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REPORT

SAILING TO NOWHERE:
LIQUEFIED NATURAL GAS IS NOT AN EFFECTIVE CLIMATE STRATEGY

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Executive Summary

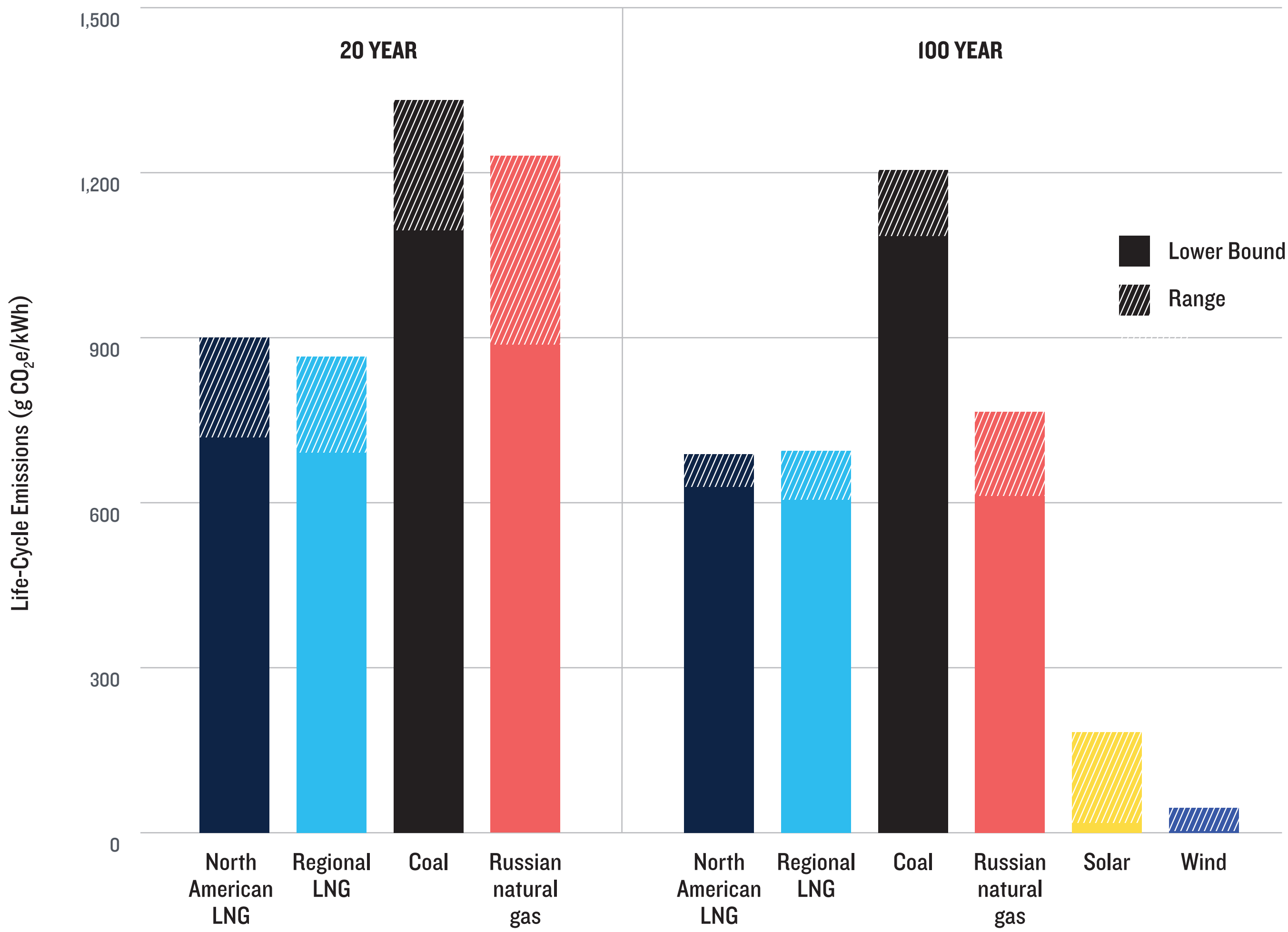
Overseas export of U.S.-produced liquefied natural gas (LNG), gas kept in a liquid form for ease of transport, is rapidly expanding. Historically, gas has been considered a "bridge fuel"—cleaner and with lower carbon dioxide emissions than coal or oil—and a potential tool to help address climate change. However, LNG is neither clean nor particularly low in emissions. In addition, the massive investments in new infrastructure to support this industry, including pipelines, liquefaction facilities, export terminals, and tankers, lock in fossil fuel dependence, making the transition to actual low-carbon and no-carbon energy even more difficult.

Our analysis shows that using LNG to replace other, dirtier fossil fuels, is not an effective strategy to reduce climate-warming emissions. In fact, if the LNG export industry expands as projected, it is likely to make it nearly impossible to keep global temperatures from increasing above the 1.5 degrees Celsius threshold for catastrophic climate impacts.

We found that:

- The greenhouse gas (GHG) emissions from the extraction, transport, liquefaction, and re-gasification of LNG can be almost equal to the emissions produced from the actual burning of the gas, effectively doubling the climate impact of each unit of energy created from gas transported overseas.
- The liquefaction, tanker transport, and re-gasification steps required for overseas export can account for up to 21 percent of total life-cycle emissions for LNG.
- Leaks and intentional releases of methane, a potent GHG, during the extraction and transport of the LNG can constitute up to 14 percent of LNG's life-cycle emissions.
- The GHG footprint of U.S. LNG is, at best, only modestly smaller than that of other fossil fuels. In fact, U.S. LNG can actually have a larger climate footprint than other sources of LNG for many importing countries.
- Over a long-term climate time frame (the next 100 years), the GHG emissions from U.S. LNG are lower than those of coal and some other sources of gas (Figure ES-1). But because methane has a much stronger and more immediate climate impact, the near-term climate effect (over the next 20 years) of LNG is close to that of coal, just 27 to 33 percent lower. This is the same 20-year period during which the Intergovernmental Panel on Climate Change has concluded that emissions must be cut by about 75 percent to avoid catastrophic climate impacts.
- Compared with clean, renewable energy sources, LNG falls far short (Figure ES-1). Life-cycle GHG emissions for solar power are less than 7 percent of LNG emissions; emissions for wind power are even lower, less than 2 percent of LNG emissions.
- If U.S. LNG exports increase as projected, this industry alone will generate 130 to 213 million metric tons of new GHG emissions in the United States by 2030, equal to the annual emissions of 28 to 45 million fossil fuel-powered cars and enough to reverse the 1 percent per year decline in total U.S. GHG emissions measured during the past decade.
- International GHG accounting rules require countries to count only emissions generated within their borders. This means that the U.S. emissions ledger will show a substantial increase in emissions due to its LNG exports while importing countries will artificially lower their "emissions cost" of using this fuel, underestimating its true climate impact by at least 31 percent.
- The estimated social cost for the climate-driven human harm and environmental damage—a cost borne by the public—from U.S. LNG exports was $8.1 billion in 2019. By 2030, when U.S. LNG exports are projected to be three times higher, the total social cost will be $30.5 billion per year.

FIGURE ES-1: LIFE-CYCLE GREENHOUSE GAS EMISSIONS FROM NORTH AMERICAN-PRODUCED LIQUEFIED NATURAL GAS EXPORTED TO EUROPE AND ASIA COMPARED WITH LIFE-CYCLE EMISSIONS FROM LNG EXPORTS FROM AFRICA AND AUSTRALIA, REGIONALLY PRODUCED COAL, RUSSIAN PIPELINE GAS, SOLAR, AND WIND.



Exporting LNG will not help meet the global goal of holding warming at or below 1.5 °C, and it will have devastating effects on frontline communities. The United States should instead prioritize clean energy investments, both at home and abroad. We make the following recommendations.

1. **LNG EXPORT IS TOO HIGH RISK**: NRDC opposes LNG export due to the substantial climate risks it poses, including its large GHG footprint, the long life span of LNG infrastructure that locks in fossil fuels instead of clean energy, and methane leaks that can eliminate any climate benefit even if LNG is used to replace coal. Policymakers and regulators should not approve or support any LNG project in the absence of a quantifiably demonstrated climate benefit relative to all alternatives, based on fully disclosed life-cycle emissions, and should require clear destination and usage restrictions. No such demonstration has been made nor restrictions applied with respect to any of the United States' currently approved or operational LNG export facilities, and existing regulatory approval processes fail to meaningfully consider LNG's full environmental impacts.

2. **NO SUBSIDIES FOR LNG-RELATED INFRASTRUCTURE**: The U.S. government should not subsidize LNG-related infrastructure with public subsidies or other incentives through, for example, the Export Import Bank of the United States, World Bank, or U.S. Development Finance Corporation. The United States should instead be providing other countries with clean, efficient, and cheaper sustainable alternatives to fossil fuels; offering U.S. innovations in technologies, services, and products; and leading by example by transitioning to a clean energy economy at home.

3. DEVELOPERS MUST ACCOUNT FOR AND DISCLOSE FULL LNG LIFE-CYCLE EMISSIONS: Proposals for LNG infrastructure must include disclosures on the full life-cycle GHG emissions of LNG, including all indirect and cumulative emissions, as these often account for the majority of emissions from a project and cannot be dismissed (these requirements include Scope 3 indirect GHG emissions coverage).

4. METHANE LEAKAGE MUST BE CONTROLLED: Much of LNG's sizable climate impact comes from methane leaks that occur throughout the production, processing, and transport of the gas. It is imperative that the United States (including state governments, as appropriate) develop and implement strategies to effectively curtail leakage.

5. FINANCIAL INSTITUTIONS SHOULD EVALUATE PROJECTS ON FULL LIFE-CYCLE IMPACTS: Any LNG project considered by a financial institution should be evaluated on the basis of the full direct, indirect, and cumulative GHG emissions impacts of the project. Financiers must accurately calculate the financial risks of high-carbon projects, as recommended by the Task Force on Climate-Related Financial Disclosures.

6. U.S. REGULATORS MUST FULLY CONSIDER THE RANGE OF IMPACTS FROM LNG EXPORTS: U.S. regulatory bodies charged with reviewing applications for LNG export and its affiliated facilities, especially the Federal Energy Regulatory Commission and the Department of Energy, should ensure that a publicly transparent, thorough, robust, and comprehensive assessment of all relevant factors, including life-cycle GHG emissions, local and regional air pollutants, impacts to frontline communities, project alternatives, and all other upstream, downstream, and cumulative environmental impacts, is conducted and subject to public input prior to issuing a final decision.

Introduction

Natural gas production in the United States has increased by more than 50 percent in the past decade, and the United States has been the world's top producer of this fossil fuel since 2009.[1] The resulting oversupply has pushed down prices—actual gas prices in 2019 were more than 70 percent lower than the U.S. government had projected they would be a decade ago—and driven the U.S. gas industry to seek alternative markets across the globe.[2] Energy companies are spending billions of dollars on the infrastructure needed to bring U.S.-produced gas to the international market, building new pipelines and liquefied natural gas (LNG) export terminals in the continental United States, and signing contracts to deliver U.S.-produced gas to dozens of countries across the globe.[3]

Until 2014 the United States did not ship any LNG overseas.[4] Today seven LNG export terminals in the United States are operational and eight more are under construction.[5] In 2019 net LNG exports reached 1.76 trillion cubic feet (Tcf), almost six times higher than in 2016.[6] Once completed, these LNG export facilities will be approved to export a total of 14.8 billion cubic feet per day (Bcf/d) of gas, equal to 110 percent of the average daily gas consumption of all U.S. homes.[7] Government agencies are now forecasting net LNG exports to hit 2.3 Tcf in 2020 and 5.75 Tcf by 2030 (Figure 1).[8]

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GAS PRODUCTION AND PROCESSING HARM HUMAN AND ENVIRONMENTAL HEALTH

Production, transport, and processing of gas pose a myriad of problems for the environment, human health, communities, and environmental justice.[9] Gas production, which for the past decade has included extensive use of fracking, and processing can increase local air pollution and contaminate water supplies, both of which harm human health.[10] Gas wells and pipelines harm local ecosystems, degrading habitat and disrupting wildlife movement and migration. Moreover, gas pipelines, compression and metering stations, storage facilities, and now liquefaction plants and export terminals are most often located in disadvantaged areas, adding new environmental stressors to those these frontline communities already face.[11]

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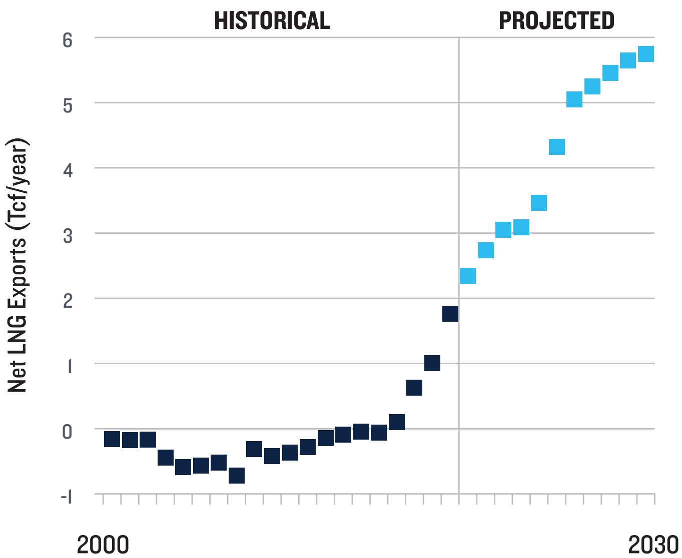
FIGURE 1: NET U.S. EXPORTS OF LIQUEFIED NATURAL GAS (TRILLION CUBIC FEET PER YEAR)



Source: U.S. Energy Information Agency.

Natural gas has long been considered by many to be a "bridge fuel," a safer, cleaner alternative to coal and oil and an incremental step to reduce the greenhouse gas (GHG) emissions that are driving climate change. It is true that, compared with coal, burning gas emits just half as much carbon dioxide, the GHG that is the primary driver of climate change.[12] However, the extraction, processing, and transport of gas also emits GHGs, including large amounts of methane from leaks and intentional releases at wells, pipelines, and storage and processing facilities.[13] Methane, which is the principal component of gas, does not persist in the atmosphere as long as carbon dioxide, but its climate impact is more than 80 times stronger in the short-term (20-year) time frame and 28 times stronger over the long-term (100-year) time frame; it is the second-biggest driver of climate change.[14] Gas production systems are already the second-largest emitters of methane in the country.[15] And now the Trump administration has rolled back rules that required the industry to reduce methane leaks.[16]

BURNING GAS PRODUCES FEWER AIR POLLUTANTS THAN COAL. THAT DOESN'T MAKE IT A CLEAN FUEL.

In addition to producing less carbon dioxide, burning gas instead of coal produces fewer harmful air pollutants like mercury, lead, sulfur dioxide, nitrogen oxides, and fine particulates like soot.[17] These air pollutants can cause environmental damage, such as acid rain, and human disease, including asthma, cancer, heart and lung ailments, and neurological problems. It is true that replacing coal with gas for electricity production or heating can improve local and regional air quality—but only to a point.

Additionally, overseas export of gas extends the gas life-cycle, adding steps for liquefaction, overseas tanker transport, and regasification during which even more carbon dioxide and methane are emitted.[18] These increase the total GHG emissions resulting from the use of gas—and raise serious questions about the effectiveness of internationally traded gas as a strategy to reduce emissions and combat climate change.

Finally, the expanded production, export, and use of LNG will require large amounts of massive, long-lived, and single-purpose infrastructure such as pipelines, liquefaction plants, LNG terminals, and tankers, as well as gas-fired power plants.[19] These types of investments lock in fossil fuel dependence and the associated emissions, making the transition to clean energy even more difficult.[20]

The Intergovernmental Panel on Climate Change (IPCC) concluded that global GHG emissions must be reduced by 75 percent in the next 20 years and to net zero by mid century to avoid global warming of more than 1.5 °C and catastrophic climate impacts across the globe.[21] But the latest assessment of emissions by the United Nations shows that many countries are not on track to meet their emission reduction commitments.[22] Given this context, it is important to know whether or not large-scale overseas export of U.S.-produced LNG is an effective strategy to reduce GHG emissions and combat climate change.

After reviewing and synthesizing analyses by government agencies, university scientists, energy consultants, and others to evaluate the GHG emissions-related environmental, social, and economic costs and benefits of U.S. LNG exports, we find that the answer is clear.[23] LNG is more likely to be a "climate buster" that makes it nearly impossible to keep global temperatures from increasing above the 1.5 °C threshold.[24]

Findings

LIFE-CYCLE GREENHOUSE GAS EMISSIONS FROM EXPORTED LIQUEFIED NATURAL GAS

A life-cycle analysis is a way to account for the environmental impacts associated with all stages of a product, from initial development to final use.[25] For gas or any other fossil fuel, life-cycle analysis is used to quantify the total amounts of GHG emissions (predominantly carbon dioxide and methane) from every step in the process, from extracting the fossil fuel at the well or mine to burning it at a power plant or other facility.

For our analysis, we broke the life-cycle down into five stages: (1) the "upstream" phase of gas production, which includes extraction, processing, and domestic pipeline transport; (2) liquefaction; (3) tanker transport; (4) regasification; and (5) power plant operations when the gas is burned to generate electricity (Figure 2).

Average life-cycle GHG emissions for exported LNG, as reported in the studies we used, range from 719 to 900 grams of carbon dioxide equivalent emitted per kilowatt hour (g CO_2e/kWh) in the short-term time frame and 629 to 688 g CO_2e/kWh in the long-term time frame (Figure 3 and Table 1).[26] The short-term climate impacts, particularly for the upstream and regasification life stages, are higher because these stages emit mostly methane, which is a much more potent GHG in the near term (about 80 times more potent than CO_2 over 20 years, but only about 30 times more potent over 100 years). Thus, emissions during the upstream stage make up 29 to 52 percent of the total emissions in the short term, but only 16 to 34 percent in the long term.

FIGURE 2: LIFE-CYCLE STAGES OF GAS EXPORTED OVERSEAS AND USED FOR ELECTRICITY PRODUCTION.

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UPSTREAM

Extraction of gas at the well, processing, and domestic pipeline transport; occurs in exporting country; greenhouse gas emitted: predominantly methane.

LIQUEFACTION

Gas is cooled to -162 degrees Celsius to reduce its volume and convert it to liquid form; ocurrs in exporting country; greenhouse gas emitted: almost all carbon dioxide.

TANKER TRANSPORT

Liquefied natural gas is loaded onto an LNG tanker and transported to its destination port; occurs on the high seas; greenhouse gase emitted: mostly carbon dioxide.

REGASIFICATION

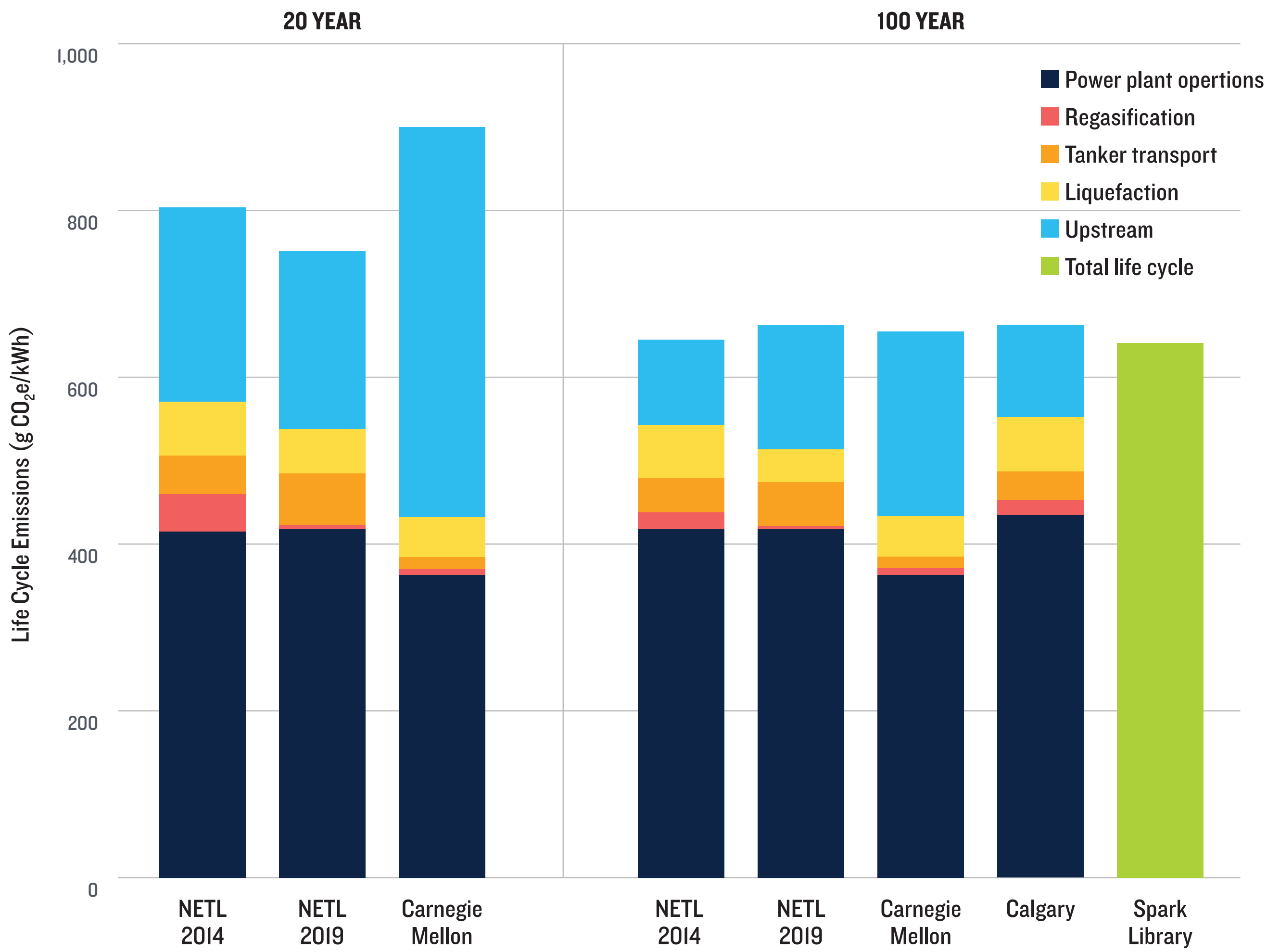
Liquefied natural gas is re-warmed to convert it to a gas; occurs in importing country; greenhouse gas emitted: mostly methane.

POWER PLANT OPERATIONS

Gas is burned in a power plant to generate electricity; ocurrs in importing country; greenhouse gas emitted: almost all carbon dioxide.

FIGURE 3: AVERAGE LIFE-CYCLE GREENHOUSE GAS EMISSIONS FROM NORTH AMERICAN-PRODUCED LIQUEFIED NATURAL GAS EXPORTED TO EUROPE AND ASIA.

See Appendix A for more information on the life-cycle studies on which this figure is based.



Most emissions occur when the gas is burned to create energy at a power plant, between 40 to 58 percent of total emissions in the near term and 55 to 66 percent in the long term (Table 1).[27] Emissions attributable to overseas export of gas (the liquefaction, tanker transport and regasification life stages) make up the final 8 to 21 percent for the 20-year time frame and 10 to 21 percent for the 100-year time frame. These emissions represent a significant addition to the climate warming consequences of using gas.

TABLE 1: GREENHOUSE GAS EMISSIONS FOR EACH LIFE-CYCLE STAGE OF LIQUEFIED NATURAL GAS EXPORTS.							
		LIFE-CYCLE STAGE (g CO_2e/kWh) (% OF TOTAL LIFE-CYCLE EMISSIONS)					
TIME FRAME FOR CLIMATE IMPACT	STUDY	UPSTREAM	LIQUEFACTION	TANKER TRANSPORT	REGASIFICATION	POWER PLANT OPERATIONS	TOTAL
Near-term 20 year	NETL (2014)– U.S. to Europe	231 29%	64 8%	30 4%	45 6%	415 53%	787 100%
	NETL (2014)– U.S. to Asia	235 29%	65 8%	62 8%	45 5%	415 50%	824 100%
	Carnegie Mellon	468 52%	48 5%	14 2%	7 1%	363 40%	900 100%
	NETL (2019)– U.S. to Europe	211 29%	53 7%	32 4%	5 1%	418 58%	719 100%
	NETL (2019)– U.S. to Asia	215 27%	54 7%	91 12%	5 1%	418 53%	783 100%
Long-term 100 year	NETL (2014)– U.S. to Europe	101 16%	64 10%	27 4%	20 3%	418 66%	629 100%
	NETL (2014)– U.S. to Asia	103 16%	65 10%	54 8%	20 3%	418 63%	660 100%
	Carnegie Mellon	222 34%	48 7%	14 2%	8 1%	363 55%	655 100%
	NETL (2019)– U.S. to Europe	149 23%	38 6%	28 4%	4 1%	418 66%	636 100%
	NETL (2019)– U.S. to Asia	149 22%	41 6%	76 11%	4 1%	418 61%	688 100%
	Calgary	111 17%	65 10%	34 5%	18 3%	435 66%	662 100%

Note: All numbers have been rounded to the nearest integer.

See Appendix A for more information on the life-cycle studies.

Methane constitutes a substantial fraction, 9 to 14 percent, of the total GHG emissions from exported LNG.[28] A recent study of methane emissions for the U.S. gas supply chain estimated that 2.3 percent of gross U.S. gas production is lost as leaks or intentional releases.[29] This means that for every unit of U.S.-produced gas consumed, the near-term global warming effect of the leaked methane has a climate impact comparable to that of the amount of carbon dioxide released when the gas is burned.

METHANE EMISSIONS ARE AN IMMEDIATE CLIMATE THREAT

The concentration of methane in our atmosphere is steadily increasing, reaching record high levels in 2019 that were nearly 15 percent higher than in the 1980s.[30] Methane persists in the atmosphere for less time than carbon dioxide but traps much more heat. That's why it has a stronger climate impact in the near-term, 20-year time frame than over the 100-year period that is used in most life-cycle assessments, climate modeling, and goal setting.[31] However, the IPCC has concluded that we have only a few decades to rapidly reduce GHG emissions and limit global warming; emissions need to be cut by more than 75 percent in the next two decades and reach net zero by mid century.[32] This makes LNG exports and, indeed, the continued and potentially increased use of gas, a more immediate—and less appreciated—climate threat than is indicated by simply comparing carbon dioxide emissions from gas combustion with those of other fuels or by using life-cycle assessments of GHG emissions that use the 100-year time frame.

CORRECTLY ACCOUNTING FOR THE GREENHOUSE GAS EMISSIONS OF EXPORTED LIQUEFIED NATURAL GAS IS CRUCIAL

GHG emissions affect climate globally, regardless of where they are emitted. Despite this, international agreements to account for and reduce emissions—such as the United Nations Framework Convention on Climate Change (UNFCC) and the Paris Agreement—require nations to measure and report in a National Emissions Inventory (NEI) only the emissions generated within their borders.[33]

However, the production, processing, transport, and use of North American-produced gas shipped overseas generates GHG emissions in more than one country. According to the Paris Agreement's accounting rules, gas exporters like the United States must count all emissions from upstream extraction, processing, domestic transport, and liquefaction at the LNG export terminal in their NEI. For importing countries, only emissions from regasification, local transport, and combustion are counted in their NEIs. Allocation of GHGs emitted during tanker transport is still being negotiated and is currently not counted by either country.[34]

UNITED STATES EXPECTED TO RETURN TO PARIS AGREEMENT

The Paris Agreement, which came into force in November 2016, is an international commitment to a collective effort to limit global warming to less than 2 °C (or 3.6 °F) above preindustrial temperatures.[35] It requires each country to measure its annual GHG emissions and report progress toward meeting national, regional, and international climate policy goals and emissions targets. Under the Paris Agreement, the United States pledged to reduce its emissions by 26 to 28 percent from 2005 levels by 2025.[36]

On June 1, 2017, the Trump administration announced its intent to withdraw from the Paris Agreement, making the United States the only nation in the world to reject this international pact. On November 4, 2019, the Trump administration formally notified the United Nations of its intent to leave the Paris Agreement, starting a yearlong countdown that became official on November 4, 2020, one day after the presidential election.[37] President-elect Biden has promised to rejoin the agreement.[38] This action does not require Senate ratification, so the United States could officially resume its role under the Paris Agreement as early as mid-February 2021.[39]

The life-cycle studies show that, over the 100-year time frame typically used for carbon accounting, more than a quarter of the total LNG export emissions, 26 to 41 percent, occur in the United States and are, therefore, counted on the United States' GHG emissions ledger. In contrast, countries that use imported LNG are required to report only the emissions within their borders. These emissions, about 56 to 69 percent of total life-cycle emissions, appear on paper to be much less than the emissions that would be generated from using an alternative fuel like coal.

For exporting countries like the United States, where production and overseas export of LNG are growing rapidly, these industries are an increasingly large source of new, in-country GHG emissions that must be counted. For countries that use imported LNG instead of regionally produced coal to generate electricity, current GHG emissions accounting rules artificially lower the "emissions cost" of using this fuel.

Put another way, use of gas produced in the United States or Canada to replace coal-powered electricity in Europe or Asia is a form of trade-related "carbon leakage." Actions taken by the importing countries to reduce their emissions are driving increased emissions in the United States and other exporting countries.[40] The current allocation of GHG emissions obscures this truth and will affect the ability of both exporting and importing countries to meet and progress toward their stated climate and emissions reduction goals under the Paris Agreement.

LIQUEFIED NATURAL GAS EXPORTS ARE DRIVING INCREASED GREENHOUSE GAS EMISSIONS IN THE UNITED STATES

The U.S. government projects that LNG exports will grow to about 5.8 Tcf of gas annually by 2030.[41] By that time, annual GHG emissions in the United States from the extraction, processing, domestic transport, and liquefaction of these LNG exports would range from 130 million to 213 million metric tons CO_2e.[42] For comparison, this is equivalent to the emissions produced by one-fifth to one-third of the entire U.S. gas power plant fleet in 2018 or to the annual emissions of 28 million to 45 million fossil fuel-powered cars.[43]

These GHG emissions will, for the most part, be new additions to the United States' NEI and count against the United States' pledge to cut emissions to 26 to 28 percent below 2005 levels by 2025. The projected 2030 emissions from this industry alone are equal to about 2 to 3 percent of net U.S. emissions in 2005.[44]

LNG PROJECTS ARE APPROVED WITHOUT REGARD FOR GREENHOUSE GAS EMISSIONS

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U.S. LNG projects are reviewed by both the Federal Energy Regulatory Commission (FERC) and the Department of Energy (DOE).[45] FERC reviews applications for new LNG export terminals and the interstate pipelines that serve them, and DOE reviews applications to actually export LNG.[46] Federal law requires each agency to determine whether the proposed terminal or export is consistent with the public interest.[47] Federal law also requires FERC and DOE to quantify and consider the significant environmental effects of an LNG project.[48] Currently, FERC and DOE fail to either quantify the significance of the greenhouse gas emissions associated with an LNG project or evaluate those emissions' consistency with the public interest, thereby masking the true environmental consequences of LNG export projects. FERC disclaims an obligation to consider greenhouse gas effects from the upstream production or downstream use of gas.[49] DOE has traditionally argued that consideration of these effects is within its exclusive authority, but it has avoided actually incorporating them into its analyses under the argument that they are not reasonably foreseeable.[50] Recently DOE adopted FERC's position that it is not under any obligation to consider these effects at all.[51] FERC and DOE must work together to ensure that the greenhouse gas emissions of an LNG project are identified, evaluated, and incorporated into their analyses.

If the U.S. LNG export trade develops as projected, GHG emissions from the LNG export industry could slow or reverse the average 1 percent per year decline in domestic GHG emissions seen in the past decade.[52] Further, these new emissions will continue (and perhaps grow) for decades, locked in by the industry's investments in expensive new pipelines, liquefaction facilities, and export terminals. Continued progress toward reducing U.S. emissions would therefore require larger emission reductions in other sectors, such as electric power generation, transportation, and agricultural, residential, and commercial energy use.

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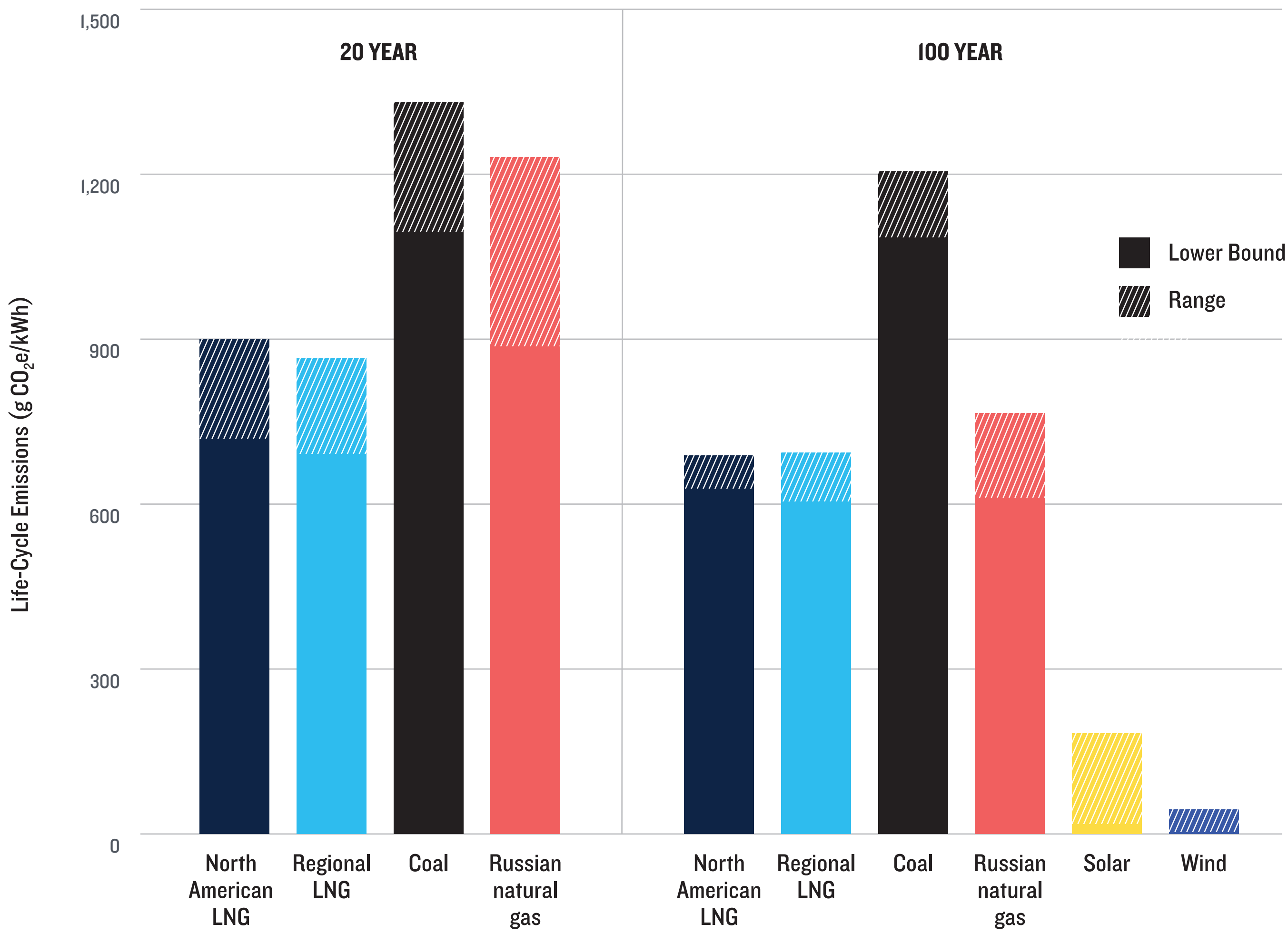
COMPARED WITH ALTERNATIVES, IMPORTED LIQUEFIED NATURAL GAS DOES NOT NECESSARILY REDUCE EMISSIONS

Most life-cycle assessments for gas and exported LNG, as well as many arguments in favor of expanding the industry, assume that this fuel will be used to replace dirtier and more carbon-intensive fuels like coal. But there is no guarantee that this will happen, and for energy and electricity production, there are already other emissions-free alternatives like wind, solar, storage, and energy efficiency that are feasible and cost effective.[53] For example, life-cycle GHG emissions for solar power are less than 7 percent of average LNG emissions; life-cycle GHG emissions for wind power are even lower, less than 2 percent of average LNG emissions.[54]

At the same time, a simple comparison of the life-cycle emissions from exported U.S. LNG to those from regionally produced coal, LNG from other producers, or Russian pipeline gas suggests that use of imported U.S. LNG often provides only a modest climate benefit, if any, to the importing country (Figure 4). Compared with coal, total GHG emissions from imported LNG are, on average, 41 percent lower in the long term, though over the short term the climate benefit is substantially reduced. Compared with Russian pipeline gas, total GHG emissions from imported LNG are actually potentially higher or, at best, only 9 percent lower. And compared with closer sources of LNG from Australia (for Asian imports) and Algeria (for European imports), imported U.S. LNG tends to be *more* emissions intensive: U.S. LNG has a climate footprint 7 percent larger than regional LNG alternatives in Asia and about 3 to 4 percent larger than regional LNG alternatives in Europe.[55]

FIGURE 4. LIFE-CYCLE GREENHOUSE GAS EMISSIONS FROM NORTH AMERICAN-PRODUCED LIQUEFIED NATURAL GAS EXPORTED TO EUROPE AND ASIA COMPARED WITH LIFE-CYCLE EMISSIONS FROM REGIONAL LNG EXPORTS FROM AFRICA AND AUSTRALIA, REGIONAL COAL, RUSSIAN PIPELINE GAS, SOLAR, AND WIND.



In addition to only modestly lowering GHG emissions under the best circumstances, high rates of methane leakage may negate any climate benefit from exported LNG. First, about half of the total emissions from LNG occur before any electricity is generated, mostly from methane leaks during the upstream life stage and the liquefaction and regasification stages required for overseas export. For example, studies from the National Energy Technology Laboratory (NETL) and Carnegie Mellon (see Appendix A for more on these and the other life-cycle studies reviewed for this report) found that using different analytical assumptions for methane leakage rates and power plant efficiency resulted in total GHG emissions from exported LNG that were comparable to or even higher than those from coal in the short term.

The Carnegie Mellon study estimated that the "break-even" point at which U.S LNG exports emitted as much greenhouse gases as coal in the near-term time frame was a methane leakage rate of 3 percent. The 2014 NETL study reported an even lower break-even point of 1.4 to 1.9 percent methane leakage. These rates are solidly within the range measured for methane emissions from the North American gas production and processing industries.[56] Therefore, unless methane leakage rates are kept at very low levels, replacing coal-fired power plants with gas plants fueled by imported U.S. LNG may actually provide little or no climate benefit to either the importing countries or the world.

TRUMP ADMINISTRATION WEAKENS PROTECTIONS AGAINST METHANE LEAKS

The Trump administration has acted repeatedly to delay and weaken two rules issued by the Obama administration to address the problem of methane emissions from the oil and gas industry. The Environmental Protection Agency's (EPA) 2016 New Source Performance Standards and the Bureau of Land Management's (BLM) 2016 Methane and Waste Prevention Rule required the industry to reduce methane emissions by monitoring their wellheads, pipelines, and processing facilities for leaks and to use up-to-date technology, equipment, and maintenance practices to reduce leaks and intentional gas releases. Together these rules would have achieved about one-quarter of the Obama administration's goal to cut methane emissions in the oil and gas sector by 40 to 45 percent from 2012 levels by 2025.[57] Short-term actions by the Trump administration to block these rules were successfully challenged in court. Subsequently, the administration took rulemaking action to dismantle both: In September 2018 the BLM issued a final rule that largely repeals the Waste Prevention Rule, and in 2020 the EPA rolled back the 2016 standards.[58] Without action to reduce methane leaks, and with continued expansion of gas production and exportation, methane emissions from this industry will remain a substantial driver of climate change.

Ultimately, even with more stringent methane leakage controls, internationally traded LNG is not a very effective emissions reduction strategy. In fact, it is likely that growing the U.S. LNG export trade could end up increasing overall energy demand and consumption instead of replacing dirtier fossil fuels in importing countries, as well as increasing the overall amounts of methane leaked into the atmosphere.[59] Spark Library researchers concluded that, as a climate change mitigation strategy, use of exported LNG would be effective only if methane leakage is reduced, the exported LNG comes from reduced consumption in the exporting country rather than increased production, and the LNG is used to replace coal for electricity production.

The International Energy Agency reached a similar conclusion several years earlier.[60] It found that widespread expansion of gas would likely lead to increased energy use and could, in some instances, displace lower-carbon alternatives like renewables or nuclear power. This, the agency projected, could increase atmospheric GHG concentrations to 650 parts per million and global temperatures by 3.5 °C, well above the temperature predicted to result in catastrophic climate impacts.[61]

LNG EXPORTS HAVE FINANCIAL RISKS

Companies and financial institutions are facing growing scrutiny for investments in fossil fuels that increase GHG emissions and exacerbate climate change. Two types of risks have been identified by the Task Force on Climate-Related Financial Disclosures: (1) risks related to the transition to a lower-carbon economy, and (2) risks related to the physical impacts of climate change.[62] LNG projects are clearly at risk from the physical effects of climate change, as evidenced by past examples of severe weather disrupting LNG shipping routes.[63] But the greater risk for companies, investors, and financial institutions considering LNG projects is the first one: LNG export infrastructure is likely to be a financial liability in the transition to a lower-carbon economy. LNG has been marketed as a "cleaner" alternative to coal, but GHG emissions from the life-cycle of LNG far exceed those of solar, wind, or other technologies that already compete against LNG.[64] The emissions reduction and temperature goals set by the Paris Agreement mean that increased LNG use is not compatible with a safer climate. As more financial institutions conduct GHG emissions reviews of their portfolios with respect to GHG emissions, assessing policy and legal risks (such as GHG pricing and new regulations) and technology risks (replacement of LNG with zero-emissions technologies), the high GHG emissions of LNG will become a greater and greater liability.

EXPANDED USE OF GAS FOR POWER WILL MAKE IT HARDER TO MEET CLIMATE TARGETS

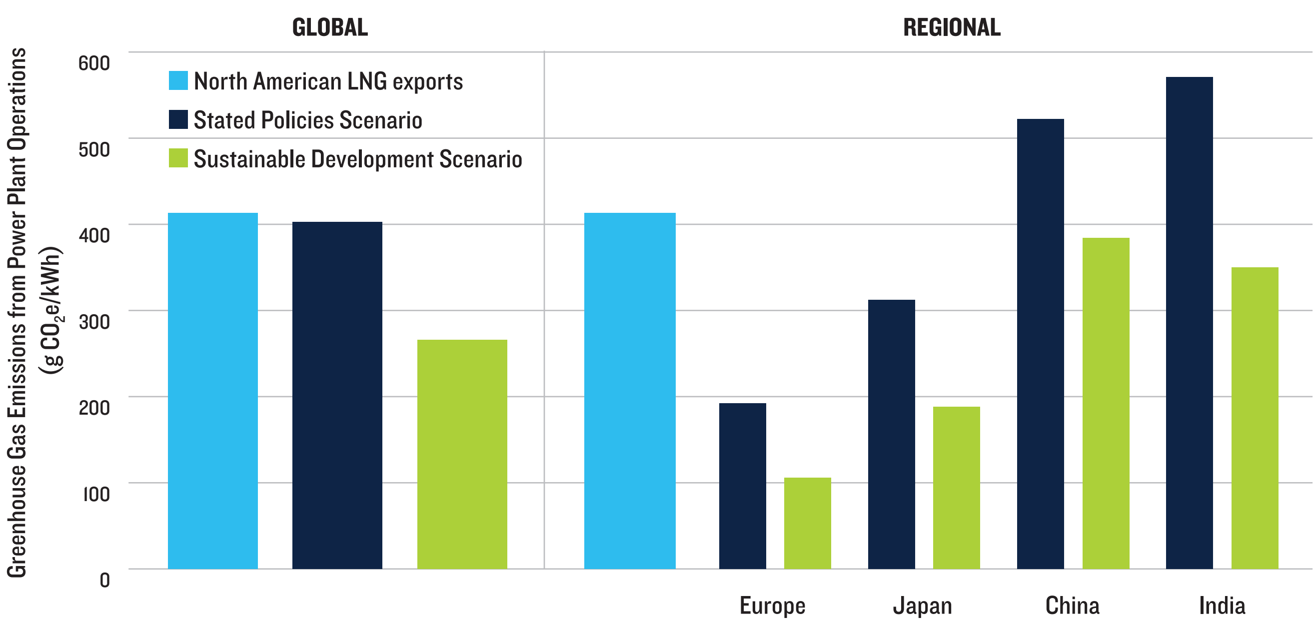
To help governments assess their policies to reduce GHG emissions, the International Energy Agency's annual *World Energy Outlook* report publishes region-by-region targets for future GHG emissions from all energy sectors, including electricity generation, under two different scenarios.[65] The "Stated Policies Scenario" predicts emissions rates if governments follow through on their current and announced energy plans, including national pledges to reduce GHG emissions and phase out fossil fuel subsidies.[66] The "Sustainable Development Scenario" is more aggressive, basing its emissions targets on the United Nations' "2030 Agenda for Sustainable Development," which includes taking urgent action to combat climate change.[67] Meeting the targets identified in either scenario will not reduce emissions enough to limit global warming to 1.5 °C, but the targets are helpful benchmarks for comparing energy strategies and evaluating progress toward reducing emissions.[68]

For electricity, these targets account for the collective emissions from the entire electricity generation portfolio, including coal, gas, oil, biomass, nuclear, renewables, and geothermal, and they incorporate carbon capture, utilization, and storage amounts that increase over time.[69] Comparing the average emissions from LNG-sourced power plant operations with both 2030 scenario targets for electricity generation shows that, for the world and most regions, expanded use of imported LNG for gas-fired electricity production will make achieving these targets more difficult.

Globally, generating all electricity by burning only gas—regardless of its source—nearly meets the Stated Policies Scenario 2030 target for worldwide electricity emissions, but it falls far short of the Sustainable Development Scenario target, with emissions that are more than 50 percent higher than the 2030 target (Figure 5, left panel).

Regionally, the results are mixed because the emissions targets for electricity generation are lower in regions like Europe and Japan than in rapidly growing countries like China and India (Figure 5, right panel). As a consequence, using gas for electricity generation in Europe produces 113 percent more emissions than the Stated Policies Scenario target and 285 percent more emissions than the Sustainable Development Scenario target. For Japan, emissions from electricity generated from gas are 31 percent higher than its Stated Policies Scenario target and more than double its Sustainable Development Scenario target. In contrast, using gas for electricity production will help China and India meet their existing and announced policy commitments to reduce emissions but will not help them meet the Sustainable Development Scenario targets, which are exceeded by 6 percent for China and 17 percent for India.

FIGURE 5: AVERAGE POWER-RELATED EMISSIONS FROM THE LNG ANALYSES COMPARED WITH GLOBAL (LEFT PANEL) AND REGIONAL (RIGHT PANEL) 2030 EMISSIONS TARGETS FOR ELECTRICITY PRODUCTION UNDER THE STATED POLICIES SCENARIO AND THE SUSTAINABLE DEVELOPMENT SCENARIO.



These results show that gas is far from being a "bridge fuel." Widespread use of gas for electricity generation will make it harder to meet even conservative emissions targets set for just 10 years from now. Should U.S. LNG exports proceed according to industry plans, and should the exported gas be used to generate electricity, countries like Europe and Japan will be unable to meet their already announced climate commitments, much less targets for more aggressive climate action, unless they compensate by generating a much larger share of the rest of their electricity from carbon-free sources, such as wind, solar, and geothermal. This underscores the reality that expanded use of gas for electricity production, including large investments in long-lived infrastructure for LNG export and gas-fired power that will reinforce an international energy system reliant on fossil fuels, is not a viable pathway to meet planned climate change mitigation goals.

LIQUEFIED NATURAL GAS EXPORTS HAVE HIGH SOCIAL COSTS

Because the damage done by climate change is spread across the globe, it can be challenging to estimate the monetary cost of GHG emissions. But these costs are real: Increasing air and ocean temperatures and changes in rainfall patterns lead to extreme weather events, such as droughts, floods, and wildfires, that will (and already do) kill people and harm human health, reduce net agricultural production, cause property and infrastructure damage, and change energy system costs.[70] Moreover, these "social costs" are currently paid predominantly by the public—as higher personal or government costs for health care, infrastructure repairs, or disaster recovery, for example—rather than by the emitter. While there is growing momentum among countries and businesses to put a price on carbon pollution as a means of bringing down GHG emissions and driving investment in cleaner options, there are few programs currently in place to pay for these external, social costs.[71]

One way to quantify the economic damages from climate change is to calculate the social cost of carbon (SCC). This is an estimate of the economic costs of damages associated with a small increase in GHG emissions, conventionally 1 metric ton, in a given year.[72] The SCC can also be used to quantify the benefits of reducing emissions, by providing the dollar value of damages avoided for a specified emissions reduction. U.S. government agencies have used the SCC to estimate the climate benefits and costs of regulations and rulemakings since 2008, although recent changes in how it is calculated ordered by the Trump administration have diminished its validity and utility.[73]

TRUMP ADMINISTRATION DUMPS SOCIAL COST OF CARBON FOR COST-BENEFIT ANALYSES OF ENERGY DEVELOPMENT PROJECTS

In March 2017 President Trump dissolved the Interagency Working Group on Social Cost of Greenhouse Gases, withdrew documents issued by the group regarding the social cost of carbon, and directed the Council on Environmental Quality to rescind its final guidance for agencies on considering GHG emissions and the effects of climate change in federal environmental reviews.[74] The new order does not direct agencies to stop monetizing climate impacts in their regulatory analyses; instead it orders them to use economic values that are consistent with guidance from a 17-year-old Office of Management and Budget document.[75] That document states that the main factor in weighing regulations should be costs and benefits to the United States and that any significant impacts outside the country should be "clearly segregated out and reported separately."

However, climate change and the GHG emissions that are driving it are not local environmental impacts; their effects manifest globally, and some of the greatest and most economically costly impacts occur in other parts of the world.[76] This 2017 executive order will, therefore, cause U.S. environmental reviews to substantially underestimate the economic costs of the increased GHG emissions from the expansion of gas production and LNG exports.

Using the SCC (as calculated by the Interagency Working Group on Social Cost of Greenhouse Gases before the Trump administration order; see Appendix A for more information on our methods), we calculated the embedded social costs of carbon for the 1.8 Tcf of U.S.-produced gas that was exported in 2019.[77] For each 1,000 cubic feet of U.S.-produced LNG, about 0.09 metric tons of greenhouse gases are emitted into the atmosphere during the complete life-cycle of the gas.[78] Thus, the social cost of the GHG emissions from exported LNG was $4.47 per 1,000 cubic feet in 2019. For comparison, the average purchase price for LNG was $4.96 per 1,000 cubic feet in 2019, meaning that social costs borne by the public resulting from the extraction, export, and use of this fossil fuel were almost as high as its commercial value to the gas industry.

For the 1.8 Tcf of LNG exported in 2019, the total social cost of carbon was $8.1 billion. By 2030, when U.S. LNG exports are projected to be almost 5.8 Tcf (15.8 Bcf/d), the total social cost would be $30.5 billion per year (in 2018 dollars).[79]

The process of exporting this gas overseas is a substantial contributor to LNG's social cost. The GHG emissions that occur during the liquefaction, shipping, and regasification life-cycle stages—10 to 21 percent of the life-cycle emissions—had a social cost of $812 million to $1.7 billion for the U.S.-produced gas that was exported in 2019 (Table 2).

If the social costs of carbon were allocated on the basis of international GHG accounting rules that count emissions only in the country where they occur, the United States would bear the social cost for only a portion of the exported LNG's life-cycle emissions. However, this portion—26 to 41 percent of life-cycle emissions—adds significant climate costs to the United States's ledger. Domestic SCC costs related to LNG exports in 2019 amounted to $2.1 billion to $3.3 billion. In contrast, because of that same rule, countries that use imported LNG to replace coal for electricity generation could reap a misleadingly high carbon benefit. Regasification and power plant operations in importing countries generate only 56 to 69 percent of the fuel's total GHG emissions. This gives imported LNG the appearance of being a lower carbon fuel, with a lower social cost, than it really is.

This SCC analysis of the life-cycle emissions of LNG exports also illustrates the limitations of current GHG emissions accounting rules for internationally traded fossil fuels. If—or when—countries and businesses put a price on climate pollution (via a carbon tax or other such mechanisms), the United States would have to foot a hefty bill for its LNG exports, while importing countries that use the fuel would have to pay for only a fraction of the emissions produced from LNG.

TABLE 2. ESTIMATED SOCIAL COST OF CARBON (SCC) FOR U.S. EXPORTS OF LNG IN 2019 (IN 2018 DOLLARS)

2019 SCC		2019 LNG EXPORTS		TOTAL SCC FOR 2019 EXPORTS	
$49.68 per tonne	$4.47 per 1,000 cubic feet	1.8 trillion cubic feet		$8,120,200,000	
LIFE-CYCLE STAGE	**UPSTREAM**	**LIQUEFACTION**	**TANKER TRANSPORT**	**REGASIFICATION**	**POWER PLANT OPERATIONS**
% of life-cycle emissions	16–34%	6–10%	2–11%	1–3%	55–66%
SCC by stage (millions)	$1,299–$2,761	$487–$812	$325–$893	$81–$244	$4,466–$5,359
SCC of U.S. emissions (millions)	$2,111–$3,329				
SCC for overseas export (millions)		$812–$1,705			

Conclusion

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The transformation of the United States from gas importer to major gas exporter—a direct consequence of the fracking-driven expansion of U.S. gas production—could have enormous environmental impacts and costs for decades to come. Not only do gas wells, pipelines, and processing facilities cause well-known local and regional environmental and health impacts, but the new pipelines, storage and liquefaction facilities, and LNG terminals add new pollution sources, often located near already impacted frontline communities. On top of these direct impacts, LNG export and import infrastructure and the increased dependence of importing countries on gas will further lock in an international energy system reliant on fossil fuels at the expense of cleaner energy sources like solar, wind, and energy efficiency.

While the global impacts are the most critical consideration when evaluating GHG emissions and climate change, we also looked at impacts to the United States and importing countries separately, since that information will have implications for each country's carbon accounting as we work to reduce climate impacts. Our analysis shows that large-scale export of U.S.-produced gas will generate large amounts of new GHG emissions in the United States while providing uncertain emissions impacts to importing countries. And, because of international GHG accounting rules, the United States will shoulder a large fraction of the emissions burden while importing countries reap all the benefits (if there are any). Clearly, overseas export of U.S.-produced gas is not an effective long-term strategy to combat climate change—for the United States, for importing countries, or for the planet.

For the United States:

- Export of U.S.-produced LNG will generate large amounts of new GHG emissions. By 2030, the emissions from this one industry would add between 130 million and 213 million metric tons of GHGs annually to the country's climate ledger, an amount equivalent to what would be produced by adding 28 to 45 million more fossil-fueled cars to U.S. roads.
- All GHG emissions generated by the industry up to the point at which the LNG is loaded onto a tanker, as much as 41 percent of total life-cycle emissions, go on the United States' GHG accounting ledger.
- As a result, new GHG emissions from the LNG export industry could slow or reverse the average 1 percent per year decline in national emissions that the United States has achieved during the past decade. This will make it much harder to meet our international commitment to reduce GHG emissions by 26 to 28 percent below 2005 levels by 2025.
- On top of this, federal rules to require the oil and gas industry to find and fix leaks to reduce methane emissions—commonsense actions that could reduce industry-generated emissions by more than 10 percent—have been rolled back by the Trump administration.
- The social cost of the domestic GHG emissions associated with U.S. LNG exports amounted to as much as $3.3 billion in 2019. By discounting the social cost of carbon, the Trump administration has set the stage for underestimating the true environmental and social economic costs of the expansion of gas production and LNG exports.

For Europe and Asia:

- Compared with alternatives, such as renewable wind or solar energy or even just closer sources of gas like Australian and Algerian LNG, U.S.-produced LNG simply does not have a climate benefit.
- Use of imported U.S.-produced gas for electricity production could have modestly lower GHG emissions compared to coal or, in some cases, Russian pipeline gas.
- Because GHG accounting rules require countries to count only their domestic emissions, countries using imported LNG may underestimate the climate impact of this fuel by at least 31 percent.
- For Europe and Japan, GHG emissions from burning gas for electricity are 41 percent to 151 percent higher than the 2030 emissions targets for electricity generation needed to meet international goals for sustainable development and limit global warming.
- Therefore, use of imported LNG is not an effective long-term strategy for these countries to reduce total emissions from their electricity sectors and meet their climate goals.

For the planet:

- Even though combustion of gas emits less air pollutants and carbon dioxide than burning coal or oil, the production, processing, and transport of gas release large amounts of methane, a GHG that has a much greater and more immediate climate impact.
- Methane leaks and intentional releases reduce—and may even eliminate—the climate benefit from use of exported LNG to replace coal.
- Overseas export of U.S.-produced gas increases the total life-cycle GHG emissions of the fuel by as much as 21 percent, further reducing any benefits from use of this fossil fuel.
- Emissions from burning gas to generate electricity are more than 50 percent higher than global sustainable development targets for the electricity sector, demonstrating that gas-fired power production is neither a strategic nor an effective approach to combat climate change and hold global warming at or below 1.5 °C.
- Expansion of LNG exports and increased reliance on imported gas will lock in fossil fuel dependence at the expense of already feasible and cost-competitive cleaner energy technologies.
- The economic costs of the climate change impacts from U.S. LNG-related exports—costs that are borne by the public rather the LNG industry—could exceed $30 billion per year by 2030.

Recommendations

Exporting LNG will not help meet the global goal of holding warming at or below 1.5 °C, and it will have devastating effects on frontline communities. The United States should instead prioritize clean energy investments, both at home and abroad. We make the following recommendations.

1. **LNG EXPORT IS TOO HIGH RISK:** NRDC opposes LNG export due to the substantial climate risks it poses, including its large GHG footprint, the long life span of LNG infrastructure that locks in fossil fuels instead of clean energy, and methane leaks that can eliminate any climate benefit even if LNG is used to replace coal. Policymakers and regulators should not approve or support any LNG project in the absence of a quantifiably demonstrated climate benefit relative to all alternatives, based on fully disclosed life-cycle emissions, and should require clear destination and usage restrictions. No such demonstration has been made or restrictions applied with respect to any of the United States' currently approved or operational LNG export facilities, and existing regulatory approval processes fail to meaningfully consider LNG's full environmental impacts.

2. **NO SUBSIDIES FOR LNG-RELATED INFRASTRUCTURE:** The U.S. government should not subsidize LNG-related infrastructure with public subsidies or other incentives through, for example, the Export Import Bank of the United States, World Bank, or U.S. Development Finance Corporation. The United States should instead be providing other countries with clean, efficient, and cheaper sustainable alternatives to fossil fuels; offering U.S. innovations in technologies, services, and products; and leading by example by transitioning to a clean energy economy at home.

3. **DEVELOPERS MUST ACCOUNT FOR AND DISCLOSE FULL LNG LIFE-CYCLE EMISSIONS:** Proposals for LNG infrastructure must include disclosures on the full life-cycle GHG emissions of LNG, including all indirect and cumulative emissions, as these often account for the majority of emissions from a project and cannot be dismissed (these requirements include Scope 3 indirect GHG emissions coverage).[80]

4. **METHANE LEAKAGE MUST BE CONTROLLED:** Much of LNG's sizable climate impact comes from methane leaks that occur throughout the production, processing, and transport of the gas. It is imperative that the United States (including state governments, as appropriate) develop and implement strategies to effectively curtail leakage.

5. **FINANCIAL INSTITUTIONS SHOULD EVALUATE PROJECTS ON FULL LIFE-CYCLE IMPACTS:** Any LNG project considered by a financial institution should be evaluated on the basis of the full direct, indirect, and cumulative GHG emissions impacts of the project. Financiers must accurately calculate the financial risks of high-carbon projects, as recommended by the Task Force on Climate-Related Financial Disclosures.[81]

6. **U.S. REGULATORS MUST FULLY CONSIDER THE RANGE OF IMPACTS FROM LNG EXPORTS:** U.S. regulatory bodies charged with reviewing applications for LNG export and its affiliated facilities, especially the Federal Energy Regulatory Commission and the Department of Energy, should ensure that a publicly transparent, thorough, robust, and comprehensive assessment of all relevant factors, including life-cycle GHG emissions, local and regional air pollutants, impacts to frontline communities, project alternatives, and all other upstream, downstream, and cumulative environmental impacts, is conducted and subject to public input prior to issuing a final decision.

DATA SOURCES AND METHODS

Life-Cycle Assessments for Liquefied Natural Gas (LNG) Exports

Data Sources: Our analysis is based on five published studies that present quantitative assessments of total, or "life-cycle," greenhouse gas (GHG) emissions from gas produced in North America, exported overseas to Europe or Asia, and burned in power plants for electricity production. The studies were conducted by the National Energy Technology Laboratory (NETL) (including both the initial 2014 publication and the revised report from 2019), Carnegie Mellon University (Carnegie Mellon), University of Calgary and collaborators (Calgary), and the Spark Library and a collaborator (Spark Library).[82] The Calgary study looked at LNG exported from Canada, while the other four covered U.S. exports. The Spark Library study reported total life-cycle emissions but did not partition emissions among the different life-cycle stages. Several of these studies compared the life-cycle GHG emissions from exported LNG with the life-cycle emissions from fossil fuels in the importing nations that could be replaced by gas imported from North America: regionally produced coal, regional LNG shipped from Algeria or Australia (depending on importing country), and Russian gas imported by pipeline.

We also reviewed a sixth study conducted by Pace Global, an energy management consulting firm, on behalf of the Center for Liquefied Natural Gas.[83] However, we did not include these results in our analysis because the report acknowledged that the study lacked elements of a life-cycle assessment as prescribed by the International Organization for Standardization and therefore should not be used as the sole basis for comparative environmental claims. This study also lacked the appearance of impartiality because it was conducted for a client with a financial interest in the outcome.

For solar and wind power, we used GHG life-cycle assessments from the National Renewable Energy Laboratory (NREL).[84]

Units of Measure and Global Warming Potential Time Frames: For each life-cycle stage, GHG emissions are expressed as the amount of the carbon dioxide equivalent (CO_2e) for a particular global warming potential (GWP) time frame (20 or 100 years)[85] relative to the amount of electricity produced when the fuel is burned at the power plant (kilowatt hours), as grams of CO_2e emitted per kilowatt-hour of power produced (g CO_2e/kWh).

All of the life-cycle studies we used, as well as most national and international energy and emissions analyses, employ the 100-year global warming time frame, or 100-year global warming potential (100-year GWP). The NETL and Carnegie Mellon studies also reported life-cycle emissions for the near-term, 20-year global warming time frame. We refer to both the 20-year and 100-year time frames for LNG export life-cycle emissions in some of our analysis because: (1) methane constitutes a substantial fraction of GHG emissions during the LNG export life-cycle; (2) methane, which has a much greater climate impact than carbon dioxide, also has a greater climate impact in the 20-year time frame than over the 100-year period; and (3) the IPCC has concluded that we have only a few decades to rapidly reduce GHG emissions and limit global warming enough to avoid catastrophic climate impacts. In our report, unless the near-term, 20-year climate time frame is specified for an emissions result, the result is for the longer-term, 100-year climate time frame.

For more information on greenhouse gases and climate change, global warming potential and climate impact time frames, and carbon dioxide equivalent, see Appendix B.

Differing Analytical Assumptions Among the Studies: Analytical assumptions for many of the key variables that affect the life-cycle stages for exported LNG differed among the studies. For example, the studies assumed different methane leakage rates: The Carnegie Mellon study assumed a methane leakage rate of 2 to 4 percent; NETL's 2014 paper assumed a methane leakage rate of 1.2 to 1.6 percent, and its revised 2019 study assumed 0.7 percent; the Calgary study, which used data from more than a dozen published reports, incorporated a range of methane leakage rates into its life-cycle assessments; and the Spark Library study reported life-cycle emissions for a hypothetical range of leakage rates from 0 to 6 percent (we used the midpoint of these emission levels in this analysis). The studies also used different assumptions for other factors, including shipping distance and power plant efficiency in the importing country. For example, the NETL studies presented destination-specific life-cycle GHG emissions data, while the Carnegie Mellon study used a weighted average of import terminals in China, India, South Korea, Japan, the United Kingdom, and the Netherlands in its transportation calculations.

Life-cycle emissions for coal also varied, depending largely on the assumptions or estimates made for the efficiency of the power plant at which the coal is burned. For example, the 2014 NETL study reported 20-year GWP coal life-cycle emissions of 1,095 g CO_2e/kWh (and 1,090 g CO_2e/kWh in the 2019 update), while the Carnegie Mellon study reported 20-year GWP coal emissions of 1,332 g CO_2e/kWh. The Spark Library study, which focused only on Asian countries for imports, reported that coal life-cycle emissions varied among importing countries on the basis of the age and efficiency of their coal power plant fleets, ranging from 894 g CO_2e/kWh in China to 1,129 g CO_2e/kWh in India.

Most life-cycle emissions from wind and solar power generation facilities occur during the upstream life stage with fabrication of materials, equipment, and facilities. GHG emissions during the power-generation life stage are essentially zero.

For our analysis, emissions values for LNG, coal, and Russian pipeline gas are averages from the life-cycle studies we reviewed. Values for solar and wind are median values from the NREL study we used.

Other Considerations: Our analysis is based on currently reported quantitative data, assessments, and models. It is possible that future life-cycle GHG emissions from LNG exports could be reduced using a number of strategies, including decreasing methane leakage during all life-cycle stages; decarbonizing LNG shipping and the electricity grid in exporting countries; and using carbon capture, utilization, and storage (CCUS) in electricity generation facilities powered by imported LNG. It is likely (and to be hoped) that implementation of some or all of these strategies will progress during the coming decades. However, for this analysis we chose to use recent, published, empirical emissions data rather than to make speculative quantitative assumptions for various emissions reduction strategies in the future.

We also recognize that LNG exports and the substitution of gas for other, dirtier fuels like coal have non-climate impacts, such as local and regional air pollution. However, these other impacts, while important to consider and note, are outside of the scope of the literature we reviewed and, therefore, not evaluated in this report.

GREENHOUSE GAS EMISSIONS IN THE UNITED STATES

We calculated the annual GHG emissions in the United States for projected 2030 LNG exports using three sources of data:

1. projected 2030 LNG gross annual exports from the U.S. Energy Information Agency;[86]

2. the percentages of total life-cycle emissions for the upstream (extraction, processing, domestic transport) and liquefaction stages that occur in the United States from the Carnegie Mellon study; and

3. a conversion factor reported in the Carnegie Mellon study for the metric tons of GHGs emitted per 1,000 cubic feet of gas loaded onto a ship (0.037 metric tons per 1,000 cubic feet of gas for the 100-year time frame).

We developed comparable conversion factors for the emissions reported by the NETL study (2014, to Europe) to determine the lower bound of GHG emissions that would result from the upstream and liquefaction life stages in the United States.

COMPARING EMISSIONS FROM GAS-FIRED POWER GENERATION TO CLIMATE PLANNING SCENARIO EMISSIONS TARGETS

The 2030 emissions targets for electricity production for the world, Europe, Japan, China, and India were calculated from the data reported in Annex A of the 2019 *World Energy Outlook* report.[87] To express the planning scenario targets as emissions per amount of electricity produced, similar to the units of measure used in the published LNG life-cycle assessment studies, we divided the total emissions for electricity generation target (labeled "Power Sector" in the Annex A table for the specified scenario) by the total electricity generation target (labeled "Total Generation" in the Annex A table for the same scenario), with appropriate conversions for different units of measure (e.g., converting Mt CO_2 to g).

For more information on the International Energy Agency, *World Energy Outlook*, and climate planning scenarios, see Appendix B.

CALCULATING THE SOCIAL COST OF CARBON

In 2010, 2013, and 2016, the U.S. Interagency Working Group on Social Cost of Greenhouse Gases was formed to estimate the SCC for use in the United States.[88] For our analysis, we used this group's 2016 update and assumed a 3 percent discount rate, which estimated a central value of $48.47 per metric ton of CO_2e in 2018, rising to $49.68/tonne in 2019, $61/tonne in 2030, and $84/tonne in 2050 (in 2018 dollars). Using this SCC trajectory and the 100-year GWP GHG emission amounts reported by the life-cycle assessments for LNG exports, we calculated the social carbon cost (in 2018 dollars) for the amount of U.S.-produced gas that was exported as LNG in 2019 and for the amount projected to be exported in 2030.

For the amount of greenhouse gases emitted during the exported LNG life-cycle, metric tons of CO_2e per 1,000 cubic feet of gas, we used information presented in several of the life-cycle studies: 0.086 to 0.091 metric tons per Mcf of gas (NETL 2014), 0.087 to 0.095 metric tons per Mcf of gas (NETL 2019), and 0.090 metric tons per Mcf of gas (Carnegie Mellon).

For more information on the social cost of carbon, see Appendix B.

Appendix B

DEFINITIONS AND ADDITIONAL BACKGROUND

Carbon Dioxide Equivalent

Because different greenhouse gases have different global warming potentials, GHG emission amounts and their global warming potential are usually expressed as the carbon dioxide equivalent, CO_2e, for a particular period of time (usually 20 or 100 years). Carbon dioxide equivalent, or CO_2e, is the standard unit for measuring carbon footprints. It quantifies the global warming impact of different greenhouse gases, or mixtures of greenhouse gases, in terms of the amount of CO_2 that would create the same amount of warming.

Carbon Leakage

Carbon leakage occurs when there is an increase in GHG emissions in one country as a result of an emissions reduction by a second country with a strict climate policy.[89] In the simplest example, carbon leakage occurs when an emissions-intensive industry in a country with strict GHG emissions reduction goals or requirements relocates its emissions-intensive activities or production to a country with less ambitious climate measures. Relocation of the emissions-generating activity may contribute to emissions reductions in one country but increases the emissions in another and can lead to a rise in global GHG emissions. Carbon leakage may also occur through changes in trading patterns and is sometimes measured as the balance of emissions embodied in trade.[90] The GHG emissions generated in the United States from the export of U.S.-produced gas to Europe and Asia, which permits these countries to replace coal-generated electricity and reduce their power-sector emissions, is a trade-related example of carbon leakage.

Carbon Lock-In

In the current global energy system, about 80 percent of our energy comes from burning fossil fuels.[91] Carbon lock-in refers to the tendency for this carbon-intensive system to persist over time, inhibiting public and private efforts to introduce alternative, lower-carbon energy technologies.[92] There are three main types of carbon lock-in: (1) infrastructural and technological; (2) institutional; and (3) behavioral. Each of these carbon lock-in elements has its own set of processes, but they are all tightly intertwined and mutually reinforcing. For example, construction of new fossil fuel-related infrastructure components like an LNG export terminal or a gas-fired power plant, which have large capital costs and long lifetimes, relies on and creates both demand and a market for gas production and use. These types of projects tend to restrict future flexibility and increase the costs of a societal shift toward less-carbon-intensive fuels and of achieving national and global climate protection goals.

Gas and Liquefied Natural Gas

What industry refers to as “natural gas” is a naturally occurring gas mixture. It is composed primarily of methane, but it also contains ethane, propane, and heavier hydrocarbons as well as small amounts of nitrogen, carbon dioxide, hydrogen sulfide, and trace amounts of water.[93] Liquefied natural gas (LNG) is gas that has been converted to liquid form by cooling it to -162 °C.[94] LNG has about 1/600th the volume of natural gas in its gaseous state and is therefore the preferred form for storage and for transport over long distances where pipelines do not exist. Specially designed cryogenic sea vessels (LNG carriers) or cryogenic road tankers are used for its transport. Once transported to markets, LNG is regasified and distributed as pipeline gas.[95]

Greenhouse Gases and Climate Change

Greenhouse gases (GHGs) are gases such as carbon dioxide (CO_2), methane (CH_4), nitrous oxide (N_2O), hydrofluorocarbons (HFCs), and water vapor that trap heat in the atmosphere and contribute to the warming of the planet known as the greenhouse effect.[96] Although greenhouse gases occur naturally in the atmosphere, the elevated levels of carbon dioxide and methane, in particular, that have been observed in recent decades are directly related to human activities such as extraction and burning of fossil fuels and destruction of tropical and temperate forests.[97] Increases in the amount of GHGs in the atmosphere since the beginning of the industrial revolution are causing climate change by increasing air and ocean temperatures, precipitation variability, and extreme weather events, as well as driving sea level rise and ocean acidification.[98]

Greenhouse Gas Emissions Accounting

The United Nations Framework Convention on Climate Change (UNFCCC) requires each country to measure its annual GHG emissions in a National Emissions Inventory (NEI). The Paris Agreement bolsters this mechanism by requiring, among other things, an emissions inventory every two years that meets the Intergovernmental Panel on Climate Change’s GHG emissions reporting guidelines and uses a common accounting framework.[99] This provides a benchmark for the country’s emissions reductions and is used to evaluate progress toward meeting regional and international climate policies and emissions targets.

There are two conflicting ways of measuring GHG emissions: consumption-based and production-based (also called territorial-based).[100] Consumption-based emissions include all emissions from the full life-cycle of a fossil fuel, from production to final combustion. With this accounting approach, all emissions from extraction, processing, and transport of the fossil fuel that occur in the exporting country and during transport as well as those generated during final combustion accrue to the country that has imported the fossil fuel. A production-based approach counts all emissions taking place "within national territory and offshore areas over which the country has jurisdiction."[101] Thus, for a gas exporter like the United States, emissions from extraction, processing, domestic transport, and liquefaction accrue to the United States, not the importing country. For the importing country, only emissions from regasification, local transport, and power plant combustion are counted in its national emissions inventory.

The UNFCC and the Paris Agreement use production-based emissions accounting.[102] However, experts prefer consumption-based accounting and argue that production-based emissions accounting is unable to allocate emissions embodied in international trade and transportation and increases the potential for carbon leakage.[103]

Global Warming Potential

The effects of GHG emissions are measured in terms of their global warming potential (GWP), a measure of how much heat the emitted GHGs trap in the atmosphere. GHGs differ in their ability to absorb heat energy (their "radiative efficiency") and in how long they stay in the atmosphere. For example, methane persists in the atmosphere for a shorter time than CO_2 (12 years compared with 100 years for CO_2), but it has higher radiative efficiency than CO_2. As a result, 1 ton of methane has the same climate-forcing impact as 84 tons of CO_2 over a period of 20 years and the same climate-forcing impact as 28 tons of CO_2 over a 100-year period.[104] Global warming potentials are most commonly calculated and expressed for either 20-year or 100-year periods.

International Energy Agency and the Stated Policies and Sustainable Development Scenarios

The International Energy Agency (IEA) is an autonomous intergovernmental organization established in the framework of the Organisation for Economic Co-operation and Development (OECD) in 1974.[105] The IEA acts as a policy adviser to its member states but also works with nonmember countries, especially China, India, and Russia. In addition to energy security and economic development, the IEA has a strong policy focus on environmental protection and mitigation of climate change. The IEA works to promote alternative energy sources (including renewable energy), rational energy policies, and multinational energy technology cooperation.

The IEA's annual *World Energy Outlook* reports include information on alternative energy pathway scenarios, including the Stated Policies Scenario and the Sustainable Development Scenario.[106] The Stated Policies Scenario broadly serves as the IEA baseline scenario. It takes account of broad policy commitments and plans that have been announced by countries, including national pledges to reduce GHG emissions and plans to phase out fossil-energy subsidies, even if the measures to implement these commitments have yet to be identified or announced. It does not include all of the Intended Nationally Determined Contributions (INDCs) made in the run-up to the 2015 Paris climate conference (COP 21) and therefore should be considered a conservative estimate of average emission rates for power production by country over the next 25 years. The Sustainable Development Scenario is more aggressive, projecting targets that set out a pathway to achieve the energy-related goals in the United Nations' "2030 Agenda for Sustainable Development," which include taking urgent action to combat climate change.[107] The IEA planning scenarios provide emission rates only over the 100-year GWP time horizon.

Life-Cycle Assessment

Life-cycle assessment (LCA) is a technique to assess and quantify the environmental impacts associated with all the stages of a product's life.[108] For gas, LCA is used to quantify the amounts of GHG emissions from its extraction at the well to its combustion at the power plant (or other facility) and all the steps in between. LCA analysis for GHG emissions is similar for coal and other fossil fuels, although the various life stages may differ (e.g., rail transport versus pipeline transport).

For both gas and coal, carbon dioxide and methane are the predominant GHG emissions that occur during production and use.[109] Therefore, for LCA of these fossil fuels, GHG emissions amounts are expressed as the carbon dioxide equivalent (CO_2e) for a particular global warming potential (GWP) time frame (20 or 100 years) and relative to the amount of energy the gas or coal yields when it is burned. For example, and in this report, the 20-year and 100-year GWPs for a particular life-cycle step are expressed as grams of CO_2e emitted per kilowatt-hour of power produced (g CO_2e/kWh).

Methane Emissions From Gas Production and Processing

Because methane is such a potent GHG, calculated life-cycle emissions for exported LNG are strongly influenced by the analytical assumptions made for the amounts of methane that leak or are otherwise released (e.g., via flaring) from the wells, pipelines, valves, compressors, and processing facilities through which the gas passes during its life-cycle. However, measuring the amounts of methane that leak or are otherwise released into the atmosphere during gas production and transport is challenging:

different measurement methods yield different results, and there is evidence that leakage rates vary substantially among individual wells and facilities.[110] Published values range from less than 1 percent to more than 10 percent.[111] Recent research has suggested that methane leakage rates are higher than previously thought.[112]

Social Cost of Carbon

The social cost of carbon (SCC) is an estimate of the economic damages associated with a small increase in CO_2 emissions, conventionally 1 metric ton, in a given year.[113] Economic damages associated with climate change include adverse changes in net agricultural productivity, human health impacts, property damage from more frequent flooding, and changes in energy system costs. In addition to being a tool to quantify the costs of GHG emissions, the SCC can be used to quantify the benefits of reducing emissions: for example, for a specified CO_2 emission reduction, the SCC dollar figure assigned represents the benefit of that reduction and is calculated as the value of damages avoided. Historically, the U.S. Environmental Protection Agency (EPA) and other federal agencies have used the SCC to estimate the climate benefits of regulations and rulemakings.

In 2010, 2013, and 2016, the U.S. Interagency Working Group on Social Cost of Greenhouse Gases was convened to estimate the SCC for use in the United States.[114] For this analysis, we used the group's 2016 update, which estimated a central value of $48.47 per metric ton of CO_2e in 2018, rising to $61/tonne in 2030 and $84/tonne in 2050 (in 2018 dollars).[115]

The Paris Agreement

The Paris Agreement is an international accord for collective effort to limit the rise in global warming to below 2 °C (3.6 °F) above preindustrial temperatures. The language of the agreement was negotiated by representatives of 196 countries at the 21st Conference of the Parties of the United Nations Framework Convention on Climate Change (UNFCCC) in Paris and adopted by consensus on December 12, 2015. As of July 2018, 195 UNFCCC member nations have signed the agreement and 179 of them have ratified it.[116] The United States formally ratified and submitted its plan to join the agreement to U.N. Secretary-General Ban Ki-moon on September 3, 2016. The agreement entered into force on November 4, 2016, after having been ratified by 55 UNFCCC parties that together account for 55 percent of global GHG emissions.

Under the Paris Agreement, each country determines, plans, and regularly reports on its own voluntary "nationally determined contribution" (NDC) toward mitigating global warming and agrees to strengthen these efforts in the years ahead. The agreement also calls for $100 billion a year in funding from developed countries to developing countries to support green energy sources, aims to strengthen the ability of countries to deal with the impacts of climate change, and provides for enhanced transparency of action and support through a more robust monitoring and reporting framework. The United States pledged to reduce its emissions by 26 to 28 percent from 2005 levels by 2025 and to provide up to $3 billion in aid to support poorer countries' climate efforts.[117]

On June 1, 2017, the Trump administration announced its intent to withdraw from the Paris Agreement, making the United States the only nation in the world to reject this international pact. On November 4, 2019, the Trump administration formally notified the United Nations of its intent to leave the Paris Agreement, starting a yearlong countdown to an exit that became official on November 4, 2020, the day after the presidential election.[118] The White House initially agreed to adhere to the United Nations rules for withdrawal, which included continuing to implement and report on its plans and pledges, including our "nationally determined contribution" to reduce GHG emissions and to provide up to $3 billion in aid to support poorer countries' climate efforts. However, the Trump Administration did not submit reports required under the UNFCCC and refused to provide the remaining $2 billion in pledged aid.[119]

President-elect Biden has promised to rejoin the Paris Agreement. This action does not require Senate ratification, so the United States could officially resume its role under the Paris Agreement as early as mid-February 2021.[120]

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