

UNITED STATES OF AMERICA
DEPARTMENT OF ENERGY
OFFICE OF FOSSIL ENERGY AND CARBON MANAGEMENT

Lake Charles Exports LLC

Docket No. 23-87-LNG

Intervention and Protest of Public Citizen, Inc.

The U.S. Department of Energy is tasked by Congress to only permit exports of natural gas to non-Free Trade Act countries which are “not inconsistent with the public interest.”¹ The U.S. Supreme Court noted that the “primary aim” of this 85-year-old law is “to protect consumers against exploitation at the hands of natural gas companies”.²

Energy Transfer’s application requests “a new long-term, multi-contract authorization for the export of 851 Bcf/year of LNG by vessel from”³ its proposed Lake Charles Terminal in Calcasieu Parish, Louisiana, which is located 12 miles northeast of Sabine National Wildlife Refuge.

Energy Transfer is owned and controlled by Kelcy Lee Warren. James R. “Rick” Perry joined Energy Transfer’s Board of Directors days after resigning as Secretary of Energy. Energy Transfer, whose billboards festoon the outfield wall of Major League Baseball’s Texas Rangers, is one of North America’s largest midstream oil and gas companies.

Energy Transfer’s application to export LNG on behalf of its affiliate Lake Charles Exports LLC must be denied as the application fails to demonstrate that its request is consistent with the public interest.

Motion to Intervene

Public Citizen, Inc. moves to intervene in this proceeding. Established in 1971, Public Citizen, Inc. is a national, not-for-profit, non-partisan, research and advocacy organization representing the interests of household consumers. We have over 500,000 members and supporters across the United States. Public Citizen is active before the Federal Energy Regulatory Commission promoting just and reasonable rates. We frequently intervene in U.S. Department of Energy proceedings involving the export of electricity and natural gas. Our Energy Program Director, Tyson Slocum, is an expert on energy market regulatory matters, serving as a witness on the Department of Energy public interest standard in testimony before the U.S. Congress in February 2023.⁴ Slocum also serves on two federal advisory committees of the U.S. Commodity Futures

¹ 15 USC § 717b(a).

² *FPC v. Hope Nat. Gas Co.*, 320 U.S. 591 (1944).

³ *Application*, at page 31.

⁴ www.citizen.org/article/house-testimony-energy-legislation/

Trading Commission (the Energy and Environmental Markets and Market Risk advisory committees). Financial details about our organization are on our web site.⁵

Energy Transfer’s Criminal Recidivist Track Record Demonstrate Comprehensive Compliance Problems

This an application of first impression for the Department of Energy because it is the first instance that a corporation with a criminal record is seeking permission to export LNG. Energy Transfer has been forced to pay more than \$137 million in penalties and fines over the last decade for violating a litany of federal and state laws,⁶ suggesting the company has comprehensive compliance problems. When compliance failures appear to be endemic to Energy Transfer’s corporate culture, the Department of Energy cannot find that its application to export LNG is “consistent with the public interest”.

On August 5, 2022, Energy Transfer LP was convicted of criminal violations of environmental laws, entering a plea agreement with the Pennsylvania Attorney General.⁷ The criminal convictions stem from Energy Transfer repeatedly allowing thousands of gallons of drilling fluid to contaminate fields, backyards, streams, lakes and wetlands. The criminal plea notes that Energy Transfer failed to report these pollution releases to the Pennsylvania Department of Environmental Protection as required by law. Energy Transfer was found to be criminally negligent for a massive explosion on its Revolution pipeline, which burned families’ homes, barns and incinerated acres of mature trees. Energy Transfer paid a \$10 million penalty, and agreed to be labeled a corporate criminal for life as an explicit part of the plea agreement.

Energy Transfer’s decision to admit to criminal violations last year was only the most recent of a long line of violations of state and federal law. Following is a mere sample of Energy Transfer’s rap sheet of violations that demonstrate comprehensive compliance problems with the company:

- Energy Transfer paid a \$10 million penalty to the U.S. Commodity Futures Trading Commission⁸ and \$30 million to the Federal Energy Regulatory Commission⁹ for manipulating natural gas prices.
- Energy Transfer’s affiliate paid a \$450,000 civil penalty for manipulating crude oil, gasoline, and heating oil futures markets.¹⁰
- In January 2020, Energy Transfer paid a \$30.6 million civil penalty for repeatedly ignoring compliance orders.¹¹

⁵ www.citizen.org/about/annual-report/

⁶ <https://violationtracker.goodjobsfirst.org/parent/energy-transfer>

⁷ www.attorneygeneral.gov/taking-action/case-update-energy-transfer-convicted-of-criminal-charges-related-to-construction-of-mariner-east-2-pipeline-revolution-pipeline-in-pennsylvania/

⁸ www.cftc.gov/PressRoom/PressReleases/5471-08

⁹ www.ferc.gov/sites/default/files/2020-05/128FERC61269.pdf

¹⁰ www.cftc.gov/PressRoom/PressReleases/8267-20

¹¹ www.ahs.dep.pa.gov/NewsRoomPublic/SearchResults.aspx?id=21792&typeid=1

- Energy Transfer paid \$5,436,274 in federal and state civil penalties for three crude oil leaks.¹²
- New Mexico imposed a \$4 million civil penalty on Energy Transfer for committing hundreds of violations that resulted in the unlawful release of more than 3 million pounds of pollutants.¹³
- Energy Transfer paid a \$1.95 million civil penalty for unlawful release of more than 200,000 gallons of pollutants into Pennsylvania's Raystown Lake.¹⁴
- Pennsylvania issued a \$12.6 million civil penalty for permit violations during Energy Transfer's construction of the Mariner East pipeline,¹⁵ and then issued an additional \$355,000 civil penalty for more violations.¹⁶
- In July 2023, Energy Transfer paid a \$660,000 penalty for violating Pennsylvania's Clean Streams Law.¹⁷
- Energy Transfer paid \$4 million for damages and a \$341,000 civil penalty for its 2020 contamination of Pennsylvania's Marsh Creek State Park.¹⁸
- In 2021, Energy Transfer paid \$497,000 in penalties for 32 unauthorized discharges of drilling fluids into Pennsylvania's Snitz Creek.¹⁹
- Energy Transfer was forced to pay a \$1 million civil penalty for the 2018 explosion and fire at its Revolution pipeline.²⁰
- Energy Transfer paid \$319,461 in civil penalties for contaminating streams and wetlands across 10 Pennsylvania counties.²¹
- PHMSA fined Energy Transfer \$163,700 in civil penalties for safety violations.²²
- In August 2021, Energy Transfer was fined \$140,000 for numerous permit violations in Pennsylvania.²³
- In March 2021, Energy Transfer paid a \$125,000 civil penalty for numerous safety violations in Pennsylvania.²⁴
- Energy Transfer paid \$355,000 civil penalty for contaminating streams and wetlands across 8 Pennsylvania counties.²⁵
- Energy Transfer paid a \$200,000 civil penalty from the leak of 850 gallons of ethane and propane from its Mariner East pipeline in Morgantown, Pennsylvania.²⁶

¹² www.epa.gov/archive/epa/newsreleases/epa-and-partners-announce-sunoco-pipeline-and-mid-valley-pipeline-settle-oil-spill.html

¹³ <https://cloud.env.nm.gov/air/pages/view.php?ref=23563&k=86b5fd8f5a>

¹⁴ www.ahs.dep.pa.gov/NewsRoomPublic/SearchResults.aspx?id=21798&typeid=1

¹⁵ www.ahs.dep.pa.gov/NewsRoomPublic/SearchResults.aspx?id=21393&typeid=1

¹⁶ www.ahs.dep.pa.gov/NewsRoomPublic/SearchResults.aspx?id=21456&typeid=1

¹⁷ www.ahs.dep.pa.gov/NewsRoomPublic/articleviewer.aspx?id=22327&typeid=1

¹⁸ www.ahs.dep.pa.gov/NewsRoomPublic/SearchResults.aspx?id=22027&typeid=1

¹⁹ www.ahs.dep.pa.gov/NewsRoomPublic/articleviewer.aspx?id=21921&typeid=1

²⁰ www.puc.pa.gov/press-release/2021/puc-approves-nearly-2-million-settlement-for-safety-probe-of-2018-pipeline-failure-and-fire-in-beaver-county

²¹ www.ahs.dep.pa.gov/NewsRoomPublic/SearchResults.aspx?id=21740&typeid=1

²² https://primis.phmsa.dot.gov/comm/reports/enforce/CaseDetail_cpf_120185009.html

²³ www.ahs.dep.pa.gov/NewsRoomPublic/articleviewer.aspx?id=21984&typeid=1

²⁴ www.ahs.dep.pa.gov/NewsRoomPublic/articleviewer.aspx?id=21922&typeid=1

²⁵ www.ahs.dep.pa.gov/NewsRoomPublic/SearchResults.aspx?id=21854&typeid=1

²⁶ www.puc.pa.gov/docket/C-2018-3006534

- Pennsylvania fined Energy Transfer \$148,000 for contaminating households' drinking water.²⁷
- PHMSA fined Energy Transfer \$226,500 for safety violations at its Panhandle Eastern Pipeline.²⁸
- Energy Transfer paid a \$165,100 civil penalty for safety violations for its Sunoco pipeline.²⁹
- Energy Transfer paid a \$141,700 civil penalty for safety violations.³⁰
- PHMSA issued a \$121,200 civil penalty for safety violations at its Sunoco pipeline.³¹
- In August 2021 Energy Transfer paid a \$85,666 civil penalty for contaminating wetlands and creeks in Pennsylvania.³²
- Energy Transfer paid a \$57,700 penalty for failing a series of PHMSA inspections of Energy Transfer's Lone Star NGL North Pipeline System in New Mexico and Texas.³³

It is not consistent with the public interest to allow a convicted criminal with poor compliance standards to export natural gas.

The Application Contradicts Itself On The Impact Exports Have On Domestic Natural Gas Production

In discussing the “potential environmental impact of the project”, the application states that “[t]he gas to be exported from the Lake Charles Terminal will be sourced from the existing United States interstate pipeline grid and *any potential increased [natural gas] production is not reasonably foreseeable.*” [emphasis added]³⁴ But within the same application, Energy Transfer cites the U.S. Energy Information Administration in highlighting that increased LNG exports directly results in increased domestic natural gas production:

*[natural gas] exports to satisfy growing international demand for natural gas encourage growth in domestic natural gas production. A significant portion of production growth is due to liquefied natural gas (LNG) export demand, which drives the overall increase in natural gas exports.*³⁵

So which is it? For purposes of analyzing the greenhouse gas emission impact, Energy Transfer claims that “any potential increased [natural gas] production is not reasonably

²⁷ www.ahs.dep.pa.gov/NewsRoomPublic/SearchResults.aspx?id=21523&typeid=1

²⁸ https://primis.phmsa.dot.gov/comm/reports/enforce/CaseDetail_cpf_320201005.html

²⁹ https://primis.phmsa.dot.gov/comm/reports/enforce/CaseDetail_cpf_120205001.html

³⁰ https://primis.phmsa.dot.gov/comm/reports/enforce/CaseDetail_cpf_420165020.html

³¹ https://primis.phmsa.dot.gov/comm/reports/enforce/CaseDetail_cpf_120185010.html

³² www.ahs.dep.pa.gov/NewsRoomPublic/articleviewer.aspx?id=21987&typeid=1

³³ https://primis.phmsa.dot.gov/comm/reports/enforce/CaseDetail_cpf_42022010NOPV.html

³⁴ *Application*, at page 48.

³⁵ *Application*, at page 41.

foreseeable” but for purposes of claiming that its request for exports won’t result in domestic supply shortages, it boldly claims the complete opposite. This discrepancy results in a fatal error for the application.

DOE Must Perform An EIS Of Lake Charles, As FERC’s EIS Is 8 Years Old, And The Application Fails To Incorporate Relevant Research Showing Climate Harm Of LNG Exports

The last comprehensive Environmental Impact Assessment of the proposed Lake Charles LNG export facility was conducted by FERC during the Obama Administration.³⁶ This EIS is therefore stale and can no longer be relied upon by the Department of Energy to determine whether the project is consistent with the public interest.

Energy Transfer’s reliance on the DOE’s greenhouse gas emission study from the Trump Administration is outdated and contradicted by newer, more informed research.³⁷ Attached as Exhibit A is Dr. Robert W. Howarth’s *The Greenhouse Gas Footprint of Liquefied Natural Gas (LNG) Exported from the United States*, which determines that “total greenhouse gas emissions from LNG are larger than those from coal, ranging from 24% to 274% greater.” This new research demonstrates that Energy Transfer’s proposed LNG exports will result in increased pollution and greenhouse gas emissions, and therefore cannot be “consistent with the public interest”.

Energy Transfer’s claim that emissions may be mitigated by “preliminary and potential design enhancements to improve efficiency and reduce greenhouse gas emissions, including the incorporation of a carbon capture and sequestration (“CCS”) component to the Liquefaction Project”³⁸ are, as the application clearly states, “preliminary” and therefore purely speculative and unreliable for purposes of determining compliance with the Natural Gas Act and NEPA. The application doesn’t even identify the “third party” that is allegedly developing the CCS for the project. This supposed CCS project may be as substantive as scribbles on a cocktail napkin, for all we know, as the application states that Energy Transfer has only had “initial discussions with FERC regarding such CCS component but any incorporation of it in the FERC process would not occur until sometime well after the start of construction of the Liquefaction Project.”³⁹

³⁶ December 17, 2015 *Order*, Docket Nos. Docket Nos. CP14-119, CP14-120 and CP14-122 <https://elibrary.ferc.gov/eLibrary/filedownload?fileid=01DA5B53-66E2-5005-8110-C31FAFC91712>

³⁷ *Application*, at page 32.

³⁸ *Application*, at page 20.

³⁹ *Application*, at page 21.

Energy Transfer’s Community Engagement and Environmental Justice Discussion Appears To Only Involve Activities That Qualify As Tax Deductions, And Fails To Include Tax Avoidance Deals

Energy Transfer claims that hundreds of thousands of dollars in charitable donations demonstrate that the company has successfully engaged the community and addressed environmental justice concerns.⁴⁰ But most of the activities that Energy Transfer describe appear to qualify as charitable deductions to allow Energy Transfer to reduce its federal and state tax liability. Energy Transfer’s discussion in this section cannot be used to determine compliance with the Natural Gas Act or NEPA until the company details how these charitable donations reduced its federal and state tax liability.

Furthermore, the application lists taxes paid by Energy Transfer to bolster its claim that the project meets the public interest test,⁴¹ but omits whether Energy Transfer has negotiated any tax avoidance deals under Louisiana’s Industrial Tax Exemption Program or any other program administered by the Louisiana Board of Commerce and Industry, Calcasieu Parish, or other state, local or federal program. Energy Transfer must disclose any and all such tax avoidance deals it has negotiated in order for the Department of Energy to determine the net tax benefit of the proposed project.

The Application Omits Evidence That LNG Exports Have Contributed To Domestic Supply Shortages

The application omits references to recent domestic supply shortages triggered in part by surging LNG exports. During Winter Storm Uri, the State of Texas faced severe natural gas supply shortages that resulted in the Governor issuing an emergency Disaster Declaration, requesting a halt to LNG exports from the state’s largest LNG exporter.⁴² Energy Transfer’s application provides no information on the procedures to halt its requested LNG exports in the event of domestic gas supply shortages.

The North American Electric Reliability Corporation’s forthcoming *2023-2024 Winter Reliability Assessment*, available November 8, finds that much of North America is at an elevated risk of insufficient energy supplies and is highly exposed to risks of energy emergencies in extreme winter conditions.⁴³ The application fails to incorporate the impact that LNG exports have in exacerbating the supply shortages that NERC has identified.

⁴⁰ *Application*, at page 26.

⁴¹ *Application*, at page 28.

⁴² www2.tceq.texas.gov/oce/eer/index.cfm?fuseaction=main.getDetails&target=350574

⁴³ https://twitter.com/NERC_Official/status/1719731639238934676

Energy Transfer’s Proposed Exports Are Inconsistent With The Public Interest As They Threaten Higher Domestic Energy Prices

Energy Transfer’s application claims that its requested export authorization is consistent with the public interest, in part because of the conclusions of DOE’s macroeconomic study conducted during the Trump Administration.⁴⁴ Not only is this 2018 study discredited, but an updated analysis by the U.S. Energy Information Administration, released May 23, 2023, concludes that increased LNG exports directly result in higher energy prices for American consumers: “higher LNG exports create a tighter domestic natural gas market (all else held equal), increasing domestic natural gas prices”.⁴⁵ Utilizing the data in this new EIA report, Public Citizen calculates that domestic consumers will face \$14.3 billion in higher annual natural gas costs in 2050 as a result of LNG exports—including those proposed by Energy Transfer.⁴⁶ This new EIA analysis not only disproves the 2018 study cited in the application, but demonstrates that the requested LNG exports are inconsistent with the public interest.

*Macroeconomic Outcomes of Market Determined Levels of U.S. LNG Exports*⁴⁷—cited by applicants as evidence that their requested natural gas exports will be consistent with the public interest—has aged poorly. It assumes that consumer welfare—defined as the present value measure of the standard of living of all U.S. households—was directly and beneficially linked with higher LNG exports.⁴⁸ The 2018 study gave only a 3% probability that significant LNG exports would result in domestic prices above \$10/MMBtu, concluding that “increasing U.S. LNG exports under any given set of assumptions about U.S. natural gas resources and their production leads to only small increases in U.S. natural gas prices.”⁴⁹ Furthermore, the study claims that “as U.S. LNG exports increase ... households who hold shares in companies that own liquefaction plants receive additional income from take-or-pay tolling charges for LNG exports. These additional sources of income for U.S. consumers outweigh the income loss associated with higher energy prices.”⁵⁰

Spot benchmark natural gas prices on the west and east coast United States in December 2022 exceeded \$30/MMBtu in December 2022, forcing Americans to pay higher prices for gas than Ukrainians, in part because of U.S. LNG exports.⁵¹

The 2018 study not only is contradicted by EIA’s 2023 report, but by recent data and events. In 2023, the United States is the world’s largest natural gas producer *and*

⁴⁴ *Application*, at page 32.

⁴⁵ *Effects of Liquefied Natural Gas Exports on the U.S. Natural Gas Market*, at page 7, www.eia.gov/outlooks/aeo/IIF_LNG/

⁴⁶ Using price differential between High LNG Case and Fast Builds Plus High LNG Price in 2050, and applying that to domestic demand (leaving out exports and pipeline fuel).

⁴⁷ www.energy.gov/sites/prod/files/2018/06/f52/Macroeconomic%20LNG%20Export%20Study%202018.pdf


⁴⁸ At page 20.

⁴⁹ At page 55.

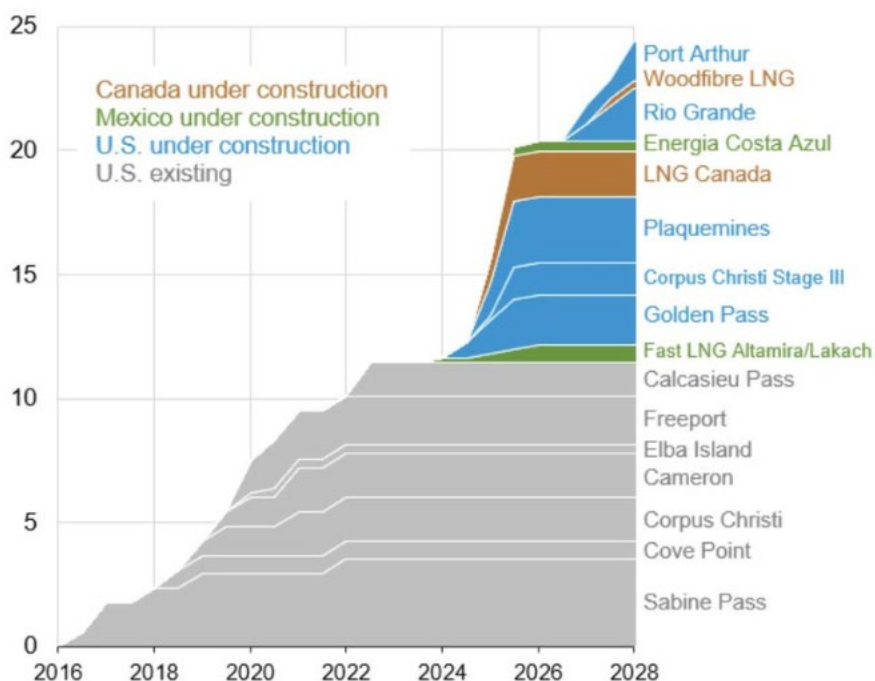
⁵⁰ At page 67.

⁵¹ See www.eia.gov/todayinenergy/detail.php?id=55279 and www.naturalgasintel.com/haynesville-output-to-top-16-bcf-d-as-total-lower-48-production-continues-to-climb/

exporter. Sixty percent of our domestically produced petroleum is now exported,⁵² and 20% of our natural gas is now allocated for export.⁵³ These numbers will only increase as domestic demand continues to flatten and export infrastructure capacity expands. While oil markets—and domestic gasoline prices—have long been directly influenced by global calamities, natural gas had been insulated from upheaval beyond our shores because until 2016 we lacked LNG export capacity. But LNG exports now for the first time in U.S. history tether American consumers to global disruptions, radically upending domestic energy markets, and forcing American families to compete with Berlin and

North America liquefied natural gas export capacity by project—existing and under construction (2016–2027) 

billion cubic feet per day



Data source: U.S. Energy Information Administration, *Liquefaction Capacity File*; trade press.

Note: LNG=liquefied natural gas. Export capacity shown is project's baseload capacity.

Online dates of LNG export projects under construction are estimates based on trade press.

Beijing for U.S. produced energy. Natural gas exports are directly responsible for Americans paying higher prices to heat and cool their homes.

The United States is far and away the world's largest natural gas producer, accounting for 25% of global production every day—producing as much as the next two biggest

⁵² <https://twitter.com/TysonSlocum/status/1617998886660112384>

⁵³ www.citizen.org/article/letter-to-dept-of-energy-to-protect-consumers-from-lng-exports/

(Russia and Iran) combined,⁵⁴ with U.S. production reaching an all-time high in 2023.⁵⁵ At the same time, natural gas exports have exploded. Exports via pipeline to Mexico and

Canada, combined with LNG exports by ship account for 20% of domestic gas production—up from 6% in 2015, establishing the United States as the world’s largest LNG exporter.⁵⁶

These record exports have come with a tragic cost: American households, power producers and other consumers are now forced to compete with their counterparts in Berlin and Beijing, globalizing domestic benchmark prices and exposing Americans to higher prices and increased volatility.⁵⁷ U.S. natural gas price volatility is at the highest levels since the 1990s.⁵⁸ Of course, extreme price volatility means that prices whipsaw up and down—so just because prices right now may be low, increased LNG exports threaten higher prices in the medium- and long-term.

The Federal Energy Regulatory Commission’s 2022-23 *Winter Energy Market and Reliability Assessment* concludes that “continued growth in net exports, including from liquified natural gas (LNG) export facilities, will place additional pressure on natural gas prices this winter . . . Traditionally, domestic fundamentals drive U.S. natural gas prices; this winter, international markets will likely also affect U.S. natural gas markets and prices . . . the expansion of LNG export capability has integrated formerly disparate North American regional natural gas markets into the global market . . . In New England, high global LNG prices are contributing to higher winter natural gas futures prices, as the New England regional natural gas market relies on imported LNG in the winter to meet natural gas demand and must compete for LNG volumes with Europe and Asia.”⁵⁹

The Center For American Progress released a report today demonstrating that record LNG exports expose American consumers to higher prices.⁶⁰

Natural gas futures fell 25% after the June 8, 2022 explosion took the Freeport LNG export terminal out of commission, as traders understood that reduced natural gas exports would result in increased supply for American consumers.⁶¹

⁵⁴ www.eia.gov/international/data/world/natural-gas/dry-natural-gas-production

⁵⁵ www.eia.gov/dnav/ng/hist/ngm_epgo_fgw_nus_mmcfdm.htm

⁵⁶ www.eia.gov/todayinenergy/detail.php?id=60361

⁵⁷ “Surging US LNG exports hike domestic gas prices amid global supply crunch,” www.spglobal.com/marketintelligence/en/news-insights/latest-news-headlines/surging-us-lng-exports-hike-domestic-gas-prices-amid-global-supply-crunch-67508815

⁵⁸ David Uberti and Ryan Dezember, “Why Gas Bills Are Going Crazy—With No End in Sight,” March 15, 2023, www.wsj.com/articles/natural-gas-prices-energy-bills-ea3ea9da

⁵⁹ <https://ferc.gov/media/report-2022-2023-winter-assessment>

⁶⁰ www.americanprogress.org/article/lng-exports-raise-natural-gas-prices-for-americans/

⁶¹ Ryan Dezember, “Natural-Gas Prices Plunge After Extended Outage at Texas LNG Facility”, June 14, 2022, www.wsj.com/articles/natural-gas-prices-plunge-after-extended-outage-at-texas-lng-facility-11655235895

These high prices are creating significant economic hardship for tens of millions of American families. Twenty-six percent of respondents to a U.S. Census Bureau survey taken in the summer of 2022 said they had forgone necessities like food or medicine to pay their energy bills sometime during the preceding year.⁶² Rising energy costs—anchored by higher natural gas prices stemming in part from record LNG exports—are the biggest factor driving inflation in the U.S.⁶³

Energy Transfer’s Contracts Will Empower China, Violating The Public Interest

Energy Transfer’s application notes that it has agreed to export from Lake Charles 3.4 mtpa of LNG with three entities based in the communist People’s Republic of China.⁶⁴ Energy Transfer’s remaining contracts are with marketers that will likely prioritize Asian markets over those in Europe.⁶⁵ China—not Europe—will be the center of LNG demand growth, and therefore China is the most likely long-term destination for Energy Transfer’s proposed exports. China’s domination of long-term supply contracts renders it as the global LNG price-maker, as it can either import the LNG cargoes or resell them on the open market, shifting the economic advantage of pricing away from the United States and onto China.⁶⁶ Indeed, the International Energy Agency concludes that natural gas “demand growth is almost entirely concentrated in fast-growing Asian markets” with gas demand rise in Asia Pacific to exceed the rest of the world *combined* by 2024.⁶⁷

The application notes that Energy Transfer signed “a 20-year term LNG Sale and Purchase Agreement with Gunvor Singapore Pte Ltd. for 2.0 mtpa of LNG”.⁶⁸ But it fails to note that in October 2022, the London Court of International Arbitration determined that Gunvor had engaged in unlawful price-gouging of LNG shipments to Pakistan.⁶⁹ In October 2019, Swiss regulators found Gunvor to be criminally liable for corruption, bribery and other offenses related to its operations in the Congo Republic and Côte

⁶² www.census.gov/data/tables/2022/demo/hhp/hhp48.html

⁶³ www.bls.gov/cpi/

⁶⁴ *Application* at pages 17-18.

⁶⁵ Ron Bousso, *Energy giants’ LNG trading results reveal diverging regional bets*, November 6, 2023, www.reuters.com/business/energy/energy-giants-lng-trading-results-reveal-diverging-regional-bets-2023-11-03/

⁶⁶ *China Is Buying Gas Like There’s Still an Energy Crisis*, July 1, 2023, www.bloomberg.com/news/articles/2023-07-02/china-is-buying-natural-gas-like-there-s-still-an-energy-crisis

⁶⁷ *Medium-Term Gas Report 2023*, <https://iea.blob.core.windows.net/assets/f2cf36a9-fd9b-44e6-8659-c342027ff9ac/Medium-TermGasReport2023-IncludingtheGasMarketReportQ4-2023.pdf>

⁶⁸ *Application*, at page 17.

⁶⁹ Faseeh Mangi and Stephen Stapczynski, *Pakistan Wins Arbitration Case Against Gunvor Over LNG Payments*, October 12, 2022, www.bloomberg.com/news/articles/2022-10-12/pakistan-wins-arbitration-case-against-gunvor-over-lng-payments

d'Ivoire, forcing the commodity trader to pay a US\$95 million penalty.⁷⁰ At the same time it settled the allegations with the Swiss, Gunvor agents made illegal payments to secure oil deals in Ecuador,⁷¹ with the U.S. Department of Justice reaching a criminal settlement with a former Gunvor trader for Foreign Corrupt Practices Act violations, and Gunvor disclosing that the U.S. Commodity Futures Trading Commission is investigating.⁷² It is not consistent with the public interest to allow companies found to have engaged in LNG price gouging and bribery to export U.S. LNG.

In conclusion, Energy Transfer's application is clearly deficient and fails to demonstrate that its proposed exports are consistent with the public interest.

Respectfully submitted,

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⁷⁰ Julia Payne, *Gunvor must pay \$95 million for Congo oil corruption: Swiss prosecutors*, October 17, 2019, www.reuters.com/article/us-gunvor-grp-congo-corruption/gunvor-must-pay-95-million-for-congo-oil-corruption-swiss-prosecutors-idUSKBN1WWoZ9

⁷¹ Andy Hoffman, *New Gunvor Bribery 'Skeleton' Haunts Oil Trader's Reform Pledge*, April 7, 2021, www.bloomberg.com/news/articles/2021-04-07/new-gunvor-bribery-skeleton-haunts-oil-trader-s-reform-pledge

⁷² Julia Payne, *Energy trader Gunvor Group says U.S. CFTC investigating Ecuador deals*, September 28, 2021, www.reuters.com/business/energy/energy-trader-gunvor-group-says-us-cftc-investigating-ecuador-dealings-2021-09-28/

VERIFICATION

Pursuant to 10 CFR § 590.103(b), I, Tyson Slocum, declare that I am Energy Program Director for Public Citizen, Inc. and am authorized to make this verification; that I have authored and read the foregoing filing and that the facts therein stated are true and correct to the best of my knowledge, information, and belief.

Pursuant to 28 U.S.C § 1746, I declare under penalty of perjury that the foregoing is true and correct. Executed on November 6, 2023.

Tyson Slocum

Tyson Slocum
Energy Program Director
Public Citizen, Inc.

CERTIFICATE OF SERVICE

I hereby certify that I have this day served the foregoing document upon the applicant and intervenors for this docketed proceeding in accordance with 10 CFR § 590.107(b). Dated at Washington, DC this 6th day of November 2023.

Signed,

Tyson Slocum

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EXHIBIT A

The Greenhouse Gas Footprint of Liquefied Natural Gas (LNG) Exported from the United States

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Pre-print copy of manuscript submitted to a peer-reviewed journal on Oct 24, 2023.

Subject to revision before final publication.

Keywords: methane, methane emissions, fugitive emissions, methane slippage, boil off, LNG tanker, liquefaction, lifecycle analysis, global warming potential, GWP, GWP₂₀

Abstract

Before 2016, the export of liquefied natural gas (LNG) from the United States was banned, but since that time exports have risen rapidly, fueled in part by the rapid growth in shale gas production. Today the United States is the largest exporter of LNG. This paper presents a full lifecycle assessment for greenhouse gas emissions from LNG. These emissions depend on the type of tanker used to transport the LNG, with emissions far larger when LNG is transported by older, steam-powered tankers burning heavy fuel oil. The largest source of emissions in this case is from venting of methane lost by evaporation from the storage tanks, called boil off. More modern tankers, whether powered by steam or 4-stroke or 2-stroke engines, can capture this boil-off methane and use it for their power, thereby greatly lowering methane emissions. For scenarios for LNG that is transported by more modern tankers, the single largest source of emissions in the full lifecycle are those from the production, processing, storage, and transport of the natural gas that comprises the feedstock for LNG. Fugitive emissions of unburned methane are particularly important, but so are the carbon dioxide emissions from the energy intensive processes behind modern shale gas extraction. In all of the scenarios considered, across all types of tankers used to transport LNG, methane emissions exceed emissions of carbon dioxide from the final combustion of LNG. Carbon dioxide emissions other than from this final combustion are significant, but smaller than the carbon dioxide from the final combustion. While some proponents of LNG have argued it has a climate benefit by replacing coal, the analysis presented here disproves this. Across all scenarios considered, total greenhouse gas emissions from LNG are larger than those from coal, ranging from 24% to 274% greater.

Introduction

In this paper, I analyze the greenhouse gas footprint of liquefied natural gas (LNG) produced in and exported from the United States. The United States prohibited the export of LNG before 2016, but since the lifting of the ban at that time, exports have risen rapidly (DiSavino 2017). In 2022 the United States became the largest exporter of LNG globally (EIA 2023). Exports doubled between 2019 and 2023, and they are predicted to double again over the next four years (Joselow and Puko 2023). As of 2022, the LNG exported from the United States represented almost 20% of all global LNG transport (based on US export of 104.3 billion m³ and total global transport of 542 billion m³; Statista 2023-a, 2023-b).

Proponents of this increase in LNG exports from the United States often claim a climate benefit, arguing that the alternative to the increased export of LNG both to Europe and Asia would be greater use of coal (Sneath 2023; Joselow and Puko 2023). In fact, even though carbon dioxide emissions are greater from burning coal than from burning natural gas, methane emissions can more than offset this difference (Howarth et al. 2011; Howarth 2014; Howarth and Jacobson 2021; Gordon et al. 2023). As a greenhouse gas, methane is more than 80 times more powerful than carbon dioxide when considered over a 20 year period (IPCC 2021), and so even small methane emissions can have a large climate impact. Clearly, greenhouse gas emissions from LNG must be larger than from the natural gas from which it is made, because of the energy needed to liquefy the gas, transport the LNG, and re-gasify it. The liquefaction process alone is highly energy intensive (Hwang et al. 2014; Pace Global 2015). A full

lifecycle assessment is required to determine how much greater the full magnitude of these LNG greenhouse gas emissions are.

There are relatively few previous lifecycle assessments of greenhouse gas emissions from LNG in the peer-reviewed literature, and as far as I am aware, none since the start of export of LNG from the United States in 2016 (Tamura et al. 2001; Okamura et al. 2007; Abrahams et al. 2015). Some prior assessments did not consider upstream emissions of methane from the production and use of natural gas, and none have considered the emissions of carbon dioxide associated with the production, processing, and transport of natural gas. Most natural gas production in the United States is shale gas produced by high volume hydraulic fracturing and high-precision directional drilling, two technologies that only began to be used commercially to develop shale gas in this century (Howarth 2019, 2022-a). It is the rapid increase in shale gas production in the United States that has allowed and driven the increase in export of LNG (Joselow and Puko 2023). Shale gas production is quite energetically intensive, and the related emissions of carbon dioxide need to be considered in any full lifecycle assessment of LNG. Further, methane emissions from shale gas can be substantial. Since 2008, methane emissions from shale gas in the United States may have contributed one third of the total (and large) increase in atmospheric methane globally (Howarth 2019, 2022-a).

The types of ships used to transport LNG have been changing in recent years, and the global fleet now consists of both steam-powered tankers and tankers powered by internal-combustion engines, particularly 4-stroke engines, although increasingly 2-stroke engines are coming into play as well (Bakkali and Ziomas 2019; Pavlenko et al. 2020). Some steam-powered vessels can only burn heavy fuel oil, but other steam-powered tankers as well as all of the tankers powered by 4-stroke and 2-stroke engines can burn fuel oils or LNG. Emissions of both carbon dioxide and methane vary significantly across these different tankers and fuels. For example, older tankers that burn only heavy fuel oils are more likely to vent unburned methane to the atmosphere from LNG that evaporates from the storage tanks, a process called “boil off.” More modern tankers can capture and use the LNG, and thus vent less boil-off methane (Bakkali and Ziomas 2019). Tankers powered by 4-stroke and 2-stroke engines are more efficient in their fuel use than are steam-powered tankers, and so have lower carbon dioxide emissions (Pavlenko et al. 2020). However, when they burn LNG as a fuel, some methane slips through unburned and is emitted in the exhaust gases (Pavlenko et al. 2020; Balcombe et al. 2021). These differences in emissions from tankers have not been fully explored in earlier lifecycle assessments and is a major focus of the analysis I present here. My analysis relies heavily on two recent, comprehensive assessments of the use of LNG as a marine fuel (Pavlenko et al. 2020; Balcombe et al. 2021).

Here, I present a full lifecycle assessment for the LNG system, from the production of shale gas that provides the feedstock through to combustion by the final consumer. My analysis focuses on emissions of carbon dioxide and methane and excludes other greenhouse gases such as nitrous oxide that are very minor contributors to total emissions for natural gas and LNG systems (Howarth 2020; Pavlenko et al. 2020). Included are emissions of carbon dioxide and methane at each step along the supply chain, including those associated with the production, processing, storage, and transport of the natural gas that is the feedstock for LNG (referred to as upstream and midstream emissions), emissions from the energy used to power the liquefaction of natural gas to LNG, emissions from the energy

consumed in transporting the LNG by tanker, emissions from the energy used to re-gasify LNG to natural gas, and emissions from the delivery of gas to and combustion by the final consumer.

Methods

Calculations use net calorific values (also called lower heating values). Note that the use of net calorific values is standard in most countries, but the United States uses gross calorific values. Emissions expressed using net calorific values are 10% greater than when using gross calorific values (Hayhoe et al. 2002; Howarth et al. 2011; Howarth 2020). LNG and heavy fuel oils are assumed to have energy densities of 48.6 MJ/kg and 39 MJ/kg respectively (Engineering Toolbox 2023). I convert methane emissions to carbon dioxide equivalents using a 20-year Global Warming Potential (GWP₂₀) of 82.5 and a 100-year GWP₁₀₀ of 29.8 (IPCC 2021).

Upstream plus midstream emissions:

Upstream plus midstream emissions are based on the total quantity of natural gas and other fuels consumed in the LNG endeavor. In addition to the natural gas burned by the final consumer, natural gas and LNG are consumed in the liquefaction, tanker transport, and regasification processes. The procedure for estimating quantities for each of these is presented below, and upstream plus midstream emissions are calculated from these total quantities and empirically determined emission factors. The methane emission factor for natural gas is based on a recent synthesis of data from 18 studies that used airplane flyovers of satellites to estimate emissions across the major shale gas field in the United States (Howarth 2022-a, 2022-b). The mean value from these studies weighted by the volume of gas production in each of the fields is 2.6% of natural gas production (Howarth 2022-b). This does not include methane that is emitted from gas distribution systems, which are separately considered. Methane emissions from producing fuel oil are estimated as 0.10 g CH₄/MJ (Howarth et al. 2011). For indirect carbon dioxide emission, I use values developed by the State of New York, converting these to metric units and net calorific values: 12.6 g CO₂/MJ for natural gas and 15.8 g CO₂/MJ for fuel oil (DEC 2021, table A.1).

Liquefaction:

A substantial amount of energy is required to liquefy methane into LNG, and this energy is provided by burning natural gas. That is, natural gas is both the feed source and energy source used to produce LNG (Hwang et al. 2014). Carbon dioxide emissions from the combustion of the gas powering the plants have been measured at many facilities in Australia, the US, Brunei, Malaysia, Indonesia, Oman, and Qatar, with emissions varying from 230 to 410 g CO₂/kg of LNG liquefied (Tamura et al. 2001; Okamura et al. 2007). Here, I use the mean estimate of 270 g CO₂/kg LNG liquefied. This is comparable to the value used by Balcombe et al. (2021) in their lifecycle assessment and is at the very low end of emission estimates provided by Pace Global (2015) for guidance for new plants built in the United States: 260 to 370 g CO₂ per kg of LNG liquefied.

In addition, carbon dioxide present in raw natural gas is emitted to the atmosphere as the methane in natural gas is liquefied. These emissions are estimated as 23 to 90 g CO₂/kg of LNG liquefied (Tamura et al. 2001; Okamura et al. 2007). Here I use a mean estimate of 57 g CO₂/kg. In addition, some natural gas is flared at liquefaction plants to maintain gas pressures for safety, with a range of measured carbon dioxide emissions from zero up to 50 g CO₂/kg of LNG, and a mean estimate of 18 g CO₂/kg (Tamura et al. 2001; Okamura et al. 2007). Further, some natural gas is vented as unburned methane at LNG liquefaction plants. For this, I use the central value of 0.35% of the LNG formed from Balcombe et al. (2021) who report a range of 0.011% to 0.63%. This corresponds to 3.5 g CO₂/kg of LNG liquified.

Some of the LNG that is liquefied is consumed in transporting and handling the LNG before it is consumed by the final consumer, as considered further below. Therefore, emissions of both methane and carbon dioxide from the liquefaction process are larger when expressed per kg of final consumption than per kg of LNG liquefied. In my analyses, this difference is estimated from the total amount of LNG that must be liquefied in order to provide a unit of LNG for final consumption.

Boil off of methane:

Leakage of heat through insulation causes some LNG to evaporate (boil off) as methane gas, and this must be removed from the tanks to maintain pressure. During loading and unloading, an estimated 0.45% of the LNG being loaded is boiled off (Hassan et al. 2009). This is generally used to power operations at the port facilities or flared to the atmosphere. For this analysis, I assume all of the boil off during loading and unloading is released as carbon dioxide emissions, with zero methane emissions. This underestimates methane emissions to some extent, but there are insufficient data available to robustly estimate these. The carbon dioxide emissions from the boil off during loading and unloading is added to the tanker carbon dioxide emissions estimated below, although this is a very small contribution to those emissions.

Boil off also occurs from tankers during transport at rates between 0.1% and 0.17% of the LNG cargo load per day (Gerlmyer et al. 2003; Hassan et al. 2009; BrightHub Engineering 2022). The ambient temperature is important, and rates of 0.1% per day are characteristic at 5° C while 0.17% per day is characteristic at 25° C (Hassan et al. 2009). Note that boil off occurs not only during the laden voyage transporting the LNG: some LNG is retained as ballast for the return voyage back to the LNG loading terminal, typically 5% of the gross cargo (Hassan et al. 2009). This is necessary to keep the tanks at low temperature, and the mass of methane boiled off per day during the return ballast voyage is essentially the same as during the laden voyage (Hassan et al. 2009). Boiled off methane can be used to fuel many tankers, and in fact contributes 80% of the fuel used globally by the LNG tanker fleet (IMO 2021). In this analysis, I assume that tankers only vent methane from boil off to the atmosphere when the rate of boil off exceeds the use of boil off as a fuel for the tanker (Bakkali and Ziomas 2019). However, some older tankers are not capable of burning boil off, and for these, I assume all boil off is vented to the atmosphere as unburned methane. While some modern tankers are able to reliquefy methane to LNLG, this is not common, and the necessary equipment is absent from older, steam-powered tankers (Hassan et al. 2009).

Fuel consumption rate and emissions from LNG tankers:

My analysis considers four different types of tankers: 1) steam-powered vessels that burn only heavy fuel oil; 2) steam-powered vessels that can use either fuel oil or methane from the boil off of LNG; 3) modern tankers built over the past 20 years that are powered by 4-cycle engines capable of using fuel oil, diesel oil, or methane from LNG boil off; and 4) tankers powered by 2-cycle engines capable of using either diesel oil or boil off. At one time, almost all LNG tankers were powered by steam engines that burned only heavy fuel oil, and some of these are still in operation. However, the LNG tanker fleet today is dominated by steam-powered engines that can burn LNG and 4-stroke engines (Bakkali and Ziomas 2019; Pavlenko et al. 2020). As of 2019, LNG tankers powered by 2-stroke engines were rare although at least one was in construction and another four were planned (Bakkali and Ziomas 2019; Pavlenko et al. 2020).

In this paper, I assume that any tanker that can use LNG for its fuel will meet virtually all of its fuel needs from this source. Boil off in excess of the energy needs of the tanker is assumed to be vented to the atmosphere as unburned methane. While some vessels have equipment for reliquefying methane to LNG rather than venting, this is not common, particularly on older steam-powered tankers, which typically vent boil-off methane (Hassan et al. 2009). Although most tankers can burn fuel oil and/or diesel oil, consumption of these fuels tends to be very low compared to LNG (Raza and Schoyen 2014; Bakkali and Ziomas 2019; Balcombe et al. 2022), except in those rare times when LNG prices are high relative to fuel oils (Jaganathan and Khasawneh 2021). And while it might be expected that tankers would burn fuel oil if the rate of boil off were not sufficient, many tankers instead are likely to force more boil off for their fuel, at rates greater than the 0.1% to 0.17% per day, in part to meet stringent sulfur emission standards for ships that went into effect in 2020 (Bakkalil and Ziomas 2019). Fuel consumption rates are assumed to be 175 tons LNG per day for steam-powered tankers, 130 tons LNG per day for ships powered by 4-cycle engines, and 108 tons LNG per day for ships powered by 2-cycle engines (Raza and Schoyen 2014; Bakkali and Ziomas 2019). Carbon dioxide emissions from the consumption of the LNG are taken as 2,750 g CO₂/ton of LNG (IMO 2021). Carbon dioxide emissions and fuel oil use for those steam-powered tankers that can only burn heavy fuel oils are scaled to those from LNG-powered tankers, assuming 80 g CO₂/MJ for heavy fuel oil and 55 g CO₂/MJ for LNG (Pavlenko et al. 2020).

Some unburned methane is emitted in the exhaust streams from LNG tankers, particularly from those powered by 4-stroke and 2-stroke engines fueled by LNG. For vessels powered by 4-stroke engines, I assume this methane release is 3.1% of the LNG burned by the tanker, based on data in (Balcombe et al. 2021). This emission rate is slightly lower than assumed by Pavlenko et al. (2020). For tankers powered by 2-stroke engines, I assume a 3.8% methane emission rate based on data in Balcombe et al. (2022) for a newly commissioned tanker. Note that this is higher than 2.3% reported in Balcombe et al. (2021) or values reported in Pavlenko et al. (2020), due to emissions of unburned methane from electric generators, which are necessary for tankers powered by 2-stroke engines. Methane emissions in the exhaust of steam-powered tankers is negligible and are ignored in this analysis (Pavlenko et al. 2020).

Volume of LNG cargo and length of tanker voyages:

Most LNG tankers have total capacities between 125,000 to 150,000 m³ (Bai and Jin 2016). In this analysis, I use a value of 135,000 m³, or 67,500 tons LNG (Raza and Schoyne 2014). Generally, not all of the gross LNG cargo is unloaded at the point of destination. Some is retained for the return voyage, both to serve as fuel and to keep the LNG tanks supercooled. Here, I assume that 90% of the cargo is unloaded (Raza and Schoyne 2014). Therefore, the average delivered cargo is 60,800 tons LNG.

For the length of the voyage, I use the global average distance for LNG tankers (16,200 km each way) as well as the shortest regular commercial route from the US (9,070 km each way, Sabine Pass, TX to the UK;) and the longest regular commercial route from the US (29,461 km each way, Sabine Pass, TX to Shanghai; Oxford Institute for Energy Studies 2018). The vast majority of LNG exports from the US are from the Sabine Pass area, so these distances well characterize US exports (Joselow and Puko 2023). Considering the average speed of 19 knots (35.2 km per hour; Oxford Institute for Energy Studies), these cruise distances correspond to times of 19 days, 10.7 days, and 35 days each way, respectively. Note that the travel distances for LNG tankers have been increasing over time (Timera Energy 2019). In 2023, a drought limited the capacity of the Panama Canal, leading to LNG tankers from Texas to Asia taking longer routes through the Suez Canal or south of Good Hope in Africa (Williams 2023).

Final distribution and combustion:

In addition to the methane emissions from upstream and midstream sources before the gas is liquefied to become LNG, considered above, emissions occur after regasification and delivery to the final customer. These emissions are less if the gas is used to generate electricity than if it is delivered to homes and buildings. For my baseline analysis, I consider electricity generation. For this, methane emissions from transmission pipelines and storage in the destination country are estimated as 0.32% of the final gas consumption (Alvarez et al. 2018).

When the gas is burned by the final consumer, I assume carbon dioxide emissions of 2,750 g CO₂/ton of LNG delivered. This is based on the stoichiometry of carbon dioxide (44 g/mole) and methane (16 g/mole). It is equivalent to 55 g CO₂/MJ for natural gas (Hayhoe et al. 2002) and is also the value assumed by the IMO 2021) for burning LNG in tankers.

Comparison to coal:

To compare the greenhouse gas footprint of LNG to that of coal, I use values from Howarth (2020) for carbon dioxide emitted during combustion of coal (99 g CO₂/MJ) and for upstream fugitive methane emissions associated with coal (0.20 g CH₄/MJ), converted to net calorific values. For the indirect emissions of carbon dioxide from the production and transportation of coal, I use the value developed by the State of New York (3.1 g CO₂/MJ), converted to metric units and net calorific values (DEC 2021, Table A-1).

Results and Discussion

The rate of LNG used to power tankers is compared with unforced boil off in Table 1, for those tankers that are capable of burning LNG. The unforced boil off predicted from the assumed percentage of gross cargo per day, 0.1% at an ambient temperature of 5° C and 0.17% at a temperature of 25° C (Hassan et al. 2009), is always less than the fuel required for tankers powered by steam engines and 4-stroke engines. This is also true for tankers powered by 2-stroke engines at the lower temperature. My analysis therefore assumes that these tankers force additional boil off to meet their fuel needs (Bakkali and Ziomas 2019), and the total LNG fuel consumption is included in the overall lifecycle assessment for each type of tanker. For tankers powered by 2-stroke engines at the higher temperature, the unforced boil off of 115 tons LNG per day exceed the fuel requirement of 108 tons LNG per day, although not by much (Table 1). All tankers powered by 2-stroke engines are relatively new and are likely to be equipped with equipment to re-liquefy boil off in excess of their fuel needs. Consequently, I assume that no boil off from these tankers is vented to the atmosphere and all is captured. However, steam-powered tankers that cannot use LNG for fuel are older and are extremely unlikely to have the re-liquefaction equipment, so their boil-off methane is assumed to be vented to the atmosphere (Hassan et al. 2009).

Table 2 presents emissions of carbon dioxide, methane, and total combined emissions expressed as CO₂-equivalents for each of the four scenarios considered, using different types of tankers and the global average time for voyages. Emissions are separated into the upstream plus midstream emissions, those from liquefaction of gas into LNG, emissions from the tankers (including from loading and unloading), emissions associated with the final transmission to consumers, and emissions as the gas is burned by the final consumer. These emissions are also summarized in Figure 1, with emissions broken down into the carbon dioxide emitted as the fuel is burned by the final consumer, other carbon dioxide emissions, and emissions of unburned methane. For both Figure 1 and the combined emissions presented in Table 2, methane emissions are compared to carbon dioxide using GWP₂₀ (IPCC 2021). The emissions for the scenario using tankers powered by steam engines burning heavy fuel oil are far larger than for the other three scenarios. This is largely due to the venting to the atmosphere of unburned methane from boil. This venting contributes 36% of the total greenhouse gas emissions for the scenario based on these steam-powered tankers using heavy fuel oil (Table 2).

Carbon dioxide emissions from final combustion are important but not a dominant part of total greenhouse gas emissions across all four scenarios. These final-combustion emissions make 23% of total greenhouse gas emissions (expressed as carbon dioxide equivalents) and up 63% of total carbon dioxide emissions (not including methane) for the case where LNG is transported by steam-powered tankers using heavy fuel oil. For the other three scenarios where tankers burn LNG rather than heavy fuel oil, the emissions from final combustion make up approximately 37% of total greenhouse gas emissions and 67% of all carbon dioxide emissions (Figure 1, Table 2). Even larger than the carbon dioxide emissions from combustion of the LNG by the final customer, though, are upstream and midstream emissions from producing, processing, storing, and transporting natural gas (Table 2). This is true across all scenarios, with these emissions composing 29% of total emissions for the scenario where tankers burn heavy fuel oil and approximately 44% of total emissions in the other three scenarios. Indirect carbon dioxide emissions are an important part of these upstream and midstream emissions, reflecting the use of fossil fuels to power the natural gas extraction and processing systems, but methane emissions from upstream and midstream sources are several times higher across all scenarios (Table 2).

The liquefaction process is an important source of emissions of both carbon dioxide and methane, with methane emissions being somewhat larger (when expressed as carbon dioxide equivalents; Table 2). These liquefaction emissions are the second largest source of emissions, after the upstream and midstream emissions, for all three scenarios where LNG is transported by tankers that burn LNG, although these are dwarfed by boil off methane emissions from tankers for the scenario where the tankers are powered by heavy fuel oil. Tanker emissions dominate for this scenario of LNG being transported by steam-engine tankers that burn heavy fuel oil, but emissions from tankers are relatively small in the other scenarios (Table 2). Of interest, among the tankers that burn LNG, carbon dioxide emissions are greatest for those powered by steam engines, with lower emissions from vessels powered by more modern 4-stroke and 2-stroke engines (Table 2), reflecting greater efficiencies (Table 1). However, methane emissions, which are negligible in the tankers powered by steam engines, are significant in tankers with 4-stroke and 2-stroke engines, with these emissions (expressed as carbon-dioxide equivalents) being larger than carbon dioxide emissions from the exhaust of these vessels (Table 2). These methane emissions result from slippage of methane, that is methane emitted unburned in the exhaust stream (Pavlenko et al. 2020; Balcombe et al. 2021, 2022). As noted above, my analysis assumes no methane emissions from boil off in these tankers.

Methane emissions from the final transmission of gas to the consumer are relatively small, 3.5% or less of total lifecycle greenhouse gas emissions across all of the different tanker scenarios (Table 2). This is because my analysis focuses on the use of LNG to produce electricity, and the transmission pipelines that deliver gas to such facilities generally have moderately low emissions (Alvarez et al. 2018). However, LNG is also used to feed gas into urban pipeline distribution systems for use to heat homes and commercial buildings. Methane emissions for these downstream distribution systems can be quite high, with the best studies in the United States finding that 1.7% to 3.5% of the gas delivered to customers leaks to the atmosphere unburned (see summary in Howarth 2022-b). This corresponds to a range of 1,400 to 2,890 g CO₂-equivalents per kg LNG burned, increasing the total greenhouse gas footprint of LNG by up to 38% above the values shown in Table 1. Emissions from distribution systems are not as well characterized in either Europe or Asia as in the United States (Howarth 2022-b), although one study suggests emissions in Paris, France are in the middle range of those observed in the United States (Defratyka et al. 2021).

My analysis includes scenarios with the shortest and longest cruise distances from the United States, in addition to the world-average distance shown in Figure 1 and Table 2. See Supplemental Tables A and B for emission estimates from these shortest and longest voyages. The shortest distance represents a voyage from the Gulf of Mexico loading port to the United Kingdom, while the longest distance is for a voyage from the Gulf of Mexico to Shanghai, China, not going through the Panama Canal. Not surprisingly, total emissions go down for the shorter voyage and increase for the longest voyage for all four scenarios considered. This is particularly true for the scenario where LNG is transported in steam-powered tankers than burn heavy fuel oil, and is due primarily to differences in methane emissions from boil off, which is a function of time at sea (Supplemental Table A, Supplemental Table B). For all four scenarios, emissions from fuel consumption increase or decrease as travel distances and time at sea increase or decrease. The upstream and downstream emissions and emissions from liquefaction also increase or decrease as the travel distances change, when expressed per mass of

LNG delivered to the final consumer. This reflects an increase or decrease in the total amount of LNG burned or boiled off by tankers during their voyages. Qualitatively, the patterns described above based on world average tanker travel distances (Table 1) hold across the cases for shorter and longer voyages.

Figure 2 compares the greenhouse gas footprint of LNG in different tanker-delivery scenarios to those of coal and natural gas that is not liquefied, using global average tanker voyage distances and GWP_{20} for comparing methane to carbon dioxide. Coal and natural gas have very similar footprints, as we have previously demonstrated (Howarth and Jacobson 2021), indicating that natural gas does not have an inherent climate advantage over coal (Gordon et al. 2023). The footprint for LNG is greater than that of either coal or natural gas even in the case of short cruises using tankers that are powered by LNG, where the LNG emissions are 24% larger than for coal. The LNG footprint is 2.7 times greater than that of coal for the case of long cruises powered by those older tankers that burn heavy fuel oil (Figure 2).

My analysis is sensitive to the global warming potential that is used, as seen in the on-line only Supplemental Figures A and B. Using GWP_{100} instead of GWP_{20} , as was used in Figures 1 and 2, decreases the methane emissions expressed as carbon-dioxide equivalents by a factor of 2.77. While methane emissions are larger than direct or indirect carbon dioxide emissions when considered through the GWP_{20} lens for all four scenarios (Figure 1), the direct emissions of carbon dioxide from the final combustion of LNG are larger than methane emissions across three of the scenarios and equal to them in one when using GWP_{100} (Supplemental Figure A). Similarly, the greenhouse gas footprint of LNG and natural gas relative to coal decreases when viewed through the lens of GWP_{100} (Supplemental Figure B; Figure 2) since methane emissions from coal are less than from natural gas and LNG. Even so, greenhouse gas emissions from LNG are at least as much as from coal, in the scenario with short voyages and tankers burning LNG, to considerably worse than coal, for the scenario of long voyages by tankers burning heavy fuel oil (Supplemental Figure B). Even when using GWP_{100} , LNG is never preferable to coal from the standpoint of greenhouse gas emissions.

While the 100-year time frame of GWP_{100} is widely used in lifecycle assessments and greenhouse gas inventories, it understates the extent of global warming that is caused by methane, particularly on the time frame of the next several decades. The use of GWP_{100} dates back to the Kyoto Protocol in the 1990s, and was an arbitrary choice made at a time when few were paying much attention to the role of methane as an agent of global warming. As the Intergovernmental Panel on Climate Change stated in their AR5 synthesis report, “there is no scientific argument for selecting 100 years compared with other choices” (IPCC 2013). The latest IPCC AR6 synthesis reports that methane has contributed 0.5° C of the total global warming to date since the late 1800s, compared to 0.75° C for carbon dioxide (IPCC 2021). And the rate of global warming over the next few decades is critical, with the rate of warming important in the context of potential tipping points in the climate system (Ritchie et al. 2023). Reducing methane emissions rapidly is increasingly viewed as critical to reaching climate targets (Collins et al. 2018; Nzotungicimpaye et al. 2023). In this context, many researchers call for using the 20-year time frame of GWP_{20} instead of or in addition to GWP_{100} (Howarth 2014, 2020; Ocko et al. 2017; Fesenfeld et al. 2018; Pavlenko et al. 2020; Howarth and Jacobson 2021; Balcombe et al. 2021, 2022). GWP_{20} is the preferred approach in my analysis presented in this paper. Using GWP_{20} , LNG always has a larger greenhouse gas footprint than coal.

In many ways, my analysis may be conservative and underestimate emissions from the global tanker fleet on average, since I am relying on data available from facilities and ships which have allowed researchers access. These are likely to have better operations and lower emissions than average. Balcombe et al. (2022) have argued for the urgent need to expand emissions measurements to a much larger number of tankers that are more representative of the global fleet, and for independent researchers to conduct these measurements. My analysis assumes that those tankers that are capable of burning LNG for their propulsion do so, and that boil-off methane is effectively captured and used on these tankers with zero venting of unburned methane. The reality for many tankers may be quite different, with potentially significant venting of methane, as is the case for tankers that cannot burn LNG.

My analysis leads to one strong recommendation: the venting of unburned methane from tanker boil off should be prohibited, and those older tankers that cannot capture and use boil-off methane should be retired within the near future. These older tankers that burn heavy fuel oil have a very large greenhouse gas footprint (Figure 2).

A broader conclusion is the need to move away from any use of LNG as a fuel as quickly as possible, and to immediately stop construction of any new LNG infrastructure. Those proponents of exporting LNG from the United States are wrong when they assert a climate benefit for the use of LNG over coal (Sneath 2023; Joselow and Puko 2023). In fact, the LNG greenhouse gas footprint is larger than that of coal (Figure 2), and short-term energy needs such as those caused by the Russian invasion of Ukraine are better met by reopening closed coal facilities, on a temporary basis, than by expanding LNG infrastructure. Any new LNG infrastructure will become a stranded asset as society moves away from all fossil fuels. In recent years, many have recognized that we need to move away from natural gas, as well as coal, to address the climate emergency (Gaventa and Patukhova 2021; Figueres 2021). With an even greater greenhouse gas footprint than natural gas, ending the use of LNG must be a global priority.

Acknowledgements

I thank Roxanne Marino for valuable discussions leading to this manuscript. This work was supported by a grant from the Park Foundation and by an endowment given by David R. Atkinson to support the professorship at Cornell University held by Robert W. Howarth.

Disclosure statement

The author confirms that he has no conflicts of interest that would adversely influence this research. The research was supported by a grant from the Park Foundation and by an endowment given by David R. Atkinson to support the professorship at Cornell University held by Robert W. Howarth.

Data availability

All data used in this paper are from publicly available sources that are identified in the manuscript.

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Figure legends

Figure 1. Full lifecycle greenhouse gas footprints for LNG expressed per mass of LNG burned by final consumer, comparing four scenarios where the LNG is transported by different types of tankers. Emissions of methane, the carbon dioxide emitted from the final combustion, and other carbon dioxide emissions are shown separately. Methane emissions are converted to carbon dioxide equivalents using GWP₂₀. See text.

Figure 2. Full lifecycle greenhouse gas footprint for coal and natural gas compared to four scenarios where LNG is transported by tankers that either burn LNG or heavy fuel oil for long or short voyages. Methane emissions are converted to carbon dioxide equivalents using GWP₂₀. See text.

Supplemental Figure A. Full lifecycle greenhouse gas footprints for LNG expressed per mass of LNG burned by final consumer, comparing four scenarios where the LNG is transported by different types of tankers. Emissions of methane, the carbon dioxide emitted from the final combustion, and other carbon dioxide emissions are shown separately. Methane emissions are converted to carbon dioxide equivalents using GWP₁₀₀. See text.

Supplemental Figure B. Full lifecycle greenhouse gas footprint for coal and natural gas compared to four scenarios where LNG is transported by tankers that either burn LNG or heavy fuel oil for long or short voyages. Methane emissions are converted to carbon dioxide equivalents using GWP₁₀₀. See text.

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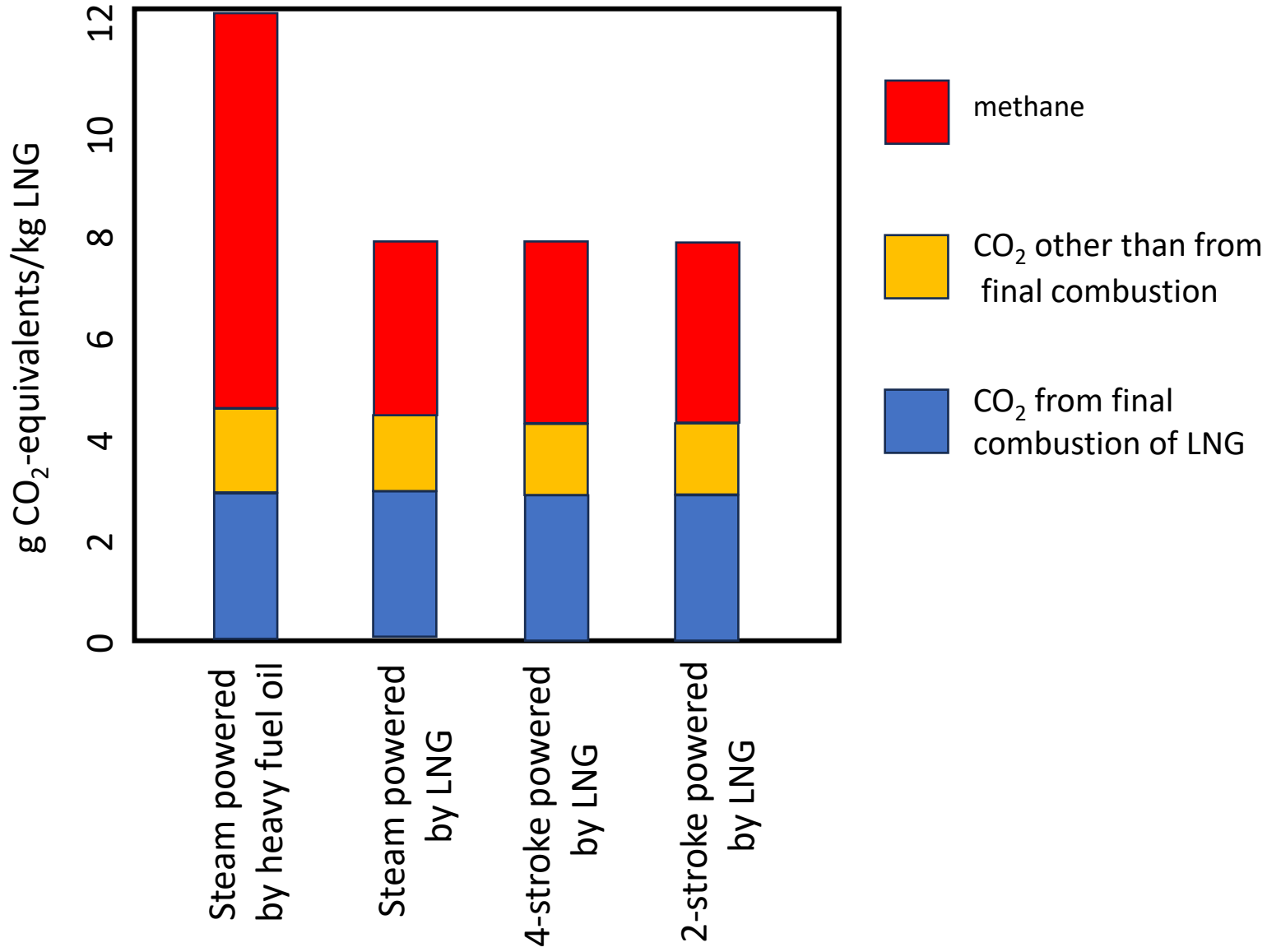
Table 1. Comparison of rate of unforced boil off and fuel needs to power different types of LNG tankers.

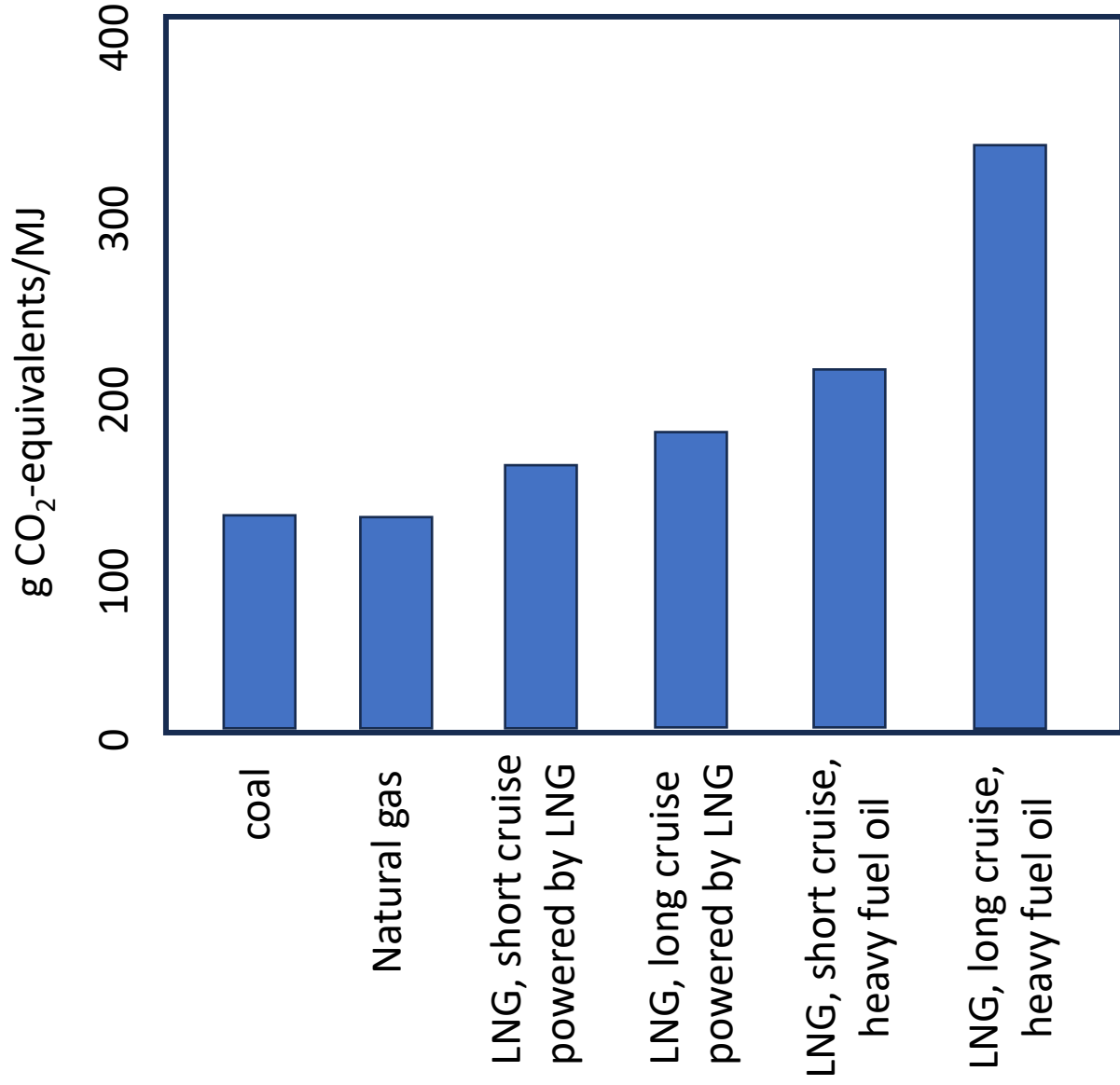
	Tons LNG per day
Unforced boil off, ambient temperature of 5° C	67.5 ^a
Unforced boil off, ambient temperature of 25° C	115 ^a
Steam-powered tanker burning LNG	175
Tanker powered by 4-stroke engines burning LNG	130
Tanker powered by 2-stroke engines burning LNG	108

a) Assumes tanker gross cargo capacity of 67,500 tons. Unforced boil off is that which occurs due to heat leakage to LNG storage tanks. Tankers can increase boil off rate to meet fuel demand.

Table 2. Full lifecycle greenhouse gas emissions for LNG with four different scenarios for shipping by tanker, using world-average voyage times. Methane emissions are shown both as mass of methane and mass of carbon dioxide equivalents based on GWO₂₀. Values are per final mass of LNG consumed.

	Carbon Dioxide	Methane		Total combined
	g CO ₂ /kg	g CH ₄ /kg	g CO ₂ -eq/kg	g CO ₂ -eq/kg
Steam tankers powered by heavy fuel oil				
Upstream & midstream emissions	736	32.2	2,657	3,393
Liquefaction	425	4.2	347	772
Emissions from tanker	425	51.3	4,232	4,657
Final transmission & distribution	---	3.2	264	264
Combustion by final consumer	2,750	---	---	2,750
Total	4,336	90.9	7,500	11,836
Steam tankers powered by LNG				
Upstream & midstream emissions	718	32.5	2,681	3,399
Liquefaction	430	4.4	363	793
Emissions from tanker	300	---	---	300
Final transmission & distribution	---	3.2	264	264
Combustion by final consumer	2,750	---	---	2,750
Total	4,198	40.1	3,308	7,506
4-stroke engine tankers powered by LNG				
Upstream & midstream emissions	700	31.7	2,615	3,315
Liquefaction	435	4.3	355	790
Emissions from tanker	217	2.5	206	423
Final transmission & distribution	---	3.2	264	264
Combustion by final consumer	2,750	---	---	2,750
Total	4,102	41.7	3,440	7,542
2-stroke engine tankers powered by LNG				
Upstream & midstream emissions	691	31.3	2,582	3,273
Liquefaction	430	4.2	347	777
Emissions from tanker	179	2.6	215	394
Final transmission & distribution	---	3.2	264	264
Combustion by final consumer	2,750	---	---	2,750
Total	4,050	41.3	3,408	7,458





Supplemental Table A. Full lifecycle greenhouse gas emissions for LNG with four different scenarios for shipping by tanker, using shortest voyage times. Methane emissions are shown both as mass of methane and mass of carbon dioxide equivalents based on GWO₂₀. Values are per final mass of LNG consumed.

	Carbon Dioxide	Methane		Total combined
	g CO ₂ /kg	g CH ₄ /kg	g CO ₂ -eq/kg	g CO ₂ -eq/kg
Steam tankers powered by heavy fuel oil				
Upstream & midstream emissions	706	31.9	2,632	3,338
Liquefaction	414	4.1	338	752
Emissions from tanker	239	29.0	2,393	2,632
Final transmission & distribution	---	3.2	264	264
Combustion by final consumer	2,750	---	---	2,750
Total	4,109	68.2	5,627	9,736
Steam tankers powered by LNG				
Upstream & midstream emissions	690	31.2	2,574	3,264
Liquefaction	428	4.2	347	775
Emissions from tanker	169	---	---	169
Final transmission & distribution	---	3.2	264	264
Combustion by final consumer	2,750	---	---	2,750
Total	4,037	38.6	3,185	7,222
4-stroke engine tankers powered by LNG				
Upstream & midstream emissions	679	30.1	2,483	3,162
Liquefaction	422	4.1	338	760
Emissions from tanker	122	1.4	116	238
Final transmission & distribution	---	3.2	264	264
Combustion by final consumer	2,750	---	---	2,750
Total	3,973	38.8	3,201	7,174
2-stroke engine tankers powered by LNG				
Upstream & midstream emissions	674	30.0	2,475	3,149
Liquefaction	419	4.1	338	757
Emissions from tanker	101	1.4	116	217
Final transmission & distribution	---	3.2	264	264
Combustion by final consumer	2,750	---	---	2,750
Total	3,944	38.7	3,193	7,137

Supplemental Table B. Full lifecycle greenhouse gas emissions for LNG with four different scenarios for shipping by tanker, using longest voyage times. Methane emissions are shown both as mass of methane and mass of carbon dioxide equivalents based on GWO₂₀. Values are per final mass of LNG consumed.

	Carbon Dioxide	Methane		Total combined
	g CO ₂ /kg	g CH ₄ /kg	g CO ₂ -eq/kg	g CO ₂ -eq/kg
Steam tankers powered by heavy fuel oil				
Upstream & midstream emissions	745	32.7	2,698	3,443
Liquefaction	439	4.3	355	794
Emissions from tanker	783	94.5	3,347	8,579
Final transmission & distribution	---	3.2	264	264
Combustion by final consumer	2,750	---	---	2,750
Total	4,717	134.7	11,113	15,830
Steam tankers powered by LNG				
Upstream & midstream emissions	771	34.9	2,879	3,650
Liquefaction	478	4.7	388	866
Emissions from tanker	554	---	---	554
Final transmission & distribution	---	3.2	264	264
Combustion by final consumer	2,750	---	---	2,750
Total	4,553	42.8	3,531	8,084
4-stroke engine tankers powered by LNG				
Upstream & midstream emissions	739	33.4	2,756	3,495
Liquefaction	459	4.5	371	830
Emissions from tanker	399	4.6	380	779
Final transmission & distribution	---	3.2	264	264
Combustion by final consumer	2,750	---	---	2,750
Total	4,347	45.7	3,771	8,118
2-stroke engine tankers powered by LNG				
Upstream & midstream emissions	723	32.7	2,698	3,421
Liquefaction	450	4.5	371	821
Emissions from tanker	329	4.7	388	717
Final transmission & distribution	---	3.2	264	264
Combustion by final consumer	2,750	---	---	2,750
Total	4,252	45.1	3,721	7,973

