Total**	**8**	**100%**	**2.81**	**5.76**	**2.86**	**1.90**	**2.21**	**4.42**	**0.98**	**-**	**20.94**
Netherlands	22.5: Heavy	3	8%	1.87	8.80	0.54	2.87	3.01	1.64	1.99	-	20.71
Netherlands	27.5: Medium	2	5%	1.29	7.55	1.53	2.44	2.67	2.88	0.34	-	18.70
Netherlands	32.5: Medium	11	32%	0.83	6.75	1.35	2.50	2.81	2.05	1.78	-	18.07
Netherlands	37.5: Light	18	55%	0.31	6.61	2.06	2.17	2.52	8.60	1.37	-	23.65
Netherlands	42.5: Light	-	0%									
Netherlands	**Total**	**33**	**100%**	**0.65**	**6.88**	**1.68**	**2.34**	**2.66**	**5.66**	**1.50**	**-**	**21.37**
New Zealand	32.5: Medium	0	2%	0.87	8.30	0.89	2.67	2.98	1.10	0.33	-	17.14
New Zealand	37.5: Light	0	5%	0.80	3.34	3.63	1.57	1.89	5.74	0.19	-	17.16
New Zealand	42.5: Light	9	93%	0.19	7.54	1.42	2.39	2.81	2.78	0.52	-	17.65
New Zealand	47.5: Light	-	0%									
New Zealand	**Total**	**10**	**100%**	**0.24**	**7.35**	**1.51**	**2.36**	**2.76**	**2.89**	**0.50**	**-**	**17.62**

				Kilograms CO2e per barrel of crude and condensate (LCA basis)								
Country	API Gravity Classification	2020 Oil Production (kbpd)	Fraction of Oil Production	Prod. well construction (CO2e kg/bbl)	Prod. vented & flared (CO2e kg/bbl)	Prod. lease compression (CO2e kg/bbl)	Prod. oil stabilization (CO2e kg/bbl)	Prod. storage fugitives (CO2e kg/bbl)	Prod. methane leaks (CO2e kg/bbl)	Prod. electricity & pumps (CO2e kg/bbl)	Prod. steam (CO2e kg/bbl)	Production GHG (CO2e kg/bbl)
Nigeria	17.5: Heavy	15	1%	0.09	25.50	1.18	2.63	2.76	2.28	0.35	-	34.80
Nigeria	22.5: Heavy	23	1%	0.22	25.10	2.57	2.07	2.30	9.24	0.98	-	42.47
Nigeria	27.5: Medium	144	8%	0.12	12.70	2.16	2.20	2.49	6.05	0.61	-	26.32
Nigeria	32.5: Medium	325	18%	0.16	23.10	2.85	1.91	2.22	10.45	1.30	-	41.98
Nigeria	37.5: Light	572	32%	0.17	24.23	2.65	1.96	2.30	7.97	0.58	-	39.86
Nigeria	42.5: Light	299	17%	0.12	24.75	2.36	2.03	2.42	6.49	0.59	-	38.76
Nigeria	47.5: Light	304	17%	0.18	9.42	2.65	1.89	2.29	9.33	0.35	-	26.11
Nigeria	52.5: Light	89	5%	0.17	16.79	3.77	1.41	1.75	15.27	2.25	-	41.41
Nigeria	57.5: Light	3	0%	0.17	20.41	3.05	1.66	2.08	4.71	0.23	-	32.29
Nigeria	**Total**	**1,775**	**100%**	**0.16**	**20.28**	**2.64**	**1.95**	**2.29**	**8.58**	**0.76**	**-**	**36.66**
Norway	17.5: Heavy	188	11%	0.09	7.38	0.85	2.77	2.89	2.63	2.54	-	19.15
Norway	22.5: Heavy	119	7%	0.24	8.45	0.79	2.75	2.96	2.51	1.88	-	19.58
Norway	27.5: Medium	52	3%	0.17	0.54	6.22	0.57	0.75	30.38	0.30	-	38.93
Norway	32.5: Medium	18	1%	0.26	7.42	1.55	2.41	2.74	5.43	2.77	-	22.58
Norway	37.5: Light	526	31%	0.27	6.09	1.94	2.23	2.60	7.10	2.28	-	22.50
Norway	42.5: Light	712	42%	0.19	3.56	4.08	1.32	1.62	18.30	1.84	-	30.92
Norway	47.5: Light	97	6%	0.20	6.35	2.26	2.06	2.48	8.31	2.22	-	23.87
Norway	**Total**	**1,713**	**100%**	**0.21**	**5.20**	**2.77**	**1.89**	**2.19**	**11.71**	**2.04**	**-**	**26.01**
Oman	12.5: Heavy	11	1%	0.14	2.80	0.06	3.07	3.07	0.06	2.15	-	11.35
Oman	17.5: Heavy	46	5%	0.28	3.43	0.07	3.04	3.13	0.08	1.22	-	11.25
Oman	22.5: Heavy	156	16%	0.35	5.44	0.11	3.01	3.16	0.13	0.76	-	12.96
Oman	27.5: Medium	43	5%	0.36	10.49	0.36	2.89	3.14	0.47	0.80	-	18.50
Oman	32.5: Medium	179	19%	0.07	11.01	0.63	2.76	3.08	0.80	0.58	-	18.93
Oman	37.5: Light	311	33%	0.19	15.85	2.55	1.98	2.33	3.94	1.31	-	28.14
Oman	42.5: Light	49	5%	0.37	19.77	1.33	2.43	2.85	1.76	1.65	-	30.17
Oman	47.5: Light	53	6%	0.19	13.21	0.85	2.59	3.05	1.19	1.42	-	22.50
Oman	52.5: Light	95	10%	0.21	13.35	1.45	2.32	2.80	2.04	1.38	-	23.54
Oman	57.5: Light	7	1%	0.13	12.66	3.25	1.56	1.97	5.00	0.21	-	24.78
Oman	**Total**	**949**	**100%**	**0.22**	**12.01**	**1.28**	**2.49**	**2.80**	**1.88**	**1.09**	**-**	**21.77**

				Kilograms CO2e per barrel of crude and condensate (LCA basis)								
Country	API Gravity Classification	2020 Oil Production (kbpd)	Fraction of Oil Production	Prod. well construction (CO2e kg/bbl)	Prod. vented & flared (CO2e kg/bbl)	Prod. lease compression (CO2e kg/bbl)	Prod. oil stabilization (CO2e kg/bbl)	Prod. storage fugitives (CO2e kg/bbl)	Prod. methane leaks (CO2e kg/bbl)	Prod. electricity & pumps (CO2e kg/bbl)	Prod. steam (CO2e kg/bbl)	Production GHG (CO2e kg/bbl)
Pakistan	12.5: Heavy	0	0%	0.17	-	-	3.09	3.09	-	0.41	-	6.76
Pakistan	17.5: Heavy	1	2%	0.32	4.72	0.09	3.05	3.08	0.10	0.40	-	11.78
Pakistan	22.5: Heavy	1	1%	0.55	20.37	0.50	2.88	3.02	0.56	0.38	-	28.27
Pakistan	27.5: Medium	3	4%	0.32	22.80	1.13	2.59	2.85	1.69	0.35	-	31.72
Pakistan	32.5: Medium	5	6%	0.24	17.04	2.67	1.97	2.24	4.47	0.84	-	29.46
Pakistan	37.5: Light	6	8%	0.22	28.99	1.74	2.29	2.66	2.55	1.49	-	39.95
Pakistan	42.5: Light	50	68%	0.17	27.30	2.37	2.03	2.40	3.64	1.13	-	39.04
Pakistan	47.5: Light	5	6%	0.15	19.30	3.27	1.63	1.98	5.36	0.59	-	32.28
Pakistan	52.5: Light	4	5%	0.28	28.53	2.76	1.80	2.20	4.33	0.25	-	40.16
Pakistan	**Total**	**74**	**100%**	**0.20**	**25.66**	**2.30**	**2.06**	**2.41**	**3.56**	**1.01**	**-**	**37.20**
Papua New Guinea	32.5: Medium	1	1%	0.16	3.60	4.60	1.21	1.49	7.64	0.16	-	18.85
Papua New Guinea	42.5: Light	5	12%	0.03	6.04	2.51	1.97	2.37	3.62	1.11	-	17.64
Papua New Guinea	47.5: Light	7	18%	0.05	3.52	4.38	1.18	1.49	7.24	0.72	-	18.57
Papua New Guinea	52.5: Light	3	8%	0.07	3.39	4.34	1.14	1.45	7.20	0.87	-	18.45
Papua New Guinea	57.5: Light	24	61%	0.01	4.49	3.49	1.48	1.86	5.46	0.65	-	17.44
Papua New Guinea	**Total**	**39**	**100%**	**0.03**	**4.39**	**3.62**	**1.45**	**1.82**	**5.73**	**0.72**	**-**	**17.77**
Peru	12.5: Heavy	3	8%	0.24	4.45	0.09	3.07	3.02	0.10	0.38	-	11.34
Peru	17.5: Heavy	4	10%	0.48	5.85	0.12	3.03	3.10	0.14	0.37	-	13.09
Peru	22.5: Heavy	5	12%	0.32	7.87	0.86	2.73	2.91	2.73	0.34	-	17.76
Peru	27.5: Medium	8	19%	0.56	8.93	0.43	2.88	3.09	0.51	0.36	-	16.75
Peru	32.5: Medium	12	31%	3.39	5.28	2.60	2.01	2.32	4.91	0.81	-	21.32
Peru	37.5: Light	6	16%	2.75	6.71	2.00	2.21	2.56	5.29	0.75	-	22.27
Peru	42.5: Light	-	0%									
Peru	62.5: Light	1	3%	0.05	-	5.04	0.68	0.93	9.05	0.65	-	16.41
Peru	**Total**	**40**	**100%**	**1.70**	**6.36**	**1.50**	**2.44**	**2.67**	**3.12**	**0.57**	**-**	**18.36**
Philippines	27.5: Medium	0	16%	0.94	1.08	0.02	3.02	3.25	0.06	0.42	-	8.79
Philippines	42.5: Light	0	22%	0.81	8.12	0.97	2.56	3.01	3.08	0.36	-	18.91
Philippines	52.5: Light	1	62%	0.43	8.48	0.69	2.62	3.13	2.10	0.38	-	17.84
Philippines	**Total**	**1**	**100%**	**0.60**	**7.22**	**0.65**	**2.67**	**3.12**	**1.99**	**0.38**	**-**	**16.63**

				Kilograms CO2e per barrel of crude and condensate (LCA basis)								
Country	API Gravity Classification	2020 Oil Production (kbpd)	Fraction of Oil Production	Prod. well construction (CO2e kg/bbl)	Prod. vented & flared (CO2e kg/bbl)	Prod. lease compression (CO2e kg/bbl)	Prod. oil stabilization (CO2e kg/bbl)	Prod. storage fugitives (CO2e kg/bbl)	Prod. methane leaks (CO2e kg/bbl)	Prod. electricity & pumps (CO2e kg/bbl)	Prod. steam (CO2e kg/bbl)	Production GHG (CO2e kg/bbl)
Poland	17.5: Heavy	0	0%	16.16	7.89	1.24	2.61	2.77	1.58	0.36	-	32.62
Poland	27.5: Medium	0	2%	4.04	6.70	0.65	2.78	3.04	0.76	0.58	-	18.55
Poland	32.5: Medium	2	9%	3.15	6.79	1.86	2.28	2.60	2.77	0.74	-	20.19
Poland	37.5: Light	1	6%	5.30	7.72	1.29	2.48	2.86	1.72	0.68	-	22.05
Poland	42.5: Light	7	35%	0.99	7.07	1.73	2.28	2.69	5.03	1.84	-	21.63
Poland	47.5: Light	9	46%	0.28	5.35	3.00	1.76	2.14	4.52	0.25	-	17.31
Poland	52.5: Light	0	1%	3.44	6.54	2.05	2.09	2.56	2.85	0.92	-	20.45
Poland	**Total**	**19**	**100%**	**1.25**	**6.29**	**2.27**	**2.06**	**2.45**	**4.26**	**0.90**	**-**	**19.49**
Qatar	22.5: Heavy	25	2%	0.38	4.82	0.09	3.00	3.20	0.27	0.42	-	12.19
Qatar	27.5: Medium	259	20%	0.17	5.63	2.43	2.11	2.37	9.34	1.62	-	23.68
Qatar	32.5: Medium	59	5%	0.11	11.12	1.78	2.31	2.66	6.27	4.85	-	29.11
Qatar	37.5: Light	933	73%	0.06	5.27	2.14	2.15	2.52	4.99	5.76	-	22.90
Qatar	**Total**	**1,274**	**100%**	**0.09**	**5.60**	**2.14**	**2.17**	**2.51**	**5.84**	**4.78**	**-**	**23.13**
Romania	17.5: Heavy	15	21%	1.10	4.24	0.10	3.04	3.10	0.11	1.26	-	12.94
Romania	22.5: Heavy	9	14%	2.22	7.24	0.67	2.80	2.98	0.87	1.23	-	18.02
Romania	27.5: Medium	8	12%	1.26	7.49	0.92	2.68	2.94	1.20	0.93	-	17.42
Romania	32.5: Medium	13	20%	1.46	8.07	1.05	2.61	2.92	1.35	0.80	-	18.26
Romania	37.5: Light	9	14%	3.81	7.14	1.74	2.31	2.68	2.41	0.82	-	20.90
Romania	42.5: Light	4	7%	3.26	7.05	1.75	2.27	2.67	2.52	0.46	-	19.98
Romania	47.5: Light	9	13%	1.03	4.53	3.60	1.51	1.86	14.61	1.66	-	28.80
Romania	**Total**	**68**	**100%**	**1.85**	**6.41**	**1.25**	**2.53**	**2.78**	**2.95**	**1.06**	**-**	**18.84**
Russia	12.5: Heavy	5	0%	1.00	5.52	0.51	2.90	2.90	0.67	0.64	-	14.15
Russia	17.5: Heavy	41	0%	0.94	3.29	0.09	3.04	3.12	0.11	1.24	-	11.82
Russia	22.5: Heavy	429	4%	0.97	12.10	0.30	2.94	3.10	0.35	1.31	-	21.07
Russia	27.5: Medium	1,297	13%	1.10	15.17	0.38	2.88	3.13	0.44	2.53	-	25.63
Russia	32.5: Medium	3,662	37%	0.81	14.92	0.68	2.75	3.05	0.92	3.23	-	26.36
Russia	37.5: Light	2,913	30%	0.87	16.38	1.36	2.46	2.80	2.03	2.73	-	28.61
Russia	42.5: Light	1,048	11%	0.98	15.05	1.86	2.23	2.62	2.71	2.29	-	27.74
Russia	47.5: Light	321	3%	0.68	15.06	1.90	2.18	2.61	2.94	1.61	-	26.97
Russia	52.5: Light	139	1%	0.71	12.58	2.64	1.85	2.28	3.93	1.99	-	25.99
Russia	57.5: Light	10	0%	1.39	13.23	2.40	1.91	2.39	3.46	1.17	-	25.95
Russia	**Total**	**9,865**	**100%**	**0.88**	**15.19**	**1.02**	**2.60**	**2.92**	**1.46**	**2.72**	**-**	**26.79**

Country	API Gravity Classification	2020 Oil Production (kbpd)	Fraction of Oil Production	Kilograms CO2e per barrel of crude and condensate (LCA basis)								
				Prod. well construction (CO2e kg/bbl)	Prod. vented & flared (CO2e kg/bbl)	Prod. lease compression (CO2e kg/bbl)	Prod. oil stabilization (CO2e kg/bbl)	Prod. storage fugitives (CO2e kg/bbl)	Prod. methane leaks (CO2e kg/bbl)	Prod. electricity & pumps (CO2e kg/bbl)	Prod. steam (CO2e kg/bbl)	Production GHG (CO2e kg/bbl)
Saudi Arabia	27.5: Medium	1,714	18%	0.03	1.07	0.52	2.84	3.07	0.96	0.26	-	8.74
Saudi Arabia	32.5: Medium	5,802	62%	0.03	1.17	1.43	2.45	2.79	2.38	0.79	-	11.06
Saudi Arabia	37.5: Light	1,217	13%	0.02	1.62	1.59	2.36	2.75	2.12	2.34	-	12.80
Saudi Arabia	42.5: Light	495	5%	0.02	1.38	2.40	2.03	2.42	3.43	1.58	-	13.24
Saudi Arabia	47.5: Light	60	1%	0.02	1.18	3.00	1.75	2.14	4.51	0.23	-	12.83
Saudi Arabia	52.5: Light	118	1%	0.05	1.76	1.06	2.48	2.96	1.51	1.86	-	11.69
Saudi Arabia	**Total**	**9,406**	**100%**	**0.03**	**1.23**	**1.34**	**2.49**	**2.82**	**2.15**	**0.95**	**-**	**10.99**
Serbia	22.5: Heavy	3	16%	2.23	3.29	2.96	1.91	2.14	4.81	1.12	-	18.46
Serbia	27.5: Medium	2	11%	1.92	8.70	0.62	2.80	3.03	0.84	2.91	-	20.83
Serbia	32.5: Medium	11	68%	0.98	7.73	1.29	2.52	2.83	1.71	1.81	-	18.88
Serbia	37.5: Light	0	1%	12.34	8.49	0.73	2.70	3.06	0.86	0.38	-	28.57
Serbia	42.5: Light	1	3%	2.08	6.48	2.23	2.08	2.46	3.41	0.29	-	19.03
Serbia	47.5: Light	0	1%	3.44	6.96	1.80	2.23	2.67	2.44	0.32	-	19.86
Serbia	**Total**	**16**	**100%**	**1.42**	**7.07**	**1.52**	**2.44**	**2.72**	**2.18**	**1.75**	**-**	**19.10**
Sudan	17.5: Heavy	10	5%	0.02	-	-	3.06	3.17	-	0.41	-	6.66
Sudan	22.5: Heavy	-	0%									
Sudan	27.5: Medium	43	19%	0.06	42.65	0.93	2.67	2.95	1.13	0.36	-	50.76
Sudan	32.5: Medium	9	4%	0.11	37.02	1.27	2.52	2.85	1.65	0.34	-	45.76
Sudan	37.5: Light	164	72%	0.06	34.25	2.12	2.17	2.53	2.96	0.76	-	44.85
Sudan	42.5: Light	1	0%	0.66	31.41	2.52	1.99	2.37	3.64	0.27	-	42.86
Sudan	**Total**	**227**	**100%**	**0.06**	**34.40**	**1.77**	**2.32**	**2.65**	**2.43**	**0.65**	**-**	**44.27**
Suriname	17.5: Heavy	15	100%	1.57	-	-	3.08	3.13	-	0.41	-	8.18
Suriname	**Total**	**15**	**100%**	**1.57**	**-**	**-**	**3.08**	**3.13**	**-**	**0.41**	**-**	**8.18**
Syria	12.5: Heavy	0	0%	2.04	5.40	0.11	3.06	3.03	0.12	0.40	-	14.15
Syria	17.5: Heavy	3	6%	0.24	39.79	0.78	2.78	2.91	0.95	2.31	-	49.78
Syria	22.5: Heavy	3	6%	0.23	56.72	1.90	2.33	2.52	2.93	0.33	-	66.96
Syria	27.5: Medium	8	18%	0.17	41.78	0.80	2.73	2.96	1.04	2.09	-	51.59
Syria	32.5: Medium	8	18%	0.12	42.80	0.82	2.69	3.01	1.00	2.10	-	52.54
Syria	37.5: Light	18	39%	0.13	68.55	1.29	2.49	2.85	1.71	3.12	-	80.14
Syria	42.5: Light	5	12%	0.20	86.63	1.63	2.33	2.73	2.22	2.67	-	98.40
Syria	47.5: Light	1	1%	0.12	103.18	1.92	2.18	2.62	2.65	2.99	-	115.66
Syria	**Total**	**46**	**100%**	**0.16**	**59.17**	**1.17**	**2.55**	**2.87**	**1.56**	**2.48**	**-**	**69.96**

				Kilograms CO2e per barrel of crude and condensate (LCA basis)								
Country	API Gravity Classification	2020 Oil Production (kbpd)	Fraction of Oil Production	Prod. well construction (CO2e kg/bbl)	Prod. vented & flared (CO2e kg/bbl)	Prod. lease compression (CO2e kg/bbl)	Prod. oil stabilization (CO2e kg/bbl)	Prod. storage fugitives (CO2e kg/bbl)	Prod. methane leaks (CO2e kg/bbl)	Prod. electricity & pumps (CO2e kg/bbl)	Prod. steam (CO2e kg/bbl)	Production GHG (CO2e kg/bbl)
Thailand	17.5: Heavy	0	0%	4.99	5.81	2.98	1.94	2.16	4.42	0.26	-	22.55
Thailand	27.5: Medium	5	3%	0.98	8.81	0.51	2.83	3.07	0.98	0.39	-	17.57
Thailand	32.5: Medium	29	14%	3.15	7.23	1.29	2.52	2.84	4.30	0.35	-	21.67
Thailand	37.5: Light	64	31%	1.61	3.32	2.91	1.87	2.20	8.06	0.81	-	20.79
Thailand	42.5: Light	60	30%	2.24	4.46	3.71	1.49	1.83	15.20	1.72	-	30.65
Thailand	47.5: Light	40	20%	2.02	1.44	4.65	1.06	1.35	20.50	0.14	-	31.17
Thailand	52.5: Light	4	2%	2.04	-	1.60	2.27	2.76	5.53	0.32	-	14.52
Thailand	**Total**	**202**	**100%**	**2.09**	**3.91**	**3.17**	**1.72**	**2.05**	**11.86**	**0.86**	**-**	**25.67**
Trinidad and Tobago	17.5: Heavy	17	30%	0.53	7.55	1.52	2.50	2.68	4.81	1.05	-	20.64
Trinidad and Tobago	22.5: Heavy	2	4%	1.82	6.70	2.17	2.23	2.48	7.91	0.30	-	23.62
Trinidad and Tobago	27.5: Medium	1	1%	1.20	8.73	0.59	2.81	3.06	1.73	0.96	-	19.08
Trinidad and Tobago	32.5: Medium	20	36%	0.47	4.11	4.20	1.38	1.66	17.68	1.21	-	30.70
Trinidad and Tobago	37.5: Light	3	6%	0.76	4.62	3.68	1.54	1.86	14.27	1.41	-	28.15
Trinidad and Tobago	42.5: Light	13	24%	0.67	0.18	3.05	1.75	2.12	11.92	0.25	-	19.96
Trinidad and Tobago	**Total**	**56**	**100%**	**0.62**	**4.39**	**2.98**	**1.86**	**2.13**	**11.73**	**0.90**	**-**	**24.61**
Tunisia	27.5: Medium	4	14%	0.59	8.59	0.68	2.77	3.04	2.07	3.27	-	20.99
Tunisia	32.5: Medium	1	3%	0.41	8.76	0.41	2.84	3.16	0.46	3.77	-	19.81
Tunisia	37.5: Light	6	20%	0.25	8.61	0.63	2.73	3.09	1.01	0.56	-	16.89
Tunisia	42.5: Light	18	57%	0.16	7.03	1.79	2.26	2.65	2.79	1.48	-	18.16
Tunisia	47.5: Light	2	6%	0.07	7.32	1.54	2.33	2.76	2.12	0.32	-	16.47
Tunisia	52.5: Light	0	0%	0.12	9.17	0.20	2.82	3.33	0.23	0.40	-	16.27
Tunisia	**Total**	**31**	**100%**	**0.24**	**7.63**	**1.35**	**2.44**	**2.81**	**2.23**	**1.53**	**-**	**18.23**
Turkey	12.5: Heavy	8	12%	0.63	1.48	0.14	3.04	3.04	0.22	1.64	-	10.18
Turkey	17.5: Heavy	2	3%	2.14	0.98	0.02	3.06	3.13	0.03	0.84	-	10.20
Turkey	22.5: Heavy	6	10%	0.85	3.95	0.08	3.03	3.17	0.09	0.40	-	11.55
Turkey	27.5: Medium	17	28%	0.57	8.46	0.75	2.75	3.00	0.90	0.41	-	16.84
Turkey	32.5: Medium	23	37%	0.60	7.60	0.60	2.78	3.08	0.77	0.39	-	15.81
Turkey	37.5: Light	6	10%	0.93	5.36	1.36	2.46	2.82	1.87	0.45	-	15.26
Turkey	**Total**	**62**	**100%**	**0.70**	**6.31**	**0.60**	**2.80**	**3.04**	**0.76**	**0.57**	**-**	**14.77**

				Kilograms CO2e per barrel of crude and condensate (LCA basis)								
Country	API Gravity Classification	2020 Oil Production (kbpd)	Fraction of Oil Production	Prod. well construction (CO2e kg/bbl)	Prod. vented & flared (CO2e kg/bbl)	Prod. lease compression (CO2e kg/bbl)	Prod. oil stabilization (CO2e kg/bbl)	Prod. storage fugitives (CO2e kg/bbl)	Prod. methane leaks (CO2e kg/bbl)	Prod. electricity & pumps (CO2e kg/bbl)	Prod. steam (CO2e kg/bbl)	Production GHG (CO2e kg/bbl)
Turkmenistan	27.5: Medium	1	1%	2.09	42.09	2.42	2.11	2.40	3.47	0.28	-	54.86
Turkmenistan	32.5: Medium	97	49%	0.48	20.64	3.88	1.50	1.78	8.47	0.68	-	37.43
Turkmenistan	37.5: Light	7	4%	0.88	36.52	3.02	1.83	2.16	4.55	0.25	-	49.20
Turkmenistan	42.5: Light	11	6%	0.38	15.88	4.13	1.33	1.65	6.72	1.24	-	31.32
Turkmenistan	47.5: Light	83	42%	0.54	38.06	2.70	1.87	2.28	3.97	2.84	-	52.26
Turkmenistan	**Total**	**200**	**100%**	**0.52**	**28.32**	**3.36**	**1.66**	**2.00**	**6.33**	**1.59**	**-**	**43.79**
UAE - Abu Dhabi	32.5: Medium	18	1%	0.96	2.60	0.75	2.73	3.03	2.28	3.18	-	15.53
UAE - Abu Dhabi	37.5: Light	1,522	51%	0.07	1.91	2.76	1.89	2.24	7.06	1.70	-	17.64
UAE - Abu Dhabi	42.5: Light	1,366	46%	0.09	1.88	2.45	1.99	2.38	6.27	2.23	-	17.29
UAE - Abu Dhabi	47.5: Light	59	2%	0.34	2.20	1.69	2.27	2.68	6.09	3.24	-	18.50
UAE - Abu Dhabi	52.5: Light	9	0%	0.14	1.27	3.83	1.39	1.73	15.92	0.19	-	24.47
UAE - Abu Dhabi	**Total**	**2,973**	**100%**	**0.09**	**1.90**	**2.59**	**1.95**	**2.32**	**6.67**	**1.98**	**-**	**17.51**
UAE - Dubai	32.5: Medium	157	100%	0.29	2.56	3.38	1.71	2.02	13.46	0.95	-	24.37
UAE - Dubai	47.5: Light	-	0%									
UAE - Dubai	**Total**	**157**	**100%**	**0.29**	**2.56**	**3.38**	**1.71**	**2.02**	**13.46**	**0.95**	**-**	**24.37**
UAE - Sharjah	42.5: Light	8	100%	0.32	0.49	5.96	0.54	0.74	29.14	0.92	-	38.11
UAE - Sharjah	**Total**	**8**	**100%**	**0.32**	**0.49**	**5.96**	**0.54**	**0.74**	**29.14**	**0.92**	**-**	**38.11**
Ukraine	32.5: Medium	2	7%	0.61	0.97	2.36	2.11	2.43	3.38	0.27	-	12.13
Ukraine	37.5: Light	12	35%	0.88	3.04	2.10	2.16	2.51	3.26	0.74	-	14.68
Ukraine	42.5: Light	19	56%	0.26	6.79	1.96	2.19	2.60	2.75	1.01	-	17.56
Ukraine	47.5: Light	0	1%	2.45	4.47	3.61	1.50	1.85	5.66	0.19	-	19.73
Ukraine	**Total**	**34**	**100%**	**0.53**	**5.05**	**2.06**	**2.17**	**2.54**	**3.01**	**0.85**	**-**	**16.21**
United Kingdom	22.5: Heavy	104	11%	0.62	9.23	1.06	2.66	2.84	3.64	1.96	-	22.01
United Kingdom	27.5: Medium	135	14%	0.34	8.22	1.73	2.38	2.65	6.21	2.06	-	23.58
United Kingdom	32.5: Medium	214	22%	0.35	9.72	0.66	2.76	3.05	2.09	2.99	-	21.62
United Kingdom	37.5: Light	307	32%	0.63	7.98	1.80	2.28	2.64	6.82	2.33	-	24.48
United Kingdom	42.5: Light	141	15%	0.52	6.55	2.60	1.93	2.29	10.74	1.77	-	26.40
United Kingdom	47.5: Light	31	3%	0.36	3.73	4.32	1.17	1.44	20.63	0.63	-	32.27
United Kingdom	52.5: Light	20	2%	0.66	5.85	3.08	1.69	2.09	12.16	1.95	-	27.48
United Kingdom	57.5: Light	-	0%									
United Kingdom	**Total**	**951**	**100%**	**0.50**	**8.15**	**1.68**	**2.34**	**2.65**	**6.46**	**2.25**	**-**	**24.04**

				Kilograms CO_2e per barrel of crude and condensate (LCA basis)								
Country	API Gravity Classification	2020 Oil Production (kbpd)	Fraction of Oil Production	Prod. well construction (CO_2e kg/bbl)	Prod. vented & flared (CO_2e kg/bbl)	Prod. lease compression (CO_2e kg/bbl)	Prod. oil stabilization (CO_2e kg/bbl)	Prod. storage fugitives (CO_2e kg/bbl)	Prod. methane leaks (CO_2e kg/bbl)	Prod. electricity & pumps (CO_2e kg/bbl)	Prod. steam (CO_2e kg/bbl)	Production GHG (CO_2e kg/bbl)
Uzbekistan	17.5: Heavy	0	2%	1.43	9.14	0.18	3.00	3.10	0.20	0.40	-	17.45
Uzbekistan	22.5: Heavy	0	0%	1.69	7.72	1.37	2.55	2.75	1.83	1.21	-	19.11
Uzbekistan	27.5: Medium	1	10%	1.11	8.59	0.70	2.77	3.02	0.86	2.59	-	19.63
Uzbekistan	32.5: Medium	0	7%	2.77	6.66	2.16	2.17	2.45	3.66	0.34	-	20.20
Uzbekistan	37.5: Light	5	73%	0.27	0.28	4.86	1.06	1.33	8.29	1.30	-	17.40
Uzbekistan	42.5: Light	1	8%	0.42	4.01	3.15	1.70	2.06	5.03	0.23	-	16.61
Uzbekistan	47.5: Light	0	1%	0.25	3.51	4.39	1.17	1.48	7.28	0.16	-	18.24
Uzbekistan	57.5: Light	0	0%	1.24	3.36	4.30	1.13	1.45	7.14	0.15	-	18.76
Uzbekistan	**Total**	**7**	**100%**	**0.55**	**2.01**	**4.04**	**1.39**	**1.67**	**6.83**	**1.25**	**-**	**17.75**
Venezuela	5.5: Extra Heav	81	15%	0.04	30.59	0.87	2.78	2.68	1.05	1.67	-	39.68
Venezuela	12.5: Heavy	151	29%	0.18	10.97	1.11	2.68	2.70	1.45	5.08	44.11	68.28
Venezuela	17.5: Heavy	9	2%	0.42	43.95	2.42	2.16	2.32	3.75	0.71	-	55.72
Venezuela	22.5: Heavy	13	2%	0.32	43.81	1.30	2.57	2.76	1.80	1.20	-	53.76
Venezuela	27.5: Medium	87	17%	0.10	55.43	1.85	2.33	2.61	2.62	3.07	-	68.00
Venezuela	32.5: Medium	127	24%	0.10	25.35	2.86	1.89	2.19	4.58	1.69	-	38.66
Venezuela	37.5: Light	30	6%	0.42	47.21	2.50	2.01	2.36	3.76	2.20	-	60.46
Venezuela	42.5: Light	9	2%	0.19	39.78	3.31	1.65	1.99	6.43	0.35	-	53.71
Venezuela	47.5: Light	16	3%	0.34	49.37	2.96	1.77	2.15	4.55	2.20	-	63.34
Venezuela	52.5: Light	3	1%	0.29	41.16	3.47	1.49	1.85	5.91	1.12	-	55.30
Venezuela	**Total**	**527**	**100%**	**0.15**	**30.12**	**1.84**	**2.34**	**2.50**	**2.73**	**2.88**	**12.65**	**55.20**
Vietnam	27.5: Medium	2	1%	0.21	6.09	2.62	2.03	2.33	9.87	0.28	-	23.43
Vietnam	32.5: Medium	106	55%	0.62	7.03	1.84	2.30	2.64	6.50	4.58	-	25.50
Vietnam	37.5: Light	85	44%	0.26	7.57	1.43	2.43	2.79	5.13	1.88	-	21.48
Vietnam	**Total**	**193**	**100%**	**0.46**	**7.26**	**1.66**	**2.35**	**2.70**	**5.93**	**3.35**	**-**	**23.71**
Yemen	17.5: Heavy	1	1%	0.36	1.27	0.02	3.06	3.15	0.03	1.32	-	9.21
Yemen	22.5: Heavy	1	2%	0.27	1.66	0.03	3.03	3.20	0.04	0.41	-	8.63
Yemen	27.5: Medium	17	27%	0.12	6.63	0.47	2.84	3.09	0.75	1.70	-	15.60
Yemen	32.5: Medium	18	27%	0.15	7.47	0.15	2.93	3.26	0.18	1.65	-	15.79
Yemen	37.5: Light	4	6%	0.16	10.94	0.24	2.88	3.25	0.31	1.26	-	19.05
Yemen	42.5: Light	5	8%	0.11	38.57	3.69	1.47	1.80	6.05	0.85	-	52.56
Yemen	47.5: Light	19	29%	0.11	58.42	2.97	1.78	2.16	4.46	1.31	-	71.22
Yemen	**Total**	**65**	**100%**	**0.13**	**24.51**	**1.34**	**2.46**	**2.78**	**2.05**	**1.45**	**-**	**34.71**

5. Appendix B: Comparisons to Other Studies and Sensitivity Analysis

Appendix B compares the results of this analysis with the results of similar public studies and presents results of sensitivity analyses.

5.1 Results Comparison with Other Studies

Exhibit 24 below provides a summary of results from other studies which quantify the GHG emission intensity from the production of crude oil. The studies shown apply different methodologies for GHG quantification and utilize unique underlying data and assumptions to arrive at results. In contrast to this analysis, the results shown below typically include GHG emission intensity from both the production at the wellhead as well as emissions from the transportation of the crude oil to the refinery gate. Results can also be expressed in terms of megajoule (MJ) or barrel of oil equivalent (BOE) delivered and utilize differing global warming potentials for methane which determine the contribution of the methane emissions to total GHG measured in carbon dioxide equivalent.

Although some of these assumptions can be determined by reviewing each study, certain aspects such as the use of lower heating value or higher heating value when expressing results in units of energy delivered are not always clearly stated. Further, the relative GHG emissions specific to each supply chain component (e.g., production versus transportation) are also not always fully transparent. To better compare the results from these studies with this analysis, ICF applied an approximation to adjust each study's result to exclude the transportation component. ICF also utilized a global average MJ LHV per barrel to convert all results into emissions per barrel.

The adjusted results for each study are shown in the bottom two rows of Exhibit 24. For the studies that encompass a wide portion of global supplies (that is, excluding the CEC study which focuses on California's mix of crudes) the resulting range is 44.3 to 58.9 CO_2e kg/bbl for oil production. This compares to this study's Base Case of 26.5 and the sensitivity range of 29.2 to 48.8 CO_2e kg/bbl. These sensitivities are discussed below.

The methodology utilized in each of the cited studies can vary widely on the scope considered, the underlying assumptions, and overall completeness. In other words, some studies quantify only the direct emissions of certain GHGs (i.e., methane) from operations, whereas others may publish results which consider all GHGs and represent a full life cycle assessment. Therefore, when reviewing and comparing results, significant care must be taken to ensure these potential inconsistencies are understood. ICF has incorporated results from the studies reviewed in this analysis as appropriate, however a comprehensive comparison of all sources addressing potential methodological inconsistencies is beyond the scope of this study.

Exhibit 24: Summary of Global Carbon Intensity of Production of Crude Oil from Other Studies

Parameter	Stanford/OPGEE (2018)	CEC (2021)	DOE/GREET (2022)	OCI Phase 2 (2016)	OCI+ (2022)	IEA (2018)
Global CI	10.3	12.8	8.7	52.1	63.9	51.2
Units	g CO2e/MJ LHV	g CO2e/MJ	g CO2e/MJ	kg CO2e/BOE	kg CO2e/BOE	kg CO2e/BOE
Data Year	2015	Carbon intensity values based on 2015 oil field data	2018	2014/2015	2020	2018
Supply Chain	Production+Transportation	Production+Transportation	Production+Transportation	Production+Transportation	Production+Transportation	Production
GWP	AR5 - 30	Unclear	Unclear but study methodology incorporates GHG impact factors which utilize AR5 - 30	AR5 - 34	AR5 - 34	AR5 - 34
Specific CI Range	3.3 - 20.3	1.6 - 48.1	3.0 - 27.3	21 - 206	24 - 447	9.1 - 656
Coverage	8,966 on-stream oil fields in 90 Countries (represents approximately ~98% of 2015 global crude oil and condensate production)	Represents in-state crude oil production and imported volumes to California	A total of 128 countries are included in the network, covering ~98% of total global crude-oil trade in 2018.	75 global oils (dictated by data availability)	Emissions for 135 upstream fields (assets) for the year 2020. Approximately 64% of the 2020 global production is included in the OCI+ modeling.	Applies country-level algorithms to all of world's oil and gas production
Reference	Global carbon intensity of crude oil production	California Low Carbon Fuel Standard (LCFS)	Greenhouse gas emissions from the global transportation of crude oil: Current status and mitigation potential	Oil Climate Index (Phase 2)	Oil Climate Index + Gas	Methane from oil & gas – Methane Tracker 2020 – Analysis - IEA
Notes	Range excludes countries with <0.1% of global crude oil production	State specific CI rather than global CI. Range is presented by specific crude type rather than by country.	Global CI given is "consumption-based", meaning it includes domestic production and imported crude oil emissions while excluding exported crude oil emissions.	-	-	-
Normalized to ICF Study (kg CO2e/bbl w/o Crude Transportation)	53.6	67.8	44.3	47.1	58.9	51.2

In contrast to some of the other studies shown above, the International Energy Agency (IEA) publishes estimates of global carbon intensity broken out by component. Exhibit 25 provides the global emissions total for 2018 across several component as defined by IEA data analysis. The results are based on a combination of country-specific algorithms which quantify emissions from all of the world's oil and gas production. The top portion of the exhibit is the original data from IEA and the bottom portion is ICF's adjustment to move GHG emissions associated with natural gas plant liquids to the natural gas supply chain to match this study's convention for allocating emissions among coproducts. Note that the "production" category for natural gas does contain some amount of GHG emissions from gas processing plants, further illustrating the complexity of these comparisons.

Exhibit 25: IEA Estimate of 2018 Global Emissions from Oil & Gas Production

Original IEA with NGPL counted as "Oil"	Production GHG 2018 (million tons CO2e)			Production GHG CO2e kg/BOE		
	Oil	Gas	Oil & Gas	Oil	Gas	Oil & Gas
Energy for extraction	466	637	1,102	13.9	25.7	18.9
Flaring	243	-	243	7.3	-	4.2
CO2 Venting	-	170	170	-	6.9	2.9
Methane Upstream	1,001	929	1,931	30.0	37.5	33.2
Sum GHG for Production	**1,710**	**1,736**	**3,447**	**51.2**	**70.0**	**59.2**
Production (kboe/day)	91,472	67,907	159,378			

After moving 7 MMboe/day of NGPL to "Gas"	Production GHG 2018 (million tons CO2e)			Production GHG CO2e kg/BOE		
	Oil	Gas	Oil & Gas	Oil	Gas	Oil & Gas
Energy for extraction	430	672	1,102	13.9	24.6	18.9
Flaring	225	19	243	7.3	0.7	4.2
CO2 Venting	-	170	170	-	6.2	2.9
Methane Upstream	925	1,005	1,931	30.0	36.8	33.2
Sum GHG for Production	**1,580**	**1,866**	**3,447**	**51.2**	**68.3**	**59.2**
Production (MMBOE/Y)	84,518	74,860	159,378			

Note: The IEA convention is to group natural gas plant liquids with crude oil and condensate. The convention used by ICF is to consider NGPL as part of the natural gas supply chain. Therefore, to develop IEA emission values that can be compared to this study, 7 million boe per day of NGPL and the related GHG emissions was moved into the natural gas category.

Source: International Energy Agency Methane Tracker

The following exhibit shows the average higher heating value and lower heating value (LHV) megajoule per barrel conversion factors computed in this analysis. To determine the global weighted average, ICF incorporated the three regional factors shown below with 2020 oil production volumes as given in Appendix A. The result is that a typical barrel of produced oil contains nearly 5,700 MJ LHV per barrel, which is used to normalize the results of several studies previously shown in Exhibit 24.

Exhibit 26: Average Crude and Condensate Heat Content by Region

Region Designation	MMBTU HHV/bbl	MJ HHV/bbl	MJ LHV/bbl
US	5.60	5,909	5,525
Canada	5.87	6,197	5,815
Non-US, Non-Canada	5.77	6,088	5,705
Global Weighted Average	5.75	6,067	5,684

Note - HHV and LHV refers to higher and lower heating value, respectively.
Source: ICF calculations

5.2 Estimates for GWP for Methane

The greatest source of differences in the results of this study and other published studies is this study's use of the EPA GHG Inventory values for (a) methane emission volumes expressed in metric tons of methane and (b) a global warming potential of 25 to convert from tons of methane to tons of carbon dioxide equivalent. A series of sensitivity analyses were performed to test how the use of methane emission tonnage estimated by the International Energy Agency and a GWP of 34 (used by IEA and others) would affect the relative standing of the GoM.

The GWP Concept

Greenhouse gases absorb and re-emit solar radiation, resulting in an overall warming effect by "trapping" heat in the earth's atmosphere. Different gases have different warming effects and different lifetimes in the atmosphere, making it difficult to compare their effects on a consistent basis. A factor called global warming potential (GWP) is often used to measure the relative effects of different GHGs by weight and, consequently, the relative value of their reduction. GWP can be defined as the amount of total energy added to the climate by a gas relative to the impact of the same weight of the baseline gas CO_2. The GHG emissions weighted by the GWP are expressed as CO_2 equivalent (CO_2e).

Two key factors in determining the effect of a GHG are its warming effect and the length of time that it remains active in the atmosphere. CO_2 is the least potent of the GHGs but it remains in the atmosphere for thousands of years. Even though it is the least potent, CO_2 is the largest GHG source from large users of fossil fuels and thus it has been a focal point for initiatives to regulate GHG emissions. On the other hand, methane is more potent, but its average lifetime in the atmosphere is only about 12 years.

Estimated GWP for Methane

The IPCC calculates the GWP based on a 100-year and 20-year lifetime to provide alternative bases for analyzing emission impacts. Depending on the lifetime of the individual gas, the 20-year GWP can be higher or lower than the 100-year GWP. Both of these values are correct but they reflect a different snapshot of the warming effect of the subject gases. While there is no scientific imperative for selecting one or the other GWP life, the GWP for a time horizon of 100 years was adopted as a metric to implement the multi-gas approach embedded in the United Nations Framework Convention on Climate Change (UNFCCC) and was made operational in the 1997 Kyoto Protocol. The 100-year GWP is also the standard for reporting national emissions to the UNFCCC and is the standard used in most national GHG reporting and regulatory programs.

Most countries and international agencies (including the U.S. EPA) follow inventory protocols set by the IPCC, which still use the AR-4 100-year GWP of 25. The AR-5 includes some changes in the treatment of the methane GWP. The first major change in AR-5 is fully including carbon cycle feedback in calculating the GWP. As the temperature increases, the biosphere retains less CO_2, which enters the atmosphere and causes further warming.

The second change is specific to methane. When methane oxidizes in the atmosphere, it creates CO_2, which has an additional warming effect. Thus methane emissions have a direct and then an indirect effect on the Earth's climate due to the CO_2 that is created. The primary GWP values for methane listed in the AR-5 are for biogenic methane, for which the CO_2 is assumed to have been absorbed from the biosphere and, therefore, the oxidation does not constitute a net increase. For fossil methane, however, the methane oxidation effect adds 1 to the 20-year GWP and 2 to the 100-year GWP.

The 100-year value without feedback or oxidation adjustment is 28 (slightly higher than the AR-4 value of 25). With the adjustment for fossil methane it is 34. The value with feedback and adjustment for oxidation is 36. The 20-year values in the AR-5 are 84 without feedback or oxidation and 87 with feedback and oxidation. AR-6 includes feedback and oxidation but the effects of these factors have been reevaluated and reduced, resulting in a 20-year value of 82.5 and a 100-year value of 29.8.

These results are summarized in Exhibit 27. These new findings in AR-5 and AR-6 have not been accepted by all parties and many entities, including some government and regulatory agencies, use the values without feedback, while few organizations are currently using the values with feedback and oxidation factor. The 100-year value adopted by IEA for its analysis (and the basis for the sensitivities shown here) is 34, which is the AR-5 value with feedback but without oxidation.

Exhibit 27: Estimated GWP for Methane

IPCC Assessment Report	Year Published	100 - Year GWP	20 – Year GWP
AR 4	2007	**25**	72
AR 5*	2014	28/**34**/36	84/86/87
AR 6**	2021	29.8	82.5

*Without feedback/With feedback/With oxidation

** Includes feedback and oxidation

5.3 Sensitivity Analysis

The sensitivity analyses incorporated both estimates of methane emission tonnage from IEA (that is, assumptions of higher release rates for methane from oil and gas operations) and a higher GWP of 34 (that is, an assumption that each ton of methane has higher potency for trapping heat). The volume adjustment was estimate from the values shown in Exhibit 28 which compares 2021 US methane emissions from IEA and the US EPA Inventory – all measured in tons of methane. The IEA's estimate for methane from oil and gas production is about twice that estimated in the EPA GHG Inventory. Therefore, the methane volume estimates for the US were doubled (in units of percent release rates, methane kilograms per year per device, etc.) for sensitivities based on IEA volume estimates.

Exhibit 28: Comparison of 2021 US Methane Emissions (kilotons CH_4)

IEA Segment	IEA Estimate	US EPA Inventory	Ratio
Oil and natural gas - upstream	10,898	5,586	1.95
Oil and natural gas - downstream	3,213	2,074	1.55
Satellite-detected large leaks	276	0	N/A
Total	**14,387**	**7,660**	**1.88**

Source: International Energy Agency and US EPA. Upstream includes natural gas processing, which is estimated in the EPA Inventory to be 494 kilotons of CH4.

As was shown earlier in **Exhibit 25** the IEA estimate of 2018 global methane emission for oil and gas production is 1,931 million tons of CO_2e, of which 925 million tons of CO_2e is attributable to crude and condensate production and 1,009 million tons is attributable to natural gas and NGPL. To adjust the Base Case methane factors for countries outside of the US (the parameters for which are usually developed from EPA GHG Inventory numbers), ICF took the US adjustment factor of 2.0 and multiplied it times the IEA assumptions for how each county's emissions factors for methane compared to the US. Those relative values are shown in Exhibit 29. For example, the Canada adjustment for methane volume for sensitivities based on IEA methane assumptions was 2.0 x 0.8 = 1.6. The countries outside of the US and Canada have an average adjustment for methane of 2.0 x 1.55 = 3.1.

Note that adjustment values of 2.0 for the US, 1.6 for Canada and 3.1 average for the rest of the world apply to methane measured in physical tons. When a higher GWP of 34 is also applied in the first and third sensitivities, the adjustment is 34/25 = 1.36 times greater in units of carbon dioxide equivalent compared to the changes in physical units.

Exhibit 29: Scaling Factors for International Oil and Gas Production Relative to US

Country	Upstream Oil	Upstream Gas	Composite Adj. Factor
United States	1.0	1.0	1.0
Russia	2.1	1.6	1.8
Saudi Arabia	1.0	0.8	1.0
Canada	0.8	0.9	0.8
Iran	2.9	1.6	2.5
China	1.2	0.9	1.1
Iraq	1.8	1.1	1.7
United Arab Emirates	1.2	1.1	1.2
Qatar	1.0	1.0	1.0
Norway	0.0	0.0	0.0
Kuwait	1.1	0.8	1.1
Brazil	1.4	1.4	1.4
Algeria	4.2	1.7	3.1
Nigeria	3.8	2.0	3.0
Mexico	1.7	1.1	1.6
Kazakhstan	2.8	2.5	2.7
Australia	0.9	0.5	0.7
Indonesia	2.4	1.6	1.9
Malaysia	1.2	0.7	1.0
United Kingdom	0.5	0.4	0.5
Egypt	2.7	1.3	2.4
Oman	1.6	1.1	1.5
Venezuela	9.0	2.4	6.8
Turkmenistan	17.3	6.3	11.1
Angola	1.5	0.7	1.4

Source: International Energy Agency (IEA). The average adjustment for countries other than the US and Canada is about 1.55. These are the ratios by which specific US-derived emission factors (percent leaks, emissions per device per year, etc.) would have to adjusted on average to account for differences between those countries and the US. For most countries, these adjustments are above 1.0 indicating that regulations and practices lead to relatively greater GHG emissions than in the US.

The results of the sensitivity analysis are shown in Exhibit 30. The first sensitivity adjusts the GWP to 34, the second sensitivity adjusts the methane emission factor expressed in physical units and the third sensitivity applies both changes. The top table in the exhibit shows that under these alternative methane assumptions, the GHG emission intensity (measured in CO2e per barrel) increases for all regions. However, the GoM's relative standing improves from being 13.4 CO_2e kg/bbl below the world average in the Base Case to being 14.2 to 26.4 CO_2e kg/bbl below in the sensitivities.

The impact of these changes on the quantities of CO_2e and methane estimated for global oil production in 2020 is shown in Exhibit 31. Also shown in the first column are values computed by applying the 2018 IEA factors (in CO_2e or methane kg/bbl) to 2020 actual oil production volumes. The last column displays the sensitivity that uses both the IEA methane volume factors and the GWP value of 34 usually applied by IEA. So as expected, the sensitivity in the last column comes closest to matching estimates in the first column derived from the IEA factors. The methane values are very close: 827 versus 832 million tons of CO2e. However, ICF's estimates for other GHGs (almost all CO_2) is about 11% lower than IEA's. This might be attributable to differences in (a) how boundaries for "production" are defined (ICF excludes all oil gathering and gas processing), (b) energy efficiency parameters (ICF uses values derived from US energy consumption data and that might understate energy use and CO_2 emissions in countries where fewer conservation measures have been applied) and (c) the mix of fuels used in oil production (ICF assumes relatively low-carbon fuels -- mostly natural gas and grid electricity for energy uses on producing leases and diesel fuel for drilling and completion).

Overall ICF's estimates in the last sensitivity are within about 4% of the IEA values for total CO_2e, indicating that much of the difference in ICF methodology and data compared to IEA can be attributed to the use of methane volume parameters derived from EPA GHG Inventory as opposed to IEA estimates and the use of a GWP of 25 versus 34. As shown here, when these assumptions are changed to match those used by IEA, the GHG emission intensity of GoM oil production improves compared to the world average. To the extent that other differences are attributable to ICF's possible overstatement of energy efficiency and the percent of low-carbon fuel in the mix of fuels used outside of the US, the relative GHG emission intensity of the GoM compared to the world average likely would improve even further after those parameters were also changed.

Exhibit 30: Results of Sensitivity Analyses

Region	All GHG in Kilograms CO2e per Barrel of Oil (Year 2020)			
	Base Case (GWP=25)	Base Case CH4 Volumes but GWP=34	IEA CH4 Volume Multipliers for All Countries (GWP=25)	IEA CH4 Vol. Multipliers + GWP=34
US GOM	13.1	15.0	18.5	22.4
US Total	18.7	20.6	23.9	27.6
Canada	77.2	81.3	84.0	90.6
Rest of World	24.4	27.3	41.1	49.9
World Average	26.5	29.2	40.9	48.8
Gap Between GoM and World Average	**-13.4**	**-14.2**	**-22.4**	**-26.4**

Region	All GHG in Million Tons CO2e per Year (2020)			
	Base Case (GWP=25)	Base Case CH4 Volumes but GWP=34	IEA CH4 Volume Multipliers for All Countries (GWP=25)	IEA CH4 Vol. Multipliers + GWP=34
US GOM	8	9	11	14
US Total	78	85	99	114
Canada	118	124	128	138
Rest of World	539	602	907	1,102
World Average	735	811	1,134	1,354

Region	Methane Only in Kilograms CO2e per Barrel of Oil (Year 2020)			
	Base Case (GWP=25)	Base Case CH4 Volumes but GWP=34	IEA CH4 Volume Multipliers for All Countries (GWP=25)	IEA CH4 Vol. Multipliers + GWP=34
US GOM	5.4	7.4	10.8	14.7
US Total	5.1	7.0	10.3	14.0
Canada	11.4	15.6	18.3	24.9
Rest of World	7.9	10.7	24.5	33.4
World Average	7.7	10.4	22.1	30.0

Region	Methane in Million Tons CO2e per Year for Oil Production (2020)			
	Base Case (GWP=25)	Base Case CH4 Volumes but GWP=34	IEA CH4 Volume Multipliers for All Countries (GWP=25)	IEA CH4 Vol. Multipliers + GWP=34
US GOM	3	5	7	9
US Total	21	29	43	58
Canada	17	24	28	38
Rest of World	174	237	541	736
World Average	213	289	612	832

Region	Methane in Kilotons CH4 per Year for Oil Production (2020)			
	Base Case (GWP=25)	Base Case CH4 Volumes but GWP=34	IEA CH4 Volume Multipliers for All Countries (GWP=25)	IEA CH4 Vol. Multipliers + GWP=34
US GOM	134	134	267	267
US Total	850	850	1,700	1,700
Canada	698	698	1,117	1,117
Rest of World	6,957	6,957	21,637	21,637
World Average	8,505	8,505	24,454	24,454

Notes: Production only. Excludes crude transportation, petroleum refining, & petroleum product distribution.

Exhibit 31: IEA Emission Estimates Compared to Base Case and Sensitivity Cases

	IEA Factors Applied to 2020 Volumes	This Study Base Case & Sensitivities: 2020 Global Emissions from Oil Production			
		Base Case (GWP=25)	Base Case CH4 Volumes but GWP=34	IEA CH4 Volume Multipliers for All Countries (GWP=25)	IEA CH4 Vol. Multipliers + GWP=34
Total CO2e in million tons	1,412	735	811	1,134	1,354
CH4 Only in CO2e million tons	827	213	289	612	832
Non-CH4 Only in CO2e million tons	585	522	522	522	522

6. Appendix C: Acronyms and Abbreviations

Acronym	Meaning
AEO	Annual Energy Outlook from the Energy Information Administration
AGO	atmospheric gas oil
ANL	Argonne National Laboratory'
AR	atmospheric residue
ASU	air separation unit
ATR	autothermal reforming
bbl	barrel
bcf	billion cubic feet
Btu	British Thermal Unit
Capex	capital expenditure
CCQMP	Canadian Crude Quality Monitoring Program
CCS	carbon capture and storage
CCUS	carbon capture, use, and storage
CO	carbon monoxide
CO_2	carbon dioxide
CO_2e	carbon dioxide equivalent
DOE	U.S. Department of Energy
EIA	Energy Information Administration within DOE
EOR	enhanced oil recovery
EPA	U.S. Environmental Protection Agency
FC	fuel cell
FCC	fluid catalytic cracker
FCV	fuel cell vehicle
FOM	fixed operating and maintenance costs
FT	Fischer-Tropsch synthesis process
GGE	gallon gasoline equivalent

GHG	greenhouse gas
GO-HC	gas oil hydrocracker
GoM	Gulf of Mexico
GREET	GREET - Greenhouse Gases, Regulated Emissions, and Energy Use in Transportation
GW	gigawatt
GWh	gigawatt-hour
H or H2	Hydrogen
HDV	heavy-duty vehicle
HEV	hybrid electric vehicle
HHV	higher heating value
HP	horsepower
HVGO	heavy vacuum gas oil
ICE	internal combustion engine
IEA	International Information Agency
kg	kilogram
kg/d	kilograms per day
kg/h	kilograms per hour
kWh	kilowatt-hour
LCA	life cycle assessment
LDV	light-duty vehicle
LHV	lower heating value
LNG	liquefied natural gas
LPG	liquefied petroleum gas (largely propane and butane)
LSR	light straight run
LVGO	light vacuum gas oil
Mcf	thousand cubic feet
MMcf	Million cubic feet
MMCFD	million cubic feet per day
Mpa	Megapascal (35 Mpa =5,000 psig =350 bar)

MWh	megawatt-hour
NETL	DOE's National Energy Technology Laboratory
NG	Natural gas
NGL	natural gas liquids
NH3	ammonia
Nm3/h	normal cubic meters per hour
NREL	National Renewable Energy Laboratory
NTP	normal temperature and pressure
OCS	Outer Continental Shelf
Opex	operating and maintenance expenditures
PRELIM	Petroleum Refinery Life Cycle Inventory Model
psi	pounds per square inch
psig	pounds per square inch (gauge pressure)
quads	quadrillion British thermal units
RFG	Refinery fuel gas (can also mean reformulated gasoline)
RNG	renewable natural gas
S	Sulphur
SCF	standard cubic feet
SMR	steam methane reforming
SNG	synthetic natural gas
SR	Straight run
t or MT	(metric) tonne
TBtu	trillion British thermal units
TWh	terawatt-hour
ULSD	ultra-low sulfur diesel
VMT	vehicle miles traveled
Vol	volume
VOM	variable operating and maintenance costs
VR	vacuum residue