Know Your Oil and Gas

Generating Climate Intelligence to Cut Petroleum Industry Emissions

Report / June 2022

About the RMI Climate Intelligence Program

RMI's Climate Intelligence Program (CIP) aims to make the invisible visible to drive climate action with transparent data, advanced analytics, novel policies, and market insights. Decision makers need timely, high-quality, context-relevant, trusted data to align industrial sectors, like oil and gas, with a 1.5°C pathway. In partnership with business, finance, and policy leaders, we increase knowledge and transparency. CIP develops open-source data platforms, taps artificial intelligence, uses machine-learning technologies, and creates new tools that improve accountability, catalyze markets, and accelerate decarbonization. The climate intelligence in this report is underpinned by the OCI+ model and numerous other resources.[i]

About RMI

RMI is an independent nonprofit founded in 1982 that transforms global energy systems through market-driven solutions to align with a 1.5°C future and secure a clean, prosperous zero-carbon future for all. We work in the world's most critical geographies and engage businesses, policymakers, communities, and NGOs to identify and scale energy system interventions that will cut greenhouse gas emissions at least 50% by 2030. RMI has offices in Basalt and Boulder, Colorado; New York City; Oakland, California; Washington, D.C.; and Beijing.

i For more information, visit **https://rmi.org/insight/kyog/**.

Authors

Authors

Deborah Gordon, RMI
Jonathan Koomey, Koomey Analytics
Adam Brandt, Stanford University
Joule Bergerson, University of Calgary

Contacts

Deborah Gordon, **dgordon@rmi.org**
Jonathan Koomey, **jgkoomey@gmail.com**
Adam Brandt, **abrandt@stanford.edu**
Joule Bergerson, **jbergers@ucalgary.ca**

Copyright and Citation

Deborah Gordon, Jonathan Koomey, Adam Brandt, and Joule Bergerson, *Know Your Oil and Gas: Generating Climate Intelligence to Cut Petroleum Industry Emissions,* RMI, 2022, **https://rmi.org/insight/kyog/**.

Acknowledgments

Our work differentiating global oil and gas emissions intensities would not have been possible without the the support of numerous organizations and individuals.

Thank you to WattTime for helping to fund the OCI+, which we are using for Climate TRACE inputs. We used the OCI+ model to generate data for the 2021 launch of its first comprehensive global emissions data platform. Thank you to former US Vice President Al Gore and Brad Hall for creating opportunities to increase data transparency, enabling us to model even more global oil and gas resources. The RMI Climate Intelligence Program is excited to continue working with the Climate TRACE coalition to expand oil and gas data transparency by incorporating more satellite data, machine learning, data fusion, and artificial intelligence into the OCI+ model.

Rose Wang, RMI Data Manager, provided stellar project management and led the team that gathered and analyzed data that made this report possible. Frances Reuland provided expertise in the strategic expansion of the OCI+ to include gas and model methane emissions. Raghav Muralidharan facilitated the conversion of the OPEM model into Python (with external help from Zachary Schmidt). Sasha Bylsma did a fantastic job assembling the graphics. Michael Rabbani provided support with PRELIM model runs. Adrienne Tecza and Lauren Schmeisser expertly handled data pipeline issues. Shannon Hughes and Sara Herrin provided pre- and post publication communications support and Amber Gensterblum and Lucy O'Sullivan provided project management and administrative support. Thank you to other RMI team members—Ebun Ayandele, Thomas Kirk, Lara Owens, TJ Conway, and Nils Jenson—for pitching in along the way. Shane Puthuparambil and Smriti Kumble provided consulting services to help RMI collect input data and analyze the emissions from hundreds of oil and gas resources. Other research support was provided by the authors' research colleagues, including Liang Jing, Mohammad Masnadi, Jeff Rutherford, and Wennan Long.

Josh Henretig, Bryan Fisher, Sarah Ladislaw, Dina Cappiello, and Jon Creyts provided valuable feedback on this report. RMI's Influence Team, with support from M. Harris & Company, was responsible for all facets of publication.

To support the OCI+ model, Development Seed is working to expand the web tool to visualize hundreds of global oil and gas resources. Our Carbon Mapper, Harvard University, and Colorado School of Mines collaborators—Riley Duren, Daniel Cusworth, Daniel Jacob, Tia Scarpelli, Xiao Lu, Christopher Elvidge, Mikhail Zhizhin, Tamara Sparks, and their colleagues—provided data, analytics, and findings from flyovers and satellites that detect methane and gas flaring. California Air Resources Board (CARB) staff were instrumental in our ability to model California's oil and gas resources. We also collaborated with numerous staff at Solomon Associates to run the OCI+ model to test it on thousands of global oil and gas resources.

This report expands on initial research conducted by the authors from 2010 to 2019 at the Carnegie Endowment for International Peace. Thank you to Jessica Mathews, former Carnegie Endowment President, and Harvey Fineberg, former Carnegie Endowment Board Chair, for their support and encouragement at the outset and initial launch of the OCI+ project. We offer our sincere appreciation to John Holdren, former White House Science Advisor to President Barack Obama, for his early support of the OCI+ and his keynote address at its release in March 2015. The 2015 *Know Your Oil* report was published by the Carnegie Endowment, and information has been archived along with a complete history of the project.[1]

Table of Contents

Acronyms and Abbreviations

API gravity – measure (in degrees) of an oil's weight relative to water, as established by the American Petroleum Institute

AR – Assessment Report published by the Intergovernmental Panel on Climate Change

AR6 – Sixth Assessment Report published by the Intergovernmental Panel on Climate Change

ARPA-E – US Advanced Research Projects Agency-Energy

bbl – barrel (of oil)

bcm – billion cubic meters (of natural gas)

boe – barrel of oil equivalent

CARB – California Air Resources Board

CCS – carbon capture and sequestration (sometimes called carbon capture and storage)

CH_4 – methane

CIP – RMI Climate Intelligence Program

CO_2 – carbon dioxide

CO_2e – carbon dioxide equivalent (including methane, nitrous oxide, volatile organic compounds, and other greenhouse gases)

DOE – US Department of Energy

EIA – US Energy Information Administration

EPA – US Environmental Protection Agency

EOR – enhanced oil recovery

GHG – greenhouse gas

GOR – gas-to-oil ratio

GOSAT – Greenhouse Gas Observing Satellite

GWP – global warming potential

GWP_{20} – 20-year global warming potential

GWP_{100} – 100-year global warming potential

IEA – International Energy Agency

IPCC – Intergovernmental Panel on Climate Change

LNG – liquefied natural gas

mbd – million barrels per day (of oil)

MiQ – Methane Intelligence Quotient (gas certification standard)

N_2O – nitrous oxide

NDC – nationally determined contribution

NOAA – National Oceanic and Atmospheric Administration

NGLs – natural gas liquids

OCI+ – Oil Climate Index plus Gas

OPEM – Oil Products Emissions Model

OPGEE – Oil Production Greenhouse Gas Emissions Estimator

Petcoke – petroleum coke

PRELIM – Petroleum Refinery Life-cycle Inventory Model

scf – standard cubic foot (of gas)

SMR – steam methane reforming

TROPOMI – Tropospheric Monitoring Instrument (instrument on board the Copernicus Sentinel-5 Precursor satellite)

UN – United Nations

VIIRS – Visible Infrared Imaging Radiometer Suite (satellite instrument)

y – year

Key Findings

Most decision makers mistakenly think that greenhouse gas (GHG) emissions from oil and gas do not vary much, are well-characterized by their carbon content, and are dominated by end-use emissions. The cutting-edge research presented in this report shows a wide range of life-cycle emissions intensities, depending on how oil and gas are extracted, processed, refined, transported, and used. This climate intelligence reveals new opportunities to harmonize oil and gas sector GHG emissions with 1.5°C climate goals.

This report presents full life-cycle GHG emissions for one-half of the world's current oil and gas production. These results assess 135 individual and heterogeneous oil and gas resources, using only publicly available data for modeling inputs. Geographically, these resources include those from subbasins in the United States and fields in the rest of the world.

The implications are far-reaching. Oil and gas life-cycle emissions vary widely and large short-term climate benefits can be achieved by attending to those resources with the highest emissions intensity.

Using an open-source, peer-reviewed model, the Oil Climate Index Plus Gas (OCI+), we estimate and differentiate oil and gas emissions, allowing governments, operators, and markets to correctly incorporate climate externalities into all transactions and public policies. With the climate intelligence generated by this effort, companies, policymakers, investors, and civil society can most effectively target their emissions-reduction efforts in the near term.

Key findings follow.

Open-Source Data Is Critical for Oil and Gas Sector Climate Alignment

The majority of self-reported oil and gas emissions (and industry pledges) today cannot be independently verified. All claims of "net-zero" and "carbon-neutral" emissions should be supported by publicly available data so that financial markets and government policymakers can use them with confidence for planning, analysis, and investments.

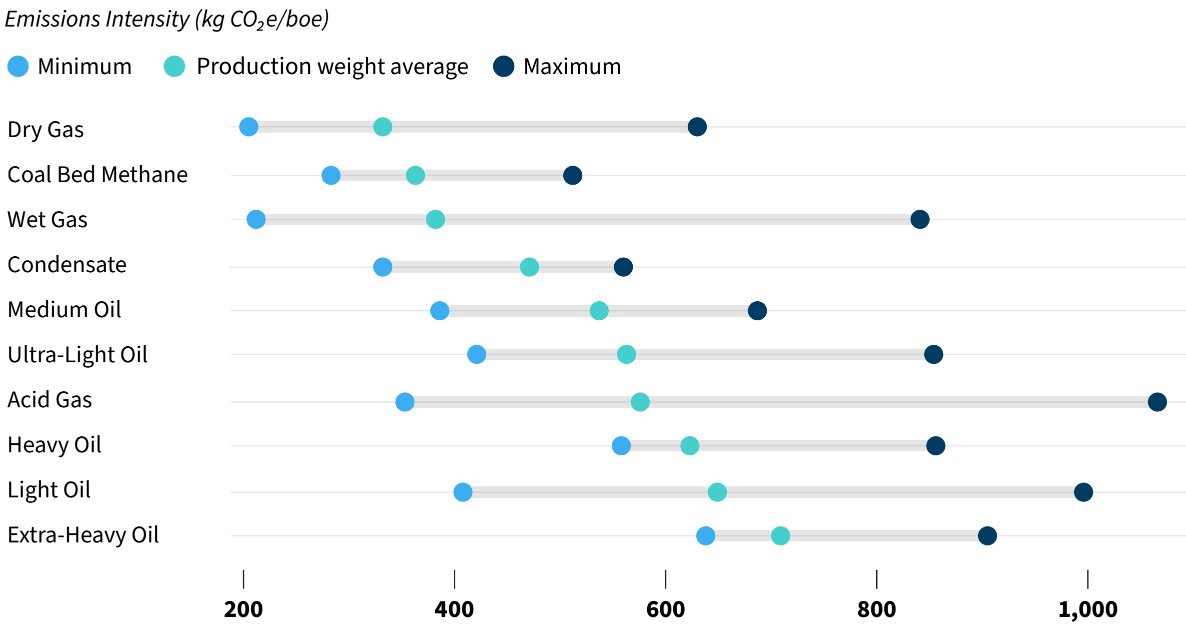
The OCI+ model offers a way forward. This life-cycle assessment model was first unveiled in 2015 by the Carnegie Endowment. The OCI+ has since received significant attention and use by governments, industry, nongovernmental organizations, and academics.[ii] The OCI+ offers an alternative to opaque and overly simplistic emissions assessments done by countries and companies using equipment counts and basic

ii In addition to peer-reviewed articles in *Science Direct* (**https://www.sciencedirect.com/science/article/pii/B9780124095489100909**) and *Environmental Research Letters* (**https://iopscience.iop.org/article/10.1088/1748-9326/aaae76/meta**), also see: International Energy Agency, *World Energy Outlook*, 2018, Chapter 11 (**https://www.iea.org/reports/world-energy-outlook-2018**).

emissions factors. Instead, the OCI+'s suite of advanced models, together with operational inputs and satellite data, estimates GHG emissions through the entire oil and gas supply chain. Emissions intensities can be parsed in different ways—by resource category, region, operation, pollutant, and more—to identify significant reduction potential.

For example, life-cycle climate footprints by resource category can vary by as much as a factor of four from the lowest- to highest-emitting resources (as shown in Exhibit 1).[iii] These differences are large enough to matter.

Exhibit 1 Ranges of Life-Cycle Emissions Intensities Vary Widely by Resource Category



Note: Compares the range of life-cycle emissions intensity estimates from upstream, midstream, and downstream operations (Scope 1, 2, and 3 emissions) of 135 modeled oil and gas resources, assuming 20-year global warming potentials for methane and other short-lived climate pollutants as reported by the IPCC in AR6.

Differentiating Oil and Gas Emissions Drives Actionable Climate Opportunities

Historically, the emissions impacts of these fossil fuels have been quantified based on their direct emissions from fuel combustion, calculated using the carbon content of the unprocessed crude and gas.[iv] This method can be misleading. Life-cycle emissions, including those from production, refining, processing, and shipping, are not equivalent between two oils or gases with the same carbon content. In spite of this

iii We report results for 135 modeled resources, defined as subbasins in the United States and oil and gas fields in the rest of the world. OCI+ asset-level operational data was gathered from publicly available data. The resource volumes modeled in this report account for one-half of 2020 global oil and gas production.

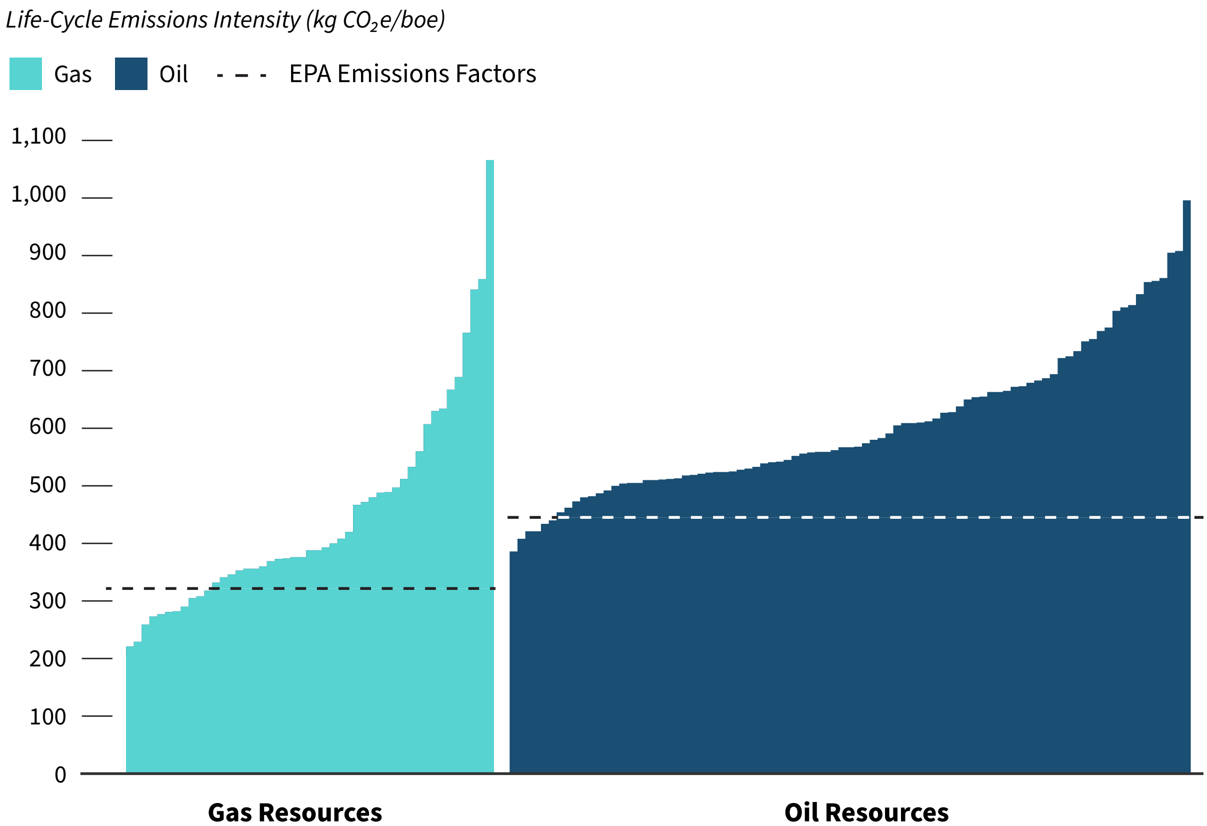
iv Direct emissions are termed "Scope 1" and emissions from purchased inputs are termed "Scope 2." The OPGEE and PRELIM models estimate Scope 1 and 2 emissions for upstream production and midstream refining, respectively. End-use combustion emissions are termed "Scope 3." The OPEM model estimates Scope 3 emissions from oil and gas, as well as product transport emissions (which are Scope 1 emissions for oil and gas shipping firms).

reality, the US Environmental Protection Agency (EPA) assigns an equivalent barrel (boe) of oil or gas a single emissions factor based on its average carbon content. A standard barrel of oil is reported to emit 434 kilograms CO_2 equivalent (kg CO_2e), and an equivalent barrel of gas is reported to emit 315 kg CO_2e.[2]

Focusing on combustion emissions associated with the carbon content of oil and gas leads to significant errors in assessing total life-cycle emissions (as shown in Exhibit 2). EPA emissions factors undercount climate impacts and lead decision makers to ignore considerable GHG emissions from oil and gas supply chains. For example, the OCI+ estimates that the US Greenhouse Gas Reporting Program undercounts oil and gas industry emissions by a factor of two.[v]

Armed with this climate intelligence, however, stakeholders can fully factor emissions into their decisions around oil and gas purchase, investment, development, and regulation.[3] More accurate emissions assessments facilitate government cost-benefit analysis, support regulatory controls, value companies based on their performance, and inform operational decisions. Focusing on life-cycle emissions from the supply chain—from upstream production, midstream refining, and downstream transport and end use—reveals new actionable and cost-effective climate solutions that can reduce oil and gas sector emissions in both the short and longer terms.

Exhibit 2 **Life-Cycle Emissions Intensities of Oil and Gas Are Greater Than EPA Emission Factors**



Note: Each vertical line on the graph represents one modeled oil or gas resource (48 gases and 87 oils). Dotted lines represent US EPA reported greenhouse gas emissions from combusting a barrel's worth of gas (left) and oil (right).
Source: EPA Emissions Factors: **https://www.epa.gov/sites/default/files/2018-03/documents/emission-factors_mar_2018_0.pdf**

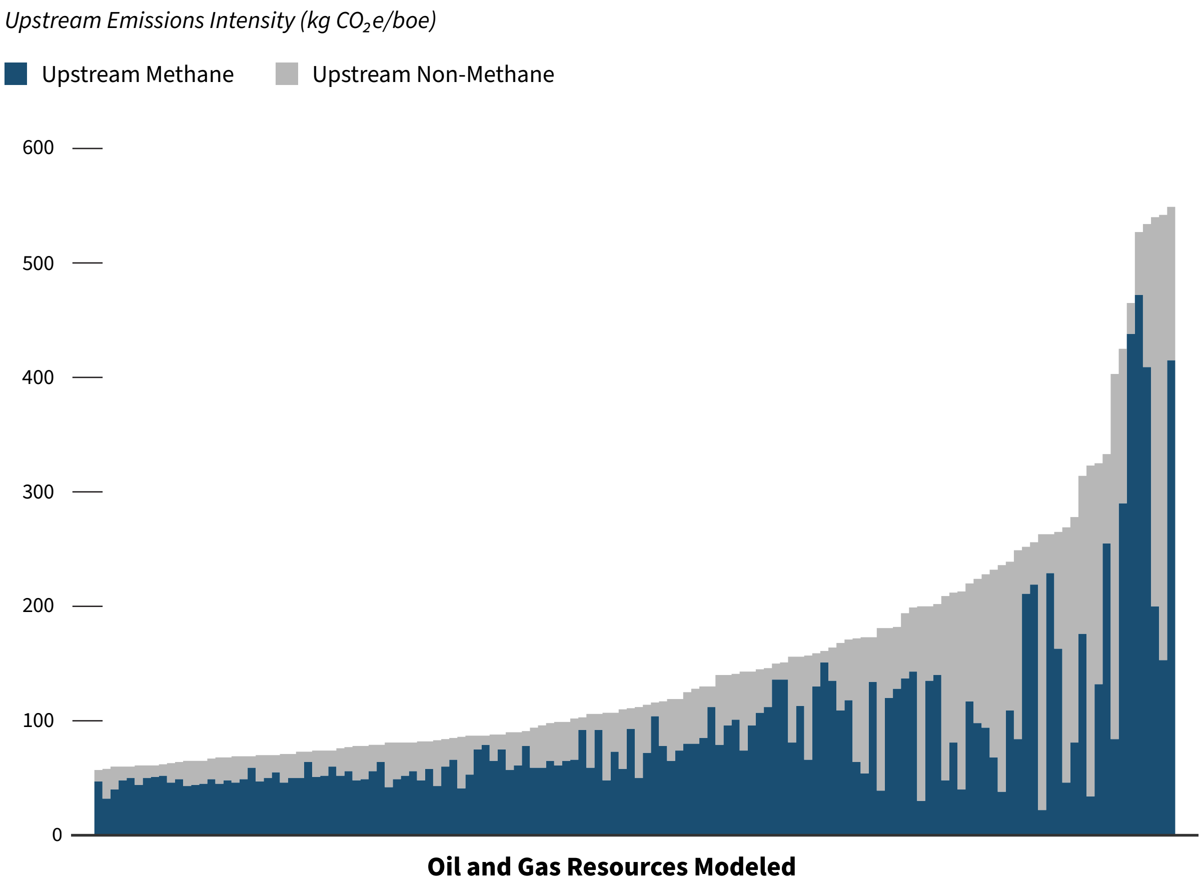
v See **https://climatetrace.org**.

Cutting Methane Is the Highest Priority for the Oil and Gas Sector

The planet is rapidly warming and will soon rise to 1.5°C over preindustrial temperatures.[4] Scientists are concerned about the effects on humanity. Recent studies pinpoint methane as a critical problem.[5] The oil and gas sector is a major source of human-made methane emissions and avoiding the release of methane has a significant climate benefit.[6] Targeting methane reduction is the highest priority for the oil and gas sector, which accounts for an estimated one in four tons of methane emitted globally from all human-made sources each year.[7]

Some oil and gas resources and operations are leakier than others (as shown in Exhibit 3). On average, methane accounts for over one-half of upstream oil and gas operational emissions.[vi] In some fields, methane drives a similar share in life-cycle emissions due to gas leakage during transmission and distribution.

Exhibit 3 **Methane Plays a Large Role in Driving Upstream Emissions**



Note: Each vertical line on the graph represents a single oil or gas resource, for a total of 135 modeled results.

vi Averages are weighted by production volume of the 135 oil and gas resources modeled and assume a 20-year global warming potential (GWP) of 82.5x for methane and 273x for nitrous oxide.

Strategically Managing High-Emitting Oil and Gas Resources Requires Targeted Actions

If operators, policymakers, and financiers are armed with greater climate intelligence, they can target emissions reductions with better maintenance, rules, and investments. The OCI+ offers the ability to compare emissions for different types of resources. Some oils and gases have greater climate risks than others, as follows:

- Extra-heavy and heavy oils emit high amounts of CO_2 in their extraction and refining.
- Light oils, wet gases, and coal bed methane typically leak the most methane.
- Depleted oils and gases employ fossil fuel-intensive enhanced recovery methods.
- Gases with high CO_2 composition (acid gas) typically leak CO_2.
- Resources that contain or inject large water volumes require fossil fuel-intensive pumping and separation methods.

The next step is to match emissions reduction strategies to these elevated climate risks for certain resources. Exhibit 4 (next page) provides a handful of example strategies that can reduce oil and gas climate footprints.

For example, before light oil production commences, operators need to secure a way to transport gas and natural gas liquids (NGLs) from their fields (takeaway capacity). Methane venting and routine flaring must be prohibited. Wet and dry gas, which are made up of mostly methane, must be tightly managed to prevent leakage through the entire life cycle—from wellheads to distribution lines. As oil and gas age and reservoirs are depleted, the best course of action is to shut in legacy fields with low energy return on investment. Decommissioning oil and gas systems can impose prohibitive costs at the wrong time, when they have little to no financial return on investment, but assets that are beyond their useful lifetimes can have outsize climate impacts. This mismatch between cash flows, company valuations, and life-cycle emissions underscores why incentives are needed for operators to safely and properly decommission old assets.

Exhibit 4 Targeting Climate Strategies for Different Oil and Gas Resources

Resource Type	Policy	Technology	Market
Light Oil	• Adopt certification standards. • Prohibit and penalize methane venting.	• Avoid routine flaring. • Perform flare maintenance. • Avoid using light oils to dilute extra-heavy oils for the sole purpose of transporting them to deep conversion refineries.	• Invest in or contract for ample gas takeaway capacity before production commences.
Wet and Dry Gas	• Enact methane leakage fee. • Prohibit methane venting.	• Replace leaky equipment. • Employ best operating practices. • Conduct routine leak detection and repair (LDAR) on a frequent basis.	• Create buyers and sellers' alliance for certified gas.
Heavy Oil	• Ban burning of residual products such as petcoke. • Prohibit use of naturally stored CO_2 for enhanced oil recovery.	• Employ renewable energy to generate heat, steam, and electricity. • Capture and sequester the carbon emitted when producing and refining heavy (high-carbon) assets. • Use green hydrogen in hydroconversion refinery.	• Price emissions in oil market trades. • Price emissions in heavy oil product market trades.
Watery Oil	• Monitor and report produced water volumes. • Tighten protocols for water disposal.	• Employ high-efficiency pumps that run on renewable energy.	• Discount value of assets that produce more water than oil.
Acid Gas	• Prohibit development of high-CO_2 gas.	• Continuously monitor for corrosion in legacy assets.	• Do not count CO_2 extracted and reinjected toward carbon credits.
Depleted Oil and Gas	• Establish protocols for decommissioning.	• Track energy return on investments. • Perform routine LDAR to ensure no leakage.	• Track asset ownership transfers.

Oil and Gas Reality Check

Oil and gas have been part of our daily lives for generations, but there are many widely held misconceptions about this sector. Civil society generally views oil and gas as simple, homogeneous resources that are in short supply and controlled by a handful of companies. This conventional wisdom is wrong: oil and gas are complex, heterogeneous resources that are abundant, are inputs to thousands of products, and are controlled by a large and diverse array of actors.[vii]

In order to align the oil and gas sector with 1.5°C, every party responsible for GHGs and other pollution must face prices that reflect the true costs to society of each part of the supply chain. This responsibility cannot fall solely on the shoulders of consumers because they alone do not command the market decisions. Supply decisions must be factored in. Oil and gas producers, refiners, and shippers are responsible for a large and growing share of emissions. Knowing how much the oil and gas industry emits will permit fairly apportioning climate costs throughout the supply chain.

Measurement enables management. With the help of models, satellites, and sensors, emissions estimates are constantly improving. Greater certainty in emissions estimates equips decision makers with better information to reinforce climate commitments. The OCI+ fills in missing data with engineering judgments and other assumptions. The relationships between data transparency and OCI+ modeling uncertainty are discussed in the appendices.

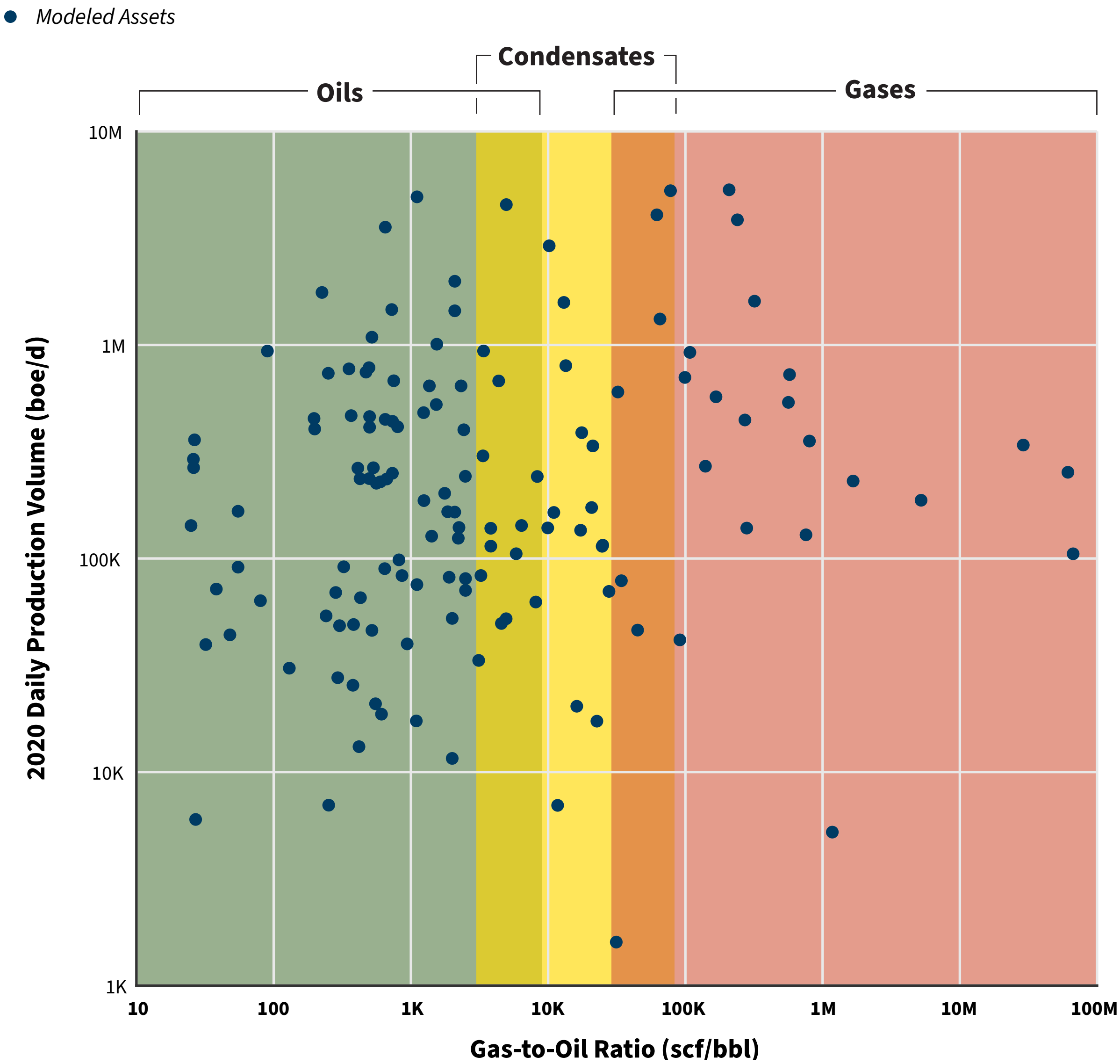
Oil and Gas Come out of the Ground Together

Oil and natural gas coexist underground and are typically produced together in varying volumes. While each individual oil and gas asset has a unique makeup, chemical composition can change over time as resources age. Oil can become gassy or solidify over time. Pooled resources can get trapped in fissures. Fracking and drilling breakthroughs are employed to unearth gassy, trapped mixtures while steam injection and mining are used to recover solidified oils. The process of separating oil from gas tends to occur aboveground during surface processing.

The marker chosen to distinguish oil resources from gas resources is the gas-to-oil ratio (GOR). Exhibit 5 (next page) plots oils, gases, and condensates (a light, wet mixture that spans oil and gas) modeled using the OCI+ based on their GORs, which can change over time.

vii For more information on the diverse array of actors that control oil and gas, see Chapter 5 in Deborah Gordon, *No Standard Oil* (New York: Oxford University Press, 2022).

Exhibit 5 Oil and Gas Are Not Always Easy to Distinguish



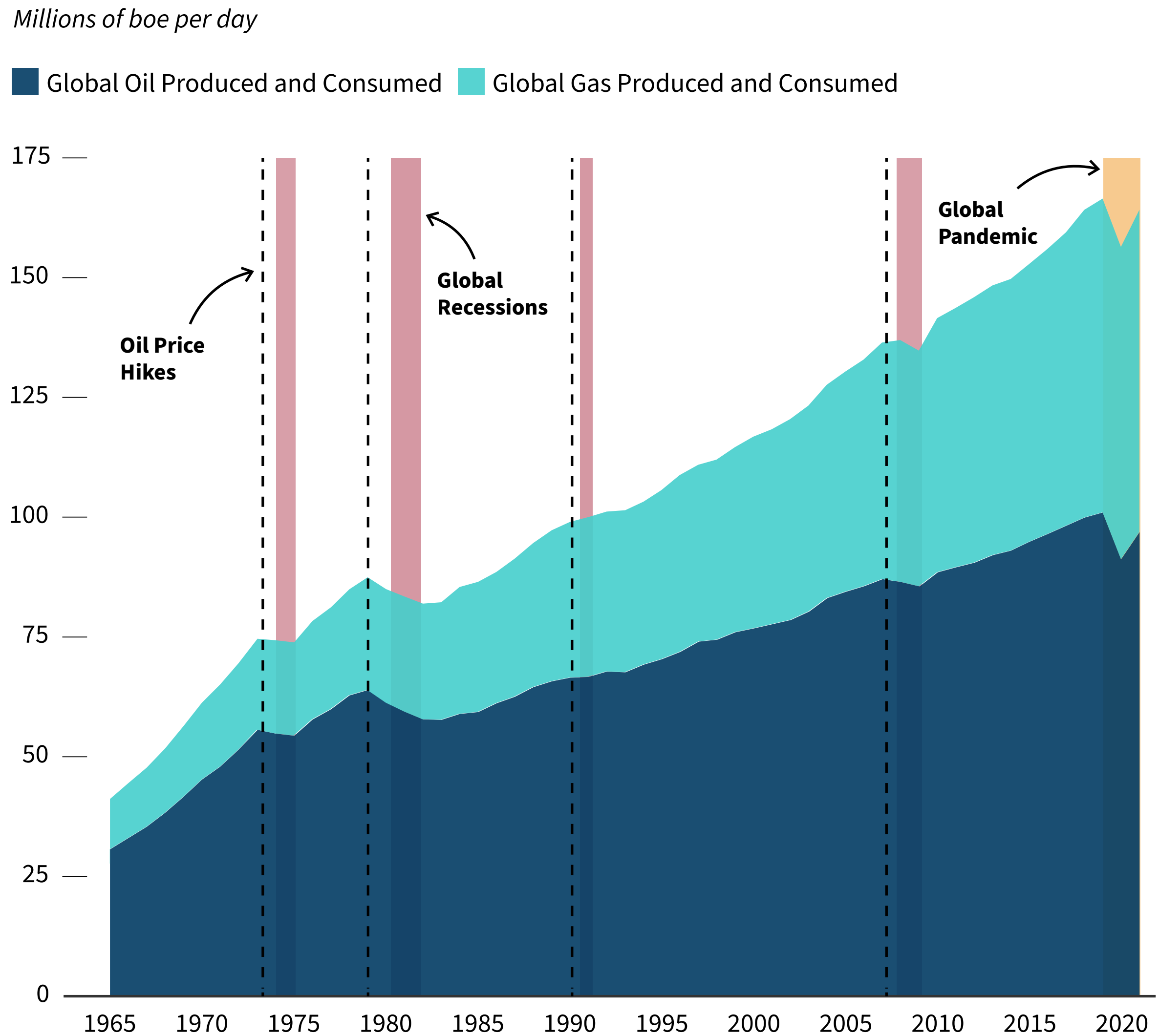
Note: There is no clear boundary between oils and gases. Condensates fall in the middle and are poorly defined. The gas-to-oil ratio (GOR) compares the volume of gas, measured in standard cubic feet (scf), with the barrels of oil (bbl) produced.

Oil and Gas Are Abundant

There is no geologic shortage of oil and gas. If current projections are accurate, there are many trillions of barrels of oil equivalent stored in untapped oil and gas reservoirs worldwide.[8] A fraction of these resources is technically recoverable today. More could be accessible in the future due to technological advances. At current consumption rates, hydrocarbons in place are projected to last some 500 more years. But, if the past is any indication, we will likely have discovered more hydrocarbons in place by then.

Worldwide oil and gas production and consumption has climbed steadily upward for decades.[viii] Exhibit 6 depicts the quadrupling of global consumption since 1965.

Exhibit 6 **Global Oil and Gas Production and Consumption Continue to Rise**



Source: Adapted from Deborah Gordon, *No Standard Oil*, Oxford University Press, 2022, Figure 1.2

Under business-as-usual conditions, the International Energy Agency (IEA) projects that, by 2023, oil and natural gas supplies will return to their pre-pandemic levels and average 101 million barrels per day (mbd) and 4,200 billion cubic meters (bcm) per year.[9] By 2030, IEA forecasts global oil demand could reach 104 mbd and 4,500 bcm, if currently stated policies—which are not climate aligned—are implemented.[10] This calls for a rapid shift away from fossil fuels. According to IEA, net-zero emissions require huge declines in the use of oil and gas. The clean energy transition can be facilitated by supply-side emissions reductions in the oil and gas sector now and into the future.[11]

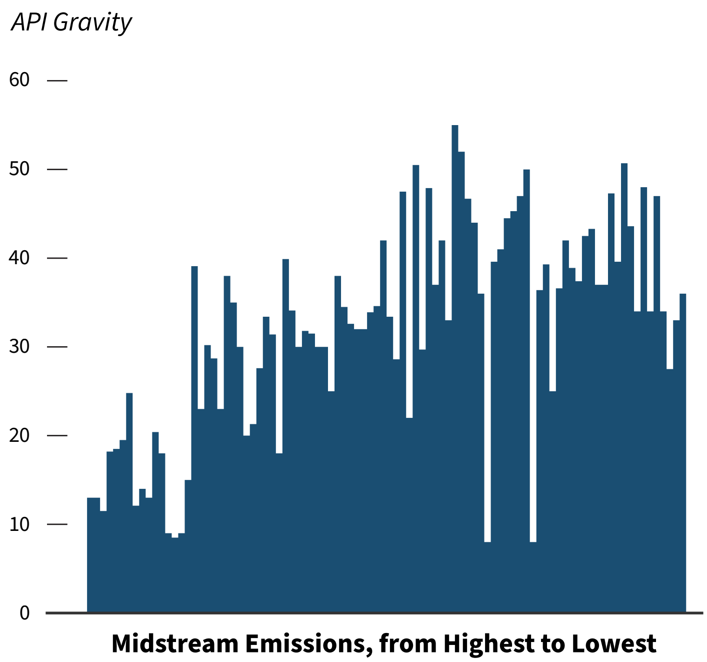
viii Projections of peak oil demand have surfaced, but not materialized yet. (For more information, see Amory Lovins, "The Troubled Oil Business," 2015, **https://medium.com/@amorylovins/the-troubled-oil-business-21ad430eff10**.)

Oil and Gas Are Heterogeneous

Oil and gas have the same basic DNA—hydrocarbons. Various impurities, like water, sulfur, carbon dioxide, metals, and other noxious chemicals, may also be present. Depending on their makeup, oil and gas can be classified in certain types, as shown in Exhibit 7.

Oil and condensate are generally priced based on their API gravity and sulfur content. Gravity, however, has no discernable relationship to a resource's emissions intensity (as shown in Exhibit 8). The same holds true of sulfur content, which likewise is not an indicator of greenhouse gas emissions. And the cost of extraction is not a robust indicator of GHG emissions. For example, a poorly operated, low-capital fracking unit can emit significantly more methane than a well-maintained, high-capital offshore drilling rig. Markets and policymakers are largely blind to oil and gas heterogeneity and the resulting wide-ranging emissions footprints of different resources. Greater transparency about basic resource conditions and operations is needed to make these differences visible to market participants.

Exhibit 8
Oil and Condensate Midstream Emissions Intensities Are Not a Simple Matter of API Gravity



Note: API gravity is a density measurement of liquid hydrocarbons. Condensates have high API gravities, usually over 50 degrees, while heavy oils usually have API gravities under 20 degrees.

Exhibit 7
Oil and Gas Can Be Classified in Different Ways

Crude Oil Types
- Ultralight oil
- Light oil
- Medium oil
- Heavy oil
- Extra-heavy oil
- Wet oil (watery)
- Condensate (liquid)

Natural Gas Types
- Condensate (gas)
- Wet gas
- Dry gas
- Acid gas
- Coal bed methane
- Liquefied gas (LNG)

Overall Types*
- Onshore/Offshore
- Deep/Ultra-deep
- Sweet/Sour
- Fracked
- Enhanced recovery (EOR)
- Depleted

*Overall Types apply to both oil and gas. Many other unconventional oil and gas classifications exist, such as methane hydrates and landfill gas.

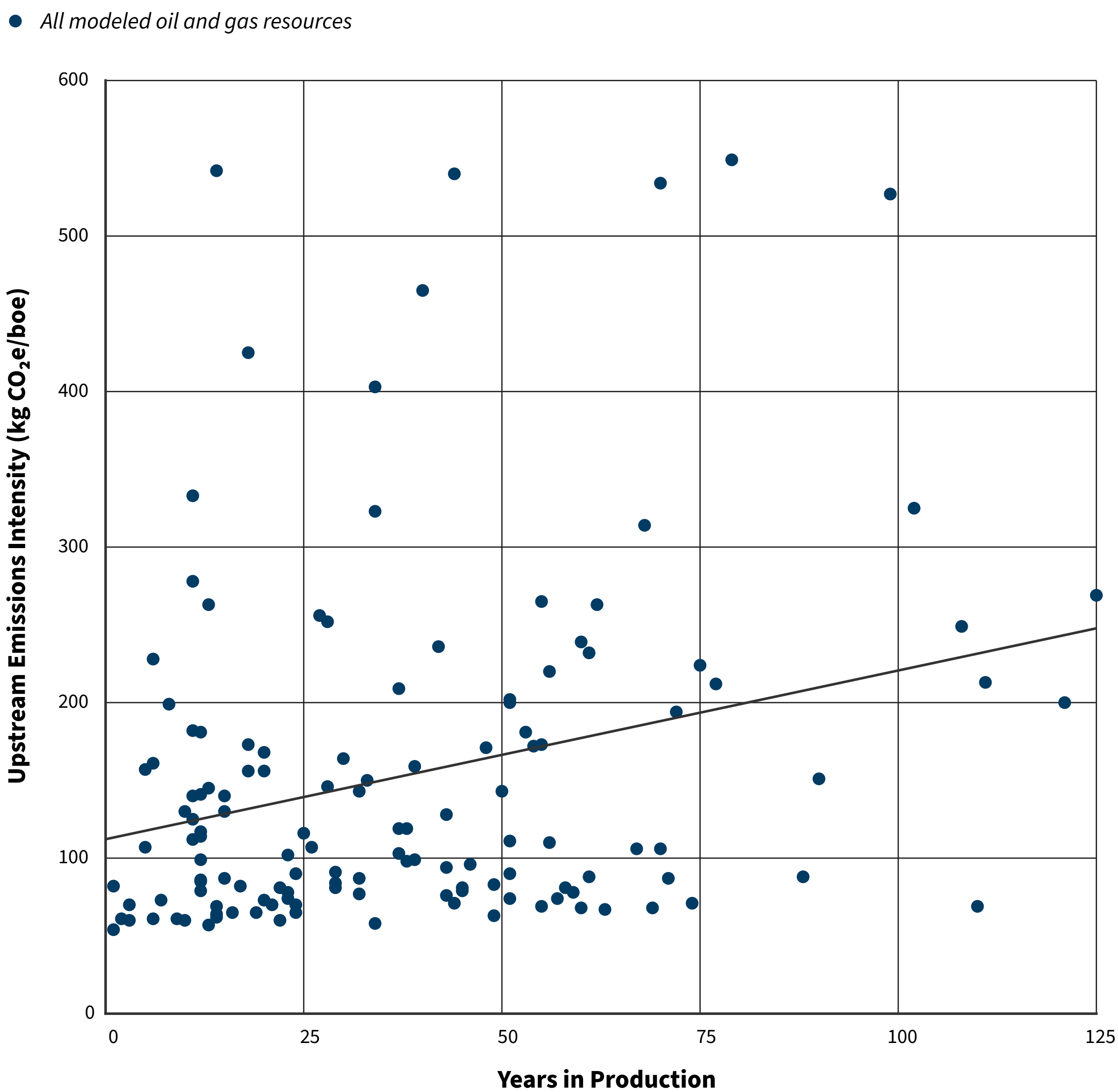
Source: Adapted from Gordon, *No Standard Oil*, Figure 2.1

Oil and Gas Emissions Increase as Resources Age

Oil and gas are inherently heterogeneous, and their composition can change markedly as they age. Over time, oils can become solid, watery, gassy, and contaminated. Gases can get wetter or acquire impurities. Both can get trapped in fissures.

The resources modeled show an upward trend between upstream emissions intensity and the asset's years in production in Exhibit 9. And the general finding that emissions intensity increases the longer oil and gas are produced from an asset is supported by decades-long time-series data. As oil and gas reservoirs are depleted and production volumes decline, new recovery methods are employed that typically require more energy and result in higher emissions. The same is true of refining less conventional resources that evolve as they age. Simulation studies show an expected doubling in average emissions over 25 years.[12] These trends call for policies governing the transfer of aging resources and the need to establish decommissioning incentives.

Exhibit 9 **Upstream Emissions Intensities Increase with Field Age**



Oil and Gas Make an Array of Petroleum Products

Contrary to conventional wisdom, oil is not produced and refined to make only a handful of fuels like gasoline and diesel. (Moreover, the public does not grasp how different formulations of diesel fuels are used in a multitude of mobile and stationary engines beyond trucks.) In fact, thousands of petroleum products are made from each equivalent barrel of oil and gas produced. A few select examples are detailed in Exhibit 10.

Exhibit 10 **Petroleum Products Are Used Everywhere in Daily Life**

RELEVANT INDUSTRY Common petroleum products

Consumer Fuels
- Gasoline
- Diesel
- Heating oil
- Propane
- Kerosene
- LPG
- Natural gas

Commercial Fuels
- Bunker fuel
- Jet fuel
- Petroleum coke
- Fuel oils
- Diesel distillates

Infrastructure
- Asphalt
- Tar

Industrial Inputs and Other Uses
- Petrochemicals
- Sulfur
- Paraffin wax
- Lubricants
- Tires
- Solvents
- Fertilizer

CONSUMER MARKET Petroleum in common products

Health and Beauty
- Cosmetics
- Shampoo
- Soap
- Bandages
- Petroleum jelly
- Vitamin capsules
- Medicines

Personal Items
- Clothes
- Eyeglasses and contact lenses
- Dentures
- Toys
- Crayons

Electronics
- Computers and smartphones
- Television sets

Household Goods
- Cleaning products
- Trash bags
- Candles
- Paint
- Roofing and insulation
- Carpet
- Upholstery

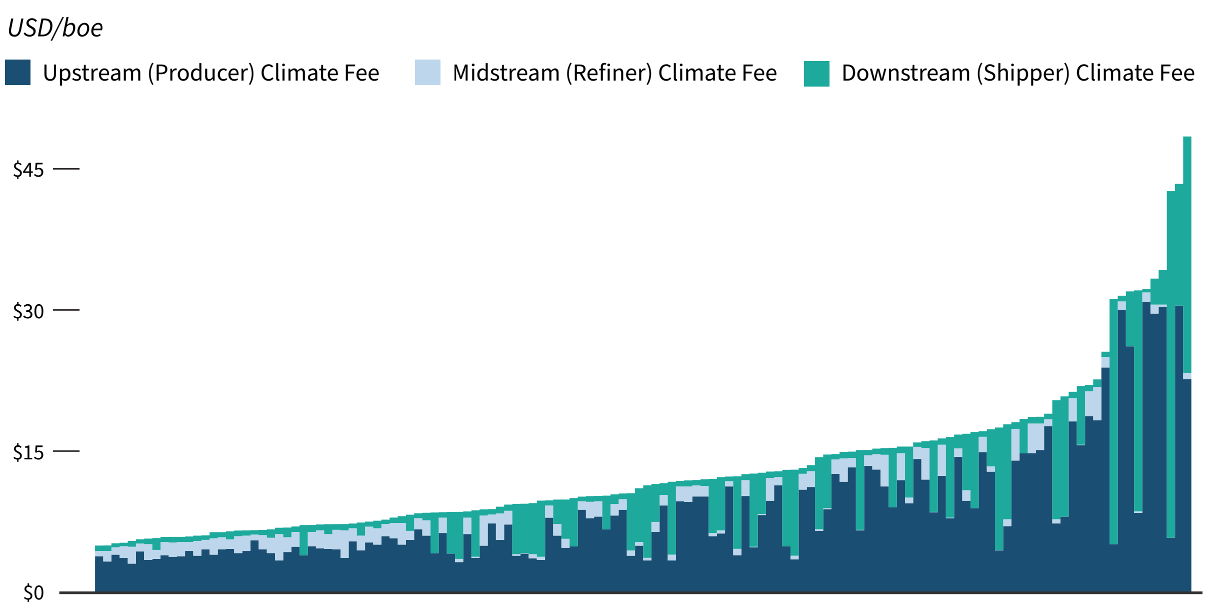
Source: Adapted from Gordon, *No Standard Oil*, Table 1.2

Although there has been considerable progress reducing emissions from a few select fuels, substitutes are lacking throughout the petroleum supply chain. Despite electrifying vehicles and substituting renewable energy to generate electricity, oil and NGLs in their many forms continue to flow through the global economy. When it comes to natural gas, however, prospects brighten for reducing use. Renewable energy sources can fuel power plants, homes, and appliances, replacing large volumes of gas. Studies find that combinations of renewable energy, efficiency, and battery storage are a cheaper option than more than 80% of US gas plants proposed to enter service by 2030.[13] And building electrification is also on the rise, supported by national and city building codes and appliance regulations.[14]

Oil and Gas Are Not Currently Priced According to Their Emissions

API gravity and sulfur relate to the ease with which heavy and light oils are refined into petroleum products sold worldwide. Pricing oil and gas resources in this way means that climate change is not currently factored into the marketplace. Based on the resources modeled and assuming a carbon fee of $56 per metric ton CO_2e (the currently published social cost of carbon accepted by the US federal government[ix]), these fees would add a production-weighted average of $7 per boe for oil and gas producers, under $1 per boe for refiners, and $4 per boe for shippers. Absolute climate fees for the highest-emitting resources, however, could be over $35 per equivalent barrel, as shown in Exhibit 11. To properly internalize these external costs, climate fees need to be imposed on oil and gas all the way up the value chain.

Exhibit 11 **Climate Fees for Oil and Gas Reflecting the US Government's Accepted Social Cost of Carbon**



Note: Calculated at $56 per metric ton CO_2e. Each vertical line on the graph represents one modeled oil or gas resource. The chart reflects highly variable oil and gas industry climate fees only on producers, refiners, and shippers, depending on the assets they operate. End-use (consumer) fees are not included for gasoline (motorists), jet fuel (airlines), diesel (truckers), etc.

Transparency is lacking about the different companies that are responsible for emissions through the oil and gas supply chain. Oil and gas emissions occur far apart — both in distance and time — from end-use combustion. Yet, the need to set an effective climate fee must reflect total life-cycle emissions, and all relevant polluters in the supply chain must pay their fair share of the fee. This will require digitization of climate attributes starting at the point of production, accumulating through processing and shipping, and adding up all the way to end use.[x]

ix The social cost of carbon is cited by the US government at $51/ton. This converts to $56/metric ton. This is a relatively low carbon fee compared with numerous credible estimates in the hundreds of dollars per metric ton. (See: **https://news.climate.columbia.edu/2021/04/01/social-cost-of-carbon/**.)

x Developing a digitally native protocol can rapidly activate climate markets and deliver "optimal" GHG pricing through supply chains that is not merely tied to the fixed carbon content of fuels. (See: Paolo Natali, "How Digitally Native GHG Tracking Can Drive Faster Climate Action," RMI, 2021, **https://rmi.org/how-digitally-native-ghg-tracking-can-drive-faster-climate-action/**.)

Exploring the OCI+ and Its Underlying Models

Measuring Emissions in the Entire Barrel

Emissions from the oil and gas supply chain — production, refining, and shipping — vary widely. Different climate risks arise depending on which oil and gas resources are extracted and how they are processed, transported, and utilized. The OCI+ model assesses life-cycle emissions from the wellhead through end use, tracking the supply chain from the "barrel forward," as sketched in Exhibit 12 (next page).[xi] This bottom-up engineering systems tool also uses top-down measurements (hybrid approach) to compare the emissions intensities from comparable volumes of different oil and gas resources.

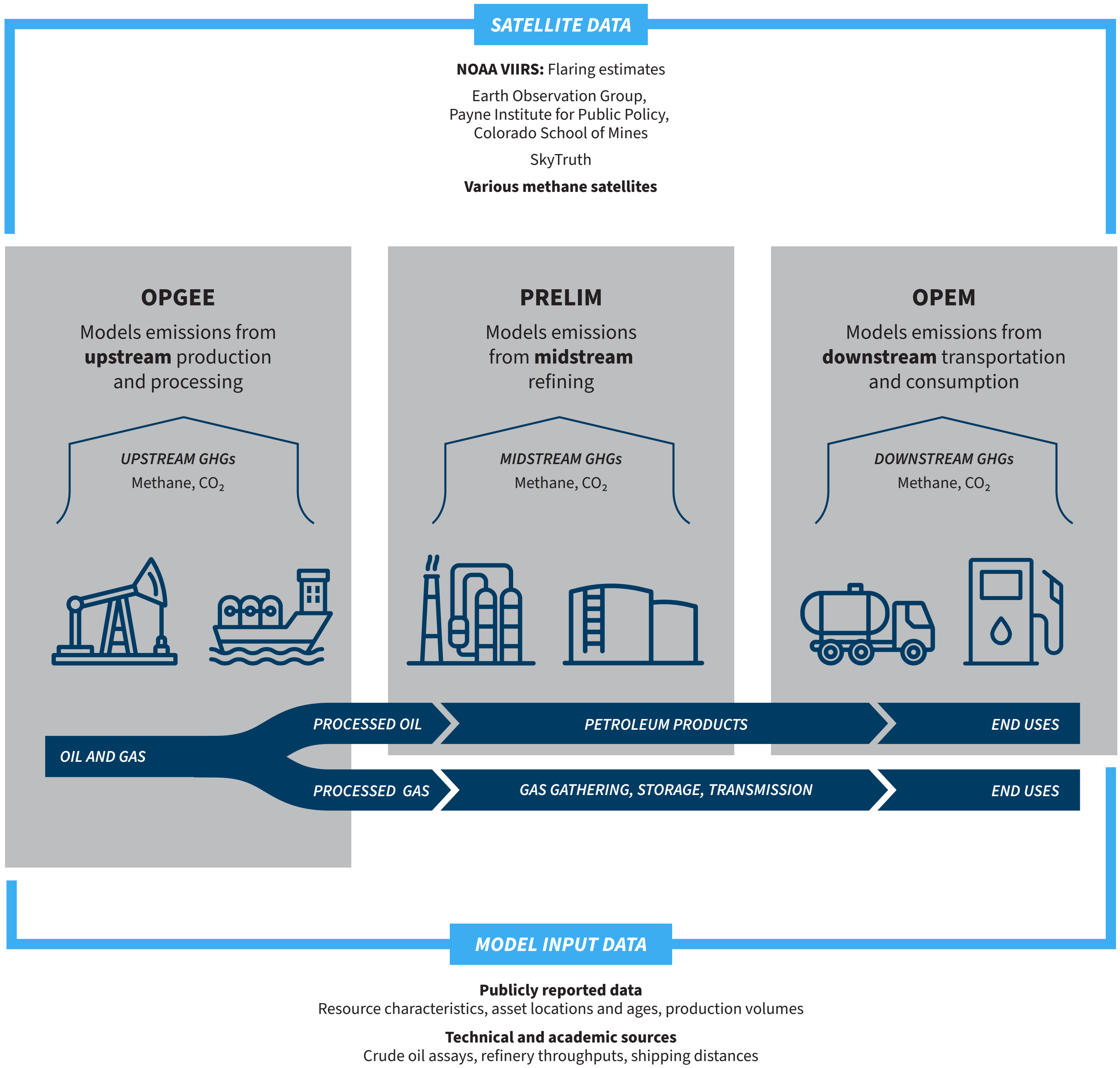
RMI updated the OCI+ to analyze emissions from an expanded volume of oil and gas resources.[xii] Following is a description of each of the OCI+'s underlying models.

Different climate risks arise depending on which oil and gas resources are extracted and how they are processed, transported, and utilized.

xi For background on the OCI's "barrel forward" approach, see: Jonathan Koomey et al., "Getting Smart About Oil in a Warming World," Carnegie Endowment for International Peace, 2016, **https://carnegieendowment.org/files/Gordon-Oil_in_a_warming_world1.pdf**.

xii **https://ociplus.rmi.org/**.

Exhibit 12 **OCI+ Model Schematic**



The OPGEE Model

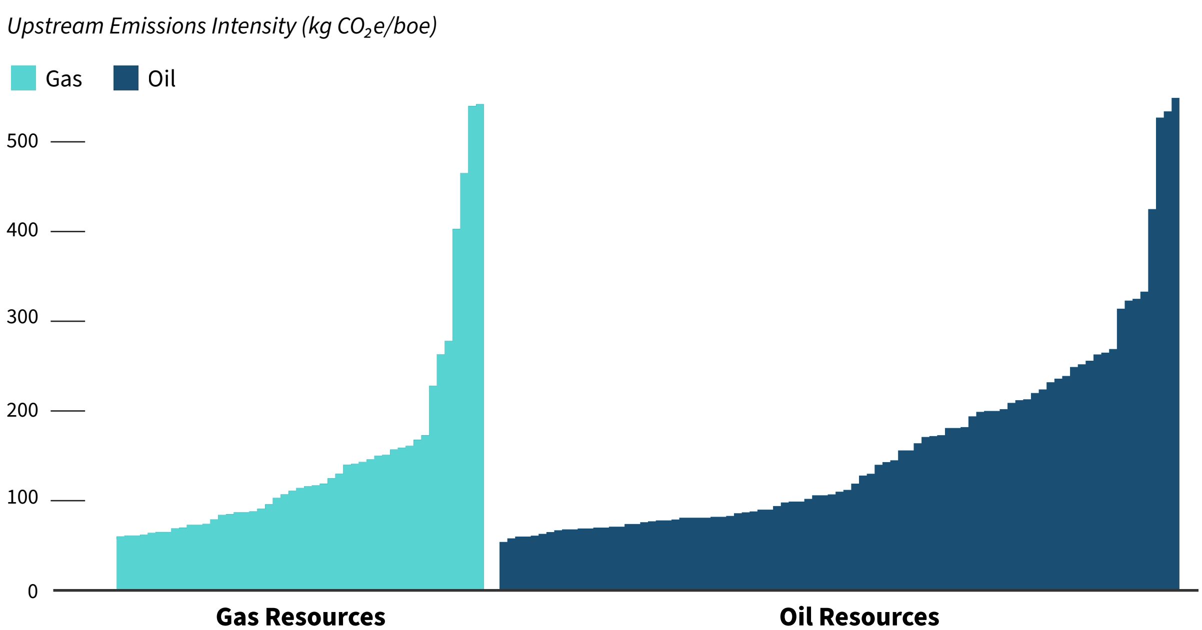
The Oil Production Greenhouse Gas Emissions Estimator (OPGEE) models upstream oil and gas production, processing, and transport to oil refineries, as well as gas handling prior to end use.[xiii] OPGEE is an open-source model that was developed by researchers at Stanford University. In the development of California's Low Carbon Fuel Standard from 2006 to 2010, the California Air Resources Board funded and collaborated on the continued development of OPGEE through three versions, beginning with OPGEE 1.0a in 2013. OPGEE 2.0c was peer reviewed.[15] The current version, OPGEE 3.0a, has been expanded to include gas production, processing, and transport. The next step is to convert OPGEE from its Excel platform into Python code to shorten run times and facilitate concurrent analysis of thousands of resources under different scenarios.

OPGEE utilizes field-level data inputs, satellite data, and equipment specifications to perform mass and energy balances on all oil produced from a field and moved to the refinery and the gas produced from a field and distributed to consumers. Input data is specified in OPGEE's "input" sheet and is collected and updated using industry reports, government reports, and academic articles. Smart defaults generated by metadata analysis are used where actual data inputs are unavailable. Greater data transparency that allows for additional OPGEE inputs reduces the uncertainty in emissions estimates.

OPGEE Results

In upstream production, emissions range markedly within and between oil and gas resources. Oil and gas have similar absolute emissions intensity ranges (as shown in Exhibit 13). Taken together, the 135 oil and gas resources modeled have a production-weighted average upstream emissions intensity of 137 kg CO_2e/boe.

Exhibit 13 **Upstream Emissions Intensities Vary Between and Among Oil and Gas Resources**

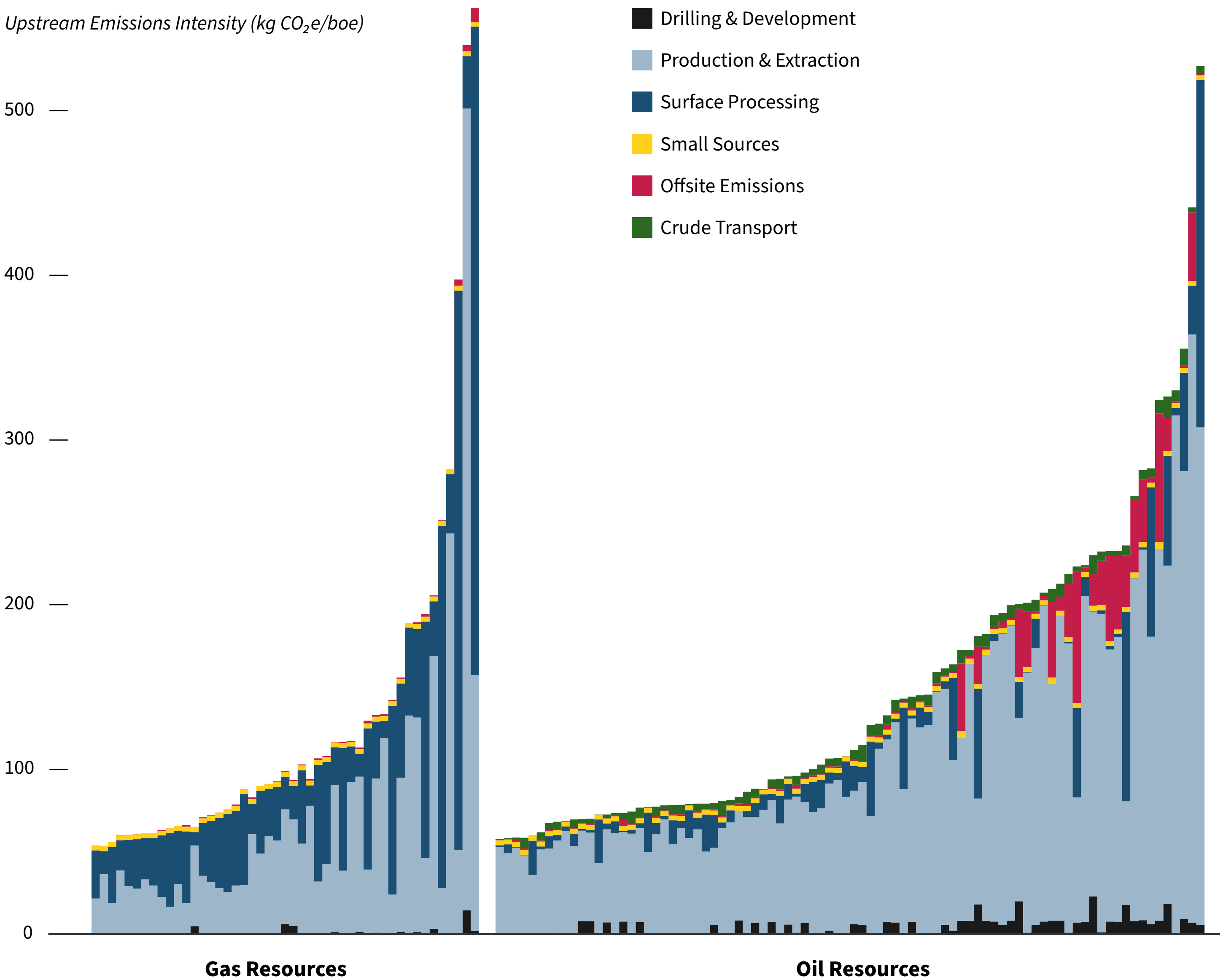


xiii For background on OPGEE, see: "OPGEE: The Oil Production Greenhouse gas Emissions Estimator," Stanford Earth, **https://eao.stanford.edu/opgee-oil-production-greenhouse-gas-emissions-estimator**.

The most emissions-intensive oil or gas emits more than 10 times as much as the least intensive resource in the production phase. However, producing and processing a barrel of oil is estimated to emit more than the equivalent throughput of gas. The oils modeled have a production-weighted emissions intensity average of 175 kg CO_2e/boe. The gases modeled have a production-weighted emissions intensity average of 95 kg CO_2e/boe.

Upstream oil and gas emissions drivers depend on many factors, including the characteristics of the resource, the energy required to extract and process it, and the amount of methane leakage that occurs in each upstream process. Exhibit 14 charts the major upstream stages that drive emissions from each of the oil and gas resources modeled. Crude production and extraction account for the largest share of emissions from some oil and gas resources. Surface processing is also a major emissions source for other resources. Different oil and gas resources have different upstream emissions footprints that can be better managed if operators, policymakers, financiers, and civil society know where to look. OPGEE helps decision makers peer into current and future production to identify the greatest opportunities for emissions reductions.

Exhibit 14 **Upstream Emissions Drivers Differ for All Modeled Resources**



The PRELIM Model

The Petroleum Refinery Life-Cycle Inventory Model (PRELIM), developed by researchers at the University of Calgary, is the first open-source refinery model that estimates energy and GHG emissions associated with various crudes processed in different refinery types using a variety of processing equipment.[xiv] PRELIM 1.0 was released in 2015 and has been peer reviewed.[16] PRELIM 1.6 is currently under development with expanded capabilities, including the emissions associated with processing petrochemicals. The PRELIM output provides two valuable pieces of climate intelligence. It estimates midstream emissions, and it computes an oil's petroleum product yield, which is then used in OPEM (described below) to estimate emissions from end uses.

As for inputs, PRELIM requires an oil assay (the chemical makeup of a crude oil that is analyzed in a laboratory at varying temperature cuts). PRELIM produces more robust emissions estimates if assays are in a standardized format. If the assay has too few temperature cuts or different temperature bands, an assay transformation can be made using an open-source tool. There is also a blending tool in PRELIM so users can blend their own assays or select multiple assays. There are hundreds of individual crude and oil blend assays in the PRELIM library. For gas fields with associated oil, there is often no directly corresponding assay. A proxy assay is then selected that closely fits the resources' characteristics.

Blending assays helps to avoid the difficulty of tracking actual crude oil movements to estimate midstream emissions. In the future, however, especially as refining operations undergo transformations in response to changing petroleum product markets and policy pressures to decarbonize, it will be necessary to publicly collect and use real-world data that pairs oils with specific refinery locations and configurations.

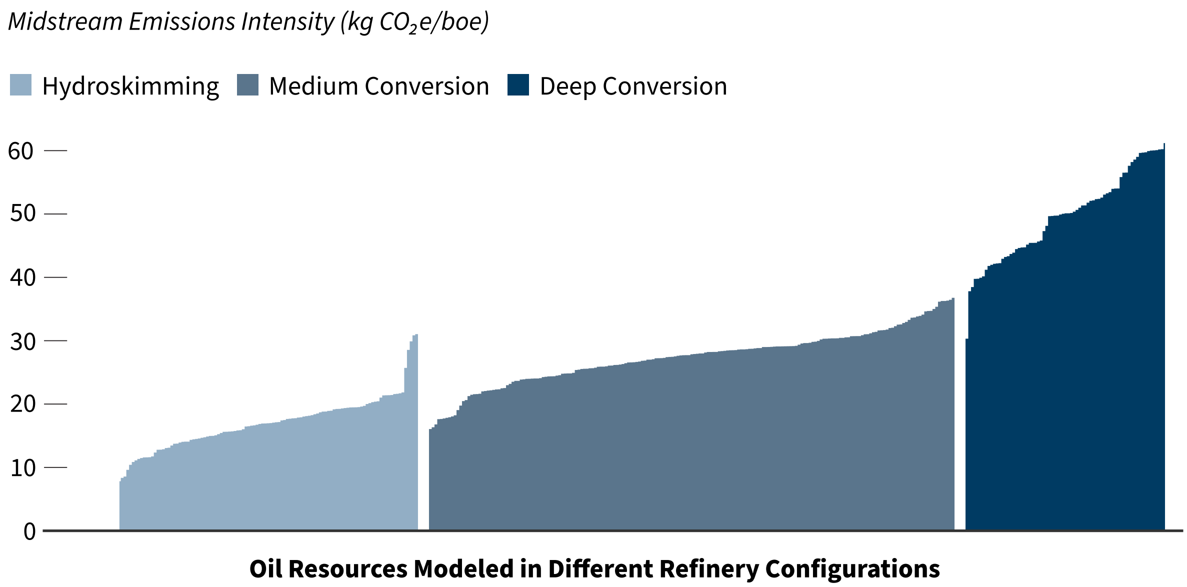
There are many different options when converting crude into products, and refinery configurations can be changed to alter product slates.

xiv For model see: **https://ucalgary.ca/energy-technology-assessment/open-source-models/prelim** and for background documentation see: **https://www.ucalgary.ca/sites/default/files/teams/477/PRELIM-v1.5-Documentation.pdf**.

PRELIM Results

Refinery emissions for all of the global oil assays collected and blended to date are plotted in Exhibit 15. In general terms, the lighter the oil, the simpler and less climate-intensive the refining process. Hydroskimming refineries distill and reform crudes to make a limited slate of petroleum products, with an estimated global average of 16 kg CO_2e/boe. Medium conversion refineries also remove sulfur and use additional techniques to crack (break apart) and reassemble heavier oils. Medium conversion refineries have an estimated global average midstream emissions intensity of 34 kg CO_2e/boe. The heaviest and most sour crudes require elevated temperatures and pressures to produce a valuable product slate. Deep conversion configurations use either a very energy-intensive coking process to extract lighter, valuable petroleum products out of the heaviest crude cuts or a residual hydrocracking process to reconfigure extra-heavy oils into marketable petroleum products. Deep conversion coking refineries have an estimated global average emissions intensity of 49 kg CO_2e/boe while deep conversion hydrocracking refineries average 55 kg CO_2e/boe. The overall global midstream refining intensity averages 40.5 kg CO_2e/boe. And deep conversion coking refineries predominate in the United States, China, India, Brazil, the United Kingdom, and Venezuela. Globally, over one-half of the world's oil is refined using deep conversion processes.

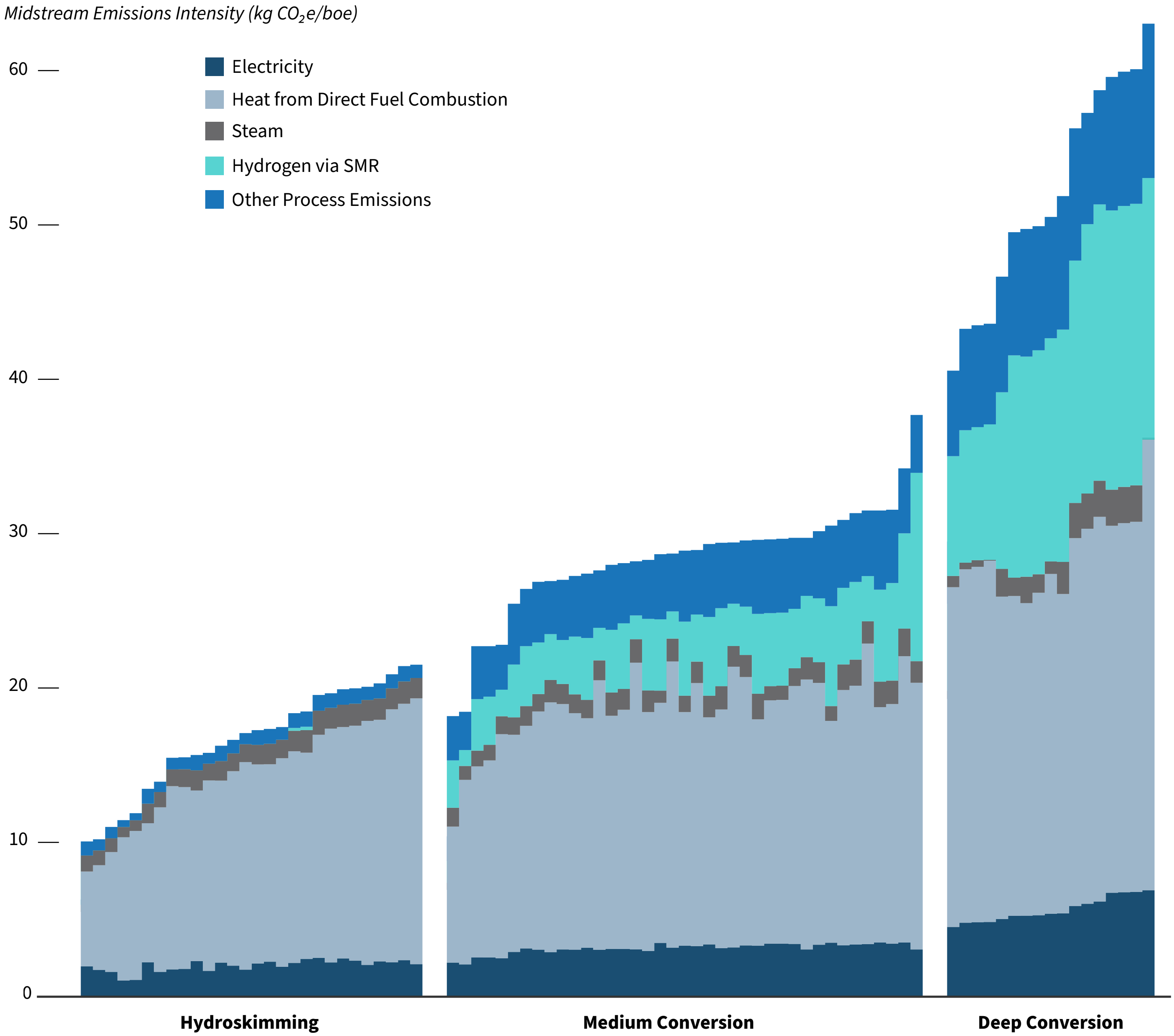
Exhibit 15 **Midstream Emissions Intensities Vary among Oils and Refinery Types**



Note: All oil resources in the PRELIM assay database are plotted; residual liquids from gas resources that are sent to refineries are omitted. The above refinery configuration assignment is based solely on API gravity and sulfur content. It does not reflect the actual refinery configuration, whereby most refineries process crude blends rather than individual oils.

Several factors lead to elevated emissions in midstream petroleum operations. Crude quality, the selected process units employed (the refinery configuration), and the energy efficiency of the process units all play important roles in determining the energy requirements and resultant emissions of an individual crude (or crude blend). Individual oils are rarely refined in isolation, and PRELIM's emissions estimates can be proportionally assigned to individual oils in a mixture of crudes fed into a refinery.

Exhibit 16 Midstream Emissions Drivers Differ for All Modeled Oil and Condensate Resources



Note: Plotted for 87 OCI+ modeled oils only.

Midstream oil and gas emissions drivers hinge on the energy sources used to generate heat, steam, electricity, and other utilities essential to refinery operation. The production of hydrogen is also a significant emissions driver, especially in refining heavier oils. Climate impacts from hydrogen depend on both the feedstock and energy sources. Today, refineries are the largest consumers of hydrogen, which is typically manufactured using steam methane reforming (SMR), an energy- and emissions-intensive process that reforms natural gas with steam and heat, venting the resulting CO_2 after it is separated from the produced hydrogen.[17] Different drivers play varying roles in refining climate footprints (as shown in Exhibit 16).

The OPEM Model

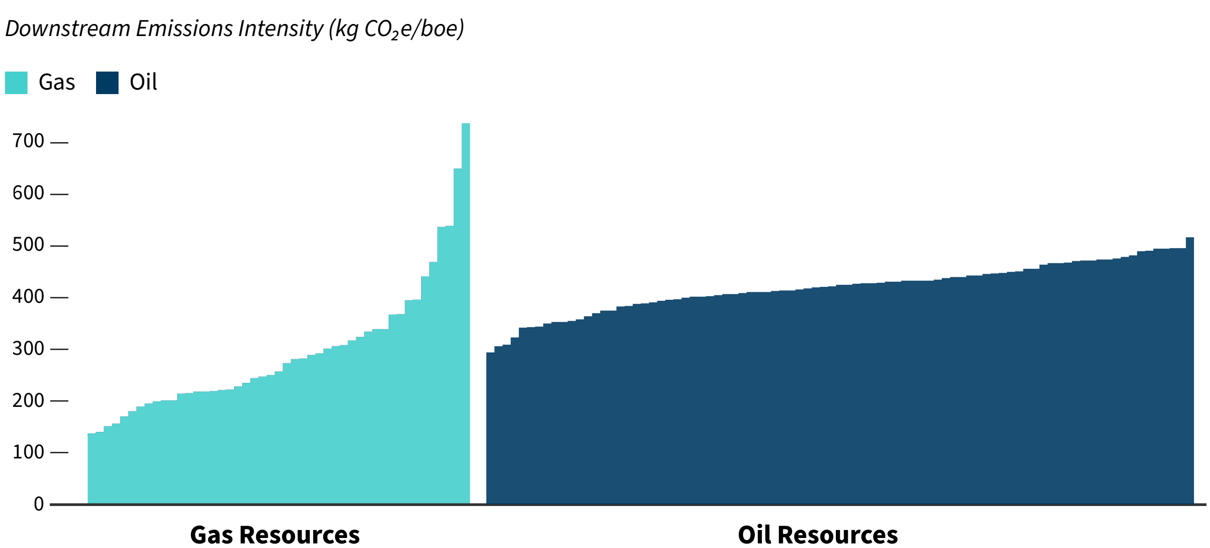
The Oil Products Emissions Model (OPEM) estimates downstream oil and gas product transport and end-use emissions. OPEM analyzes transport fuels—gasoline, diesel, and jet fuel—as well as fuel oil, petroleum coke, heavy residual fuels, natural gas liquids, liquefied petroleum gas, and petrochemical feedstocks.[xv] Natural gas boosting, gathering, and transmission emissions are modeled in OPGEE, but reported out as downstream emissions in the OCI+.

OPEM uses petroleum product emissions factors reported by the US EPA.[18] These emissions factors assume near-complete fuel combustion. However, depending on the quality of the engine in which a fuel is burned, EPA emissions factors may offer a best-case (lowest emissions) estimate for combustion emissions in countries with older equipment in use.

OPEM Results

Individual oil and gas resources yield different petroleum products, which in turn affects their downstream emissions (also termed "Scope 3" emissions). With a volume-weighted average of 341 kg CO_2e per boe, the highest-emitting resource modeled has a downstream emissions intensity that is six times greater than the lowest-emitting resource (as plotted in Exhibit 17). The oils modeled have nearly twice the volume-weighted average downstream emissions intensity (402 kg CO_2e per boe) compared with the average gas (273 kg CO_2e per boe).

Exhibit 17 **Downstream Emissions Intensities Vary by Resource**

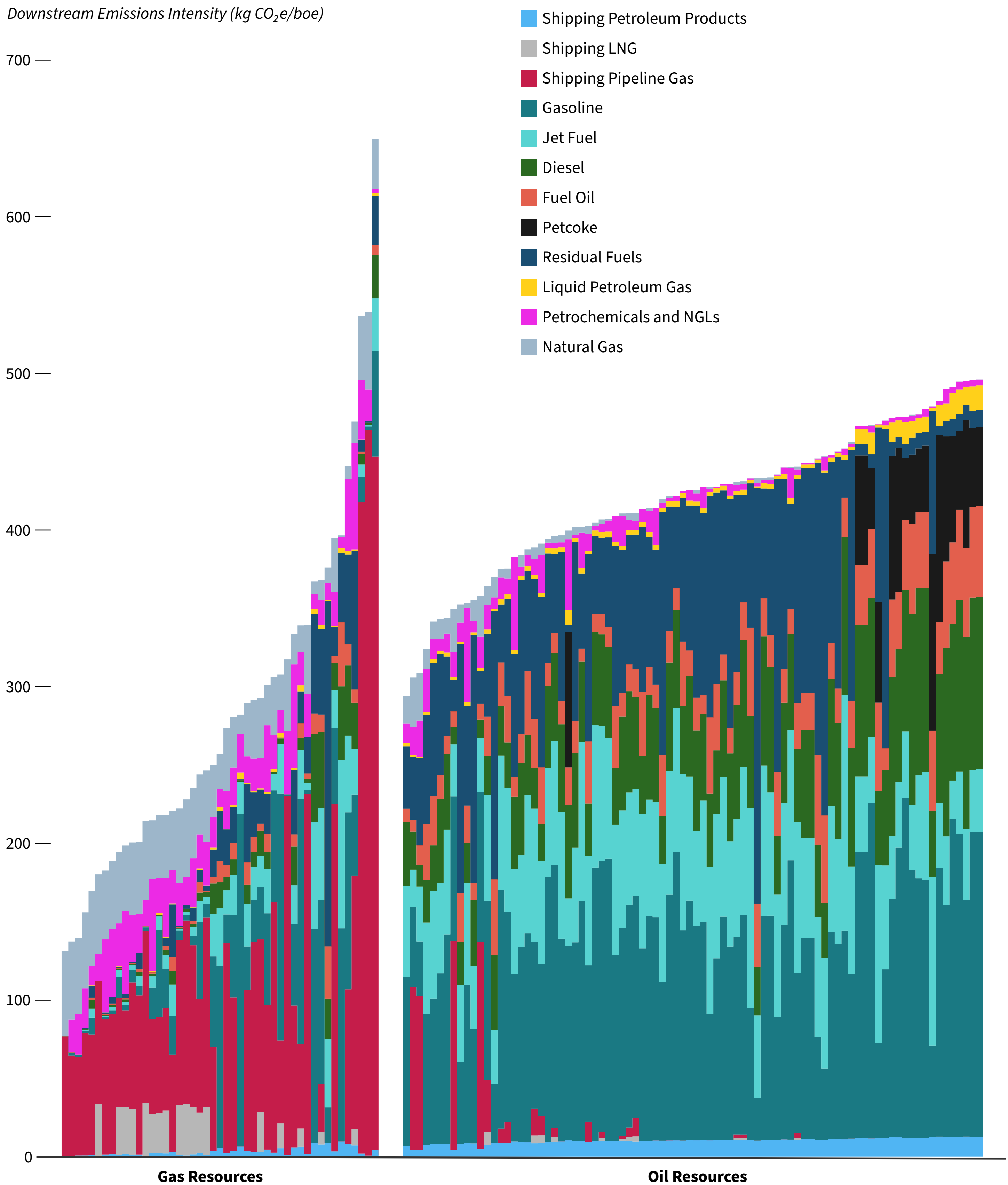


xv Asphalt production is not included in these results. It is made in a different refinery configuration and in limited volumes. Note that PRELIM can model asphalt production, but it does not significantly change refining emissions, nor does it increase end-use emissions since it is not combusted.

Depending on the resource, processing method employed, and external market factors, downstream emissions are concentrated on different petroleum product slates (as plotted for 135 oil and gas resources in Exhibit 18, next page). While natural gas combustion emissions dominate gas fields (left side in the exhibit), NGLs also make up a significant share of these downstream emissions. Downstream emissions from different oil resources are spread across multiple petroleum products, however. This plot underscores that there are many different options when converting crude into products, and refinery configurations can be changed to alter product slates. It is noteworthy that the transport of petroleum products (excluding natural gas) has a minimal emissions intensity per unit processed.

Oil and gas are readily converted into a wide array of petroleum products for a multitude of end uses.

Exhibit 18 **Downstream Emissions Drivers Differ for All Modeled Resources**



Strategies to Reduce Oil and Gas Emissions

Different oils and gases require tailored strategies to reduce their emissions. Some approaches are more effective than others, depending on the resource in question. Scenarios are run on sample oils and gases to compare the emissions reduction potential of upstream, midstream, and downstream strategies. The field names, locations, and resource types of those sample oils and gases modeled are listed in Exhibit 19 (next page). In some cases, strategies can be combined that result in mitigation multiplier effects. The results of the scenarios follow. Examples of emissions intensity reductions modeled are shown at the end of this section in Exhibit 20.[xvi]

Different oils and gases require tailored strategies to reduce their emissions. Some approaches are more effective than others, depending on the resource in question.

xvi See **https://ociplus.rmi.org/**.

Exhibit 19 **Locations and Properties of Scenario Test Oils and Gases**

Country	Resource	Offshore	Ultra & Light Oils	Medium Oil	Heavy Oil	Extra-Heavy Oil	Watery Oil	Acid Gas	Wet Gas	Dry Gas	Sour Oil/Gas	Deep Oil/Gas	Fracked	LNG
Australia	Greater Gorgon	■						■				■		■
Brazil	Frade	■			■						■			
Canada	Cold Lake					■					■			
	Suncor Synthetic A					■	■				■			
Ecuador	Sacha			■			■				■	■		
Indonesia	Duri				■		■							
	Minas			■										
	Tangguh	■					■	■			■	■		■
Iraq	Rumaila			■							■			
Libya	Waha		■											
Norway	Oseberg	■	■				■					■		
Russia	Yamburgskoye									■	■		■	
Turkmenistan	South Caspian		■											
United Kingdom	Brent	■							■		■			
United Arab Emirates	Shah							■			■			
United States	Anadarko								■				■	
	Bakken		■										■	
	Denver Julesberg								■				■	
	Eagle Ford — black oil		■										■	
	Kern River					■					■			
	Midway Sunset					■	■				■			
	South Belridge					■								
	Wilmington				■						■			

Upstream Mitigation Potential

There are several promising strategies for cutting emissions from upstream oil and gas production. These modeled scenarios are summarized below. Other upstream reduction strategies exist and can be explored using the OCI+ model.

- Preventing methane leakage from production equipment
- Curtailing flaring and maintaining flare efficiency
- Electrifying sources of combustion and powering them with renewable electricity
- Pumping water more efficiently
- Capturing the carbon emitted from processing acid gas

PREVENTING METHANE LEAKAGE

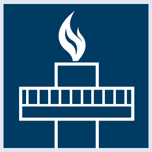
Methane is the main component in natural gas. It is a small, invisible, odorless molecule that readily leaks and is easily hidden from sight. Oil and gas systems are chock-full of methane gas, which moves under pressure, making it even more likely to escape from any minute openings at the production site and while in transit to end use.

Preventing methane leakage through equipment upgrades, improved maintenance, and ongoing monitoring can result in an estimated 35% reduction in upstream emissions intensity for the resources modeled. The economic potential to reduce methane may be even greater, especially for light oils and wet gases. According to IEA, nearly one-half of oil and gas methane leakage could be avoided with measures that have no net cost at current natural gas prices.[19] Heavier oils that do not typically contain significant volumes of gas may be secondary candidates for methane leak prevention. Still, climate impacts from methane leakage add up quickly given the massive volumes that move globally each year.

CURTAILING FLARING AND MAINTAINING FLARES

Methane is explosive, especially when it is released in high volume. As such, oil and gas operators install flares, "emergency" devices that gather and burn unwanted gas and convert it to CO_2. Historically, flare efficiency has been assumed by operators and regulators to be 98%.[20] In other words, the remaining 2% of gas (mostly methane) is assumed to escape unburned from global flaring. However, in the real world — impure gas compositions, highly variable flowrates, remote locations, harsh weather, and poor maintenance practices —

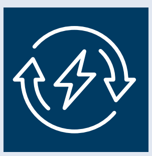
CURTAILING FLARING AND MAINTAINING FLARES (CONTINUED)



flare efficiency can drop as low as 10%–90%.[21] Ideally, a flare consistently operates at 99.99% efficiency, fully combusting all but less than 0.01% of the gas.

Several flaring efficiency ranges are tested in the OCI+ with wide-ranging potential to cut emissions depending on operations. The largest flaring emissions reductions from those resources modeled is just under 50%. And the actual reduction potential could be far greater. Policies are needed to prevent operators from turning off pilots that keep flares lit and simply venting pressurized gas out of the flare and into the atmosphere. Unlit and inefficient flares also impact local communities when they spew out various hazardous air pollutants. Some companies are focusing on better monitoring of their flares using sensors.[22] And new tools can be developed to track these high-emissions practices uses remote sensing from satellites and aerial campaigns.

EMPLOYING RENEWABLE ELECTRICITY IN PRODUCTION



Producing oil and gas requires a lot of energy. Today's systems use petroleum products to extract, process, and ship oil and gas. However, if the bulk of the energy is supplied by renewable electricity rather than by fossil fuels like natural gas, diesel, and petcoke, upstream emissions can be significantly reduced.[23] Depending on overall energy needs for production operations, electrifying heavy oil field operations could massively cut upstream emissions and reduce gas field production emissions by a smaller but meaningful amount. Moreover, installing solar, wind, and other renewable electricity sources in oil and gas operations would have ancillary benefits, such as cross-training the industry's workforce to install and maintain such equipment. Such technological reassignments also would infuse large sums of capital from the oil industry into renewables within their own operations, facilitating the transformation of 20th-century petroleum companies into 21st-century energy companies.

INSTALLING SOLAR STEAM

As oil and gas reservoirs decline, greater effort is required to extract remaining resources. Enhanced oil recovery (EOR) techniques are employed after earlier options—using pumps and pressure (primary recovery) and injecting gas and water (secondary recovery)—are no longer effective. Today, 400 active EOR projects around the world produce some 2 million barrels of oil per day.[24] Thermal recovery—injecting steam to make heavy oils flow—is one of the major commercialized EOR techniques.[25] Steam injection requires large energy inputs, heating large volumes of water with natural gas. Substituting concentrated solar steam can significantly lower climate intensities. Switching to 75% solar steam could reduce emissions by upward of 50%.[26]

PUMPING WATER MORE EFFICIENTLY WITH LESS ENERGY

As oil and gas fields are depleted over time, some reservoirs fill up with water. Moreover, recovery methods like fracking inject water to free trapped oil and gas, compounding potential water waste and flooding problems. Handling these resources moves large volumes of water around production sites. Water is dense and takes a lot of energy to pump. Installing more efficient pumps and using renewable electricity to run them can significantly reduce emissions, especially in the most waterlogged and fracked fields. The OCI+ modeled the energy to move less water as a proxy for greater pumping efficiency. The most water-intensive oils could reduce their upstream emissions by as much as one-third.

CAPTURING CARBON FROM ACID GAS FIELDS

Some gas resources are especially high in CO_2. This climate pollutant is also a corrosive contaminant that must be removed during surface processing before gas is shipped in a pipeline. Once removed, however, the CO_2 is then vented into the atmosphere. Capturing and sequestering CO_2 can significantly reduce climate impacts from acid gas resources. Governments are starting to require carbon capture and sequestration (CCS) for acid gas production. Australia, for example, required Chevron to install CCS on its Gorgon field that contains 15% CO_2. CCS requires careful oversight, however. In the case of Gorgon, the equipment has failed to operate properly since the field started up in 2017. Rather than capturing 80% of its CO_2, as required under permit conditions, Gorgon has emitted millions of tons of CO_2 into the atmosphere.[27] Installing and safely operating CCS, when successful, can reduce upstream emissions by 50% or more.

Midstream Mitigation Potential

Crude oil refining and gas processing operations have not changed much in the past century and are long overdue for a revamp.[xvii] There are many novel ways to cut these midstream emissions.[28] Three promising methods are optimizing refinery configurations, employing "green" hydrogen, and using renewable electricity (as plotted in Exhibit 20, page 39). Given large heat demands in refining as well as gas and chemicals processing, integrating renewables more fully into operations also has significant climate benefits. Emissions savings can add up quickly given that, every day, the industry refines and processes over 150 million boe of oil and gas.

- Optimizing refinery configuration
- Generating renewable hydrogen to replace steam methane reforming (SMR)
- Using renewable electricity in refining

OPTIMIZING REFINERY CONFIGURATION

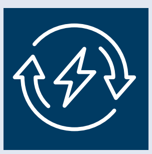
Refining employs a series of processes, some of which date back a century. Updating and reoptimizing these old and dirty processes can significantly cut emissions. As petroleum product demands continue to shift with greater vehicle electrification and climate policy pressure, refineries will need to be reconfigured.[29] In the short term, project economics will dominate refinery decision-making because companies need to generate sufficient margins to stay in business. But over time, new bespoke refinery reconfigurations and adjustments to integrated refineries will allow for greater emissions optimization. Today, however, carefully pairing crudes to the optimal refinery can readily cut emissions. On average, based on sensitivity analysis, running a light oil through a medium-conversion refinery is estimated to nearly double the midstream climate footprint, while processing a medium oil in a deep-conversion refinery can increase the emissions intensity by an estimated 35%. Oil and gas are traded and arbitraged on economic and geopolitical factors. Adding climate impacts to these criteria will be critical to cutting midstream emissions.

xvii Note that shipping is considered a "midstream" operation. The OCI+ places these operations in "downstream" as part of the distribution of petroleum products from each boe of oil and gas modeled.

GENERATING RENEWABLE HYDROGEN TO REPLACE STEAM METHANE REFORMING (SMR)

Today, “gray” hydrogen is made from an outdated, highly climate-intensive process (SMR) that dates back many decades. SMR has been propped up by abundant supplies of natural gas. Replacing natural gas plus SMR with “green” hydrogen made from splitting water with renewable electricity could significantly reduce refining emissions. Given that refineries are currently the largest hydrogen consumer, green hydrogen production carries significant GHG reduction potential. Green hydrogen in refining also could facilitate global expansion of these carbon-free supplies in other sectors, bridging to a low-carbon hydrogen economy.[30] Based on scenario model runs, green hydrogen could reduce estimated midstream emissions intensity by about 30%. And with millions of barrels moving through refineries every day, reduced emissions intensity could rack up emissions savings quickly.

USING RENEWABLE ELECTRICITY IN REFINING



For a generation, the oil and gas industry has talked about renewable energy without making much progress. Nevertheless, the industry could leverage renewable energy in both production (discussed above) and refining. Doing so could cut estimated midstream emissions intensity by 10% or more. But system-wide benefits may be far greater. Since most refinery electricity is supplied off-site, this measure could increase industrial demand for renewables and help transition utilities off gas to renewables. This effort should be part of a larger move to align the oil and gas industry with current climate targets.

Downstream Mitigation Potential

The surest way to cut downstream emissions is for consumers to cut their consumption, but there are also targeted actions that the oil and gas industry could take to cut downstream emissions. Exhibit 20 (page 39) plots a few of these opportunities:

- Sequestering petcoke or marketing its noncombustive uses
- Favoring local use of natural gas
- Shipping all petroleum products over shorter distances

ELIMINATING PETCOKE COMBUSTION

Petcoke is the excess carbon wrung from the world's heaviest oils once they are run through deep conversion coking refineries. While it is too polluting to be burned in the world's most affluent countries, petcoke is often exported to Global South nations (with less-stringent environmental regulations) and blended with coal to generate dirty power.[31] Combusting petcoke is especially hazardous because it emits more CO_2 than coal, along with heavy metals and black carbon (particulate matter) that harm human health. Banning the sale of petcoke leads to permanently sequestering or converting this hazardous petroleum by-product so it is not burned.[xviii] Preventing petcoke from being burned could reduce downstream emissions by as much as an estimated 24%. This would lower the total life-cycle emissions impact of the heaviest oils to be comparable to that of conventional medium oils.

USING GAS LOCALLY BEFORE SHIPPING IT GLOBALLY

Gas production is on the rise. But there is a mismatch between where gas is being tapped — in North and South America, Australia, and Africa — and where it is in high demand: in Asia. This mismatch is spurring wider distribution beyond regional consumption and into global markets. To ship over water, natural gas is first liquefied into LNG to save space and then regasified when it reaches its destination. These operations require significant energy and increase the risk of methane leakage along vastly lengthened supply chains. Moreover, LNG does not

xviii For examples, see: https://syncrude.ca/2021/05/28/warrens-innovation-will-help-reclaim-tailings-ponds-faster/; https://www.reuters.com/article/us-global-oil-canada-environment-focus-idCAKBN26Z2NL; https://www.suncor.com/en-ca/sustainability/environment/tailings-management.

USING GAS LOCALLY BEFORE SHIPPING IT GLOBALLY (CONTINUED)

replace gas pipelines, which are still needed to move gas from production sites to LNG terminals and from regasification sites to demand centers. LNG increases the climate footprint of total shipping emissions by over 30%. Emissions add up quickly. In 2020, 488 billion cubic meters (52% of the total international gas trade) was liquefied in the form of LNG and moved by ocean tankers.[xix, 32]

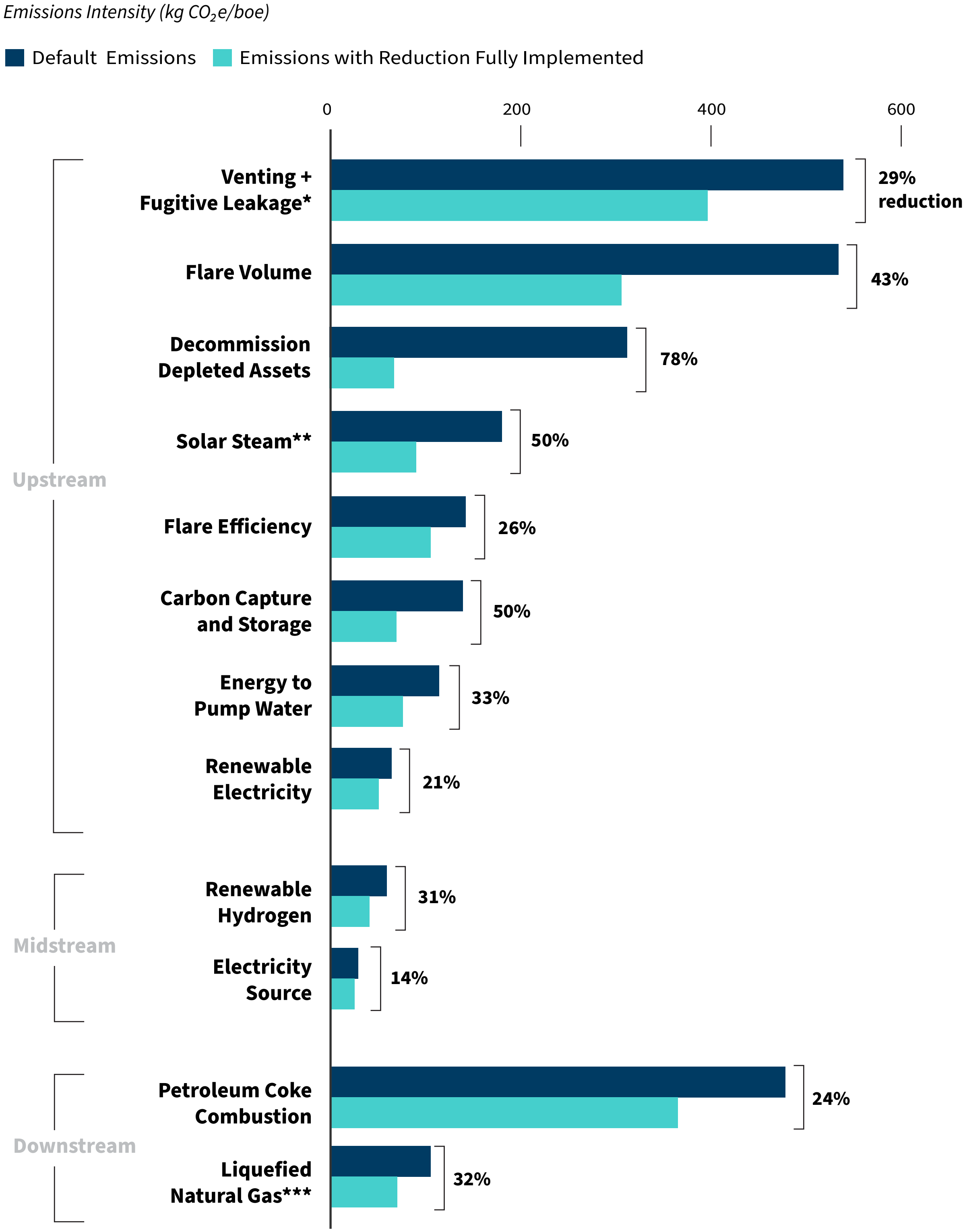
MINIMIZING LONG-DISTANCE TRANSPORT

Crude oil, natural gas, and their resulting petroleum products are routinely transported thousands of miles, crisscrossing the globe as they move through the complex supply chain. Better shipping optimization could reduce emissions, and there are new market actors that could help reduce distance by pairing buyers and sellers more efficiently.[xx] While the emissions intensity associated with these downstream activities is only a small share of life-cycle emissions, it is significant in the aggregate given the large volumes traded. On average, oil transport emits 25 kg CO_2e/boe, but gas is estimated to be significantly more climate intensive (191 kg CO_2e/boe) to transport than oil due to methane leakage in transit. Considering that an estimated 88 million boe of oil, 60 million boe of gas, and another 88 million boe of petroleum products are in transit every day, shipping has a massive climate footprint. But the emissions intensity of moving oil and gas, like the other emissions in this sector, varies widely. Transport emissions from the highest-emitting gas are 12 times greater than the lowest-emitting gas. Oil transport emissions vary by a factor of three. If globalization increases transport distances, especially for gas, emissions could increase markedly.

xix In 2020, 452 billion cubic meters (bcm) of pipeline gas was traded internationally. An additional 304 bcm was pipelined intra-regionally. (For more information see: **https://www.bp.com/en/global/corporate/energy-economics/statistical-review-of-world-energy.html**.)

xx For example, portfolio players like TotalEnergies and Shell have a growing ability to meet demand with more localized sources due to their portfolio depth and less restrictive contract structures, while buyers like JERA are building bigger portfolios they can optimize as well. (Historically, contracts were restricted to point-to-points with destination clauses, etc.) Arguably there is greater potential for LNG portfolio optimization than crude because LNG is a homogeneous product that delivers methane, while crude quality is varied, and refineries are configured to take specific types of crude.

Exhibit 20 Scenarios for Upstream, Midstream, and Downstream Emissions Intensity Reductions



*Assumes upstream and shipping methane reductions.
**Solar steam assumes 100-year GWP. Percentages are upper estimates based on scenario runs for select resources and percentages are not additive.
***LNG assumes only shipping emissions. All other reductions are share of total upstream, midstream, or downstream emissions (as noted).

Integrating Climate Intelligence with the OCI+

The intelligence gained from the OCI+ is part of a virtuous cycle to reduce oil and gas emissions. Modeling enables the integration of satellite measurements with reported emissions data. Models also help orient satellite observations by pinpointing high-emissions-intensity resources. And models are used to update and validate emissions inventories. In return, satellites provide input data to models and facilitate their expansion by capturing additional emissions that occur beyond routine operations.

Robust emissions visibility that generates climate intelligence can spur policy development, technology improvements, and market activation. Each of these is essential to help the oil and gas sector meet its climate targets. Without efforts like those discussed below, there is little chance of keeping the Earth's temperature from rising to dangerous levels.

Building Open-Source Emissions Platforms

Increasing climate intelligence involves making emissions visible. The OCI+ is a constructive part of this process and is being employed to advance others' efforts to publicly reconcile emissions inventories and remotely quantify open-source GHG emissions. Climate TRACE is a powerful example.

Climate TRACE tracks human-caused GHG emissions and their sources to address problems caused by self-reported emissions that are often erroneous or out of date. Together, the groups involved in Climate TRACE cover 10 sectors and 38 industries. RMI provides oil and gas sector emissions estimates to Climate TRACE using the OCI+ model. In 2021, Climate TRACE released its first-version data platform, quantifying emissions in countries worldwide using advanced modeling, artificial intelligence, machine learning, and satellite data processing. Exhibit 21 (next page) illustrates initial results for the oil and gas sector. In 2022, Climate TRACE will release asset-level data with greater temporal granularity in the oil and gas sector and select other sectors.

Robust emissions visibility that generates climate intelligence can spur policy development, technology improvements, and market activation.

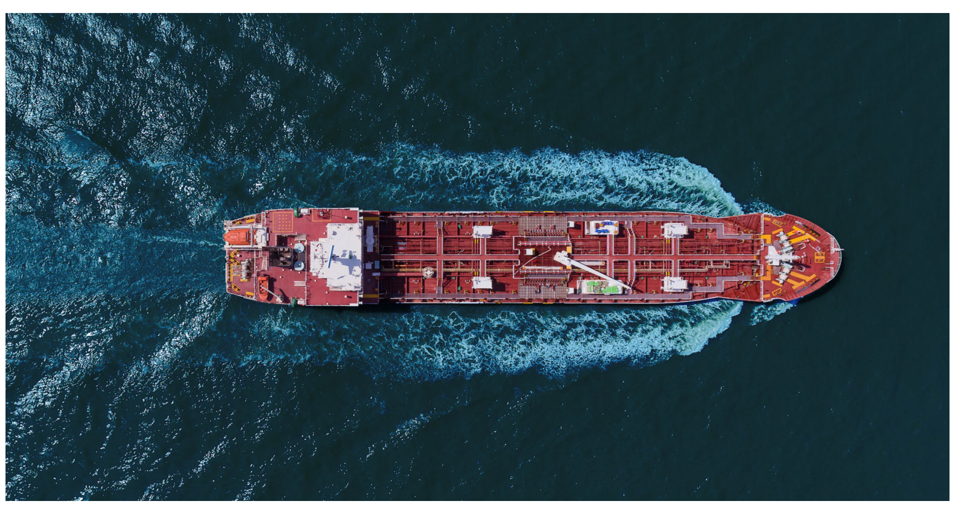
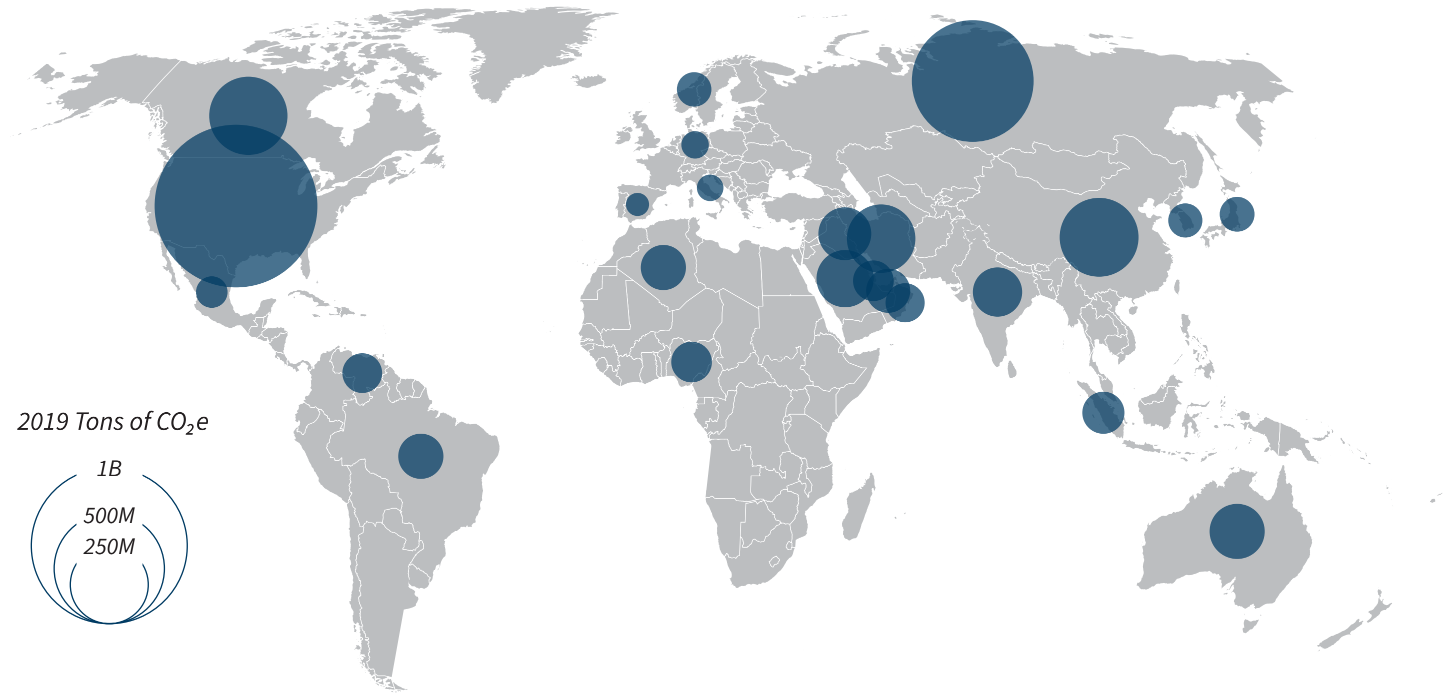


Exhibit 21 **Map of Climate TRACE Country Results for Top Oil and Gas Producers and Refiners**



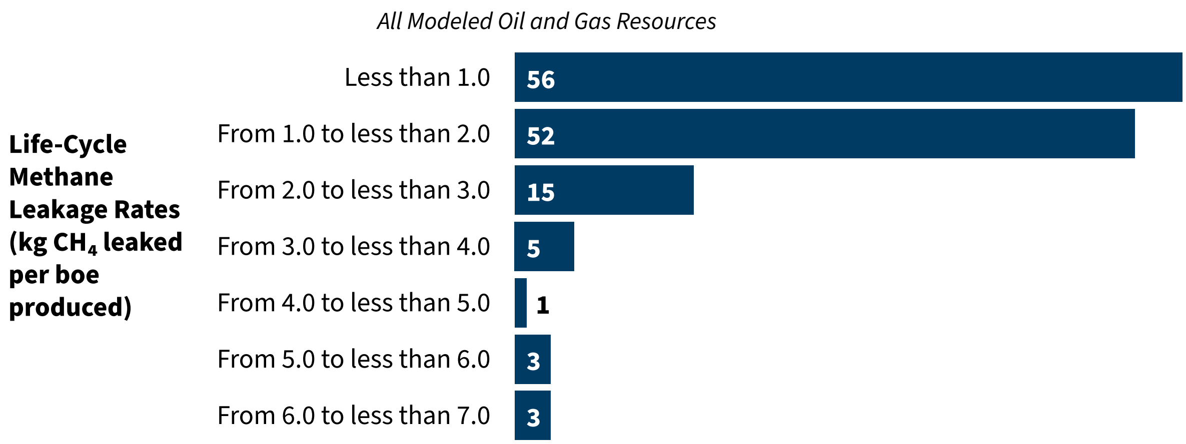
Sources: **https://www.climatetrace.org/**; Deborah Gordon, "Getting a Clearer Picture of Emissions from Major Oil and Gas Countries," Climate TRACE: The Source, September 16, 2021, **https://medium.com/climate-trace-the-source/getting-a-clearer-picture-of-emissions-from-major-oil-and-gas-countries-54f9a4710233**.

Differentiating Emissions Using Open-Source Certification Standards

Self-reported, unproven claims of "low-emissions" and "carbon-neutral" oil and gas must be independently verified using open-source certification. Instead, it is routine practice for companies to state their own emissions with little to no oversight. This is where MiQ comes in. MiQ.org is a new nonprofit organization that developed an open-source standard to certify natural gas based on life-cycle methane emissions — from production through pipeline or LNG delivery. Gases are graded according to their methane intensity, company operations, and monitoring capacity. The goal is to rapidly reduce methane emissions in the oil and gas sector by improving the emissions performance of global natural gas.

The OCI+ can be used to model natural gas methane intensity. It can also be used by MiQ.org to improve oil and gas methane management, advance emissions tracking, project future emissions, and support climate market activation. Oil and gas methane emissions intensities vary widely. Exhibit 22 (next page) plots a sample histogram distribution of life-cycle methane emissions leakage rates as currently modeled by OCI+. The majority of resources modeled range by a factor of 10, from 0.3 to 3.0 kg methane leaked per boe produced. And some systems leak over 6 kg methane per boe gas produced.

Exhibit 22 **Estimated Life-Cycle Methane Leakage Rate Distribution**



Note: Includes 135 oil and gas resources modeled.

The MiQ registry is relevant for all operators in the gas supply chain — producers, midstream operators, shippers, traders, and buyers. In 2021, MiQ initiated certification for about 10% of US gas production.[xxi] In 2022, MiQ aims to certify 5% of global gas, with 100% certified gas by the end of the decade. Expanding certification to LNG will rapidly deploy MiQ globally with producers in the North Sea, Middle East, Australia, and Africa. A new buyers' alliance could connect gas purchasers in the EU and Southeast Asia with MiQ-certified sellers.

Measuring and Attributing Emissions in Near Real Time

The OCI+ estimates emissions under certain conditions, including normal operations and certain emergencies (like well blowouts, discussed below). Actual emissions, however, can include additional intermittent or persistent problems that can be seen by satellites and other remote sensors. Building this intelligence into the OCI+ model can help operators, investors, regulators, and the public evaluate the near real-time impacts of oil and gas systems. Moreover, the OCI+ can help identify where satellites should observe and attribute their measurements to specific equipment.

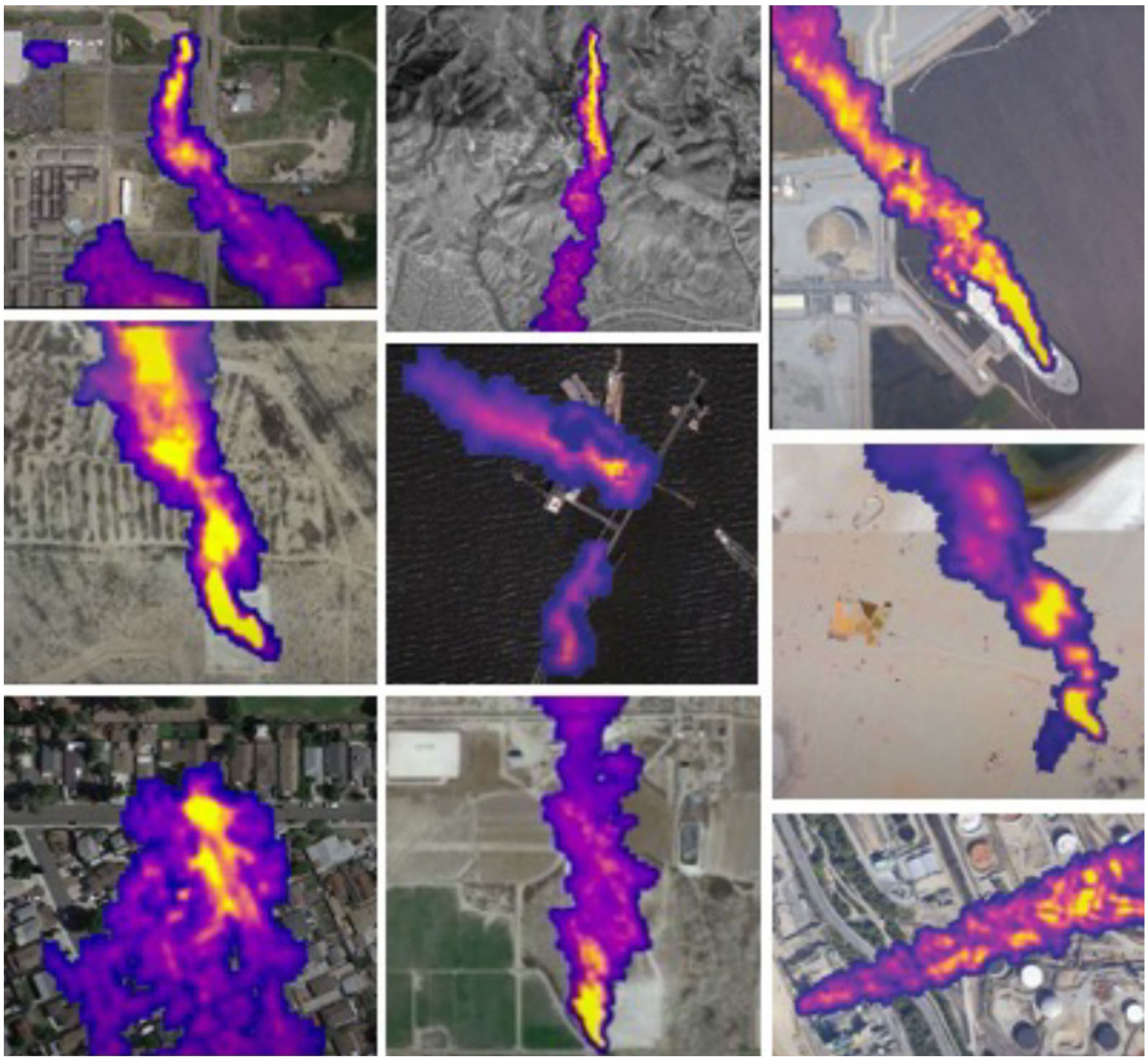
A growing constellation of satellites is setting up to navigate the globe, measuring methane from oil and gas and other sources. Some satellites can measure point sources while others are less granular and measure methane from entire regions. Some satellites can detect small plumes while others are geared toward larger super-emitters. Some satellites have daily coverage and others are less frequent. Most satellites are operated by governments while a few are run by private companies or nonprofit organizations. Carbon Mapper, for example, is a first-of-its-kind satellite enterprise that is a consortium of public, private, philanthropic, and nonprofit organizations including RMI. This balance of interests makes Carbon Mapper unique.[xxii]

xxi See **https://miq.org/**.

xxii The Carbon Mapper consortium includes: Planet, NASA's Jet Propulsion Laboratory, the State of California, the University of Arizona, Arizona State University, RMI, and various philanthropic sponsors, including High Tide Foundation and Bloomberg Philanthropies. (See: **https://carbonmapper.org/**.)

Starting with flyover campaigns, Carbon Mapper is using visible infrared spectrometers to identify and quantify large methane point-source emissions at the scale of individual facilities and equipment. Many of these methane super-emitters are from oil and gas systems (as shown in Exhibit 23). Carbon Mapper is also the first system capable of detecting methane emissions over water from offshore oil and gas operations. In 2023, Carbon Mapper will launch its first two satellites to obtain daily readings of global methane and CO_2 emissions.

Exhibit 23 **Carbon Mapper Flyover Methane Detection from US Oil and Gas Systems, 2021**



Note: Yellow plumes represent the highest methane emissions measurement. Image identification from left to right, top row: oil well unloading, gas storage tank, and LNG tanker; middle row: unlit flare, offshore platform, and gas compressor station; bottom row: gas pipeline leak, unlit flare, and chemical plant.
Source: "Making Methane Visible for Action," Carbon Mapper, November 3, 2021, video, 2:57, **https://youtu.be/LzB3dR6zRyU**; and "Impact," Carbon Mapper, **https://carbonmapper.org/our-mission/impact/**

Amplifying Climate Intelligence by Combining Satellite Data and the OCI+

While the OCI+ is geared toward modeling normal oil and gas operations, it can also peer inside the system when things go awry. In 2019, for example, there was a major well blowout in Texas's Eagle Ford basin that required evacuations for a two-mile radius around the well. Blowouts are more common than one might think. There were some 100 well failures recorded in Texas alone over the past five years.[33] Evaluating the volume and impact of oil and gas released (methane and other emissions) during an accident is difficult. In this instance, it took 20 days for the operator to shut in its failed well.

In 2020, Carbon Mapper researchers noted elevated methane emissions when reviewing satellite data in the vicinity of the prior year's Eagle Ford blowout. Carbon Mapper collected an array of different remote sensing data and estimated 4,800 (± 980) metric tons of methane was emitted during the event. The OCI+ was used to independently confirm these satellite estimates.[34]

To put this in perspective, this particular gas field blow that lasted for 20 days emitted as much methane as nearly 1 million cows over the same time frame.[xxiii] The ability to estimate such super-emitter events will facilitate imposing penalties, quantifying offsets, and encouraging their prevention. The integration of modeled and satellite data can offer new insights and more powerful tools to determine climate damage when oil and gas upsets occur.

xxiii One cow burps up 220 pounds of methane per year, which amounts to 12 pounds over 20 days — the duration of this blowout that emitted 4,800 metric tons of methane. (See: Amy Quinton, "Cows and Climate Change," UC Davis, 2019, **https://www.ucdavis.edu/food/news/making-cattle-more-sustainable**.)

Putting the OCI+ into Policy Action

Require Greater Data Transparency

Oil and gas markets cannot function efficiently without transparent, high-quality information. Comprehensive, standardized information is also a necessary condition for effective policymaking. As such, publicly collecting and reporting open-source oil and gas data is the key to assessing data quality, reducing emissions, and transforming petroleum supply chains.

Oil and gas resources differ markedly, as highlighted in this report. The belowground chemical characteristics of oil and gas resources together with aboveground operational decisions are critical data inputs. However, several obstacles have made it difficult to obtain and verify oil and gas data inputs to the OCI+ model.[xxiv] These include omissions and inconsistencies in existing oil and gas data, private-sector institutional constraints on whether and how data can be sold and used, and government limitations on data collection. These conditions that interfere with data availability are discussed in *Appendix A*.

Greater data transparency allows greater climate protection. Decision makers need oil and gas data to help determine which resources to turn on, how to reduce the climate footprints of operating assets, and when to turn assets off.

Efforts to systematically gather industry data have been proposed at the federal and state levels. For example, in the United States, the Know Your Oil Act was introduced in 2016 and again in 2017 to authorize federal agencies to collect and publish emissions-related oil and gas data.[xxv, 35] Similar state legislation was introduced in California in 2020 to create public repositories with production and refining data.[36]

If enacted, these laws would facilitate OCI+ modeling to better identify cost-effective climate strategies for global oil and gas resources. They would also provide surrounding communities with greater knowledge about health and other impacts. Oil and gas data can also enhance energy security, for example in tracking the emissions characteristics of oil stored in the US Strategic Petroleum Reserve. [xxvi]

Policymakers can begin by prioritizing data collection on the largest global assets, including fields and refineries. Data transparency should focus on key information such as production volumes, gas-to-oil ratios, reservoir depths, gas composition, asset ownership, oil assays, and shipping distances. Several articles in the Paris Agreement specify the need for transparency and public access to information to support the UN's Sustainable Development Goals. Efforts to digitize big data in the oil and gas sector could further enable climate transparency. In the end, more data will lead to greater climate intelligence about oil and gas resources, beginning with indexing their emissions intensities as shown in Exhibit 24 (next page; Exhibit 24A depicts oils modeled and Exhibit 24B depicts gases modeled).

xxiv This section references Deborah Gordon et al., *Know Your Oil: Creating a Global Oil-Climate Index*, Carnegie Endowment for International Peace, 2015, **https://carnegieendowment.org/files/know_your_oil.pdf**.

xxv For legislative text see: Know Your Oil Act of 2016, H.R. 6082, 114th Cong. (2016), **https://www.govtrack.us/congress/bills/114/hr6082**; and H.R. 3286, 115th Cong. (2017), **https://www.congress.gov/bill/115th-congress/house-bill/3286?s=1&r=82**.

xxvi See for example Deborah Gordon et al., "Is the US Stockpiling Dirty Oils?" RMI, 2022, **https://rmi.org/is-the-us-stockpiling-dirty-oils/**.

Exhibit 24A **Total Life-Cycle Emissions Intensity and Production of Modeled Oil Resources**

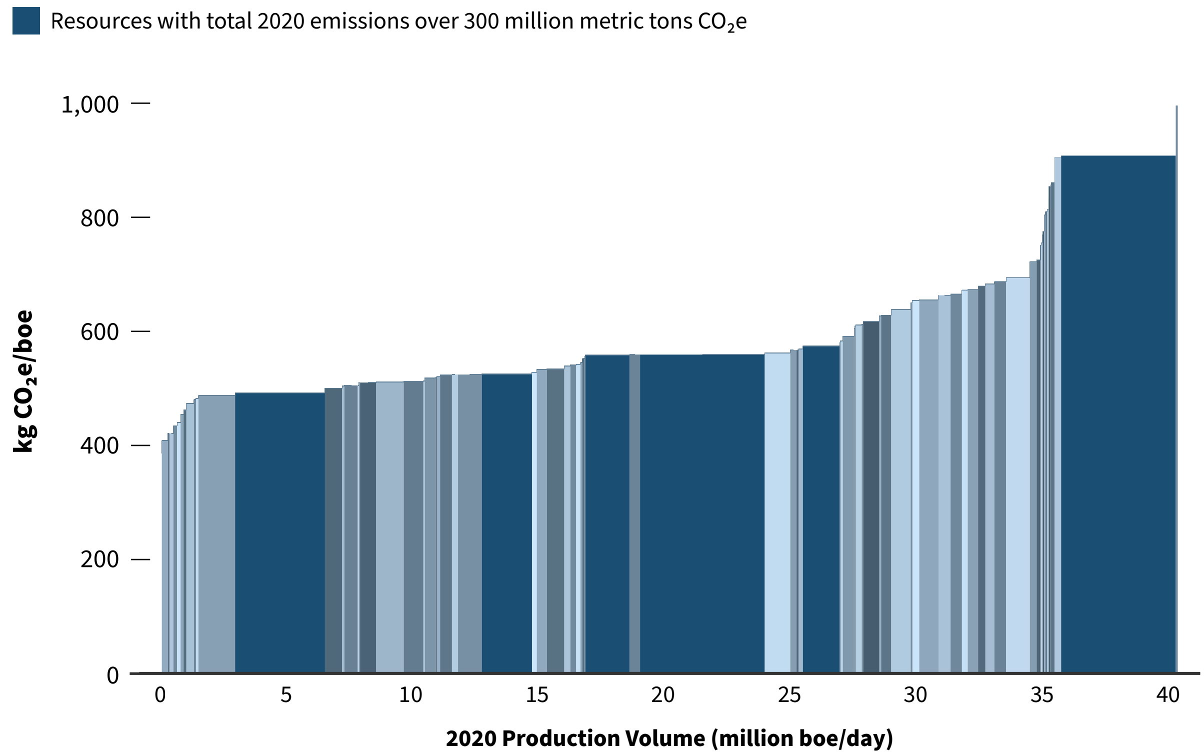
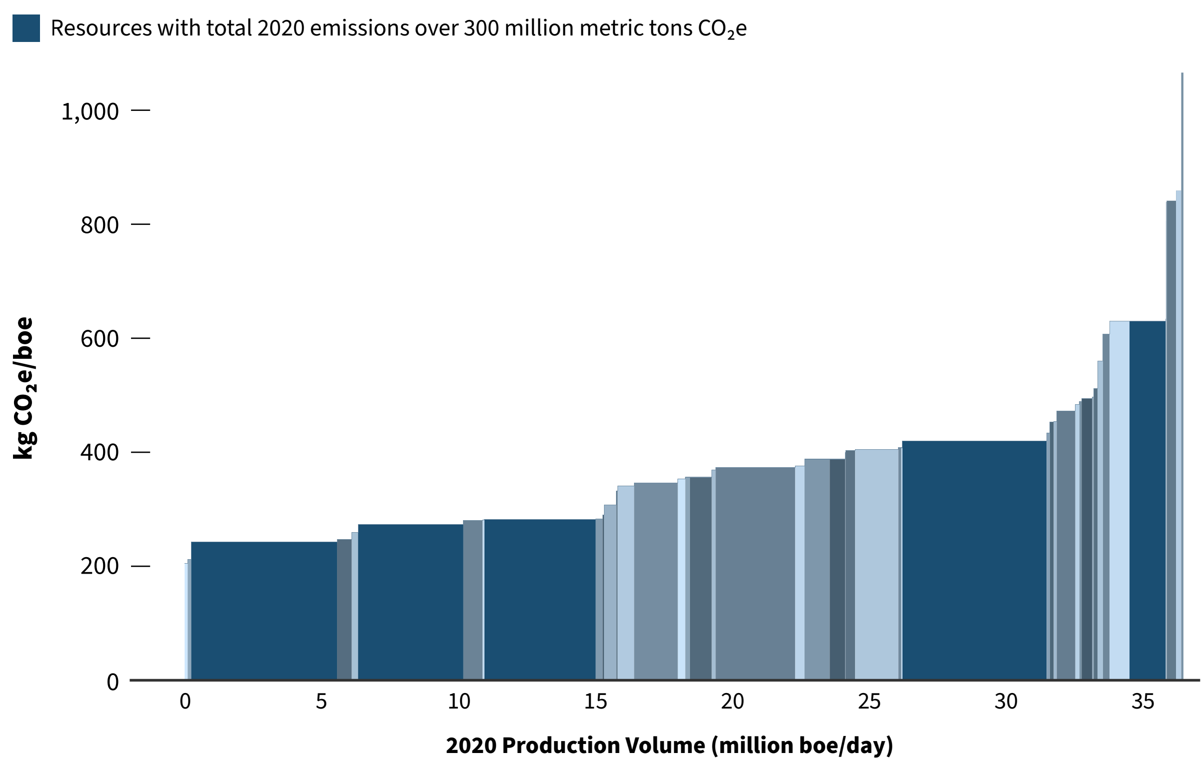


Exhibit 24B **Total Life-Cycle Emissions Intensity and Production of Modeled Gas Resources**



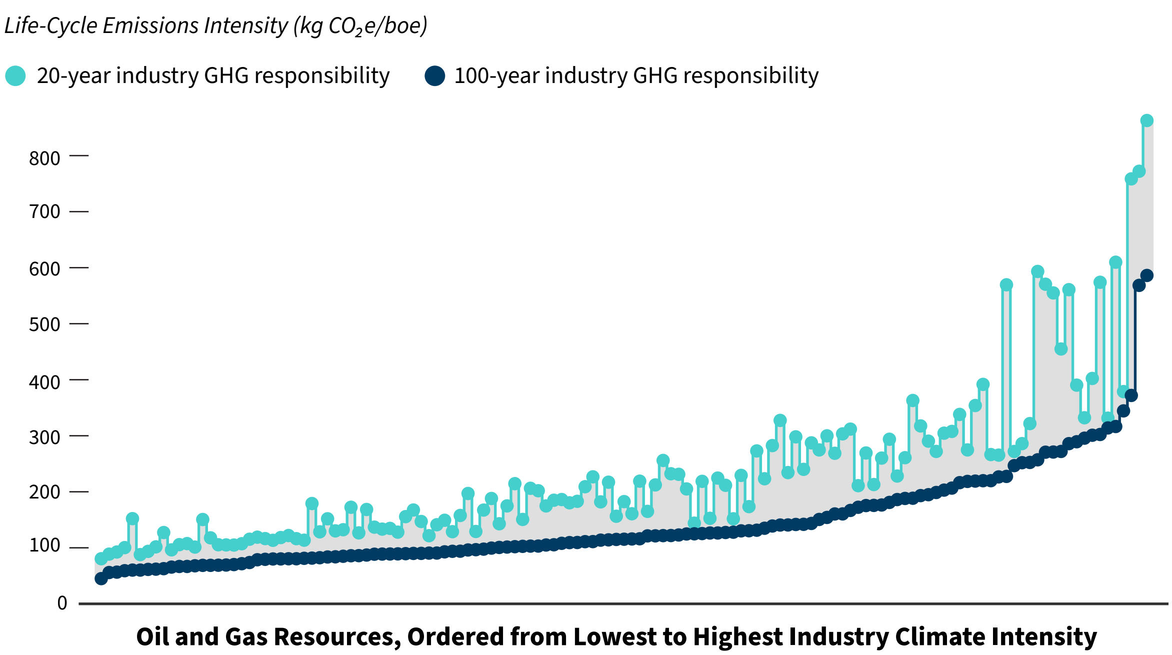
Provide Guidance for Policymakers on Short-Lived Climate Pollutants

The IPCC defines global warming potential (GWP) as an "index measuring the radiative forcing following an emission of a unit mass of a given substance, accumulated over a chosen time horizon, relative to that of the reference substance, carbon dioxide (CO_2)." In other words, GWP allows modelers and decision makers to evaluate the combined radiative forcing of different climate pollutants with differing atmospheric lifetimes.[37]

One metric, the 100-year global warming potential (GWP_{100}), has been extensively employed in climate policymaking, according to the IPCC.[38] However, GWP_{100} significantly undercounts the role methane plays in oil and gas life-cycle emissions in the short term. The year 2100 currently dominates scientists' thinking, whereas 2030 is as far out as most policymakers can hope to act. And the timeline is even shorter for industry, with its eye on the next quarter.

This deficiency is recognized in the IPCC's Sixth Assessment Report (AR6). While methane is the most significant climate driver after CO_2, the Paris Agreement "rulebook" currently states that parties use GWP_{100} to report aggregate emissions and removals of greenhouse gases, expressed in CO_2e.[xxvii] Other GWP-type metrics are technically allowed, and the IPCC directs policymakers to choose the metric, including the time horizon, that accurately reflects their objectives.[39]

Exhibit 25 **Importance of Using GWP_{20} to Assess Oil and Gas Life-Cycle Emissions Intensities**



Note: "Industry GHG Responsibility" refers to emissions from the upstream, midstream, and transportation components of the oil and gas life cycle.

xxvii Alternatively, parties can use the 100-year time horizon GWP values from a subsequent IPCC assessment report as agreed upon in the Paris Agreement. (See: **https://www.ipcc.ch/report/ar6/wg1/downloads/report/IPCC_AR6_WGI_Full_Report.pdf**; Box 1-3; page 1-88.)

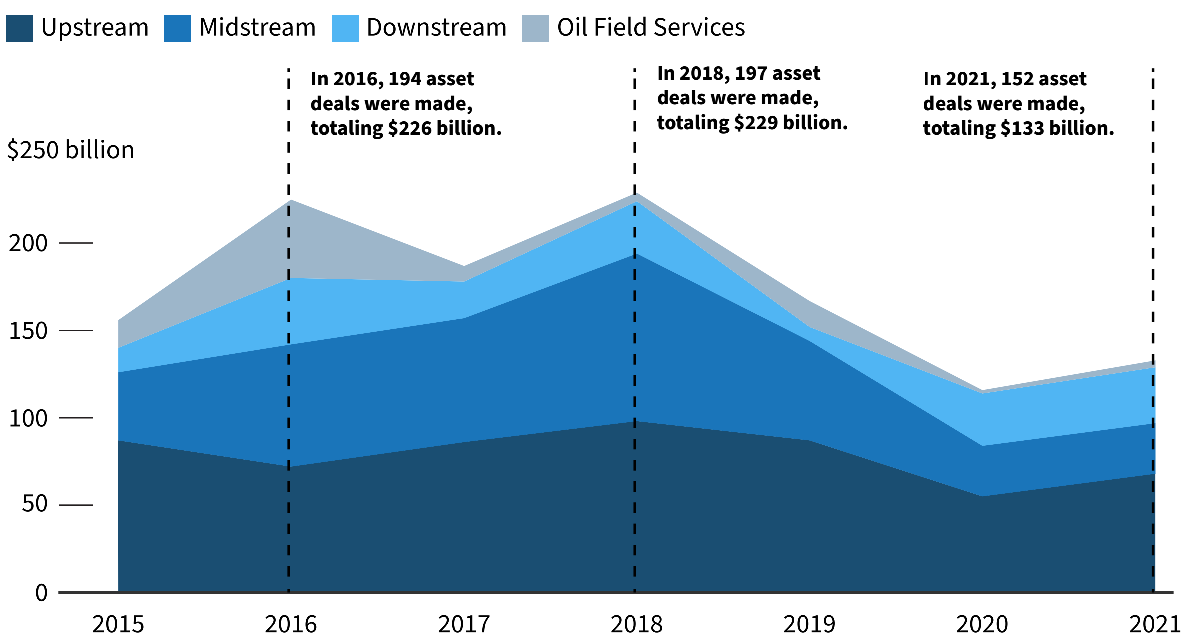
The climate policymaking community, however, needs more direction from the scientists. Using GWP_{100} results in systematically lower oil and gas emissions than using GWP_{20}, as plotted in Exhibit 25 (and the other exhibits in this report). Undercounting the critical role methane plays in climate models leads to inattention by policymakers and regulators. Using GWP_{20}, or a similar GWP-alternative metric,[40] would more accurately reflect the role methane plays in assessing life-cycle emissions in the oil and gas sector.

Reducing Emissions When Assets Transfer

The oil and gas industry provides incomplete and inconsistent climate disclosure at present. This makes it difficult for financial markets to track oil and gas sector emissions. The OCI+ offers a tool for routinely assessing and forecasting emissions. But tying asset emissions to owners can be onerous. Oil and gas assets repeatedly transfer from sellers to buyers over their lifetime. Oil and gas market volatility facilitates the changes in ownership. Bankruptcy, asset consolidation, corporate mergers, and the like all shift assets and operations. Historically, economics were the main drivers of changing ownership. Increasingly, however, climate risks are playing a decisive role.

While oil and gas asset deal value fell during the COVID-19 pandemic, in 2021 there was an uptick in sales (as plotted in Exhibit 26).[41] A regulation or even the adoption of an investor-driven norm that requires life-cycle emissions intensity and absolute emissions of an asset to be disclosed during a transaction could go a long way to evaluate how market transactions affect climate change.

Exhibit 26 **Oil and Gas Asset Transfers, 2015–2021**



Note: Data reported in nominal dollars.
Source: PwC, 2022

For example, in the past few years, BP disposed of all its Alaska assets, which Hilcorp bought.[42] Shell went on a selling spree, disposing of its Texas Permian assets to ConocoPhillips and unloading over half of its refineries, including one of its dirtiest, in Martinez, California, which it owned for over a century.[43] Now, another Shell asset is on the chopping block: its share in Aera, a joint venture with Exxon in California's oldest, largest, and dirtiest oil field, Midway Sunset.[44]

Unloading dirty assets to clean up a company's ledger is becoming more prevalent.[xxviii] And when international oil companies sell these difficult-to-operate assets to smaller companies out of the mainstream, emissions can increase.[45] The OCI+ has been and can continue to be used to evaluate emissions trends, before and after a sale. This would incentivize those selling their assets to disclose climate risks and reduce the emissions intensity of their operations as a condition of asset transfer.

Incentivize Decommissioning of Marginal, Climate-Intensive Assets

Transfers of low-production assets not only call for greater oversight, but they also underscore the need for accelerated decommissioning. The spotlight is on oil and gas assets with near-zero productivity and negligible economic returns that are underfinanced, undermaintained, or very leaky. Yet equipment end-of-life policies, mandates, protocols, and incentives are lacking.

For example, little-known Diversified Energy operates tens of thousands of oil and gas wells throughout Pennsylvania, Ohio, West Virginia, and Kentucky. Diversified now eclipses ExxonMobil as the largest well owner in the United States by massively buying assets that trickle or do not produce at all. Diversified's claims that its wells have 50 more years of production call into question their future climate footprint. In modeling other such marginally producing assets like UK Brent, the OCI+ finds that they have outsize climate intensities that continue to swell as time passes. In the case of Diversified, it is reported that the company's marginal wells can emit more natural gas than they produce.[46] This claim can be analyzed with the OCI+ given the necessary input data. With this knowledge, governments can use environmental performance as a basis for oversight and regulations.

Because oil and gas assets can change hands many times over during their lifetimes, such complicated histories must be considered in establishing rules and best practices for financing asset decommissioning. Without proper incentives, assets will continue to be operated beyond their useful life. Take the case of UK Brent, Shell's famous North Sea oil field that, over time, transformed into a climate-intensive, leaky gas field as it was depleted. Brent's four offshore platforms should have been decommissioned decades earlier than they were.[47] Between 2012 and 2018, data indicates that Brent oil production declined 30% while its GOR increased 22%, resulting in a 52% increase in emissions intensity as estimated by OCI+.[xxix] Decommissioning depleted legacy assets and supplying remaining demand with low emissions intensity resources can reduce upstream emissions by 75% or more.

The OCI+ is a valuable tool that estimates current and projects future emissions based on changing operating conditions. Modeling functionality can be used to evaluate whether dirty assets should be allowed to transfer, and when decommissioning would yield large climate benefits.[xxx, 48]

---

xxviii It is important to note that companies are driven by investor demands. So, for example, Shell is under great pressure from investors to hit emissions reduction targets, and that is a factor in its divestment decisions. External factors, like a Dutch court ruling last year forcing Shell to reduce its life-cycle CO_2 emissions by 45% (net) by the end of 2030 compared with its emissions in 2019, put more pressure on Shell to divest. A successful set of incentives would include consideration of investors' priorities as well.

xxix OCI 1.0 (published in 2015) modeled UK Brent with 2012 input data, **https://oci.carnegieendowment.org/#methodology** compared with OCI+ Preview (published in 2020) modeling UK Brent with 2018 input data, **https://rmi-climate-intelligence.github.io/oci/#methodology**.

xxx Note that bonding requirements were set out in the United States in the Kennedy administration but were never updated. (See: Lucas Davis, "Modernizing Bonding Requirements for Natural Gas Producers," The Hamilton Project, 2012, **https://www.hamiltonproject.org/papers/modernizing_bonding_requirements_for_natural_gas_producers**.)

Including the OCI+ in the Climate Intelligence Arsenal

To meet the 1.5°C target, the world needs a path to significantly reduce petroleum industry emissions. The first step in the journey is acknowledging that the climate footprints of oil and gas resources vary widely. Next, decision makers can publicly analyze and report these emissions differences using the OCI+, an open-source tool that models the emissions intensity of any equivalent barrel of oil and gas from extraction to end uses. Armed with this knowledge, market actors, policymakers, and civil society can make climate-aligned decisions.

The implications are far-reaching. The OCI+ results charted in this report identify numerous highly emissions-intensive oil and gas resources that should be the highest priority for rapid reductions. Attending to those resources with the highest emissions intensity is the quickest and most effective way to reduce the massive climate footprint from the oil and gas sector. Moreover, the OCI+ identifies where in the supply chain the greatest opportunities arise to reduce emissions from any resource. Focusing on specific emissions drivers can help steer climate action across the entire oil and gas sector.

The petroleum industry continues to change even as the world warms. The progression from simpler to more complex oil and gas supply chains calls for more information, smarter decision-making, sound policy guidance, and increased market intelligence. Opportunities to build digital climate attributes into markets are becoming more numerous and potentially influential.[49] The OCI+ can supply this information throughout the supply chain.

In a warming world, all market participants need better climate intelligence. Investors and industry need to make durable asset valuations and infrastructure decisions that will not be stranded by future climate policies and outcomes. Policymakers need up-to-date knowledge to approve permits, set standards, price carbon, and adopt better governance practices. Companies need to prove their carbon-neutral claims, protect their corporate reputations, and compete on a level playing field. And the public needs robust open-source information about life-cycle emissions to better understand the trade-offs between global oils and gases to make wise energy choices.

Since its inception a decade ago, the Oil Climate Index project has consistently shown large variations in climate footprints between global oils. Adding global gases and modeling one-half of the world's oil and gas supply confirms these findings. The climate differences between otherwise equivalent barrels of oil and gas are big enough to matter. Greater data transparency is all that stands in the way of routinely assessing every global oil and gas resource and incorporating this climate intelligence into market transactions.

By making emissions visible, attributing their sources, developing supporting policies, and activating markets, the OCI+ offers a way forward for the opaque, complex, and highly polluting oil and gas sector. With this knowledge, we can make measurable and effective gains now to shrink the industry's large and growing climate footprint, as we clear a path to a secure a clean, prosperous, zero-carbon future for all.

Appendix A: Oil and Gas Data Inputs and Gaps

The OCI+ is founded on principles of data transparency, and its results are dependent on standardized, consistent, updated, and publicly available input data. Since there is currently no single comprehensive oil and gas data public repository, the OCI+ relies on data from a multitude of sources. Efforts are under way to establish greater data transparency. The absence of trustworthy, open-source data for key model inputs can introduce uncertainty in the GHG emissions estimates. The broader purpose of expanding the public collection of vital operational and resource data is to verify and track global emissions. Oil and gas markets cannot function efficiently without high-quality public information. Comprehensive and timely information is also a necessary condition for effective energy and climate policymaking.

Identifying Data Limitations

The inherent chemical characteristics of oil and gas, their operational specifications, and how they differ from one another under varying conditions are critical informational inputs. In seeking to obtain and verify the needed oil and gas data inputs for the OCI+, several obstacles have been encountered:

- **Oil and gas data inconsistencies:** There are thousands of different global oil and gas resources, but there is no standardized, open-source format for field names, field boundaries, resource compositions, multi-cut crude oil assays, operational specifications, ownership transfers, and more. The diversity of data formats presents significant challenges to conducting open-source modeling to validate industry and government reporting or to compare oil and gas climate intensities over time.

- **Data often cannot be used without companies' permission:** The oil and gas industry at times publishes and sells data. For example, data can be purchased, but contracts may not allow purchased data to be cited or even modeled results to be posted. Moreover, oil assays for marketed crudes are available on corporate websites. But the fine print can present problems. Users who wish to comply with companies' policies have to obtain permission to reproduce oil and gas data in any format. Therefore, a large share of the oil and gas data that is available, both publicly and commercially, cannot actually be used in practice.

- **Data is often not for sale or use:** Up-to-date oil and gas databases are compiled by the private sector, often energy research firms and industry consultancies. Data companies' contractual terms serve the oil and gas industry's business interests by providing visibility on competing companies' operational data. However, data providers' profit motives often conflict with the public interest. Their incentive structure is at odds with civil society groups and policymakers whose interests revolve around publicly reporting their analytic findings and using data for industry oversight. At present, data firms "rent" oil and gas data for a high price with uncertain prospects for subscription renewal. Subscriptions may be terminated midcourse, and the historic data that was used must be deleted and returned to the company. Even if NGOs, think tanks, academics, and governments can afford the price to purchase data, the data is not necessarily for sale. Terms can change over time and after lengthy negotiations, firms may deny the sale of data because they view civil society actors as their competitors.

- **Government limitations to collecting data:** The government is responsible for public oversight. However, governments also profit handsomely from oil and gas development. This is especially true regarding national oil companies. Even in the United States, the Department of Energy (DOE) is limited in its reach to expand oil and gas reporting requirements. In previous conversations with DOE, OCI+ researchers were informed that the department could not establish consistent reporting requirements for oil and gas data because the US Office of Management and Budget considers such data collection a duplication of effort from a budgetary perspective. This means that policymakers and the public are at the behest of industry to divulge information that may not be timely, accurate, or consistent. International governments can be even more opaque and less willing to make public their oil and gas operational data.

Many of these issues have existed for decades and reflect the economic and political power of the oil and gas industry. To truly address greenhouse gas emissions from the oil and gas sector, structural problems related to data availability and use need to be addressed head-on.

Overview of Model Data Inputs

A full discussion of the OCI+ model and its inputs can be found in the OCI+ Methodology.[50] OPGEE can accept hundreds of user data inputs and relies on public data wherever possible (see OCI+ Methodology for full list of main OPGEE inputs). However, where input data is lacking, smart defaults allow the model to assign reasonable estimates based on fewer than a dozen key oil and gas characteristics. Key inputs include: field name; field age; field depth; oil, gas, and water production volumes; gas composition; number of injecting wells; satellite-derived flaring volumes; crude API gravity; production methods; and means and distance of crude transport. OPGEE can also model fracked and LNG resources with specific

Exhibit A-1 **PRELIM Assay Temperature Cuts**

Temperature (°C)	Product Cut Name
80	Light Straight Run
180	Naphtha
290	Kerosene
343	Diesel
399	Atmospheric Gas Oil (AGO)
454	Light Vacuum Gas Oil (LVGO)
525	Heavy Vacuum Gas Oil (HVGO)
525+	Vacuum Residue
399+	Atmospheric Residue (AR)

Source: Adapted from Gordon et al., *Know Your Oil*, Carnegie Endowment for International Peace, 2015 inputs if the user has details. When using OPGEE, the model requires "component" or "site" level analysis to be selected. Users can also input equipment component data and adjust methane loss rates to fine-tune these results.

Given the lack of data on crude-refinery mapping, the default configurations are the OCI+'s best engineering judgments at present. Users with more information can pinpoint the destination refinery and input specific data, however. One of the important inputs to the PRELIM model is crude assay properties corresponding to fixed temperature cuts. An example of the required data input is below. (Please refer to PRELIM documentation on distillation curve formatting.) PRELIM contains hundreds of oil assays in its inventory and is in the process of being expanded. Additional assays were obtained from various public sources for the previous release version of the OCI+, as well from project contributors at Solomon Associates. For optimal results, oil assays should contain nine temperature cuts, as shown in Exhibit A-1.

OPEM data inputs require a detailed product slate (measured in barrels per day for liquid products, kilograms per day for solid products, or gas mass for gaseous products), which are reported in PRELIM, and gross volumes of crude, gas, NGLs, and upgrader coke produced, which are reported in OPGEE. Petroleum coke, LPG, and petrochemical feedstock densities are used to convert solid and gaseous refinery products to barrels equivalent. LPG and petrochemical feedstock are assumed to have a 270-to-one ratio of gas volume to liquid volume. LPG and petrochemical feedstock gas densities are sourced from PRELIM, under 20°C and one atm conditions. It is assumed that petrochemical feedstock is ethane, while LPG is three-fourths propane and one-fourth butane. The product slates for OPEM inputs are generated from PRELIM by modeling a standard crude input volume of 100,000 barrels per day and then normalized per barrel crude input to the refinery.

Origins and destinations of petroleum product shipments are not transparently tracked. Given current limitations posed by the reporting of global petroleum product transport data, the OCI+ assumes that lighter petroleum liquid products (petrochemical feedstocks, gasoline, diesel, jet fuel, NGL, LPG) are transported via pipeline 2,414 kilometers or 1,500 miles (roughly the distance from Houston to New York) and then by heavy-duty tanker truck 380 kilometers or 236 miles (the approximate distance from New York to either the Washington, D.C., or Boston metropolitan areas). Heavy liquid products (fuel oil, residual fuels) are assumed to travel 1,200 km by rail, 1,200 km by tanker, and 805 km by truck. Solid fuels (petroleum coke and sulfur) are assumed to travel 3,352 km by tanker and 1,207 km by rail. Users can input different distances, shipping modes, and shipping fuels into OPEM to model different transport scenarios. Changes to these inputs can significantly shift the emissions intensity from oil, pipeline gas, LNG, or product transport.

Evaluating Data Availability and Quality

Here, we describe elements of data availability and quality. These parameters could eventually be used to evaluate and assign an overall score to each OCI+ resource.

We define data availability as the proportion of key inputs able to be found and entered into the model (out of the total number of desired key inputs). Greater data availability means that most key inputs needed to accurately estimate emissions intensities were included in the model, while poorer data availability indicates that several key inputs are missing. For example, in OPGEE, oil production volume was available for every modeled field, while well counts were only available for some, and very few contained well depths.

We define data quality as a combination of four subelements — credibility, accessibility, recency, and specificity. Credibility asks, "How much trust can we place in this data source?" and is assessed based on the categorization of the data source. For example, data from academic literature receives a higher credibility score than industry publications and non-peer-reviewed sources. Accessibility asks, “How readily usable is the data?” Data behind a paywall and/or in an unworkable format is less accessible than publicly available data. Recency asks, “Is the data source up to date?” Data inputs that are updated on an annual or semiannual basis are better inputs than data updated sporadically or only available on a one-off basis. Specificity asks, “Is the data specific to the modeled field?” For example, field-specific flaring-oil-ratio data carries more value than a regional or country average.

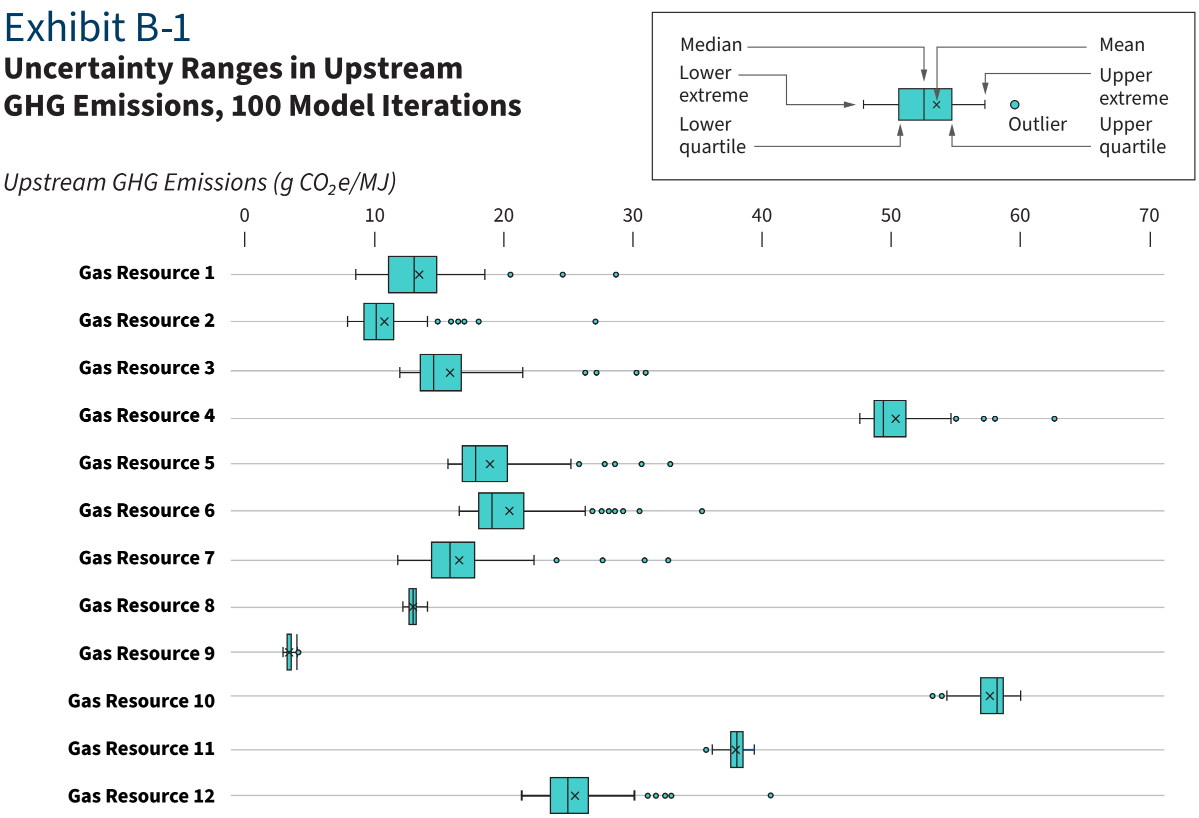
Appendix B: Understanding Model Uncertainty

The OCI+ is built on dynamic, complex engineering models. As such, the results of each model (OPGEE, PRELIM, and OPEM) carry inherent uncertainty, as does the overall result. For OPGEE, user inputs affect the way the model functions (i.e., how statistical simulations are performed). This is documented further in the OPGEE methodology, available on the GitHub site.[51]

For the base runs in OCI+, OPGEE was run with one uncertainty simulation. This means that for any inputs whose values occur along a distribution, the mean was selected as the smart default. As an additional exercise, we perform 100 uncertainty runs for a select handful of fields to demonstrate the impact on the upstream emissions intensities (Exhibit B-1). In the next phase of OCI+, with a Python version of the OPGEE model, we will be able to run sufficient uncertainty iterations for every field modeled so that an uncertainty band is included for every field.

Exhibit B-1

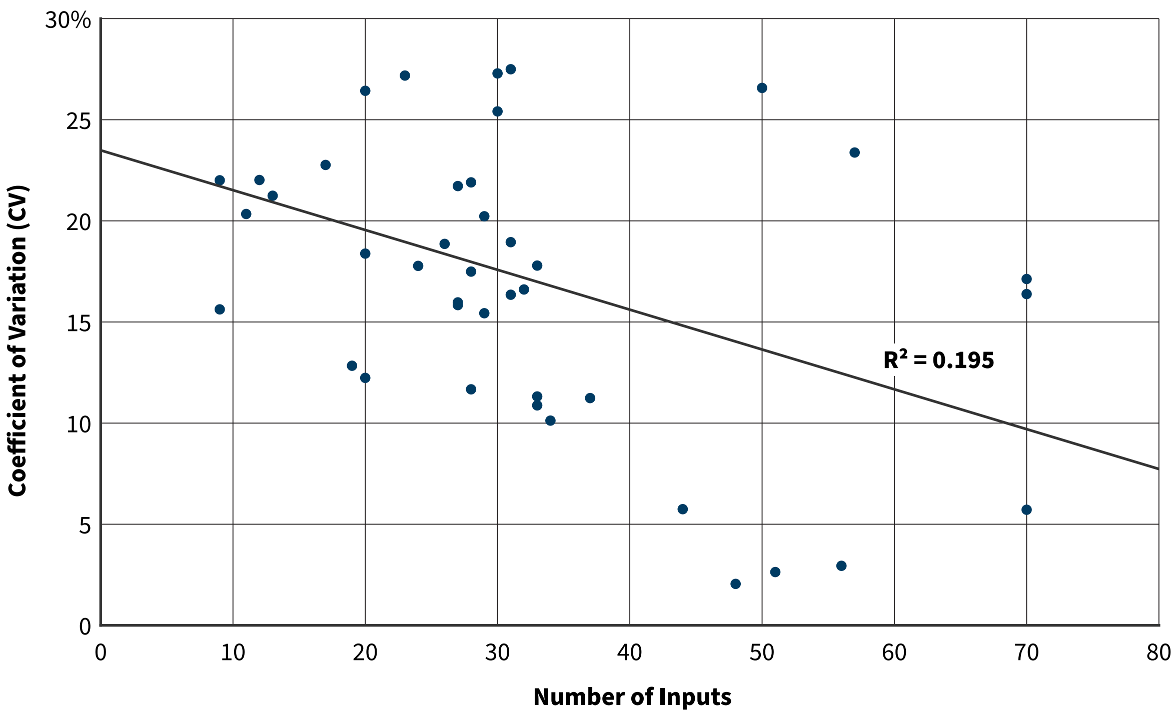
Uncertainty Ranges in Upstream GHG Emissions, 100 Model Iterations



Note: All of the resources plotted here are global gas fields; a similar exercise can be done for global oil field uncertainty ranges in OPGEE.

The coefficient of variation for OPGEE, calculated by dividing the standard deviation in emissions intensity by the mean, reflects uncertainty of the modeled results. Uncertainty is reduced as the number of provided model inputs increases (Exhibit B-2). This emphasizes the need for greater data availability to improve confident understanding of the climate impacts of every oil and gas resource.

Exhibit B-2 **Coefficient of Variation for OPGEE vs. Number of Model Inputs, 100 Model Iterations for Sample Gas Resources**



For the midstream model PRELIM, a previous uncertainty study on five crudes using version 1.2.1 concluded that "the most influential parameters are processing unit energy use (including electricity, gas, and steam), hydrogen production emission factor (via steam methane reforming), natural gas combustion emission factor, and electricity emission factor." [52]

The study cited above shows that "the refining confidence intervals of all five crudes studied vary within a range of 10–15 kg CO_2e per barrel, which is around 30% of the baseline case results. At the process unit level, uncertainty associated with PRELIM parameters and modeling structure can also be propagated to the modeling results (e.g., refining emissions intensity and energy use). Modeling structure, such as fluid catalytic cracking yields and gas oil hydrocracker yields, is fixed in PRELIM for each configuration. However, refineries with the same configuration may have different yield patterns (e.g., more gasoline and less diesel, or more diesel and less gasoline) driven by refining margin and market dynamics. Due to the lack of data in such refinery-wise yield patterns, this type of uncertainty is not considered in this study."

Although the current iteration of the OCI+ release uses a different version of the PRELIM model, the previous uncertainty study results are qualitatively applicable. In the future, when all OCI+ underlying models are converted to Python, the researchers are planning to undertake a detailed uncertainty analysis that will accompany estimated life-cycle emissions intensities.

Endnotes

1 Deborah Gordon et al., *Know Your Oil: Creating a Global Oil-Climate Index*, Carnegie Endowment for International Peace, 2015, **https://carnegieendowment.org/2015/03/11/know-your-oil-creating-global-oil-climate-index-pub-59285**; "Oil and Climate," Carnegie Endowment for International Peace, archived 2018, **https://carnegieendowment.org/specialprojects/carnegieoilinitiative/oilandclimate**; and "Oil Climate Project: Our History," Oil Climate Project, **https://www.oilclimateproject.com/our-history**.

2 "Emission Factors for Greenhouse Gas Inventories," US Environmental Protection Agency (EPA), last modified March 26, 2020, **https://www.epa.gov/sites/default/files/2020-04/documents/ghg-emission-factors-hub.pdf**.

3 Adam Brandt et al., "Climate-Wise Choices in a World of Oil Abundance," *Environmental Research Letters* 13, no. 044027 (April 5, 2018), **https://doi.org/10.1088/1748-9326/aaae76**.

4 "World of Change: Global Temperatures," NASA Earth Observatory, accessed December 1, 2021, **https://earthobservatory.nasa.gov/world-of-change/global-temperatures**.

5 *Global Methane Assessment*, Climate and Clean Air Coalition (CCAC) and United Nations Environment Programme (UNEP), 2021, **https://www.ccacoalition.org/en/resources/global-methane-assessment-full-report**.

6 *Methane Emissions from Oil and Gas*, International Energy Agency (IEA), November 2021, **https://www.iea.org/reports/methane-emissions-from-oil-and-gas**.

7 *Global Methane Assessment: Benefits and Costs of Mitigating Methane Emissions*, United Nations, 2021, **https://www.unep.org/resources/report/global-methane-assessment-benefits-and-costs-mitigating-methane-emissions**.

8 Deborah Gordon, *No Standard Oil*, (New York: Oxford University Press, 2022), **https://www.nostandardoil.com/**; and Brandt, "Climate-Wise Choices," 2018.

9 *Oil 2021*, IEA, 2021, **https://iea.blob.core.windows.net/assets/1fa45234-bac5-4d89-a532-768960f99d07/Oil_2021-PDF.pdf**; and *Gas 2020*, IEA, 2020, **https://www.iea.org/reports/gas-2020/2021-2025-rebound-and-beyond**.

10 "Oil Demand by Scenario, 2010-2030," IEA, last modified October 12, 2021, **https://www.iea.org/data-and-statistics/charts/oil-demand-by-scenario-2010-2030**; and *World Energy Outlook 2021: Fuels Old and New*, IEA, 2021, **https://www.iea.org/reports/world-energy-outlook-2021/fuels-old-and-new**.

11 *Net Zero by 2050: A Roadmap for the Global Energy Sector*, IEA, May 2021, **https://www.iea.org/reports/net-zero-by-2050**.

12 Ker Than, "Climate Impacts of Super-Giant Oilfields Go up with Age, Stanford Scientists Say," **https://news.stanford.edu/2017/07/17/climate-impacts-super-giant-oilfields-go-age/**.

13 Lauren Shwisberg et al., *Headwinds for US Natural Gas Power*, RMI, December 2021, **https://rmi.org/wp-content/uploads/2021/12/clean_energy_portfolios_2021.pdf**.

14 Abigail Alter, "A Landmark Year for Building Electrification," RMI, December 16, 2021, **https://rmi.org/a-landmark-year-for-building-electrification/**.

15 Mohammad Masnadi et al., "Global Carbon Intensity of Crude Oil Production," *Science* 361, no. 6405 (August 31, 2018): 851-853, **https://www.science.org/doi/10.1126/science.aar6859**.

16 Liang Jing et al., "Carbon Intensity of Global Crude Oil Refining and Mitigation Potential," *Nature Climate Chang*e 10 (June 2, 2020): 526-532, **https://doi.org/10.1038/s41558-020-0775-3**.

17 *Hydrogen*, IEA, November 2021, **https://www.iea.org/reports/hydrogen**; and "Current Hydrogen Market Size: Domestic and Global," DOE Hydrogen and Fuel Cells Program Record, **https://www.hydrogen.energy.gov/pdfs/19002-hydrogen-market-domestic-global.pdf**.

18 "Emission Factors for Greenhouse Gas Inventories," US EPA, 2020, **https://www.epa.gov/sites/default/files/2020-04/documents/ghg-emission-factors-hub.pdf**.

19 *Methane Emissions*, IEA.

20 Marc McDaniel, *Flare Efficiency Study*, US EPA, 1983, **https://www.epa.gov/sites/default/files/2020-10/documents/flare_efficiency_study_.pdf**; and Eric Kort, "Flares and Their Contribution to Methane Emissions," ARPA-E REMEDY, October 20, 2020, **https://arpa-e.energy.gov/sites/default/files/Session%201.4%20-%20Kort_0.pdf**.

21 Audrey Mascarenhas, "Re-Imagining Flares," ARPA-E REMEDY, October 20, 2020, **https://arpa-e.energy.gov/sites/default/files/Session%204.2%20-%20Mascarenhas_0.pdf**.

22 *Reducing Methane Emissions: Best Practice Guide Flaring*, Methane Guiding Principles, 2019, **https://methaneguidingprinciples.org/wp-content/uploads/2019/11/Reducing-Methane-Emissions-Flaring-Guide.pdf**.

23 *The Oil and Gas Industry in Energy Transitions*, IEA, 2020, **https://www.iea.org/reports/the-oil-and-gas-industry-in-energy-transitions**.

24 Christophe McGlade, Glenn Sondak, and Mei Han, "Whatever Happened to Enhanced Oil Recovery?," IEA, 2018, **https://www.iea.org/newsroom/news/2018/november/whatever-happened-to-enhanced-oil-recovery.html**.

25 "Enhanced Oil Recovery," US DOE, accessed December 1, 2021, **https://www.energy.gov/fe/science-innovation/oil-gas-research/enhanced-oil-recovery**.

26 R. Roig, A. Agarwal, and A. Kovscek. "Sensitivity Analysis for Solar-Generated Steam for Enhanced Oil Recovery," SPE Western Regional Meeting, April 26, 2018, **https://doi.org/10.2118/190075-MS**.

27 Carolyn Davis, "Chevron Pledges to Further Reduce Gorgon LNG Emissions," *Natural Gas Intelligence*, November 11, 2021, **https://www.naturalgasintel.com/chevron-pledges-to-further-reduce-gorgon-lng-emissions/**.

28 Kavan Motazedi, Jessica Abella, and Joule Bergerson, "Techno–Economic Evaluation of Technologies to Mitigate Greenhouse Gas Emissions at North American Refineries," *Environmental Science & Technology* 51, no. 3 (December 21, 2016): 1918-1928, **https://doi.org/10.1021/acs.est.6b04606**.

29 Deborah Gordon and Madhav Acharya, "Oil Shake-Up: Refining Transitions in a Low-Carbon Economy," Carnegie Endowment for International Peace, April 3, 2018, **https://carnegieendowment.org/2018/04/03/oil-shake-up-refining-transitions-in-low-carbon-economy-pub-75954**.

30 Tessa Weiss, "Growing Gigawatts of Green Hydrogen," RMI, October 11, 2021, **https://rmi.org/growing-gigawatts-of-green-hydrogen/**.

31 Associated Press, "Alberta Oilsands Waste Exported by American Refineries to Pollution-Choked India," CBC News, last modified December 1, 2017, **https://www.cbc.ca/news/canada/edmonton/exporting-pollution-american-refineries-oilsands-india-1.4428065**.

32 US EIA, "Global Liquefied Natural Gas Trade Was Flat in 2020 amid Pandemic," July 9, 2021, **https://www.eia.gov/todayinenergy/detail.php?id=48656**; and "The Global Gas Report 2020," BloombergNEF, **https://data.bloomberglp.com/professional/sites/24/BNEF-IGU-Snam-2020-Global-Gas-Report_FINAL.pdf**.

33 "Well Control Problems," Railroad Commission of Texas, accessed December 1, 2021, **https://www.rrc.texas.gov/oil-and-gas/compliance-enforcement/blowouts-and-well-control/**.

34 Daniel Cusworth et al., "Multisatellite Imaging of a Gas Well Blowout Enables Quantification of Total Methane Emissions," *Geophysical Research Letters* 48, no. 2 (January 28, 2021), **https://doi.org/10.1029/2020GL090864**.

35 "Rep. Huffman Introduces Energy Transparency Legislation: 'Know Your Oil Act' & 'Carbon Pollution Transparency Act,'" Office of Rep. Jared Huffman, last modified July 19, 2017, **https://huffman.house.gov/media-center/press-releases/rep-huffman-introduces-energy-transparency-legislation-know-your-oil-act-and-carbon-pollution-transparency-act**.

36 An Act to add Section 39735 to the Health and Safety Code, relating to greenhouse gases, AB-3217, State of California, (2020), **http://leginfo.legislature.ca.gov/faces/billTextClient.xhtml?bill_id=201920200AB3217**.

37 *Climate Change 2021: The Physical Science Basis*, Intergovernmental Panel on Climate Change (IPCC), August 7, 2021, AVII-28, **https://www.ipcc.ch/report/ar6/wg1/downloads/report/IPCC_AR6_WGI_Full_Report.pdf**.

38 *Climate Change 2021*, IPCC, 7-118.

39 *Climate Change 2021*, IPCC, AVII-29.

40 John Lynch et al., "Demonstrating GWP*: A Means of Reporting Warming-Equivalent Emissions That Captures the Contrasting Impacts of Short- and Long-Lived Climate Pollutants," *Environmental Research Letters* 15, no. 044023 (April 2, 2020), **https://doi.org/10.1088/1748-9326/ab6d7e**.

41 "Energy: Deals 2022 Outlook," PWC, accessed December 1, 2021, **https://www.pwc.com/us/en/industries/energy/library/deals-insights.html**.

42 "BP Completes Sale of Upstream Alaska Business," BP, modified July 1, 2020, **https://www.bp.com/en_us/united-states/home/news/press-releases/bp-completes-sale-of-upstream-alaska-business.html**.

43 Clifford Krauss, "Royal Dutch Shell Sells Permian Basin Oil Holdings for $9.5 Billion," *New York Times*, October 28, 2021, **https://www.nytimes.com/2021/09/20/business/energy-environment/shell-conoco-permian-sale.html**; *Bay City News*, "After 105 Years, Martinez Refinery No Longer 'Shell,' " Patch, February 2, 2020, **https://patch.com/california/martinez/after-105-years-martinez-refinery-no-longer-shell**; and "Factbox: Shell to Reduce Refinery Portfolio by More Than Half," Reuters, July 8, 2021, **https://www.reuters.com/business/energy/shell-reduce-refinery-portfolio-by-more-than-half-2021-07-08/**.

44 Jessica Resnick-Ault, Arathy Nair, and Shariq Khan, "Shell Plans to Exit California Joint Venture With Exxon Mobil — Sources," Reuters, June 30, 2021, **https://www.reuters.com/business/energy/exclusive-shell-plans-exit-california-joint-venture-with-exxon-mobil-sources-2021-07-01/**.

45 Rachel Adams-Heard, "What Happens When an Oil Giant Walks Away," Bloomberg Green, April 14, 2021, **https://www.bloomberg.com/graphics/2021-tracking-carbon-emissions-BP-hilcorp/**.

46 Zachary Mider and Rachel Adams-Heard, "An Empire of Dying Wells," Bloomberg Green, October 11, 2021, **https://www.bloomberg.com/features/diversified-energy-natural-gas-wells-methane-leaks-2021/**.

47 "Brent Field Decommissioning Programme," Shell, accessed December 1, 2021, **https://www.shell.co.uk/sustainability/decommissioning/brent-field-decommissioning/brent-field-decommissioning-programme.html**.

48 Jacqueline Ho et al., "Managing Environmental Liability: An Evaluation of Bonding Requirements for Oil and Gas Wells in the United States," *Environmental Science & Technology* 52, no. 7 (March 13, 2018): 3908-3916, **https://doi.org/10.1021/acs.est.7b06609**.

49 Paolo Natali, "How Digitally Native GHG Tracking Can Drive Faster Climate Action," RMI, 2021, **https://rmi.org/how-digitally-native-ghg-tracking-can-drive-faster-climate-action/**.

50 **https://ociplus.rmi.org/methodology**.

51 **https://github.com/arbrandt/OPGEE**.

52 Jing, "Carbon Intensity," *Nature Climate Change.*

Deborah Gordon, Jonathan Koomey, Adam Brandt, and Joule Bergerson, *Know Your Oil and Gas: Generating Climate Intelligence to Cut Petroleum Industry Emissions,* RMI, 2022, **https://rmi.org/insight/kyog/**.

RMI Innovation Center
22830 Two Rivers Road
Basalt, CO 81621

www.rmi.org