ARC energyresearch institute

Crude Oil Investing in a Carbon Constrained World

Jackie Forrest and Marcus Rocque
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Executive Summary

Investors in crude oil assets are largely unaware of the risks they are being exposed to under more stringent climate change policies. Growing concerns around climate change are likely to result in new policies to reduce greenhouse gas (GHG) emissions. As a result, crude oil producers are likely to face increasing costs for complying with new regulations. Due to a lack of information, a consistent, accessible, and widely adopted method for measuring the GHG intensity of crude oil assets and their associated carbon liability does not exist.

Macroeconomic and environmental factors over recent years have led to concerns around the risks associated with crude oil investing. Because of these concerns, especially those related to GHG emissions, some organizations, agencies, and individuals are suggesting that crude oil investors are being exposed to excessive risks of product obsolescence, and that divestment is the only option to mitigate risk. We suggest this is not the case. What can be measured can be managed, especially in the case of GHG emissions.

In this report, investors are introduced to the ARC method for assessing, reporting and comparing the GHG intensity of crude oil operations. Using the ARC method, investors can evaluate how more stringent GHG policies could impact their investment returns, allowing investors to rationally assess their oil investments in a carbon constrained world.

Although the investment returns on some crude oil investments are challenged by more stringent GHG policies, the authors have found that many investments can continue to make attractive returns under a realistic range of carbon prices. Not all impacts of potential carbon policy will be negative to oil companies and their investors. Producers that have the ability to reduce their carbon emissions could realize positive benefits, such as higher demand for their products, lower energy use and reduced operating costs.

Beyond the benefits of using the ARC method to understand and quantify investment risk, there are additional benefits from understanding GHG intensity for crude oil investing. By gathering data and modeling the GHG intensity of a crude oil operation, an investor can gain a greater awareness of the characteristics that lead to higher GHG intensity. Awareness of these dynamics should lead to better decisions on future investments; either by avoiding assets that are more challenged, or by making decisions early in a project's design that reduce the GHG intensity for a relatively low cost (compared to making a change later in a project's life).

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Table of Contents

Tables and Figures

Figures

Tables

Tables and Figures

Tables continued…

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Peter Tertzakian is Chief Energy Economist and Managing Director at ARC Financial Corp. Peter provided the initial vision for this project. About two years ago, he began canvasing a wide set of investors and experts in GHG emissions analysis to understand the range of views on how investors could measure and assess investment risk in a carbon constrained world. In doing so, Peter identified the need for a common framework to help investors assess the risk of future carbon policy to their portfolios. Peter has been a sounding board in the development of this paper, providing guidance and edits.

Megan Lancashire is an Energy Analyst at ARC Financial Corp. Megan provided editing, content feedback, and also worked on the final lay-out of the report, providing great attention to detail in the initial and final stages of preparing this material.

About ARC Financial Corp.

ARC is an energy focused private equity firm based in Calgary, Alberta, Canada with $C 5.3 Billion of capital across the eight ARC Energy Funds. Leveraging the experience, expertise and industry relationships of the team, ARC invests in Canadian exploration and production and oilfield service companies.

ARC offers sophisticated energy research, analysis, and assessment established through technical and operating industry experience. Through this deep domain knowledge and energy capital markets expertise, ARC plays a valuable role in the companies we finance and in the Canadian oil and gas industry as a whole. Employing high quality corporate governance and business process, ARC seek to build successful companies through transactional advice, deal sourcing, and evaluation support.

Crude Oil Investing in a Carbon Constrained World

"Information about the carbon intensity of investments allows investors to assess risks to companies business models and to express their views in the market."
Mark Carney, Governor of the Bank of England, September 29, 2015

Introduction

Climate change is a growing issue. All segments of the economy are being called on to act in the pursuit of reducing GHG emissions. The finance industry is no exception.

Countries around the world are actively committing to GHG reduction targets, and government policies that regulate emissions are likely to become more stringent over time. As a result, producers of crude oil and natural gas are likely to face increasing costs for complying with new GHG reduction policies, which means investors in such companies may also be impacted.

Not all impacts of potential carbon policy will be negative to crude oil and natural gas companies and their investors. Producers that have the ability to reduce their carbon emissions could realize positive benefits, such as higher demand for their products, lower energy use and reduced operating costs. Of course, neither positive nor negative impacts can be assessed without proper measurement and analysis of a company's emissions.

Investors in crude oil and natural gas assets are largely unaware of the risks they would be exposed to under more stringent GHG policies. This is because a consistent, accessible, and widely adopted method for measuring and comparing the GHG intensity of fossil fuels does not exist. A lack of information has led to concerns about investing in fossil fuels, including crude oil and natural gas. Some environmental groups are suggesting that divestment is the only way to mitigate risk. Other voices, including Mark Carney, the Governor of the Bank of England, argue that climate change related investment risks can be reduced with better information. What can be measured can be managed.

The active debate surrounding the possible risks associated with fossil fuel investing has highlighted a lack of understanding of the large range of carbon intensities associated with fossil fuel production. However, thanks to an established body of research and models on the topic, it is now possible for crude oil investors to make relatively accurate assessments of their own GHG emissions exposure.

The goal of this report is to provide investors (banks, hedge funds, investment advisors, private equity, endowments, pension funds, etc.) with an applied method for estimating the GHG emissions for crude oil assets in their portfolio. The ARC method uses publicly available research and models for assessing, reporting, and comparing the GHG intensity of a crude oil investment to others. Properly interpreted, data from the ARC method will allow investors to rationally assess their crude oil investments in a carbon constrained world.

While there are a range of methods that could be employed for measuring and comparing the GHG emissions from crude oil assets, the advantage of the ARC method is that it uses publicly available, transparent, accredited models that are relatively easy to use.

There are four sections in the main body of this report: (1) An Introduction to GHG Emissions Life Cycle Analysis (2) Basic Concepts in Measuring GHG Emissions for Crude Oil and the ARC Method (3) Assessing the GHG Emissions and Investment Risk of a Specific Crude Oil Investment and (4) the Conclusion.

The Appendix of this report provides detailed guidance on how to estimate the GHG emissions for crude oil assets, including a hands-on example of how to use the method to analyze a specific crude oil investment decision.

Finally, readers may be wondering why the ARC method is limited to crude oil investing, and does not cover other fossil fuels such as natural gas or coal. Compared with crude oil, the body of research and tools for estimating the relative GHG intensity of other fossil fuels is less evolved at this time. However, there is a considerable amount of academic and industry research currently underway and it is possible that similar tools and methods used for crude oil could become available for other fossil fuels in the coming years.

Organizations that Participated in a Review of this Report

Prior to publication, a draft version of this report was reviewed by both experts in the field of GHG emissions analysis and crude oil and natural gas investors. The feedback from these participants was invaluable and helped shape the final version. Participation by an organization does not mean endorsement of the paper, however, ARC would like to acknowledge and thank the following organizations for their contribution to this report:

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Section 1: An Introduction to GHG Emissions Life Cycle Analysis

What is GHG Emissions Life Cycle Analysis?

"Cradle to grave" is a common term to describe processes from start to finish. In the world of energy systems, the equivalent term is "life cycle."

For example, the life cycle of a tonne of coal starts at a mine and can end at the light you see from a bulb in your house. All the processes and conversions that occur in-between – transporting the coal, burning it in a power plant, generating the electricity, transmitting it through the wires to your wall plug, and up to your lamp – are part of that life cycle. A specific beginning-to-end life cycle, such as the coal mine to light bulb is termed a "pathway."

Energy life cycles provide the context for measuring many different elements relating to the way society sources and uses its energy. For the purposes of this paper, we are interested in the amount of GHG that is emitted into the atmosphere at every stage of an energy pathway – from production, to energy conversions, to delivery, and to end use.

GHG life cycle analysis (LCA) is an established method that seeks to quantify all of the GHG emissions associated with each stage of the life cycle of a primary fuel such as oil or natural gas, along an explicit pathway. The analysis can provide information about an entire pathway, or partial segments in-between. LCA can also be used to compare the GHG emissions among fuels. For instance, it can compare the total GHG emissions for turning a car's wheels using electricity or gasoline.

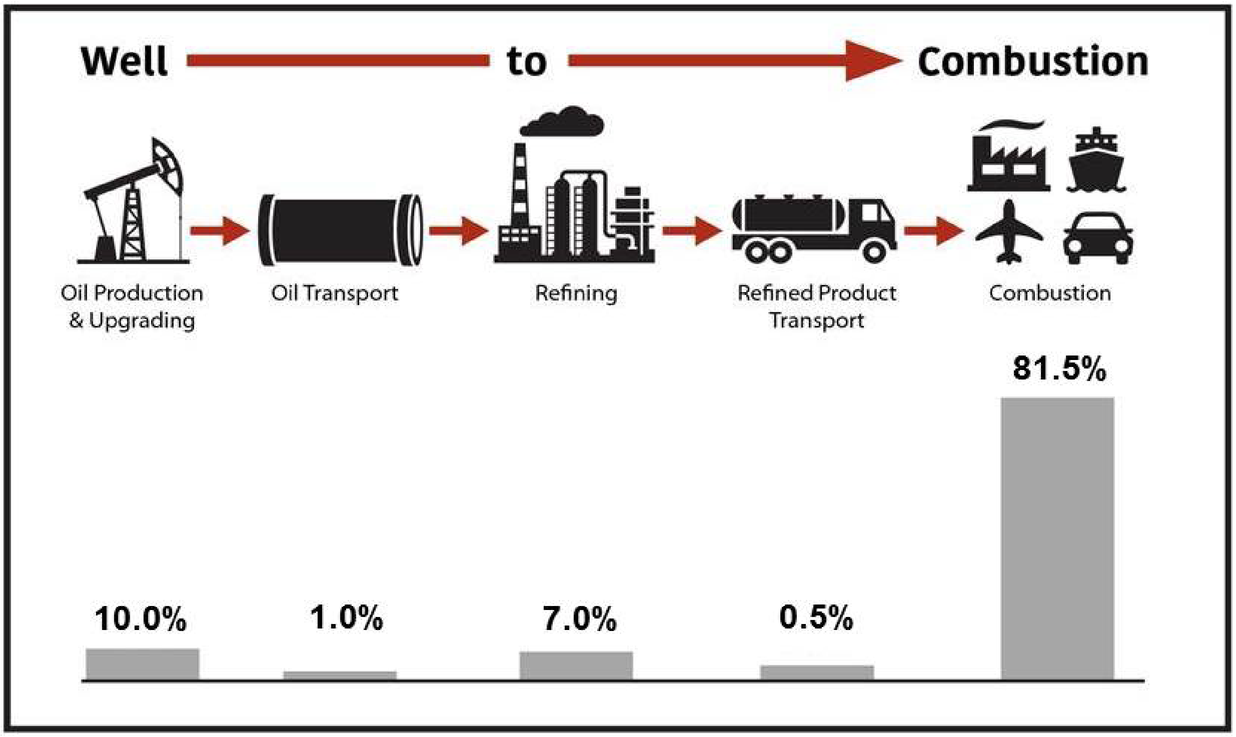
When LCA is undertaken for crude oil, the accounting considers all of the detailed stage-by-stage GHG emissions, from production through to using a petroleum fuel such as gasoline or jet fuel in an engine. There are upstream emissions associated with the exploration and production of crude oil from a well, and there are emissions released into the atmosphere when the oil is piped to a refinery. Refining the oil into gasoline and other products sends emissions up the stacks, and there are also emissions when the tanker truck delivers the gasoline to a retail station. Finally the bulk of the emissions come from combusting the petroleum fuel in the engine of a car, airplane or ship. For crude oil, we refer to this "full cycle" pathway of GHG emissions as "well-to-combustion."

LCA or well-to-combustion analysis yields very specific numbers that can vary significantly by crude oil source. Differences in the chemical composition of crude oils, oilfield practices, mode of transportation, and varying refinery complexity all lead to substantially different LCA assessments.

This method of differentiating between various crude oil pathways using LCA is well accepted and is commonly used in government policies. In fact, such granular emissions analysis is already the basis for existing policies including the Environmental Protection Agency's (EPA) Renewable Fuel Standard, California's Low Carbon Fuel Standard and the European Union's Fuel Quality Directive.

Figure 1 shows the percentage breakdown of the well-to-combustion emissions for the average barrel of crude oil refined in the United States, from production through to combustion. Five broad stages are considered across this generalized pathway: (1) oil production and upgrading (upgrading is when very heavy crude oils are partially refined into lighter crude oils); (2) oil transportation to a refinery; (3) refining; (4) refined product transportation to the end user; and (5) combustion of the petroleum fuel in a car, airplane, power plant or

Figure 1: Estimated Well-to-Combustion GHG Emissions from Crude Oil*



Source: ARC Financial Corp. (using data from DOE/NETL for characterizing production and upgrading emissions).

*US Average Crude Oil Refined in 2005.

ship. The chemical reaction involved in burning oil in a combustion engine creates 81.5 percent of the carbon dioxide emissions. Meanwhile, on average, the upstream activities that a producer of crude oil is responsible for constitute ten percent of all the well-to-combustion emissions.

Why is GHG LCA Appropriate for Considering Investment in Assets that Produce Hydrocarbons?

Fossil fuel producers operate at the front end of the well-to-combustion pathway. Many of these companies are coming under increasing scrutiny for their segment's contribution to GHG emissions and the related climate change effects.

For crude oil producers, a GHG policy imposed by government could act to increase extraction costs. If extra costs are imposed further down the life cycle toward combustion, they can increase costs for refining crude oil, or boost the retail price of petroleum fuels, such as gasoline. By making oil based systems more expensive across their full life cycles, GHG policy intends to lessen consumer demand of petroleum fuels by encouraging greater efficiency and lower carbon alternatives.

In the absence of meaningful carbon policy, some financial institutions are being challenged to divest of all their hydrocarbon assets, or at least the assets that are perceived to originate from the most carbon intense pathways, such as heavier crude oils or coal. The objective of such divestment is a means to financially sanction all, or part of the hydrocarbon industry, effectively raising its cost of capital.

Since the consumer's end use drives the majority of the GHG emissions from hydrocarbons, the effectiveness of an upstream-only mitigation strategy remains open to debate, as higher production costs (either through a carbon fee on production, or by applying a higher cost of capital for producers), may not materially change how many hydrocarbons are ultimately combusted. Nevertheless, increasing carbon costs for hydrocarbon producers is an important trend that necessitates better measurement of GHG emissions across all carbon pathways, including for crude oil.

Proper, consistent, and integral reporting of LCA emissions is necessary for assessing risk as it pertains to investment decisions. Context is also vital. Full LCA reporting allows the investor to understand the GHG emissions generated by a specific investment, and how that compares to others. From a financial perspective, the data generated from this type of exercise enables an investor to consider the full range of potential carbon costs that may impact their portfolio of hydrocarbon investments in the future.

Section 2 : Basic Concepts in Measuring GHG Emissions for Crude Oil and the ARC Method

A number of governments already use crude oil LCA as a basis for their GHG policies. In order to develop these policies, numerous studies have been published on the topic, from academic papers, to studies published by consultants and government agencies. Most often, past research has been technical in nature, providing answers to specific policy questions. What makes the ARC method unique is that it outlines a method of how to measure GHG intensity using publicly available models, providing the investor with a tool for completing their own assessment of the GHG emission investment risk associated with a particular crude oil asset.

The following section outlines some basic LCA concepts and some introductory information on how GHG emissions are measured. For more detailed guidance, please refer to the Appendix of this report, which includes a sample calculation.

Challenges in Measuring Life Cycle GHG Emissions for Crude Oil

To measure the GHG emissions from a specific crude oil, data must be collected and the estimator must make numerous decisions about what emissions to include. Depending on the purpose of the study, different levels of measurement and scope are applied. Because of differences in scope and method, it is improper to directly compare GHG emissions estimates across various studies. This would be the equivalent of comparing "apples to oranges." When using the ARC method, an investor can compare their project of interest on an "apples-to-apples" basis with a group of other benchmark crude oils that are included in the report.

The following section outlines some of the key drivers that led to different results between studies, along with details on the ARC method:[1]

1. Data Issues – Collecting data that describes the production characteristics of crude oil can be a challenge. It is especially difficult in international jurisdictions that do not require oil and natural gas data to be made publicly available. For regions with limited, non-transparent data, defaults or best estimates are commonly used in

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[1] The issues that are outlined within the paper have all been well documented in other reports, including: Forrest, Dereniwski and Birn, "Comparing the GHG Intensity of the Oil Sands and the Average US Crude Oil," *IHS Energy Special Report*, May 2014.

place of collected data. When working with a more limited data set, the margin of error associated with the estimate is greater. [2]

This report includes GHG emissions estimates for 33 crude oils using the ARC method. These benchmark crude oils provide an investor with some context as to how the GHG intensity of their specific investment compares to others. All of the estimates provided rely on publicly available data for characterizing the crude oils. While data on North American crude oils is relatively transparent, in general, estimates for international crude oils rely on less precise information.

2. Different Boundaries for Measurements – Some studies only measure the GHG emissions that are directly emitted from the oil and natural gas production site or oil refinery, whereas other studies choose to consider the full range of emissions, including upstream impacts. Studies that include the full range of emissions consider the direct combustion emissions for burning natural gas at the oil production site or refinery, as well as the upstream emissions. For instance, carbon dioxide from electricity generated off-site or for producing, processing, and delivering the natural gas to the well site or refinery is included.

Some studies also account for the emissions impacts from land use change. For example, prior to the development of an oil field, vegetation has accumulated and is storing carbon on the land. When an oil production facility is built, the vegetation is removed and this reduces the land's ability to absorb carbon. Quantification of this GHG impact is referred to as land use change.

Depending on the purpose of the study, different boundaries are appropriate. In the ARC method, a wide boundary is used for measuring GHG emissions, including both the direct on-site emissions, the upstream GHG emissions for producing and delivering fuels that are used to extract, refine, and transport the crude oil, and impacts from land use change. It is appropriate to measure GHG emissions with a wide boundary since this provides the most insight to the full set of GHG emissions associated with crude oil.

3. Accounting for the By-Products of Crude Oil Extraction – When crude oil is extracted, by-products can be produced, such as natural gas, natural gas liquids (NGLs) and electricity. In the case where natural gas is extracted as a by-product of oil, the associated gas replaces the need to produce natural gas elsewhere. The same holds for the production of electricity. When electricity is produced and exported as a by-product of oil production, it is reducing the need to generate power somewhere else. Because of this substitution effect, life cycle GHG studies often apply a credit for the by-products (since they reduce the amount of GHG emissions generated at another location). A different approach is to divide up the GHG emissions for extraction among all the products, and not apply a credit for by-products; this method is often called the "allocation method."

In the ARC method, a credit is applied for the by-products. This is the most appropriate way to compare crude oils from the perspective of how much carbon they add to the atmosphere.

4. Accounting for Co-Products in Refining – Crude oil is refined into various products – such as gasoline, diesel, aviation, and bunker fuel. Most crude oil LCA studies report their results on the basis of the fuels produced. For example, they publish the carbon intensity per unit of gasoline or diesel. To report on the final fuel basis, the studies must allocate the total GHG emissions among the various fuels that come from a barrel of crude oil. Studies differ widely in their method for

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[2] For more information on the greater the margin of error becomes when data is more limited, refer to Vafi and Brandt's paper "Uncertainty of Oil Field GHG Emissions Resulting from Information Gaps: A Monte Carlo Approach," *Environmental Science and Technology* 48, no. 17 (2014): 10511-10518.

allocating the emissions among fuels, and this is a major source of discrepancy when comparing results among studies.

The ARC method reports the GHG emissions on a per barrel of crude oil basis. This is the most logical basis for evaluating an oil investment, and avoids the complications associated with allocating the GHG emissions to each petroleum fuel.

How to Measure the Life Cycle GHG Emissions from Crude Oil

The goal of this paper is to present a transparent, simple method for quantifying the GHG emissions from crude oil, for investors. To measure the life cycle GHG emissions for crude oil, sources of emissions are divided into five stages: (1) oil production and upgrading; (2) oil transportation to a refinery; (3) refining; (4) refined product transport to the end user; and (5) fuel combustion in a car, airplane, power plant or ship (see Figure 2). To measure the GHG emissions for each of these five well-to-combustion stages, the ARC method draws on publicly available GHG estimation models and data.

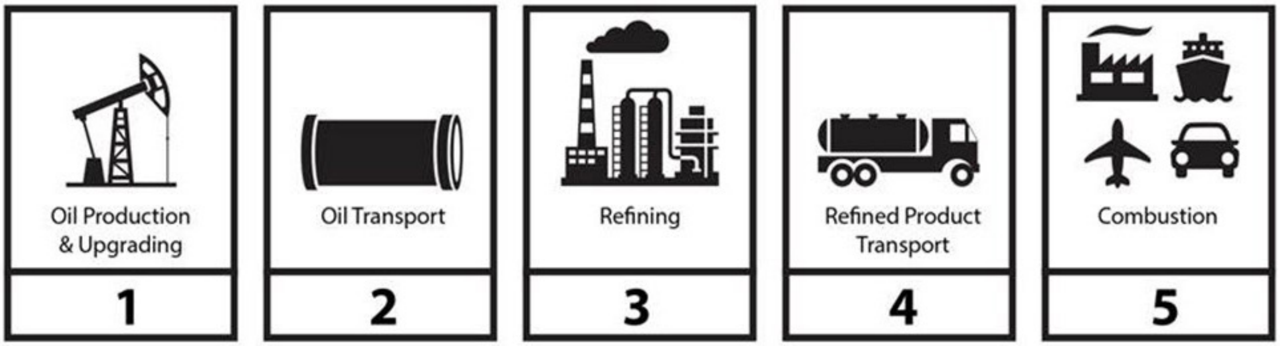
The following briefly outlines the ARC method for calculating the GHG emissions for each stage:

1. Oil Production and Upgrading

Stanford University's Oil Production Greenhouse Gas Emissions Estimator (OPGEE) is used for estimating the GHG emissions from crude oil production. This Excel-based model is the basis of the crude oil GHG intensity values used in California's Low Carbon Fuel Standard program. The model is publicly available and can be downloaded at Stanford's website. [3]

The OPGEE model uses more than 50 data inputs to estimate the GHG emissions for producing and trans-

Figure 2: The Five Stages of Well-to-Combustion GHG Emissions from Crude Oil



Source: ARC Financial Corp.

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[3] To access the OPGEE model on the Stanford University website use the following link: https://pangea.stanford.edu/researchgroups/eao/research/opgee-oil-production-greenhouse-gas-emissions-estimator
For more information on OPGEE refer to: El-Houjeiri, Brandt and Duffy's paper "Open-Source LCA Tool for Estimating Greenhouse Gas Emissions from Crude Oil Production Using Field Characteristics," *Environmental Science and Technology* 47, no. 11 (2013): 5998-6006.

porting crude oil; however, when less data is available the model relies on pre-loaded default values. Once the inputs to characterize the oil production are entered in OPGEE, it automatically estimates the GHG emissions for production and upgrading.

2. Oil Transport

The OPGEE model also estimates the emissions for moving the crude oil between the oil production field and the refinery. To estimate, the model requires the distance that the oil is transported to the refinery and the mode of transportation that is used (i.e. pipeline or tanker).

In order to compare the life cycle GHG intensity among different crude oils, the geographical location of the oil refinery must be the same. Therefore, the ARC method assumed the refinery's location to be in Houston, Texas, as the Gulf Coast region is by far the largest single refining center in the United States. Crude oils that are further away from North America could be slightly disadvantaged by choosing Houston as their location. This is because they would end up having higher oil transport emissions than if a refinery location closer to the oil field were chosen. However, the locations assumption is not that significant to the final results, since the transportation of crude oil is a relatively small amount of total LCA emissions, typically being between 0.5 to 2.0 percent.

3. Refining

The University of Calgary's Petroleum Refinery Life Cycle Inventory Model (PRELIM) is used for estimating the GHG emissions for crude oil refining. This Excel-based model is publicly available and can be downloaded at the university's website. [4]

In estimating the GHG emissions for crude oil, the PRELIM model serves two purposes. First, it estimates the GHG emissions for refining each oil, and second, it predicts the slate of petroleum fuels – gasoline, jet fuel, diesel, bunker fuel, and petroleum coke – that a refinery can make from each crude oil.

To estimate GHG emissions for refining, the PRELIM model requires a detailed profile of the crude oil called a "crude oil assay." The assay reports the volume and quality of the crude oil that is boiled-off in each temperature range (for example the density, sulfur, and other properties). In the case that a crude oil assay is not available, the ARC method uses an analog method for predicting the GHG emissions, whereby a pre-loaded crude oil with similar properties is selected. While using the actual crude oil assay is the most accurate method, the analog approach is the best available technique in many cases, especially since detailed data on the characteristics of some crude oils – including common US crude oils such as the Bakken and Eagle Ford – are not publicly available.

Refineries vary in their complexity, and by default, the PRELIM model will determine the appropriate refinery for each crude oil based on its characteristics.

4. Refined Product Transport

To estimate the emissions for transporting crude oil from the refinery to the retail station, the ARC method uses research from the US Department of Energy National Energy Technology Laboratory (DOE/NETL). In a paper titled "Development of Baseline Data and Analysis of Life Cycle Greenhouse Gas Emissions of Petroleum-Based Fuels," DOE/NETL estimated the average GHG emissions for transporting refined products in the United States. [5] Using the DOE/

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[4] To download the PRELIM model, log onto the University of Calgary's website: http://www.ucalgary.ca/lcaost/prelim

[5] For estimates of the GHG emissions for transporting refined products to the retail station, see Table 5-10 on page 94 of: Skone and Gerdes', "Development of Baseline Data and Analysis of Life Cycle Greenhouse Gas Emissions of Petroleum-Based Fuels," *DOE/NETL*, November 2008.

NETL data, the ARC method assumes that all refined products are transported by pipeline to the retail station with a carbon intensity of 2.4 kgCO2e/barrel of refined product transported.

5. Combustion

The amount of GHG emissions from combusting a unit of fuel (gasoline, diesel or bunker fuel) is a well-known physical property. Whether the gasoline is derived from a light African crude oil or a heavy Mexican crude oil, the combustion emissions are the same. This is because the refineries objective is to make refined products that have similar chemical properties, no matter what oil feedstock is used. Table 1 outlines the GHG emissions factors for combusting each type of petroleum fuel for the ARC method.

Table 1: Carbon Dioxide Emissions Factors for Combusting Refined Products

	kgCO2/barrel of refined product
Motor Gasoline	370.3
Diesel Fuel	429.8
Jet Fuel	411.1
Bunker	452.8
Fuel Oil	462.1

Source: EPA 2014 Emissions Factors for GHG Inventories.
(Diesel is the average of Distillate #1 and #2, Bunker is the average of Residual Fuel #5 and #6, Fuel Oil is Distillate #4).

The ARC method includes combustion emissions from liquid petroleum products only (i.e. motor gasoline, diesel fuel, jet fuel, bunker fuel and fuel oil). The GHG emissions for burning the solid petroleum coke, which is a by-product of refining heavy crude oils, are not included. The reason for excluding the solid petroleum coke is because, most often, the emissions for combusting the petroleum coke from crude oil are not included in LCA comparisons.[6] They are excluded because petroleum coke is commonly used as a substitute for coal in power generation. Since the amount of coal burnt in power generation is determined by the number of coal fired power generation plants and the demand for electricity, the production of the petroleum coke at a refinery is not viewed to be material to the amount of GHG emissions emitted to the atmosphere. Consequently, the ARC method assumes that, due to substitution, the combustion of petroleum coke is immaterial in the comparison of crude oil types. This assumption only impacts heavy crude oils (since lighter crude oils do not produce coke). If the petroleum coke were to be included for heavy oils, this would increase the well-to-combustion GHG emissions in the range of 10 to 20 percent.

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[6] There are numerous studies that do not include petroleum coke in their calculations. For example: (1) Keesom, Blieszner and Unnasch, "EU Pathway Study: Life Cycle Assessment of Crude Oils in a European Context," *Jacobs Consultancy*, March 2012 (2) Keesom, Unnasch and Moretta, "Life Cycle Assessment Comparison of North American and Imported Crudes," *Jacobs Consultancy*, July 2009 (3) Forrest, Gross and Meyer, "Oil Sands, Greenhouse Gases, and US Oil Supply: Getting the Numbers Right – 2012 Update," *IHS CERA*, November 2012 (4) Forrest, Dereniwski and Birn "Comparing the GHG Intensity of the Oil Sands and the Average US Crude Oil," *IHS Energy Special Report*, May 2014.

Section 3 : Assessing the GHG Emissions and Investment Risk of a Specific Crude Oil Asset

This section demonstrates how to use data from the ARC method for evaluating investment decisions. The first part introduces the ARC benchmark set of crude oils, and the second part shows how to estimate the carbon cost for a specific oil field. To help illustrate how the ARC method can be used to inform the crude oil investor, see the text box "Using the ARC Method to Evaluate a Crude Oil Investment Decision."

Using the ARC Method to Evaluate a Crude Oil Investment Decision

Bob's investment portfolio has two existing crude oil investments, Asset A and Asset B. Using the ARC method, Bob has estimated the well-to-combustion GHG intensity for each of his existing oil fields and the direct emissions from his oil field production sites (see Table 2). Currently, there is no charge for emitting carbon from his oil fields. However, Bob believes that a $20/tonne of CO2e charge could be introduced in the coming years and this would increase his production cost by $0.63/barrel on average. Adding this extra cost to his financial models, Bob determines that the average internal rate of return (IRR) for his two investments would decrease by 4.3 percent if the carbon fee were introduced.

Bob is now evaluating a new heavy oil investment. The oil field looks like a profitable venture, but Bob is concerned about its higher GHG intensity. The heavy oil field has direct, on-site production emissions that are 50 percent higher than Bob's existing crude oil assets. Yet, despite the higher carbon intensity, Bob finds that a $20/tonne of CO2e carbon levy only reduces his investment returns by 4.0 percent — a similar level to his existing portfolio. The higher margins of this heavy oil asset allow it to absorb the extra carbon cost without greatly impacting the investment returns. Bob now has the data he needs to make an informed decision on whether or not to invest in the heavy oil asset.

Table 2: Bob's Investment Portfolio GHG Emissions and Return Data

	Well-to-Combustion		Direct, On-site Production		
	(kgCO2e/barrel)	Difference From US Average Refined (2005)	Direct On-site Production Emissions (kgCO2e/barrel)	Extra Production Costs From $20/Tonne of CO2e Carbon Fee	Change to IRR With $20/Tonne of CO2e Carbon Fee
Asset A	473.0	-6%	29.0	$0.58/barrel	-3.2%
Asset B	505.0	1%	34.0	$0.68/barrel	-5.4%
Average for Bob's Investment Portfolio (Asset A and B)	**489.0**	**-2%**	**31.5**	**$0.63/barrel**	**-4.3%**
New Heavy Oil Onshore Asset	566.0	13%	47.0	$0.94/barrel	-4.0%
Average for Bob's Investment Portfolio with New Heavy Oil Investment	**515.0**	**3%**	**37.0**	**$0.74/barrel**	**-4.2%**

Source: ARC Financial Corp.

A Benchmark Set of Crude Oils

To enable investors to understand how the carbon intensity of a specific investment compares to others, a benchmark set of crude oils has been created using the ARC method within this report. When using the ARC method, an investor can compare the GHG emissions intensity of their specific investment to the data sets shown in Figure 3 and Table 3. The benchmark set includes: 30 crude oils that were modeled using input data from the Carnegie Endowment's Global Oil Climate Index, [7] two estimates for US tight oil (the Bakken and Eagle Ford plays) using input data from IHS, [8] and an estimate for the average crude oil refined in the United States (2005) using input data from DOE/NETL.[9]

The average crude oil refined in the United States (2005) is a commonly quoted yardstick for comparing crude oil GHG emissions intensities. The baseline was first established by DOE/NETL to support the EPA's Renewable Fuel Standard. While it is a decade old, we still view the 2005 baseline as a relevant point of comparison because it has been adopted into US legislation, making it the most commonly used point of reference for comparing crude oil GHG intensities.

Evaluating the Carbon Risks for a Specific Crude Oil Investment

Using the ARC method outlined in this paper, an investor can estimate the life cycle GHG emissions for a specific crude oil that is related to their investment and compare it to the benchmark set of crude oils. This will give the investor context on the relative level of climate change potential for any new crude oil added to their portfolio. But, how can an investor apply this information to understand their specific level of investment risk?

Assuming that oil and gas production facilities need to pay for the carbon they emit, the charge would apply to their direct GHG emissions only (i.e. the carbon dioxide equivalent that is produced directly from the oil production site). As explained in the LCA method previously, the production GHG intensity includes the direct GHG emissions, but also includes the emissions that are generated off-site (for example, emissions for producing electricity at an off-site power plant), and a credit for any by-products (natural gas, electricity, or natural gas liquids). It also includes the impacts from the change in land use when an oil and gas facility is built.

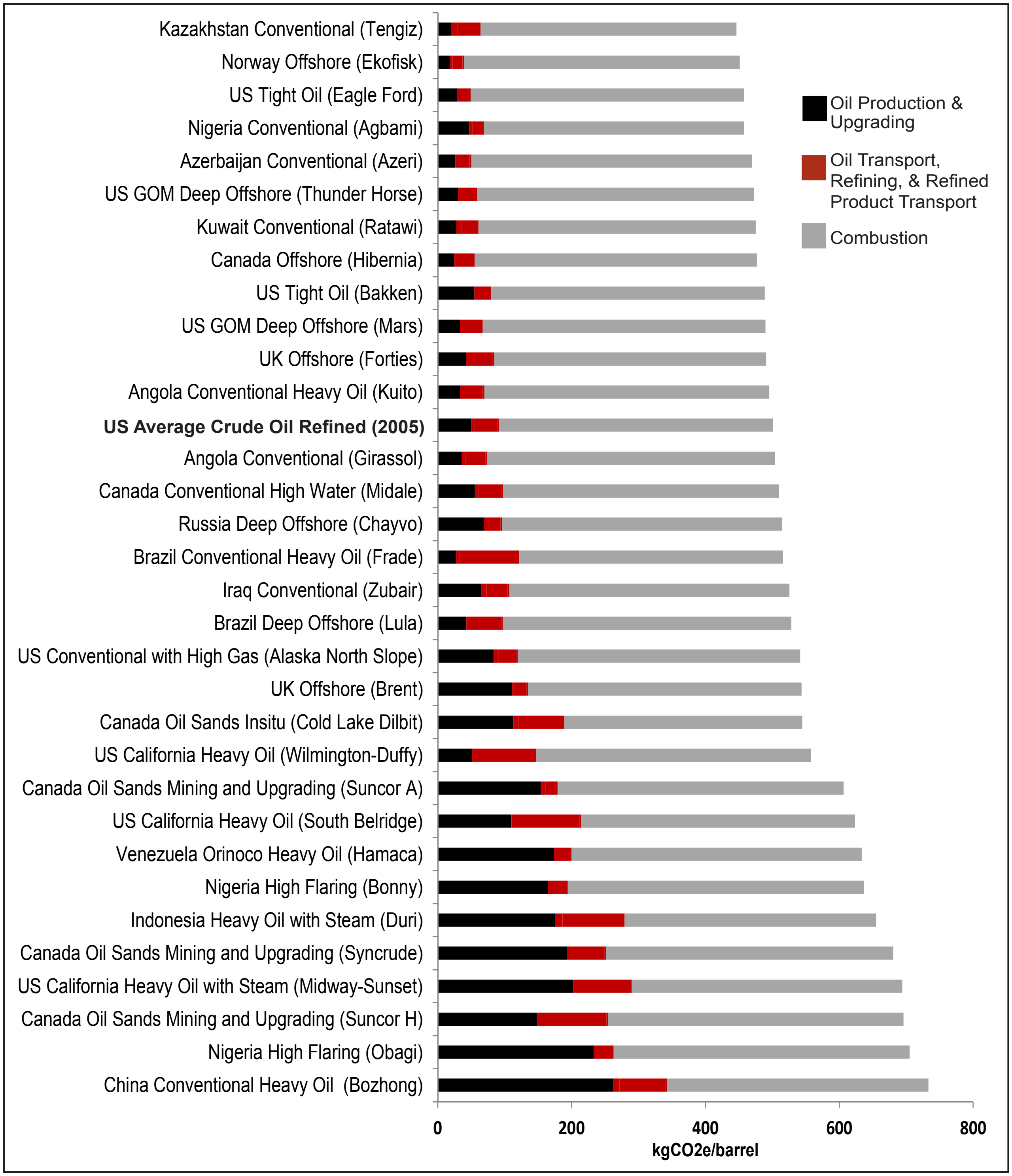
For the purpose of LCA comparisons a wide boundary for measuring GHG emissions is appropriate. However, it is not reasonable to include these effects when calculating the direct carbon emissions that a producer would be responsible for. To estimate the direct emissions for producing each barrel of crude oil, the credits from by-products, land use and any off-site emissions must be subtracted. Once the direct production emissions are understood, this value can then be used to estimate the cost under a range of possible carbon levies (see text box "What is a Realistic Range to Consider for Future Carbon Pricing?"). To understand the level of investment risk, the carbon cost calculated from this

[7] For data to describe the production practices for the 30 crude oils, we used Excel input data from Gordon, Brandt, Bergerson and Koomey's, "Know Your Oil: Creating a Global Climate Index," *Carnegie Endowment for International Peace*, March 2015. To access the Excel data sheet that describes the 30 crude oils production practices, visit the following website: http://carnegieendowment.org/2015/03/11/know-your-oil-creating-global-oil-climate-index/i3v1
See the Appendix, Section 1.1 for more details.

[8] For the US tight oil estimates, ARC used data from the IHS Energy Special Report, "Comparing GHG Intensity of the Oil Sands and the Average US Crude Oil." IHS characterizes the average production practices of the Bakken and Eagle Ford in 2012, in this report. Refer to the Appendix, Section 1.2 for more details.

[9] The DOE/NETL 2005 baseline was established in two separate papers: (1) Gerdes and Skone, "Development of Baseline Data and Analysis of Life Cycle Greenhouse Gas Emissions of Petroleum - Based Fuels," *DOE/NETL*, November 2008 and (2) Gerdes and Skone, "An Evaluation of the Extraction, Transport and Refining of Imported Crude Oils and the Impact on Life Cycle Greenhouse Gas Emissions," *DOE/NETL*, March 2009. See the Appendix Section 1.3 for more details.

Figure 3: Well-to-Combustion GHG Emissions for a Benchmark Set of Crude Oils



Source: ARC Financial Corp. using input data from the Global Oil Climate Index, IHS and DOE/NETL.

Table 3: Well-to-Combustion GHG Emissions for a Benchmark Set of Crude Oils

	ARC Method						
kgCO2e/barrel	**Data Source**	**Oil Production and Upgrading**	**Oil Transport**	**Refining**	**Refined Product Transport**	**Combustion**	**Total: Well-to-Combustion**
China Conventional Heavy Oil (Bozhong)	1	262.9	8.7	68.8	2.3	390.4	**733.2**
Nigeria High Flaring (Obagi)	1	232.9	4.7	22.6	2.5	442.5	**705.2**
Canada Oil Sands Mining and Upgrading (Suncor Synthetic H)	1	148.1	7.4	96.5	2.6	441.2	**695.8**
US California Heavy Oil with Steam (Midway-Sunset)	1	202.2	0.3	84.9	2.4	404.2	**694.1**
Canada Oil Sands Mining and Upgrading (Syncrude Synthetic)	1	193.0	7.4	48.9	2.5	428.9	**680.7**
Indonesia Heavy Oil with Steam (Duri)	1	175.6	10.8	90.5	2.3	375.8	**655.0**
Nigeria High Flaring (Bonny)	1	164.5	4.6	22.6	2.5	442.5	**636.7**
Venezuela Orinoco Heavy Oil (Hamaca)	1	173.7	2.4	21.2	2.5	433.4	**633.2**
US California Heavy Oil with Steam (South Belridge)	1	109.8	0.4	101.5	2.4	409.2	**623.4**
Canada Oil Sands Mining and Upgrading (Suncor Synthetic A)	1	153.8	7.4	15.5	2.4	427.4	**606.5**
US California Conventional Heavy Oil (Wilmington-Duffy)	1	51.5	0.1	93.4	2.5	410.1	**557.5**
Canada Oil Sands Insitu (Cold Lake Dilbit)	1	112.9	7.3	66.8	2.1	355.5	**544.7**
UK Offshore (Brent)	1	111.3	3.6	17.9	2.3	408.6	**543.6**
US Conventional with High Gas (Alaska North Slope)	1	83.5	7.3	26.4	2.5	421.6	**541.3**
Brazil Deep Offshore (Lula)	1	42.8	3.7	48.3	2.6	431.0	**528.4**
Iraq Conventional (Zubair)	1	64.9	7.9	31.6	2.4	418.6	**525.4**
Brazil Conventional Heavy Oil (Frade)	1	27.4	4.5	87.5	2.4	394.0	**515.8**
Russia Deep Offshore (Chayvo)	1	68.4	7.2	18.3	2.4	417.8	**514.1**
Canada Conventional High Water (Midale)	1	55.4	5.4	34.4	2.4	411.8	**509.5**
Angola Conventional (Girassol)	1	35.9	5.4	29.6	2.5	430.5	**503.9**
US Average Crude Oil Refined (2005)	**2**	**50.3**	**4.7**	**33.8**	**2.4**	**409.9**	**501.1**
Angola Conventional Heavy Oil (Kuito)	1	33.5	5.8	27.9	2.4	425.7	**495.4**
UK Offshore (Forties)	1	42.4	3.3	36.3	2.4	406.5	**490.8**
US GOM Deep Offshore (Mars)	1	33.1	1.3	30.2	2.4	422.6	**489.8**
US Tight Oil (Bakken)	3	54.7	5.0	17.9	2.3	408.6	**488.5**
Canada Offshore (Hibernia)	1	24.6	2.0	26.1	2.4	421.9	**477.0**
Kuwait Conventional (Ratawi)	1	27.7	8.1	22.7	2.3	414.0	**474.9**
US GOM Deep Offshore (Thunder Horse)	1	30.1	1.3	24.9	2.4	413.6	**472.3**
Azerbaijan Conventional (Azeri)	1	26.5	6.8	14.5	2.4	419.5	**469.6**
Nigeria Conventional (Agbami)	1	47.1	4.3	15.3	2.2	388.7	**457.7**
US Tight Oil (Eagle Ford)	3	28.3	0.5	17.9	2.3	408.6	**457.7**
Norway Offshore (Ekofisk)	1	18.3	3.8	15.0	2.4	411.8	**451.2**
Kazakhstan Conventional (Tengiz)	1	19.6	10.3	31.9	2.3	382.1	**446.2**

Source: ARC Financial Corp. using input data from, (1) Global Oil Climate Index, (2) DOE/NETL and (3) IHS.

exercise must be applied to financial cash flow models to understand the sensitivity of various levels of carbon cost on investment returns.

Besides direct emissions, the investor could add other indirect carbon costs into their financial models. For instance, if a power plant has to pay a carbon levy then the price of electrical power for the oil producer may increase. An investor could account for this higher cost in their calculations of economic return. Similarly, if a crude oil refiner is burdened with a carbon levy they may be unwilling or unable to pay the same price as before for the raw oil, especially for a crude oil that has higher-than-average GHG emissions for refining. In this case, an investor may want to account for a crude oil discount in their investment decision, however, in this regard, market dynamics are complicated and exactly how the burden of a carbon levy on a refinery or on a power plant would be shared between consumers and producers is uncertain.

In a world with a price on carbon, an investor might assume that lower carbon crude oil investments will always fair better than higher carbon investments. As is often the case, there are exceptions; projects with superior assets and margins will fair best in a carbon constrained world, even if they happen to be investments with higher carbon intensities.

For more detailed guidance on calculating the GHG emissions for a specific asset and applying a carbon cost in financial models, see Section 2 and Section 3 of the Appendix.

What is a Realistic Range to Consider for Future Carbon Pricing?

Future carbon policy could take many forms, from rules that require operators to replace specific equipment to a price for emitting carbon dioxide. Whichever method is used, GHG policy will increase production costs. Since it is impossible to predict how policy will evolve in the many countries where crude oil is produced and consumed, the simplest method is to use a carbon price as a proxy of how costs could increase with more stringent GHG policy.

One perspective on future carbon pricing can be found in the International Energy Agency's (IEA) World Energy Outlook from 2015 that includes a number of future carbon policy scenarios. In their reference case – called the New Policy Scenario – they assume carbon taxes reach about $20/tonne of CO2e in 2020 and rise to $40/tonne by 2030. The ARC method considers the New Policy Scenario a realistic range of carbon price over this time period. The IEA also models a 450 Scenario, a case that limits the concentration of carbon dioxide in the earth's atmosphere below the 450 parts per million threshold. In this case, the carbon price hits $20/tonne of CO2e in 2020 before rising to $100/tonne by 2030.[10]

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[10] "World Energy Outlook 2015," *The International Energy Agency,* 2015: 42.

Section 4: Conclusion

Investors in crude oil assets are largely unaware of how to monitor, analyze, report and assess risks associated with holding carbon assets in their portfolios. This has led to concerns about investing in oil and gas, especially considering that climate change mitigation measures are likely to result in more stringent government policies over time. Because of this dynamic, some organizations are suggesting that crude oil investors are exposed to excessive risks of product obsolescence, and that divestment is the only option to mitigate risk. We suggest this is not the case. Using the proposed methods contained within, the authors conclude that many crude oil investments can continue to make attractive returns under a realistic range of carbon prices over many decades.

Beyond the benefits of using the ARC method to understand and quantify investment risk, we have found additional benefits from this work by understanding the GHG emissions from our existing investment portfolio. By gathering data about our investments and modeling the GHG intensity, we have gained a greater awareness of the characteristics that lead to higher GHG intensity operations. Awareness of these dynamics will lead to better decisions on future investments, either by avoiding more challenged assets or by making decisions early in a facility's design that can reduce the GHG intensity at a relatively low cost (compared to making a change later in a project's life). As mentioned in the introduction, managing emissions requires measuring them first.

With this report, the goal is to add to the existing body of work on the topic, and provide investors with a quantitative method for estimating the GHG emissions for crude oil assets. The tools within, offer a consistent protocol for assessing, reporting and comparing the GHG intensity of their crude oil investments on the basis of GHG intensity. Properly interpreted, data derived from the ARC method will allow investors to quantitatively and rationally make investment decisions about oil investments in a carbon constrained world.

Appendix

This Appendix includes three main sections. The first section provides an overview of the method that was used (the "ARC" method) for generating the greenhouse gas (GHG) emissions measurements for the benchmark set of crude oils. This includes a subsection for each unique data source that was utilized by the ARC method (the Global Oil Climate Index, IHS, and the Department of Energy National Energy Technology Laboratory (DOE/NETL)). The second section provides guidance on how to use the ARC method for informing investment decisions, and the third section provides the reader with a step-by-step example on how to evaluate the GHG emissions intensity and carbon costs for a hypothetical crude oil investment.

Section 1 Generating Life Cycle GHG Emissions Estimates for ARC's Benchmark Set of Crude Oils

1.1 Global Oil Climate Index Crude Oils

In March 2015, the Carnegie Endowment for International Peace published a report titled "Know Your Oil: Creating a Global Oil Climate Index," [1] which measures the life cycle GHG emissions for 30 unique crude oils. At the Global Oil Climate Index website, you can download the Excel file that describes the production and upgrading emissions assumptions for each of the 30 crude oils in the index.

The following sections explain the ARC method for estimating the life cycle GHG emissions, using input data for the production and upgrading from the Global Oil Climate Index.

Oil Production, Upgrading, and Oil Transportation

The ARC method uses the "OPGEE Model v1.1 Draft D" (October 10, 2014) for generating the GHG emissions for crude oil production, upgrading, and oil transport. OPGEE is an Excel based model, which allows a user to enter over 50 inputs related to the upstream production of a particular type of crude oil. The OPGEE model, along with detailed documentation, can be downloaded at Stanford University's website. [2]

In addition to estimating the direct on-site and off-site GHG emissions associated with crude oil production (discussed in Section 2 of the main report), the OPGEE model also calculates the GHG emissions from land use changes.

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[1] To access, Gordon, Brandt, Bergerson and Koomey's, "Know Your Oil: Creating a Global Oil-Climate Index" website, use the following link: http://carnegieendowment.org/2015/03/11/know-your-oil-creating-global-oil-climate-index/i3v1
The Excel data is available for download under the "Author's Calculations" link.

[2] To access the OPGEE model on the Stanford University's website use the following link: https://pangea.stanford.edu/researchgroups/eao/research/opgee-oil-production-greenhouse-gas-emissions-estimator

ARC used the same inputs as the Global Oil Climate Index to model the production and upgrading emissions from the 30 crude oils. The inputs are available in the Author's Calculations Excel workbook, and can be downloaded from the Global Oil Climate Index's website. [3]

The unique inputs for each crude oil were entered into OPGEE. In addition to entering the input data that describes the crude oil production, information on the distance and mode of transportation for moving the crude oil from the production field to the refinery were also entered. Consistent with the inputs included in the Global Oil Climate Index, the ARC method assumes that the crude oils are refined in Houston, Texas.

Refining

The "PRELIM Model V1.0" (March, 2015) was used to estimate the refining emissions for each of the 30 crude oils. This model, along with detailed documentation, can be downloaded from the University of Calgary's website. [4]

The only input into the PRELIM model is the crude oil assay. A crude oil assay describes the crude oil properties in great detail by quantifying the amount and characteristics of the crude oil that is boiled off at each temperature range. PRELIM comes pre-loaded with over 60 crude oil assays and all 30 crude oils used in the Global Oil Climate Index are found in the model.

Refineries differ greatly in their complexity, and typically the most complex refineries convert heavy crude oils into refined products, whereas simple refineries consume the lightest crude oils. To accommodate the varying range of refinery types, the PRELIM model includes three different refinery configurations. The most complex refinery is called a deep conversion refinery, and by default PRELIM assumes that the heaviest crude oils (API gravity of 22° and lower) are refined in deep conversion refineries. The model also assumes that the lightest, sweet crude oils (with API gravity over 32°) are refined in a simple refinery, known as a hydroskimming refinery. Finally, crude oils not covered by the light and heavy crude oil categories are assumed to be processed in a medium conversion refinery.

Refined Product Transport

To estimate the emissions for transporting the crude oil from the refinery to the retail station, the ARC method uses past research from DOE/NETL. In a 2008 paper titled "Development of Baseline Data and Analysis of Life Cycle Greenhouse Gas Emissions of Petroleum-Based Fuels," [5] DOE/NETL estimated that the average GHG emissions for transporting refined products in the United States by pipeline was 2.4 kgCO2e/barrel of refined product, and this is the assumption used in the ARC method.

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[3] To download the Author's Calculations Excel workbook, use the following link: http://carnegieendowment.org/2015/03/11/know-your-oil-creating-global-oil-climate-index/i3v1 and click on the "Author's Calculations" link to download the Excel file.

[4] To download the PRELIM model log onto the University of Calgary's website: http://www.ucalgary.ca/lcaost/prelim

[5] For estimates of the GHG emissions for transporting refined products to the retail station, see Table 5-10 on page 94 of: Gerdes and Skone's, "Development of Baseline Data and Analysis of Life Cycle Greenhouse Gas Emissions of Petroleum-Based Fuels," *DOE/NETL*, November 2008.

Combustion

To calculate the GHG emissions for combustion, PRELIM outputs are used to estimate the volume of liquid refined product (blended gasoline, jet-A, ultra-low-sulfur diesel (ULSD), fuel oil, and bunker) that is produced from a barrel of crude oil. The volume of each fuel is multiplied by its specific carbon dioxide emissions factor (see Table 1 in the main report) to arrive at the total emissions for burning all of the liquid refined products that are produced from a single barrel of crude oil.

As discussed in the main report, the ARC method does not include the impacts from combusting petroleum coke because, due to substitution with coal, we view the impact as immaterial to the amount of GHG emissions in the atmosphere.

1.2 US Tight Oil

This section details how the ARC method estimates the life cycle GHG emissions for US tight oil plays, looking specifically at Bakken and Eagle Ford tight oil.

Oil Production, Upgrading, and Oil Transportation

The OPGEE model was used to estimate the GHG emissions for tight oil production and transport. Tight oil production practices were characterized in a May 2014 paper by IHS Energy titled "Comparing GHG Intensity of the Oil Sands and the Average US Crude Oil." [6] To our knowledge, the IHS data is the most comprehensive public data available for estimating the GHG emissions from these plays. The IHS data represents the average characteristics for each play in 2012. However, the emissions for a specific Bakken or Eagle Ford crude oil investment may vary from this average. If, for example, a tight oil well regularly flares its associated gas, then the GHG intensity would be higher than average.

Consistent with the ARC method, the crude oil is assumed to move from the oil field to a refinery in the Houston area via pipeline. The OPGEE inputs for the Bakken and Eagle Ford plays are summarized in Table A1. For all other OPGEE inputs, defaults are used.

Refining, Refined Product Transport, and Combustion

For the final three stages of the GHG emissions life cycle (refining, refined product transport and combustion) outputs from the PRELIM model are used. The only input to the PRELIM model is the crude oil assay. Since the Bakken and Eagle Ford crude oil assays are not publicly available, an analog crude oil (one with a similar API gravity and sulfur content) was used. Based on the IHS data, both crude oils are assumed to have an API gravity of

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[6] For more information on the IHS assumptions see: Forrest, Dereniwski and Birn, "Comparing the GHG Intensity of the Oil Sands and the Average US Crude Oil," *IHS Energy Special Report,* May 2014.

Table A1: OPGEE Inputs for Modeling Bakken and Eagle Ford Crude Oils

Input	OPGEE Input Tab	Bakken	Eagle Ford	Units
Field Depth	“User Inputs & Results”	10,000	11,000	Ft
Oil Production Volume	“User Inputs & Results”	580,000	525,000	Bbl/d
Number of Producing Wells	“User Inputs & Results”	3169	2869	#
Number of Water Injecting Wells	“User Inputs & Results”	1686	1527	#
Productivity Index	“User Inputs & Results”	0.1	0.1	Bbl/psi-d
Average Reservoir Pressure	“User Inputs & Results”	6800	6750	Psi
API Gravity	“User Inputs & Results”	40	41	Degrees
Gas-to-Oil Ratio (GOR)	“User Inputs & Results”	1,020	4,500	Scf/Bbl of Oil
Water-to-Oil Ratio (WOR)	“User Inputs & Results”	0.6	0.6	Bbl of Water/Bbl of Oil
Ratio of Flaring to Oil Production	“User Inputs & Results”	356	14	Scf/Bbl of Oil
Fraction of Oil Transported by Each Mode (Ocean Tanker)	“User Inputs & Results”	0	0	N/A
Transport Distance (Pipeline) – Source ARC Financial Corp.	“User Inputs & Results”	1971	200	Miles
Expected Lifetime Well Productivity	“Drilling & Development”	252,000	285,000	Bbl
Energy Intensity of Drilling	“Drilling & Development”	2	2	N/A
Discharge Pressure (Water Reinjection Pump)	“Production & Extraction”	2000	2000	psi

Source: IHS Energy and ARC Financial Corp.

near 40°, and from other published data the sulfur content of both crudes oils is low, typically less than 0.4 weight percent.[7] Using these properties, the closest match in PRELIM was the “Brent_Chevron” crude oil assay, which has an API gravity of 38° and a sulfur content of 0.37 weight percent. Using the “Brent_Chevron” as a crude oil analog, the emissions for refining, refined product transport, and refined product combustion were estimated using the same method as described in Section 1.1 of this Appendix.

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[7] Other published data on US tight oil properties includes: (1) Bryden, Federspiel, Habib Jr and Schiller, “Processing Tight Oils in FCC: Issues, Opportunities and Flexible Catalytic Solutions,” *Grace Catalysts Technologies Catalagram*, no. 114 (2014): 3-22 and (2) Wier, Sioui, Metro, Sabitov and Lapinski, “Optimizing Naphtha Complexes in the Tight Oil Boom,” *UOP LLC*, (2014): 1-39.

1.3 US Average Crude Oil Refined (2005)

The average crude oil refined in the United States in 2005 is a common yardstick for comparing crude oil GHG intensities. This baseline was established in two separate papers published by DOE/NETL, with the first being published in November, 2008 and titled "Development of Baseline Data and Analysis of Life Cycle Greenhouse Gas Emissions of Fuels," [8] and the second being released in March, 2009 and titled "An Evaluation of the Extraction, Transport and Refining of Imported Crude Oils and the Impact on Life Cycle Greenhouse Gas Emissions." [9]

The 2005 baseline was created to support the US Environmental Protection Agency's (EPA) Renewable Fuel Standard. As discussed in the main report, we view the DOE/NETL value as a relevant yardstick since it is the most common point of reference for comparing the GHG intensity between crude oils and has been adopted into US legislation.

The following outlines the ARC method for creating an estimate of the emissions for the average US crude oil refined in 2005.

Oil Production and Upgrading

The DOE/NETL papers estimated the production and upgrading GHG emissions intensity for countries that were major sources of US crude oil supply in 2005. The papers also provided information on how much crude oil was supplied from each country. From these two inputs, the weighted average GHG emissions for producing and upgrading the average crude oil refined in the United States (2005) was calculated at 42.3 kgCO2e/barrel (see Table A2).

In their original papers, DOE/NETL did not use the OPGEE model to estimate the carbon intensities of producing and upgrading the crude oil from each country. However, DOE/NETL did assume comparable boundaries for measurement as the OPGEE model, with just one exception. The one difference is that the DOE/NETL value did not include land use change. To make the US average crude oil refined in 2005 comparable with the other estimates using the ARC method, we needed to add an estimate of the GHG emissions for land use (See Table A2 for more details).

Oil Transport, Refining, Refined Product Transport, and Combustion

For crude oil transport, the results from OPGEE are used to estimate the GHG emissions for transporting crude oil from each country to a refinery in Houston, Texas.

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[8] Gerdes and Skone, "Development of Baseline Data and Analysis of Life Cycle Greenhouse Gas Emissions of Petroleum - Based Fuels", *DOE/NETL*, November 2008.

[9] Gerdes and Skone, "An Evaluation of the Extraction, Transport and Refining of Imported Crude Oils and the Impact on Life Cycle Greenhouse Gas Emissions," *DOE/NETL*, March 2009.

Table A2: DOE/NETL Breakdown of US Refinery Crude (2005), Carbon Intensities, and ARC Estimate for Land Use Emissions

US Crude Oil Sources	Input to US Refineries (Thousand barrels/d)*	Percent of US Refinery Crude Input (2005)	Carbon Intensity for Oil Production and Upgrading (kgCO2e/barrel)**
US Crude Oil	5140	37.3	24.5
Canadian Conventional Crude Oil	1102	8.0	35.2
Canada Oil Sands Crude Bitumen**	227	1.6	81.0
Canada Oil Sands Upgraded**	300	2.2	134.0
Mexico Crude Oil	1551	11.3	38.4
Saudi Arabia Crude Oil	1436	10.4	13.6
Venezuela Crude Oil**	1235	9.0	59.8
Nigeria Crude Oil	1075	7.8	128.6
Iraq Crude Oil	522	3.8	19.6
Angola Crude Oil	455	3.3	81.8
Ecuador Crude Oil	276	2.0	31.3
Algeria Crude Oil	228	1.7	35.1
Kuwait Crude Oil	222	1.6	16.5
US Average Crude Oil Refined (Calculated) - No Land Use	N/A	N/A	42.3
US Average Crude Oil Refined (ARC Estimated) - With Land Use Added* **	**N/A**	**N/A**	**50.3**

Source: ARC Financial Corp., Gerdes and Skone, “Development of Baseline Data and Analysis of Life Cycle Greenhouse Gas Emissions of Petroleum - Based Fuels,” *DOE/NETL*, November 2008 and Gerdes and Skone, “ An Evaluation of the Extraction, Transport and Refining of Imported Crude Oils and the Impact on Life Cycle Greenhouse Gas Emissions,” *DOE/NETL*, March 2009.

* Data from DOE/NETL (March 2009), Table 2-1 and Table 2-2, and ARC calculated the percent of total.

** Data from DOE/NETL (March 2009) . From Figure 2-4 Venezuelan carbon intensity was assumed to be the average of conventional production (24.2) and upgraded bitumen (95.4). Canadian Oil Sands carbon intensity data was taken from Table 2-2.

*** ARC estimated using OPGEE, which provided estimates for land use for the main export crude oil from each country, the average was then calculated by weighting the land use impact by the percent of each crude oil refined in the United States in 2005.

Using the same method as described in Section 1.1, the ARC method used data from the PRELIM model for estimating both the GHG emissions for refining, and the volume of refined products produced from a barrel of crude oil.

The amount of refined products was used to calculate the GHG emissions for refined product transport, and combustion. If the PRELIM model included a pre-loaded crude oil assay that represented a significant export stream for the country, that crude oil assay was used to model the refining emissions for oil from the country. In the case that the PRELIM model did not have a pre-loaded crude oil that represented a major oil export from a country, a crude oil analog was used (by choosing a crude oil with a similar density and sulfur content to the dominant crude oil export). To calculate the average, the GHG intensity of each oil was weighted by the amount from each country (see Table A2 for weightings).

Section 2 Evaluating the Carbon Risk of a Specific Crude Oil Investment

2.1 How to Estimate the Impact of a Carbon Levy on Investment Returns

Although life cycle analysis (LCA) is a useful tool for comparing crude oils from the perspective of how many GHG emissions are emitted into the earth's atmosphere, other adjustments are needed to understand the range of carbon costs that could be expected for a specific oil production asset.

Assuming that crude oil facilities need to pay for the carbon they emit, the charge would apply to their direct GHG emissions only (eg. the carbon dioxide equivalent that is produced directly from the oil production site). As explained in Section 2 of the main report, the production and upgrading GHG emissions estimated by the OPGEE model includes the direct GHG emissions, but it also considers a wider boundary, accounting for other emissions that are generated off-site (for example, emissions for producing electricity at an off-site power plant), it applies a credit for any by-products (natural gas, electricity, or natural gas liquids (NGLs)) and it includes an estimate of the GHG impacts from land use change.

Since an oil production facility is not likely to be directly responsible for the emissions which occur upstream of the site, or for emissions due to land use, they do not need to be included in the estimate of the producer's carbon cost. Including the costs for these emissions would overstate the company's direct liability. Similarly, while applying a credit for by-products is appropriate for comparing crude oils against each other from the perspective of the amount of GHG emissions they will be contributing to the earth's atmosphere, this method is less useful when examining the total carbon cost that a specific oil production facility may be burdened with. Since, under a carbon levy, an oil production facility will likely be responsible for all of the direct GHG emissions produced at the site, and will not get a credit for any by-products. Removing the off-site emissions, land use emissions, and by-product credits is a simple adjustment to make with the outputs from the OPGEE model (see Section 3 of this Appendix for an example calculation which shows how to calculate the amount of direct, on-site emissions using OPGEE outputs).

Table A3: Production and Upgrading GHG Emissions for Crude Oils – Comparing the Direct, On-site Emissions with the Wide Boundary LCA Emissions

Crude Oil	Direct, On-site Emissions for Carbon Levy Calculation (kgCO2e/barrel)	Wide boundary for LCA (kgCO2e/barrel)
Nigeria High Flaring (Obagi)	335	233
Indonesia Heavy Oil with Steam (Duri)	300	176
UK Offshore (Brent)	297	111
China Conventional Heavy Oil (Bozhong)	290	263
Nigeria High Flaring (Bonny)	281	165
US California Heavy Oil with Steam (Midway-Sunset)	238	202
Canada Oil Sands Mining and Upgrading (Syncrude Synthetic)	173	193
Canada Oil Sands Mining and Upgrading (Suncor Synthetic A)	143	154
Canada Oil Sands Mining and Upgrading (Suncor Synthetic H)	137	148
Venezuela Orinoco Heavy Oil (Hamaca)	132	174
US California Heavy Oil with Steam (South Belridge)	112	110
US Conventional with High Gas (Alaska North Slope)	101	84
Russia Deep Offshore (Chayvo)	84	68
Canada Oil Sands Insitu (Cold Lake Dilbit)	78	113
Iraq Conventional (Zubair)	65	65
US Tight Oil (Bakken)	51	55
US Tight Oil (Eagle Ford)	51	28
Brazil Deep Offshore (Lula)	47	43
Nigeria Conventional (Agbami)	47	47
US California Heavy Oil with Steam (Wilmington-Duffy)	46	51
Canada Conventional High Water (Midale)	45	55
US GOM Deep Offshore (Mars)	44	33
UK Offshore (Forties)	40	42
Angola Conventional (Girassol)	38	36
US GOM Deep Offshore (Thunder Horse)	34	30
Azerbaijan Conventional (Azeri)	34	26
Angola Conventional Heavy Oil (Kuito)	33	34
Kuwait Conventional (Ratawi)	32	28
Brazil Conventional Heavy Oil (Frade)	28	27
Norway Offshore (Ekofisk)	25	18
Canada Offshore (Hibernia)	24	25
Kazakhstan Conventional (Tengiz)	21	20
US Average Crude Oil Refined (2005)	**N/A**	**50.3**

Source: ARC Financial Corp.,using the OPGEE model with input data for describing production practices from the Global Oil Climate Index, IHS and DOE/NETL.

For each of the crude oils in the ARC benchmark set, Table A3 shows the direct, on-site GHG emissions (that an investor should use for calculating a carbon levy) versus the wide boundary life cycle GHG emissions. For the crude oils that generate and export electricity or produce large volumes of associated natural gas, the producer's on-site, direct GHG production emissions are much higher than when LCA is considered. This is because the credit for by-products is not being applied. All things the same, if a carbon levy were introduced then the facilities that produce by-products will tend to have higher absolute carbon costs. However, it is important to consider that while these by-products are associated with higher carbon costs, they can also be valuable revenue streams for these facilities. For example, if a facility produces and sells excess electricity or natural gas then, along with a higher carbon cost, the asset is also generating additional revenue, which helps to offset the carbon burden.

The producer's direct, on-site GHG emissions are used to determine the potential impact of a carbon levy on investment returns. The first step is to make an estimate of a potential carbon cost for a specific asset. For example, to test the impact of a carbon levy, the direct on-site GHG emissions intensity for each barrel of crude oil produced must be multiplied by the carbon levy. This will result in a per barrel carbon cost that can be considered as an additional cost for economic modeling. For example, if the direct on-site GHG emissions for an oil production site are 50 kgCO2e/barrel, a $30/tonne of CO2e carbon levy equates to an extra cost of $1.50 for every barrel of crude oil produced. This extra cost must be added to the investor's economic models to understand how it would reduce investment returns. To understand the sensitivity of returns to differing levels of carbon price, the investor can repeat this calculation over a range of carbon prices.

2.2 Other Considerations for the Investor

Besides direct emissions, the investor could add other indirect carbon costs into their financial models. For instance, if a power plant has to pay a carbon levy, then the price of power for the oil producer may increase, and the investor will want to account for this in their calculations. Similarly, if an oil refiner is burdened with a carbon levy they may be unwilling, or unable to pay the same price as before for the raw crude oil.

It also stands to reason that crude oil varieties which require greater energy, and thus produce greater emissions during the refining process, may be more susceptible to this price discounting than more easily refined crude oils in a carbon constrained world. The investor may want to account for this, however, in this regard some caution is required. Market dynamics are complicated, and exactly how the burden of a carbon levy on a refinery would be shared between consumers, refiners, and producers remains unclear.

Section 3 Putting it all Together: A Sample Calculation

The following applied example explains how to model the life cycle GHG emissions for a hypothetical oil field that produces light crude oil from the US Midwest. The sample calculation also illustrates how to use the information from the ARC method for calculating a range of carbon costs. By following along with these steps and reproducing your own results, you should be in a better position to apply these methods to your own unique crude oil investments.

Step 1: Gather Data about the Asset

The first step is gathering data to describe the characteristics of the oil field and its emissions. Previous research by Stanford University, [10] explains the four criteria that are the most important in estimating upstream GHG emissions: (1) steam-to-oil ratios (2) water-to-oil ratios (3) flaring rates and (4) crude oil API gravity. Other inputs that are key to having precise measurements include gas-to-oil ratios, oil production rates, and drilling depths (for extremely deep wells).

Table A4: Input Data for Hypothetical Oil Field in the US Midwest

Input	Value	Units
Field Name	Example	
Field Depth	11,000	Ft
Oil Production Volume	5,800	Barrels/day
Number of Producing Wells	32	#
Number of Water Injecting Wells	17	#
Crude Oil API	40	Degrees
Crude Oil Sulfur	0.3	Wt% (only required for PRELIM modeling)
Gas-to-Oil Ratio	1,020	Scf/Bbl of oil
Water-to-Oil Ratio	0.6	Bbl of Water/Bbl of Oil
Ratio of Flaring to Oil Production	182	Scf/Bbl of oil
Water Injection Ratio	1.6	Bbl of Water/Bbl of Oil
Fraction of Oil Transported by Each Mode (Pipeline)	1	Set all other transportation modes to "0" (Ocean tanker, Barge, and Rail)
Transport Distance (Pipeline)	1,971	Miles (distance is based on Midwest location to Houston)

Source: ARC Financial Corp.

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[10] For more information on this topic, you can refer to Vafi and Brandt's "Uncertainty of Oil Field GHG Emissions Resulting from Information Gaps: A Monte Carlo Approach," *Environmental Science and Technology* 48, no. 17 (2014): 10511-10518. Additionally you may also refer to Brandt, Sun and Vafi's, "Uncertainty in Regional-Average Petroleum GHG Intensities: Countering Information Gaps with Targeted Data Gathering," *Environmental Science & Technology* 49, no. 1 (2015): 679-686.

Table A5: OPGEE Output of Production and Transportation Emissions and ARC Calculations

OPGEE Output		ARC Calculations*	
	GHG Emissions (gCO2e/MJ)	Convert gCO2e/MJ to KgCO2e/Barrel Using Lower Heating Value (MJ/barrel)	GHG Emissions (kgCO2e/barrel)
Exploration	0.00		
Drilling	1.47		
Production	0.39		
Processing	0.86		
Upgrading	0.00		
Maintenance	0.00		
Waste	0.00		
VFF	5.28		
Diluent	0.00		
Misc.	0.50		
Transport	0.89	5556.30	4.95
Offsite Emissions	-0.83	5556.30	-4.61
Net Lifecycle Emissions	8.56	5556.30	47.56

Source: OPGEE, ARC Financial Corp.

* The OPGEE table displays the results in gCO2e/MJ. To convert the units to kgCO2e/barrel the crude oil's lower heating value is required. The lower heating value is found in Cell M15 of the OPGEE Model's "Fuel Specs" tab. This value will depend on the API gravity of the crude oil modeled.

Note: To convert the results from units of gCO2e/MJ to kgCO2e/barrel, multiply the OPGEE GHG emissions in the second column by the lower heating value in the third column, and then divide the total by 1000g/kg, this results in the value found in the fourth column in units of kgCO2e/barrel.

For the example calculation, the four essential inputs are included, along with some other basic data. OPGEE defaults are used for all other inputs. Refer to Table A4 for the inputs used to describe the example oil field.

Step 2: Model the GHG Emissions for Crude Oil Production and Transportation

Next, you must enter the data that describes the oil field from Table A4 into the OPGEE excel model (v1.1 Draft D). [11]

The input data is entered on the "User Inputs and Results" tab of the OPGEE model, in column J of the section labeled "3 User inputs – Conventional." After inputting all of the data, OPGEE will automatically generate an estimate of the GHG emissions for producing and transporting the crude oil. The results are summarized in the "User Inputs & Results" worksheet in Table 1.1 "Summary GHG Emissions." [12] Table A5 shows the OPGEE

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[11] Note: The crude oil sulfur content in Table A4 is not required for OPGEE but it is needed for Step 3.
[12] Note: Depending on the version of Excel you are using you may need to enable macros for OPGEE to function properly.

Table A6: PRELIM Version 1.0 Crude Oil Inventory and Properties

Crude Oil	Sulphur (Wt Percent)	API Gravity
Belridge Knovel	0.25	15.00
China Bozhong	0.28	16.90
Kuwait Ecocene Chevron	5.26	18.29
Wilmington CA Knovel	1.56	19.40
Albian Heavy Synthetic Crude Monitor	2.24	19.48
Brazil Frade Chevron	0.80	19.81
Suncor Synthetic H Crude Monitor	3.06	19.91
Brazil Polvo	0.96	20.27
Indonesia Duri Chevron	0.24	20.29
Western Canadian Select Crude Monitor	3.38	20.54
Lloyd Kerrobert Crude Monitor	3.33	20.62
Seal Heavy Crude Monitor	5.14	20.63
Western Canadian Blend Crude Monitor	3.30	20.64
Cold Lake Crude Monitor	3.89	20.73
Lloyd Blend Crude Monitor	3.69	20.87
Wabasca Heavy Crude Monitor	4.00	20.94
Bow River North Crude Monitor	2.70	21.09
Angola Kuito Chevron	0.87	22.05
Midway Sunset Knovel	1.19	22.60
Kuwait Ratawi Chevron	5.02	24.20
Hamaca Venezuela Knovel	1.63	26.00
Mars USA Gulf of Mexico BP	1.56	28.75
Brazil Lula BG Group	0.27	29.30
Midale Crude Monitor	2.34	29.60
Angola Girassol Statoil	0.35	29.81
Angola Girassol Exxon	0.31	29.90
Iraq Basra BP	2.66	30.16
Nigeria Bonga Exxon	0.18	30.60
Alaska North Slope Exxon	0.85	31.40
Syncrude Synthetic Crude Monitor	0.14	31.53
Husky Synthetic Blend	0.09	32.63
Bonny Light Chevron	0.17	32.71
Thunderhourse Exxon	0.76	32.90
Suncor Synthetic A Crude Monitor	0.16	33.11
Thunderhorse BP	0.67	33.46
North Sea Dansk Blend Statoil	0.32	33.50
Nigeria Escavaros Chevron	0.24	33.51
Canada Hibernia Chevron	0.56	33.53
Canada Hibernia Exxon	0.62	34.60
Nigeria Erha Exxon	0.18	34.80
Azeri Light Statoil	0.15	34.80
High Sour Edmonton Crude Monitor	1.35	34.94
Canada Hibernia Statoil	0.48	35.00
Nigeria Pennington Chevron	0.15	35.42
Norway North Sea Skarv BP	0.37	35.98
Nigeria Quaib Exxon	0.12	36.00
Azeri Light Chevron	0.15	36.08
Azeri Light Exxon	0.19	36.10
Russia Sokol Exxon	0.37	36.40
Brent BP	0.34	37.43
Brent Chevron	0.37	38.20
Ekofisk Chevron	0.33	38.40
Ekofisk BP	0.21	38.42
Ekofisk Statoil	0.24	38.42
Brent Exxon	0.56	38.50
Forties Blend BP	0.75	38.62
Forties Statoil	0.85	38.70
UAE Murban BP	0.88	40.07
Forties Chevron	0.85	40.31
Indonesia Tangguh BP	0.14	44.12
Tengiz Chevron	0.71	46.42
Nigeria Agbami Chevron	0.08	47.88
Nigerian Agbami Statoil	0.07	48.03

Source: PRELIM.

output for the sample crude oil. The first two columns of Table A5 are directly from the OPGEE model, while the other columns and associated footnotes illustrate the ARC method for converting from OPGEE's original units into the units of kgCO2e/barrel.

OPGEE reports the total emissions (including production and crude oil transportation) in the "Net Lifecycle Emissions" output. To derive the emissions for the crude oil production step only, you must subtract the "Transport" emissions (4.95 kgCO2e/barrel), from the total "Net Lifecycle Emissions" (47.56 kgCO2e/barrel) to arrive at crude oil production emissions of 42.61 kgCO2e/barrel.

Step 3: Model the GHG Emissions for Crude Oil Refining

The PRELIM model (version 1.0) is used for generating two outputs: (1) The GHG emissions associated with refining the crude oil, and (2) the volume of each refined product (gasoline, diesel, fuel oil, etc.) that can be produced from one barrel of crude oil (the latter output is used in steps 4 and 5).

The PRELIM model comes pre-loaded with data that characterizes the properties of more than 60 unique crude oils. If your crude oil is not found in the pre-loaded list, then you can choose a crude oil analog by selecting a PRELIM crude oil that has similar properties (API gravity and sulfur). While using an analog crude oil method is not as accurate as having the actual crude oil assay, it is the most practical method. [13]

To help in the selection of analog crude oils, Table A6 lists the density and sulfur content of the crude oils that are pre-loaded in PRELIM version 1.0. The crude oil for this hypothetical example has an API gravity of 40° and 0.3 wt percent sulfur. After looking through Table A6, PRELIM's "Brent_Chevron" crude oil assay is the closest to the example crude oil. Once deciding to use this crude oil assay, return to the "Main Input & Output" tab of the PRELIM model and choose "Brent_Chevron" from the "Pick a crude assay" drop box.

After selecting the crude oil, PRELIM automatically calculates the GHG emissions for refining the crude oil in cell W34 of the "Results Single Assay" tab. For the example crude oil, the model calculates refining emissions of 17.90 kgCO2e/barrel of oil. [14]

Step 4: Model the GHG Emissions for the Transportation of Refined Products

To estimate the GHG emissions for transporting the refined products to the consumer by pipeline you first require the volume of all the liquid refined products. PRELIM displays the volume in the "Results Single Assay" tab, assuming that 100,000 barrels/day of crude oil are fed to the refinery (see Table A7). Therefore, to calculate the total volume of refined products for one barrel of crude oil, the volume in PRELIM must be divided by 100,000 barrels/day and each individual product must be added together to get the total for all of the products (0.976 barrels

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[13] The PRELIM model does provide the option for entering a new crude oil assay. However, it can be difficult to find assays with enough detail, and even then PRELIM requires a specific format.

[14] The model calculates a value for the GHG intensity for both the coking and hydrocracking refinery options, most often the value is the same. In the case that the values are different, the coking refinery value is used in the ARC method.

Table A7: Calculation of the GHG Emissions for Transporting Refined Products for Hypothetical Crude Oil Example

PRELIM Output			ARC Calculations		
Product Slate	**%**	**Bbl Product Per Day**	**Convert to Barrel of Crude Oil Basis ***	**Carbon Dioxide Emission Factors for Transporting Fuel (kgCO2e/barrel of Refined Product) ****	**Transportation GHG Emissions from all Liquid Fuels (kgCO2e/barrel of Crude Oil)**
Blended Gasoline	29.60%	28,896.59	0.289	-	-
Jet-A/AVTUR	20.99%	20,494.63	0.205	-	-
ULSD	8.21%	8,015.59	0.080	-	-
Fuel Oil	8.66%	8,454.55	0.085	-	-
Coke	0.00%	0.00	0.000	-	-
Bunker C	32.53%	31,760.40	0.318	-	-
Surplus Refinery Fuel Gas (RFG)	0.00%	0.00	0.000	-	-
Total			**0.976**	**2.39**	**2.33**

Source: PRELIM, ARC Financial Corp.

* The original PRELIM results are on a basis of 100,000 barrels/day of crude oil fed to the refinery. They must be divided by 100,000 to arrive at the per barrel of crude oil basis.

**Gerdes and Skone's, "Development of Baseline Data and Analysis of Life Cycle Greenhouse Gas Emissions of Petroleum-Based Fuels," *DOE/NETL*, November 2008, published an average value for transportation of refined products by pipeline in the United States of 2.39 kgCO2e/barrel.

Table A8: Calculation of the GHG Emissions for Combusting Refined Products for Hypothetical Crude Oil Example

PRELIM Output			ARC Calculations		
Product Slate	**%**	**Bbl Product Per Day**	**Convert to Barrel of Crude Oil Basis ***	**Carbon Dioxide Emission Factors for Combusting Fuel (kgCO2e/barrel of Refined Product) ****	**Combustion GHG Emissions from Each Fuel (kgCO2e/barrel of Crude Oil) *****
Blended Gasoline	29.60%	28,896.59	0.289	370.3	107.00
Jet-A/AVTUR	20.99%	20,494.63	0.205	411.1	84.25
ULSD	8.21%	8,015.59	0.080	429.8	34.45
Fuel Oil	8.66%	8,454.55	0.085	462.1	39.07
Coke	0.00%	0.00	0.000	-	-
Bunker C	32.53%	31,760.40	0.318	452.8	143.81
Surplus Refinery Fuel Gas (RFG)	0.00%	0.00	0.000	-	-
Total			**-**	**-**	**408.59**

Source: PRELIM, ARC Financial Corp., EPA

* The original PRELIM results are on a basis of 100,000 barrels/day of crude oil fed to the refinery. They must be divided by 100,000 to arrive at the per barrel of crude oil basis.

** Factors from Table 1 of the main report (Source: EPA 2014 Emission Factors for GHG Inventories).

*** To calculate the GHG emissions for combustion, the volume of fuel produced from a barrel of crude oil must be multiplied by the GHG intensity for combusting each fuel. Next, the emissions for each fuel are added up to arrive at the total combustion emissions from burning the products from a single barrel of crude oil.

of product/barrel of crude oil). Although it makes no material difference for this example, (as we are using a light crude oil that does not produce any coke) petroleum coke is excluded from the totals in the ARC method.

Table A7 shows the volume of refined products from PRELIM, and the ARC calculation for GHG emissions associated with the refined product transportation. Using the DOE/NETL emissions factor of 2.39 kgCO2e/barrel of refined product for moving the refined product via pipeline, the total emissions for moving the refined products that are derived from one barrel of crude oil are calculated to be 2.33 kgCO2e/barrel.

Step 5: Model the GHG Emissions for the Combustion of Refined Products

To estimate the GHG emissions for combusting the refined products from a barrel of crude oil, the volume of each refined product is required. Table A8 shows how to calculate the combustion emissions for one barrel of crude oil, excluding the petroleum coke. In this example, the total GHG emissions for combustion are 408.59 kgCO2e/barrel of crude oil.

Step 6: Compare the Life Cycle Emissions of the Crude Oil to the Other Sample Oils

With all the LCA stages now calculated, each stage is added together to arrive at the total life cycle emissions for our hypothetical crude oil (see Table A9).

The life cycle GHG emissions values for the hypothetical crude oil in Table A9 are comparable to the benchmark crude oils that are detailed in Table 3 of the main report. At 476.38 kgCO2e/barrel, on a well-to-combustion basis, this particular crude oil is in the top 25 percent of the benchmark set of crude oils and five percent below the average US crude oil (2005). The ranking is helpful for getting a notional sense of how the GHG footprint of this crude oil compares to others, and how the competitiveness of that crude oil may be impacted in a carbon constrained world. However, to determine a more precise impact of carbon policy on a given investment, a more targeted approach is required. This is discussed in Step 7.

Step 7: Evaluate the Impact of a Potential Carbon Tax on your Investment Returns

More stringent GHG emissions policies will increase the cost for emitting carbon. If the policy put in place is a carbon levy, then a producer will be responsible for paying a fee related to their direct emissions. To estimate the direct financial burden from a carbon levy on a crude oil asset, the direct GHG emissions from the oil production site are needed.

To estimate direct, on-site emissions, return back to the OPGEE modeling results. As outlined in Section 2.1 of this Appendix, OPGEE models the direct emissions for the oil production facility, and it then applies a credit for any by-products, and a debit for the upstream emissions associated with producing the fuels that are used on the site. It also adds GHG emissions for land use change.

Table A9: Total Well-to-Combustion GHG Emissions for Hypothetical Crude Oil Example

Stage of Lifecycle	**Emissions (kgCO2e/barrel)**
Oil Production	42.61
Oil Transport	4.95
Refining	17.90
Refined Product Transport	2.33
Combustion	408.59
Total	**476.38**

Source: ARC Financial Corp.

Table A10: Equation to Calculate Direct, On-site Emissions for an Oil Production Site with OPGEE Outputs

Producer's Emissions=	Direct Crude Oil Production Emissions (Calculated) - Offsite Emissions (OPGEE output*) - Land Use Emissions (Calculated)
Where:	Direct Crude Oil Production Emissions (Calculated) = Net Lifecycle Emissions (OPGEE*) - Transport (OPGEE*)
And:	Land Use Emissions = Daily Land Use Emissions (OPGEE output**) / (1000 x Daily Oil Production) (OPGEE Output***)

Source: ARC Financial Corp. using inputs calculated by OPGEE.

*Located in the OPGEE Excel model on the "User Inputs & Results" worksheet in Table 1.1 "Summary GHG Emissions."

**Located in the OPGEE Excel model on the "GHG Emissions" Tab in cell I51.

***Located in the OPGEE Excel model on the "User Inputs & Results" tab in cell J70.

To derive the direct, on-site emissions only, first remove the credit for by-products and the debit for off-site emissions. The formulas for calculating the direct emissions are shown in Table A10. In the OPGEE results table (see Table A5), OPGEE reports the net effect of the by-product credits and fuel debits in the "Offsite emissions" row of the results table. For this example, the value is -4.61 kgCO2e/barrel. Therefore, to calculate the direct on-site emissions, you simply take the oil production emissions of 42.61 kgCO2e/barrel (the 47.56 kgCO2e/barrel "Net Lifecycle Emissions," less 4.95 kgCO2e/barrel "Transport") and subtract the "Offsite Emissions" of -4.61 kgCO2e/barrel to arrive at a value of 47.22 kgCO2e/barrel for the direct emissions.

Next, you must remove the emissions due to land use. As described previously, OPGEE estimates the emissions that result when vegetation at the oil production site is disturbed. While land use is important to consider, when

Table A11: Calculating the GHG Emissions From Land Use for Hypothetical Crude Oil Example

Metric	OPGEE Tab	OPGEE Cell	Value	Units
Daily Land Use Emissions	GHG Emissions	I51	40,444,266	gCO2e/day
Oil Production Volume	User Inputs & Results	J70	5,800	barrels/day
Land Use Emissions Intensity	Calculated		6.97*	kgCO2e/barrel

Source: ARC Financial Corp. using inputs calculated by OPGEE.

*The intensity of land use emissions is calculated by dividing the total land use emissions by the daily oil production volume, and dividing by 1000g/kg.

Table A12: Cost of Carbon Levy per Barrel of Crude Oil Produced for Hypothetical Crude Oil Example

Carbon Levy Scenario ($/tonne CO2e)	Direct On-site Production Emissions (kgCO2e/barrel)	Carbon Cost on Each Barrel Produced at the Oil Production Facility ($/barrel)
20	40.25	0.81
30	40.25	1.21
40	40.25	1.61

Source: ARC Financial Corp.

looking from the perspective of total carbon in the atmosphere, it is unlikely to fall under a carbon pricing regime, and can thus be excluded when a producer estimates their carbon tax burden. The calculation for determining the intensity of land use emissions in the OPGEE model for our hypothetical crude oil field example is detailed in Table A11.

In this example, OPGEE estimates that land use is 6.97 kgCO2e/barrel. To find the producer's GHG intensity without land use, the value must be subtracted from the direct emissions calculated in the previous step (47.22 kg-CO2e/barrel, see Equation in Table A10), giving a result of 40.25 kgCO2e/barrel for the direct, on-site emissions, which excludes upstream effects, product credits, and land use.

The direct, on-site emissions intensity is used to calculate the extra cost per barrel if a carbon levy were imposed on the investment. To do this, take the dollar-per-tonne carbon tax assumption, multiply it by the emissions intensity, and divide by 1000kg/tonne. For instance, if an investor assumes a carbon fee of $30/tonne of CO2e, this equates to $1.21/barrel of extra cost for each barrel of crude oil produced (see Table A12 for range of costs at different carbon fees). This extra cost can then be added to the economic models for the crude oil asset, to provide insight on how the carbon levy would change investment returns.

The hypothetical Midwest oil field example was meant to aid those who wish to apply the ARC method to their own investment portfolio. After following this step-by-step example, and completing each stage, you should be in a better position to apply the ARC method to evaluate the GHG intensity, and risk to the investment returns for your own unique crude oil investment choices.

Glossary of Key Terms

API Gravity

API gravity is a measure of density for petroleum products. The measuring scale is calibrated in terms of API degrees. The lower the API gravity measure, the heavier the crude oil. In the PRELIM model and for the ARC method, a crude oil is considered to be heavy when it has an API gravity measure of 22˚ and lower. [15] A crude oil is considered to be light when it has an API gravity measure over 32˚, and when the API gravity measure is between 22˚ and 32˚, it is considered to be a medium crude oil.

Bakken Formation

The Bakken Formation is an oil producing play in the Williston Basin. Recently, the use of horizontal drilling and fracturing technology has allowed for rapid oil production growth in the play, mainly in North Dakota.

Crude Oil Assay

A detailed profile of a crude oil, an assay reports the volume and quality of the crude oil that is boiled-off in each temperature range. This profile commonly includes properties such as the density and sulfur content to define the characteristics of a specific crude oil.

Density

A measure of the compactness of a substance, density is expressed in units of mass per unit of volume.

Deep Conversion Refinery

The most complex type of refinery, it includes a coker process unit that converts the heaviest part of the crude oil barrel into light transportation fuels. The PRELIM model assumes that the heaviest crude oils in their model will be refined in a deep conversion refinery.

Eagle Ford Shale

The Eagle Ford Shale is an oil and gas producing play in South Texas. The rock is notably brittle, making it a prime target for oil and gas extraction through hydraulic fracturing. As a result of horizontal drilling and hydraulic fracturing, oil production has been growing rapidly from the play in recent years.

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[15] Abella, Motazedi and Bergerson, "Petroleum Refinery Life Cycle Inventory Model (PRELIM) - User Guide and Technical Documentation," March 2015: 93, http://www.ucalgary.ca/lcaost/files/lcaost/prelim-v1-0-documentation.pdf

Flaring Rates

Many oil wells produce natural gas alongside the crude oil. Often the natural gas is captured and sold as a by-product of the crude oil production. Sometimes, however, due to infrastructure constraints or for economic reasons, the natural gas is not captured. Instead, the gas is combusted in a flare at the well site.

GHG Intensity

The ratio of greenhouse gases produced for each unit of product. For example, in the case of crude oil production, GHG intensity is measured by the mass of CO2 equivalent gas created for each barrel of crude oil extracted.

Hydroskimming Refinery

The simplest type of refinery, it separates the crude oil into petroleum fuels and improves the properties. The refinery does not have the ability to convert heavier parts of the crude oil into lighter liquids. The PRELIM model assumes that the lightest crude oils in their model are refined in hydroskimming refineries.

Internal Rate of Return

A metric used to evaluate the profitability of an investment. Is the interest rate at which the net present value of all cash flows (both positive and negative) from a project or investment is equal to zero.

Medium Conversion Refinery

Sometimes called a cracking refinery, it includes a Fluid Catalytic Cracking unit that converts the middle part of the crude oil barrel into light transportation fuels. The PRELIM model assumes that medium crude oils are processed in a medium conversion refinery.

Natural Gas Liquids (NGLs)

Raw natural gas from the wellhead is mostly comprised of methane but also contains various other heavier hydrocarbons such as ethane, propane, butane and pentanes plus. These heavier hydrocarbons are referred to as NGLs.

Petroleum Coke

When heavy crude oil is converted into lighter fuels in a deep conversation refinery using a coker, the process creates a solid by-product that is similar to coal, called petroleum coke.

Steam-to-Oil Ratio

For some heavy oil plays, steam is injected into the reservoir to produce the oil. The measure of the volume of steam used to produce one barrel of oil is called the steam-to-oil ratio.

Upstream

In the oil and gas industry, the term upstream refers to operations that deal with exploration and extraction of crude oil and natural gas. Upstream does not include any processing of the raw crude oil or natural gas, these activities are considered part of the midstream and downstream operations.

US Tight Oil

Refers to the light crude oil found in tight reservoirs. As the oil is trapped in low permeability rocks, horizontal drilling and hydraulic fracturing are used to enable the hydrocarbons to flow to the wellbore.

Water-to-Oil Ratio

Many oil wells produce water alongside the crude oil. The ratio of produced water to produced oil is the water-to-oil ratio.