BURNING BRIDGE:

Debunking LNG as a Climate Solution

By Daniel Horen Greenford
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FOREWORD

Fossil gas, LNG and the climate crisis — a re-examination

Already facing the impacts of climate change and extreme weather, B.C. has set climate targets and advanced a number of climate policies to drive emissions down across sectors of the economy. It has legislated climate targets of 40 per cent below 2007 by 2030, 60 per cent by 2040 and 80 per cent by 2050. This last target was ratcheted up more recently to net-zero emissions by 2050 in the province's "Roadmap to 2030."[1]

Despite these commitments, the province also had an ambitious agenda to increase production of fossil methane gas and to export it in the form of liquefied natural gas, or LNG. Methane is a potent greenhouse gas that is emitted throughout the supply chain. When burned, it adds to the atmospheric concentration of carbon dioxide, accelerating human-caused climate change.

The province and industry claim that expanding B.C.'s LNG exports can be a climate solution by displacing dirty coal in Asian markets.

In 2023, arguments for fossil fuel infrastructure expansion require tough scrutiny. After all, both the International Energy Agency and the Intergovernmental Panel on Climate Change are clearly on record stating that the world does not need any additional investment in fossil fuel infrastructure.

This report by Daniel Horen Greenford, postdoctoral fellow in climate policy at Concordia University, draws on the latest peer-reviewed literature, the International Energy Agency and other sources to assess the merits of government and industry claims. Is B.C. LNG better than LNG produced elsewhere? Is LNG a "bridge fuel" that can help lower global emissions over the next two to three decades? Or is it a false peak on the urgent global expedition to the summit of mount net zero?

Horen Greenford assesses the evidence and determines that investing in LNG infrastructure in B.C. and in receiving markets is not a climate solution. It exacerbates B.C. and Canada's challenges in achieving their climate targets and is highly unlikely, even under best case scenarios, to reduce aggregate global emissions. It is a diversion that wastes time and capital and locks in emissions the world can ill afford. And it undermines expansion of renewable energy that the world urgently needs.

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[1] Clean B.C. Roadmap to 2030, October, 2021, https://www2.gov.bc.ca/assets/gov/environment/climate- change/action/cleanbc/cleanbc_roadmap_2030.pdf

THE PROPONENTS' CLAIMS OF LNG'S CLIMATE BENEFITS

The province has argued that by exporting B.C. LNG, cleaner gas will displace coal, reducing global emissions overall despite increasing emissions in B.C. Then-Premier Christy Clark described the rationale for exporting B.C. LNG in the province's 2016 climate leadership plan:

> We are ensuring that we develop industries like liquefied natural gas in ways that are cleaner than competing jurisdictions, allowing us to ship it to other nations where it can reduce their reliance on higher carbon energy sources like coal and oil. By seizing the opportunity of a low carbon economy and securing global trade partnerships, we can create thousands of green jobs in areas like clean technology and clean energy, contributing to reductions in emissions not just here at home, but around the world.[2]

A 2018 government briefing document argues:

> B.C. can choose to supply low GHG-intensive gas, helping to offset some of the developing world's carbon footprint. Or we can leave this demand to be supplied with higher GHG-intensive gas from other parts of the world.[3]

The Canadian Association of Petroleum Producers provides its rationale for exporting Canadian LNG as follows:

> Because natural gas burns 50 per cent cleaner than coal, Canadian LNG can be used in Asia-Pacific markets to displace coal-fired electricity generation, creating jobs and prosperity at home while significantly reducing global GHG emissions.
>
> Lifecycle emissions within Canada will increase when projects currently proposed or under construction begin operation. However, when Canadian LNG is exported and used as an alternative to coal-fired power generation in global markets, this exported LNG will displace higher GHG emissions in overseas markets, resulting in a net reduction in global emissions.[4]

LNG Canada describes its project as delivering the "lower-carbon energy that the world needs." In June 2019, then-Minister of Natural Resources Amarjeet Sohi was reported by the *Globe and Mail* as arguing that Canada could get credit under Article 6 of the Paris Agreement for lowering emissions by replacing coal used in Asia to generate electricity, through the use of internationally transferred mitigation outcomes (ITMOs). They quoted Sohi as saying, "We feel that by supplying clean energy — such as LNG that allows other countries to reduce emissions in diesel and coal — it will not only allow us to play a leadership role in making the world cleaner and less polluting, but at the same time get credit toward our emission reductions."[5]

The claim that B.C. LNG projects could earn credits for global emissions reductions is flimsy for two reasons. The first, as explained by experts at the Canadian Climate Institute, is that that such transactions would not be valid, and the importing countries, focused on reducing their own emissions, would see no benefit to them.[6] The second is the focus of this report: It is unlikely that B.C. LNG would actually reduce global emissions.

The above industry and government claims are bold, and deserve scientific scrutiny. If they are more hot air than evidence-based, then public and private investments in LNG infrastructure are suspect.

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[2] BC Government 2016. Climate Leadership plan. https://www2.gov.bc.ca/assets/gov/environment/climate-change/action/clp/clp_booklet_web.pdf

[3] https://news.gov.bc.ca/files/Natural_Gas_Technical_Briefing_Final.pdf

[4] https://www.capp.ca/explore/natural-gas-and-the-lng-opportunity-in-british-columbia/

[5] https://www.theglobeandmail.com/business/article-canada-touts-lng-exports-as-opportunity-to-reduce-emissions-in-asia/

[6] https://climateinstitute.ca/canada-cannot-get-credit-low-carbon-exports/

B.C. LNG SUPPORTS AND CLIMATE POLICIES

British Columbia has enabled and promoted expansion of the gas sector and LNG exports through a generous royalty regime and other forms of public financing and provincial sales tax relief. It exempted LNG facilities from regulations under the *Clean Energy Act*, which would have required 93 per cent of their electricity to come from hydroelectric or renewable energy sources.[7] Without other policies, the exemption in effect allows LNG producers to avoid electrifying their facilities, despite the fact that gas-powered liquefaction will result in large emissions.

The federal government has likewise supported LNG expansion by waiving import duties on steel needed for the plants.

At the same time as it has put in policies to favour LNG exports, the province has put in place policies to mitigate its climate impacts. This includes a carbon intensity limit (at 0.16 tonnes CO_2e/tonne LNG).

In 2018, the newly elected B.C. government, concerned that no LNG projects had received a positive investment decision, developed a new framework for LNG.[8]

In October 2018, consortium partners Shell, PETRONAS, PetroChina, Mitsubishi Corporation and KOGAS decided to proceed with LNG Canada Phase 1, the largest private sector investment in Canadian history. Construction of this massive terminal will be complete in 2025 and will export 14 million tonnes per annum of LNG, and it will become the province's biggest carbon polluter, emitting the equivalent of 20 per cent of B.C.'s 2020 emissions.

In March 2023, under the leadership of a new premier, the B.C. government announced a new energy action framework. A key component of this framework is to implement a new provincial oil and gas emissions cap to ensure that the sector meets the sectoral emissions reduction target of 33 to 38 per cent below 2007 levels by 2030.[9] This framework represents the beginnings of a more cautious attitude toward LNG, and recognition that the economy of the future must zero out emissions and be powered by renewable energy.

In his analysis, the author considers the province's policies to mitigate LNG's life cycle emissions. The conclusion is unchanged: exporting B.C. LNG makes the climate crisis worse, not better. It's time for the province to pull the plug on any further LNG expansion and to cease providing public financing, infrastructure support or preferential treatment for the sector. Indigenous nations would likely benefit from careful scrutiny of any proposals to participate in the LNG projects, given that they are likely to accentuate the climate crisis and may end up as stranded assets rather than a foundation for future prosperity.

Tom Green
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7 https://www.bclaws.gov.bc.ca/civix/document/id/complete/statreg/234_2012/search/CIVIX_DOCUMENT_ROOT_STEM:(liquid%20natural%20gas)%20AND%20CIVIX_DOCUMENT_ANCESTORS:775844721?2#hit1

8 https://news.gov.bc.ca/releases/2018PREM0012-000480

9 https://news.gov.bc.ca/releases/2023PREM0018-000326

Executive summary

Fossil methane gas, marketed as "natural gas" (or simply "gas") and its liquefied form used for long-distance maritime transport, "liquefied natural gas" (LNG), have been proposed as a middle ground between more carbon-intensive fossil fuels and renewable energy. Proponents of using gas as a "bridge fuel" argue it can provide reliable energy with lower greenhouse gas emissions than coal or oil as the world transitions over the longer term to carbon-free energy. However, since this proposition first appeared, the case for gas as a bridge fuel has weakened. Recent studies have discovered that rates of methane loss throughout the oil and gas supply chain are much higher than previously believed, eroding the climate advantage of gas over other fossil fuels. At the same time, renewables have matured, becoming reliable and cost-competitive. Scientific and international consensus has also formed around the need to limit global heating to 1.5 C or at most "well below" 2 C, since heating in excess of the Paris Agreement goals will likely lead to catastrophic climate change, including the risk of irreversible, uncontrollable runaway processes that lock in changes to the climate regime that could jeopardize the basis for organized human society.

Avoiding these levels of climate disruption requires immediate drastic reductions in GHG emissions and concomitant reductions in fossil fuel production and consumption. Gas production must also begin declining immediately if there is to be a reasonable chance of meeting the Paris goals and averting climate disaster. This leaves no room for additional gas production or additional investments in LNG export infrastructure, as existing and under-construction supply is sufficient to meet demand under a 1.5 C–aligned energy transition. Research also shows that overall, switching from coal to gas power does little if anything to change the overall trajectory of GHG emissions since increased supply even when displacing coal creates a long-term commitment to additional fossil fuel infrastructure and incentivizes additional consumption of gas. Canadian LNG, as additional supply, is superfluous and works against the needed energy transition. This is true regardless of possible marginal reductions in its life cycle emissions gained through LNG terminal electrification and reduced methane losses during gas extraction, processing, transport and other upstream processes. This finding would remain true even if all upstream processes were electrified, as downstream emissions from gas combustion still represent the majority of gas's life cycle emissions. Electrifying gas production would require significant amounts of clean energy that would have to be diverted from decarbonizing the rest of B.C.'s economy, which still lacks the clean energy to meet demand in a decarbonized economy without electrifying any upstream oil and gas processes. Together, these realizations cast doubt on industry claims that B.C. LNG is part of a credible global energy transition.

This report covers in greater detail the current state of the science on the climate impacts of gas, the necessary reductions in gas supply and demand under the Paris Agreement, and how this disqualifies Canadian LNG as a "climate solution." Rather, this report concludes, based on the wealth of evidence from climate science and economics, that possible incremental reductions in global GHG emissions resulting from Canadian LNG are not enough, and Canadian LNG is "too little, too late" to be part of a Paris-aligned energy transition. Instead of this inadequate "bridge too close," the future of Canadian energy would be better directed at promoting a direct transition to renewable energy at home and abroad, which is not only necessary but well within reach.

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Glossary

C	Degrees Celsius
APS	Announced Pledges Scenario
AR6	Sixth Assessment Report
BAPE	Bureau d’audiences publiques sur l’environnement
B.C.	British Columbia
bcm	Billion cubic metres
CDR	carbon dioxide removal
CER	Canada Energy Regulator
CH_4	Methane
CO_2	Carbon dioxide
COP	Conference of the Parties
CCS	Carbon capture and storage
EPA	Environmental Protection Agency
GHG	Greenhouse gas
GHGI	Greenhouse gas inventory
Gt	Gigatonne (billion tonnes)
IEA	International Energy Agency
IISD	International Institute for Sustainable Development
IPCC	Intergovernmental Panel on Climate Change
IRENA	International Renewable Energy Agency
LNG	Liquefied natural gas
NZE	Net zero emissions by 2050
OGI	Optical gas imaging
PV	Photovoltaic
RCB	Remaining carbon budget
STEPS	Stated Policies Scenario
Tcm	Trillion cubic metres
UNFCCC	United Nations Framework Convention on Climate Change
STEPS	World Energy Outlook 2022
WGIII	Working Group III

1. Introduction

1.1 CLIMATE SOLUTION OR MORE FUEL ON THE FIRE? GAS'S ROLE IN THE ENERGY TRANSITION

The climate crisis is intensifying, but the world has failed to turn the tide on greenhouse gas emissions and its largest source: burning fossil fuels (1). Globally, energy use is outpacing decarbonization, leading to overall growth in carbon dioxide emissions (2). Fossil fuel emissions continue to increase, again reaching a record high in 2022 (3). It is against this backdrop that the fossil fuel industry is seeking a new lease on life, touting gas[10] as a so-called "bridge fuel" that could be used to reduce GHG emissions by switching from coal and oil to gas, especially for electricity generation but also for heating and transport, as the world gradually transitions to renewable energy.

The bridge fuel argument is based on several debatable premises:

1. Gas is "cleaner" (i.e., less GHG emissions-intensive) than coal and oil,
2. Gas displaces "dirtier" (i.e., higher-emitting) fuels, and
3. Renewables are not ready or affordable enough for large-scale deployment or capable of deeply decarbonizing the energy system, especially in industrial applications where high temperature heat is needed.

This report reviews:

- How addressing the climate crisis requires weaning the world off fossil fuels (Section 1.2)
- The speed at which fossil fuels need to be phased out in order to avoid catastrophic climate disruption (Section 1.3)
- The latest scientific literature on the climate impact of gas, especially how methane venting and leaks throughout the oil and gas supply chain greatly exacerbate its climate impact and raise doubts about whether converting coal to gas power reduce overall emissions (Section 2.1)
- The latest scientific literature contextualizing gas production within the global energy transition (Sections 2.2, 2.3)
- The dynamics and economics of a global energy transition, with a special emphasis on Asian markets, to assess the credibility of these arguments (Section 2.3)
- How climate action constrains Canadian gas production (Section 2.4)
- The readiness and competitiveness of renewables versus incumbent fossil fuels (Section 3)

After assessing this body of evidence, this report will draw conclusions as to whether gas should play a role in the unfolding energy transition.

[10] Here we use "gas" to refer to any methane-containing fuel product, including gas from fossil sources (referred to by industry as "natural gas") and from biological sources (referred to by industry as "renewable natural gas").

1.2 THE CLIMATE CRISIS IS ALREADY UNFOLDING AND REQUIRES IMMEDIATE ACTION

The planet's surface temperature has already increased by around 1.1 C in just over 100 years, with most of this warming occurring over recent decades (4). This rate of warming is unprecedented in Earth's history, and is unequivocally caused by human activity that heats the planet by increasing the concentration of GHGs in the atmosphere (4). With this amount of warming, we are already seeing serious harms that include increasing frequency and intensity of flooding, wildfires, droughts, heat waves, expanded impacts of pests and pathogens and other effects (4). All of these are linked to climate change, and will be exacerbated by further warming (5). Canada is warming at twice the global average rate (6), and is already experiencing many of climate change's deleterious effects (7). For example, 2021's catastrophic flooding in British Columbia was made at least twice as likely due to climate change, and its devastating heat wave that destroyed the town of Lytton was made 150 times more likely (8). Heat waves throughout the province killed 595 people that summer, the vast majority during the heat wave itself (9).

As noted above, the impacts of climate change are only expected to worsen, with intense heat waves, wild fires and floods becoming the new normal in B.C. and much of the Pacific Northwest.[11] Around the world, extreme weather events will occur with increasing frequency and intensity; for example, with 1.5 C, 2 C and 4 C of heating in global temperatures, heat waves that occurred once every 10 years during preindustrial times will be 4.1, 5.6 and 9.4 times as likely to occur and 1.9 C, 2.6 C and 5.1 C hotter, respectively.[12]

Many climate impacts are expected to be far more severe at 2 C or more of global heating relative to a 1.5 C hotter world, where even this additional half a degree will substantially increase the risks to natural, managed and human systems — such as warm water corals (already likely to be lost in a 1.5 C world), mangroves, coastal and fluvial flooding, crop yields, and heat-related morbidity and mortality (10). Increased global temperatures also exacerbate the risk of passing climate "tipping points," with especially catastrophic irreversible runaway changes to the climate becoming more likely in a 1.5 C or hotter world (11, 12).

This scientific consensus has informed a global political consensus. Under the Paris Agreement, countries have committed to "holding the increase in the global average temperature to well below 2 C above pre-industrial levels and pursuing efforts to limit the temperature increase to 1.5 C above pre-industrial levels." (13) Canada was a staunch advocate for increasing ambition from a 2 C to a 1.5 C limit. Since the Paris Agreement was drafted, the scientific community has been updating research to find more ways to limit warming to 1.5 C, while assessing the impacts of a 1.5 C or hotter world and how they can be mitigated and managed (4, 5, 10, 14).

The challenge is formidable but achievable. Climate risks can only be adequately addressed through deep reductions in GHG emissions in the next decades, with the window for limiting warming to 1.5 C or 2 C rapidly closing (4). Most recently, the Intergovernmental Panel on Climate Change released Working Group III's contribution to the "Sixth Assessment Report," which is responsible for reviewing the literature on emissions pathways. They concluded with high confidence that "all global modelled pathways that limit warming to 1.5 C (>50%) with no or limited overshoot, and those that limit warming to 2 C (>67%), involve rapid and deep and in most cases immediate GHG emission reductions in all sectors." (14) In other words, they found that without immediate and dramatic action, it will be impossible to limit global temperature rise to 1.5 C or well

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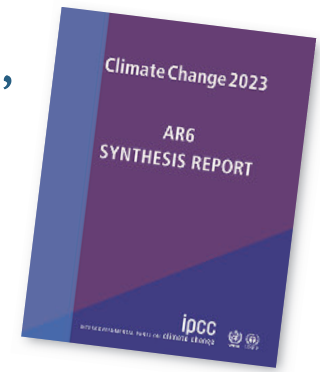
[11] See, e.g., a primer on climate change in B.C. by D. Daust: https://www2.gov.bc.ca/assets/gov/environment/natural-resource-stewardship/nrs-climate-change/applied-science/2a_va_bc-climate-change-final-aug30.pdf, and explore climate impacts across Canada using the Climate Atlas: https://climateatlas.ca/map/

[12] One in 50-year heat waves will be 39.2 times more likely to occur and be 5.3 C hotter. For a more complete list of how marginal increases in global warming will increase the frequency and intensity of weather extremes, see Figure SPM.6 in IPCC (2021), SPM WGI, p.18-19.

below 2 C above pre-industrial levels, but if we act now, we can still cut emissions in half by 2030 and have a reasonable chance of avoiding the worst effects of climate change .

> **Continued greenhouse gas emissions will lead to increasing global warming ... Every increment of global warming will intensify multiple and concurrent hazards.**
>
> **All global modelled pathways that limit warming to 1.5 C (>50%) with no or limited overshoot, and those that limit warming to 2 C (>67%), involve rapid and deep and, in most cases, immediate greenhouse gas emissions reductions in all sectors this decade.**
>
> *- March 2023, Note (13)*



While modest progress has been made since the advent of global climate negotiations, the world is still on track for catastrophic levels of warming. Analysis following the 26th Conference of the Parties (COP26), held in Glasgow, U.K., in fall 2021, shows progress is stalling and predicts that current policies will lead to a 2.8 C temperature rise by the end of the century (15). If countries meet their current pledges, temperature rise by the end of the century will only be reduced to 2.4 to 2.6 C, for conditional and unconditional pledges, respectively. New research also suggests that if countries meet their conditional and unconditional pledges and net-zero targets, peak warming could be limited to just below 2 C; however, limiting warming "to 'well below' 2°C or 1.5°C urgently requires policies and actions to bring about steep emission reductions this decade, aligned with mid-century global net-zero CO_2 emissions." (16) The energy infrastructure added in Canada over the current decade has a critical role to play in shaping this future and in making climate targets easier or more difficult to achieve.

1.3 NEEDED EMISSIONS REDUCTIONS AND CONCOMITANT REDUCTIONS IN FOSSIL FUEL DEMAND AND SUPPLY

These needed emissions reductions require a massive reduction in fossil fuel combustion across all scenarios explored by the scientific community. WGIII found that "in modelled pathways that limit warming to 1.5 C (>50%) with no or limited overshoot, the global use of coal, oil and gas in 2050 is projected to decline with median values of about 95%, 60% and 45% respectively, compared to 2019." These fossil fuel reductions also need to begin immediately. Coal needs to decline most rapidly — at an average linear decline of 7.5 per cent of 2019 levels each year from 2020 to 2030 (a decline of 12.9 per cent year-over-year) — while oil and gas still must each decline at an average linear rate of one per cent per year of 2019 levels (one per cent year-over-year) from 2020 to 2030 before accelerating to annual reductions at an average linear rate of 2.5 per cent (four per cent year-over-year) and 1.8 per cent linearly (2.4 per cent year-over-year), respectively (Table 1).

New research finds that there is an overreliance on coal phase-out rates in the 1.5 C pathways used by the IPCC, and that this preference for phasing out coal over gas is unrealistic since it expects too much of poorer countries that are highly dependent on coal power generation and lack the means to phase out coal power at these envisioned rates (17). Incidentally, this allows richer countries to consume more oil and gas. Correcting for this overreliance on coal phase-outs would require a commensurate increase in the rate of gas phase-out. In light of these findings, the pace of oil and gas phase-out will likely need to proceed faster than current models suggest.

	LINEAR			EXPONENTIAL (YEAR-OVER-YEAR)		
	COAL	OIL	GAS	COAL	OIL	GAS
2020 TO 2030	-7.5%	-1.0%	-1.0%	-12.9%	-1.0%	-1.0%
2030 TO 2050	-1.0%	-2.5%	-1.8%	-7.7%	-4.0%	-2.4%

Table 1. Reduction rates in fossil fuel usage under 1.5 C (>50%) global energy transition with no or limited overshoot. Author's calculation from IPCC AR6 WGIII, chapter 3 (18).

In stark contrast to the needed downward trend, fossil fuel production continues to grow. Countries' planned extraction dwarfs what is needed under 1.5 C or 2 C energy transitions. The latest stock-take of planned extraction found that, in sum, the world's planned fossil fuel production in 2030 would be over twice what is consistent with limiting warming to 1.5 C, and 45 per cent more than what would be consistent to limiting warming to 2 C (19). Countries are planning to produce 71 per cent and 15 per cent more gas by 2030 than would be consistent with 1.5 C and 2 C, respectively.

Credit: Sky_Blue, iStock

2. Is gas a "bridge fuel" or a "bridge too close"?

2.1 THE CLIMATE IMPACT OF GAS IS HIGHLY UNDERSTATED (AND GHG INVENTORIES UNDERSTATE EMISSIONS)

The main component of gas is methane (CH_4), which is the second-largest contributing GHG to global heating after carbon dioxide (CO_2). Methane has 82.5 and 29.8 times the global warming potential of carbon dioxide over 20 and 100 years, respectively (20). Methane emissions are responsible for approximately 20 per cent of present global heating.[13] Extraction and use of fossil fuels accounts for about 20 per cent of total methane emissions and 30 per cent of total anthropogenic methane emissions, while the remainder comes from anthropogenic (e.g., agriculture, landfills, hydroelectric reservoirs) and natural (e.g., wetlands, permafrost releases) biogenic sources (21). Global warming also melts permafrost and causes more evaporation from wetlands, creating a positive feedback releasing more methane from natural sources (22–25).

Research that measures methane concentrations using isotopes can determine the origin and amount of methane in the atmosphere, and has found that globally, methane emissions from fossil fuel production and consumption are underestimated by 20 to 60 per cent (26, 27). Similar methods have been used to show that more than half of increased emissions from fossil fuels globally are attributable to the increase in shale gas production in North America (28). It is concerning that despite recent mitigation efforts, atmospheric methane concentrations have been increasing at an accelerating rate (Figure 1).

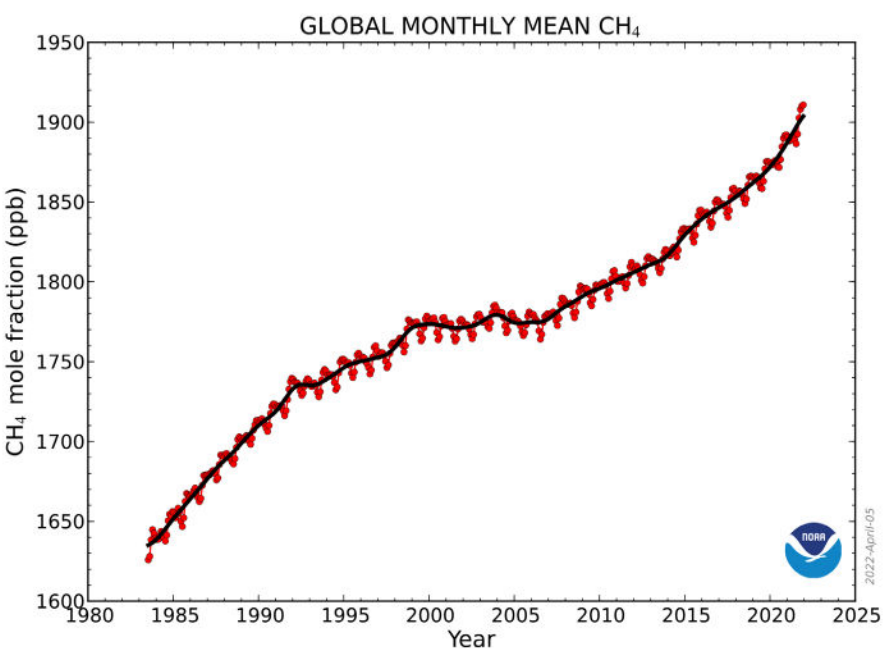


Figure 1. Level of methane (CH_4) in the atmosphere, showing accelerating rate of increase since 2007.[14]

[13] In 2019, methane was responsible for 0.54 W/m² out of 2.84 W/m² total effective radiative forcing or 2.72 W/m² anthropogenic effective radiative forcing (Table AIII.3, Annex III, AR6 WGI), available at: https://www.ipcc.ch/report/ar6/wg1/downloads/report/IPCC_AR6_WGI_AnnexIII.pdf

[14] https://www.noaa.gov/news-release/increase-in-atmospheric-methane-set-another-record-during-2021

Gas emits dramatically more GHG emissions than non-fossil sources of energy, such as solar or wind power. The life cycle emissions of combined cycle gas power (490 gCO_2e/kWh) are about 10 and 45 times that of utility scale PV (48 gCO_2e/kWh) and onshore wind power generation (11 gCO_2e/kWh), respectively.[15] Although, gas has lower CO_2 emissions when combusted than coal or oil, such downstream CO_2 emissions don't come close to representing the entire climate impact of gas, as emissions originate substantially from methane that escapes to the atmosphere uncombusted. A growing body of scientific research has shown that the climate impact of gas is highly understated due to systemic underreporting of methane losses throughout the oil and gas supply chain. These losses are often referred to as "fugitive emissions," which include intentional and accidental releases of methane gas during all phases of upstream (e.g., exploration, extraction, gathering, processing, improper well decommissioning or well abandonment), midstream (e.g., transmission and storage) and downstream processes (e.g., local distribution, end uses). Many decisions being made today to build gas infrastructure are based on the assertion that gas has a lower climate impact than other fossil fuels. Here we review the latest literature on methane emissions from the oil and gas supply chain.

Methane escapes into the atmosphere throughout the oil and gas supply chain. Methane is often released both intentionally, as in the case of venting from equipment or the release of unwanted gas, or unintentionally, because of equipment leaks or malfunctions such as unlit or inefficient flares.[16]

These losses include:

- venting and leaks during extraction from the wellhead or surrounding areas,
- venting and leaks during gathering, processing, transmission and storage (aboveground tank or underground storage facilities) during normal operation from faulty equipment,
- emissions during compression, loading, offloading and regasification of LNG,
- boiling off of LNG during shipping, leaks from distribution networks and end-use infrastructure (e.g., power plants, industrial heating, ground transportation, home usage for cooking and heating),
- emissions during marine shipping when gas used as fuel is incompletely combusted (called "methane slip"),
- and leaks upstream after wells have been abandoned or improperly decommissioned, where sometimes substantial amounts of methane continue to escape wells even after their economic depletion.

Recent studies conducted in the United States and Canada have confirmed that methane losses from oil and gas production occur primarily during irregular events that are not typically reported by bottom-up modelled estimates used by industry and government agencies, such as large emissions that occur when off-gassing or emptying equipment to perform regular maintenance or when equipment is damaged or fails (see below). Major leak events are especially substantial contributions to global methane emissions, sometimes referred to as "super" or "ultra emitters," which make up eight to 12 per cent (~eight million tonnes (Mt) of CH_4 per year) of global oil and gas production methane emissions (29). These include major leak events from pipeline ruptures, like the October 2018 rupture near Prince George, B.C., of a 91-centimetre pipeline operated by Enbridge Inc., which the Transportation Safety Board review estimated emitted 140 million cubic feet of gas.[17]

[15] IPCC Working Group III – Mitigation of Climate Change, Annex III: Technology - specific cost and performance parameters - Table A.III.2 (Emissions of selected electricity supply technologies (gCO 2eq/kWh)). IPCC. 2014. p. 1335. Retrieved from: https://www.ipcc.ch/site/assets/uploads/2018/02/ipcc_wg3_ar5_annex-iii.pdf#page=7

[16] Note that it is impractical to disaggregate fugitive emissions from oil and gas production, since the two fuels are often co-produced.

[17] https://www.tsb.gc.ca/eng/rapports-reports/pipeline/2018/p18h0088/p18h0088.html

Globally, studies using isotope identification of atmospheric methane have estimated the fugitive emissions rate from fossil fuel production and use, finding that the loss rate declined from a rate of ~eight per cent in 1985 to ~two per cent in the early 2010s (26). This may be due to improvements in industry performance that may have been incentivized by increasing demand for gas, which was formerly often treated as a waste byproduct of oil extraction and vented or flared on-site. However, this rate may be increasing. The recent hydraulic fracturing ("fracking") boom began in the early 2010s and the amount of unconventional oil and gas production continues to grow, which tends to have much higher rates of methane loss (likely over twice that of conventional) due to the more invasive injection methods used in hydraulic fracturing processes to access oil and gas deposits and the larger span and shorter lifetimes of well pads (30–32). Canada's share of unconventional gas is projected to grow (to 98 per cent of total gas production by 2050), especially as unconventional gas from the Montney Formation on the border of Alberta and B.C. becomes the largest source of gas production (73 per cent of total gas production by 2050), as is forecasted in the CER's Evolving Policies Scenario.[18] Much of this production would take place to provide a source of LNG for export from B.C. (LNG exports growing to 37 per cent of total gas production by 2050).[19]

2.1.1 FUGITIVE EMISSION RATES (AND HOW THEY AFFECT THE CLIMATE IMPACT OF GAS)

The most comprehensive estimate of methane lost throughout the oil and gas supply chain is 2.3 per cent of gross gas production from well to gate (i.e., from extraction to city gate), a value published in the most highly cited general scientific journal in the United States, *Science*, in 2018 (33). This study is a compilation and synthesis of at least 10 different data sets from both bottom-up and top-down studies published since 2012, across six different oil and gas production areas in the United States, drawn from 433 different sites, all validated against a separate, top-down method. In contrast to ordinary studies, it independently verifies nearly a decade's worth of data collected across the country to reach the best possible estimate from the entire body of research done to date. Because of the scientific understanding of how and when methane loss occurs — extensively documented by Alvarez and colleagues (33) and its supporting references and confirmed in subsequent studies, e.g., by Rutherford and colleagues (34) — it is not acceptable to rely only on studies that only estimate methane leakage from specific pieces of equipment during controlled operating conditions, as industry and government often do. Alvarez and colleagues found that methane lost was 60 per cent higher than that reported by the U.S. Environmental Protection Agency (33). Rutherford and colleagues (34) confirmed that the Alvarez study is still the most trustworthy estimate of methane emissions from the oil and gas sector, and verified that the production segment of the oil and gas supply chain is responsible for the largest proportion of leaks — 1.5 to two times greater than estimates in the EPA's GHG inventory.

No study yet exists comparable to that by Alvarez and colleagues for the Canadian industry; however, mounting scientific evidence from ground-based and airborne measurements suggests that Canadian methane emissions from oil and gas production are also vastly underestimated. One notable study conducted in Alberta estimated a methane loss rate from gas fields in the Red Deer region of about three per cent (35). Using aerial surveys, Johnson and colleagues found that oil and gas operators in the Red Deer region emitted 17 times more methane than indicated by the industry's bottom-up inventory methods (36). When extrapolating their sample of oil and gas activities from Red Deer and Lloydminster to all of Alberta, they found that methane emissions from the upstream oil and gas sector (excluding mined oilsands) are likely to be at least 25 per cent to 50 per cent higher than government estimates. A team of scientists from Environment and Climate Change Canada conducted the most geographically and temporally comprehensive study to date

[18] https://www.cer-rec.gc.ca/en/data-analysis/canada-energy-future/2021naturalgas/

[19] *ibid.*

using similar methods, performing an eight-year survey of Western Canadian oil and gas production, and found that methane emissions were 90 per cent higher than (i.e., almost twice that) reported in national inventories (37). For comparison, this would amount to a methane loss (or "fugitive emissions") rate of 4.3 per cent gross product.[20]

There have also been preliminary studies of methane emissions from oil and gas extraction in the Montney Formation. Atherton and colleagues published the first mobile collection of methane emissions from oil and gas infrastructure in British Columbia in 2017 (38). They surveyed 1,600 unique well pads and facilities managed by more than 50 different operators, using ground-based measurements of methane plumes. By extrapolating their findings to the entire Montney oil and gas industry, they estimated that inventories underreported methane emissions by 43 per cent. A more recent ground survey using vehicle-based optical detection concluded that methane emissions from oil and gas production in Canada could be 50 per cent higher than reported inventory estimates (39), while British Columbia may be slightly less than this average, at about 40 per cent higher than reported in national inventories reporting (38). While some may suggest these studies imply there are better practices underway in the Montney Formation, studies using only ground-based measurements are likely incomplete measures of fugitive emissions. Surveys of Canadian oil and gas operators using composite methods that calibrate ground-based measurements using aerial surveys have shown a large discrepancy between aerial and ground-based estimates, and conclude that ground-based detection may miss a significant portion of emissions. This is likely due to difficulties in capturing plumes from elevated equipment like storage tanks (see Section 2.1.3 below). Tyner and Johnson, funded in part by the BC Oil and Gas Commission and Natural Resources Canada, and with oversight from ECCC, conducted the most recent study to assess Canadian oil and gas using this composite method, and found methane emissions in British Columbia are 60 to 120 per cent higher than current federal inventory estimates (40). These findings are in close agreement with the aforementioned research and suggest that Canadian producers do not perform better than their U.S. counterparts.

2.1.2 DISCREPANCIES BETWEEN GOVERNMENT INVENTORIES AND THE LATEST ACCOUNTING

At present, there remains a large discrepancy between government inventories and the latest science. In the U.S., the EPA's emissions factors used in the GHGI were constructed in the 1990s and are now largely out of date (41). Over the past decade, site-level synthesis of bottom-up and top-down methods have suggested that the divergence between the two approaches' estimates is likely from a systematic bias in bottom-up accounting, which presumes that facilities operate normally, while in reality, abnormal super-emitter events create an emissions distribution with a long tail where most methane emissions occur (33, 41, 42). Some research has also suggested that top-down measurement campaigns detect systematically higher emissions (43). However, this seems to be isolated to a particular region in the U.S., where liquid unloadings are unusually high (33). Alvarez and colleagues' (33) method removes these overestimates by verifying aerial measurements with ground-based detection.[21] They ruled out an upward bias caused by emissions being higher during the daytime than at nighttime, which they found to be unique to the Fayetteville Shale, "caused by manual liquids unloadings, which represent a much higher fraction of total production emissions than in any other basin."

[20] Chan and colleagues (37) found mean annual methane emissions from Alberta and Saskatchewan from 2010 to 2017 to be three million tonnes (Mt). The Canada Energy Regulator estimates gas production from 2010 to 2017 in these two provinces was an average of ~3,900 billion cubic feet per year. Assuming natural gas is 90 per cent CH_4 by volume, and that CH_4 weighs 19 g per cubic foot at standard temperature and pressure means that annual CH_4 production is 67 Mt per year. Adding the 3.0 Mt CH_4 lost from Chan and colleagues that was not counted in official production statistics brings the total to 70 Mt per year. Finally, three million is 4.3 per cent of 70 million.

[21] See Alvarez and colleagues (33), Supplementary Material, Section 1.6

There are now new proposals for how to reconcile bottom-up and top-down methods such that bottom-up emissions factors can be bootstrapped through an iterative process to better reflect top-down measurements (34), or to at least add them to GHG inventories by attributing them to an unclassified category as “unassigned” emissions when they cannot be attributed directly to individual pieces of equipment (44). Canada is beginning to revise its GHG inventory upward to catch up with the latest science, and has plans to continue this process, though there is a lack of transparency over the process involved. Over the past two years, fugitive emissions from oil and gas production in Canada have been revised upward by 33 per cent.[22] Note that this adds to the challenge of reducing methane emissions, as they are turning out to be higher than originally thought. Revising bottom-up inventories to account for evolving discoveries in underreporting should likewise warrant revising methane-reduction goals and the approach of methane regulations, so that they can target emissions sources that have only recently been identified as major sources of fugitive emissions. If policies were to be adapted to focus on fugitive emissions sources revealed by the latest science, there would be better odds of actually reducing these emissions and meeting ambitious goals such as those recently set out by the federal government. The next section discusses these methane regulations and explores whether they can effectively reduce emissions by targeted amounts.

2.1.3 METHANE REGULATIONS IN CANADA AND THEIR IMPLICATIONS FOR THE GHG EMISSIONS INTENSITY OF LNG EXPORTS

Responding to the problem of fugitive emissions, the Government of Canada committed in 2016 to reducing methane emissions from 2012 levels by 40 to 45 per cent by 2025. Similarly, the B.C. government committed to a 45 per cent reduction from a 2014 baseline by 2025.[23] In 2018, new federal methane regulations came into force under the *Canadian Environmental Protection Act*,[24] spurring new provincial methane regulations in British Columbia, Alberta and Saskatchewan. In 2020, the federal government reached equivalency agreements with the provinces, recognizing that provincial regulations would achieve equivalent outcomes to the federal regulations, so provincial regulations could replace federal ones for five years.[25] More recently, ECCC announced a new framework on methane mitigation that will inform development of the next round of federal methane regulations for the oil and gas sector, targeting at least a 75 per cent reduction in oil and gas methane by 2030 relative to 2012.[26]

The framework promises enhanced regulations that will address a wide variety of sources, such as requiring that pneumatic pumps and controllers be non-emitting, that destruction equipment operates at 99 per cent control efficiency, that 95 per cent of emissions from glycol dehydrators would need to be captured and that methane emitted in compressor engine exhaust be vastly reduced. It also sets new requirements for conservation or destruction of methane from routine processes that emit methane, such as planned blowdowns. If implemented and enforced, measures under this framework would expand the scope of existing regulations to a broader range of sources and expand the application and intensity of inspections and monitoring, with a potential to substantially decrease upstream methane emissions.

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[22] Author’s calculation. Refer to CRF 2022 and CRF 2020 submissions to the UNFCCC. Data available at: https://unfccc.int/documents/461923

[23] https://www.bcogc.ca/files/documents/Equivalency-Report_FINAL.pdf

[24] https://laws-lois.justice.gc.ca/eng/regulations/SOR-2018-66/index.html

[25] https://www.canada.ca/en/environment-climate-change/services/canadian-environmental-protection-act-registry/review-methane-regulations-upstream-oil-gas-sector.html

[26] https://www.canada.ca/en/services/environment/weather/climatechange/climate-plan/reducing-methane-emissions/proposed-regulatory-framework-2030-target.html

This increasing attention to methane emissions from the oil and gas sector is encouraging and has the potential to contribute to reducing the carbon intensity of LNG exported from Canada, though it does not address emissions associated with shipping or end use in importing countries. Mitigation of methane emissions also requires robust measurement and monitoring. Currently, because emissions occur throughout the production chain, and there is considerable uncertainty with respect to emissions source, the quantities involved and the frequency with which emissions are occurring, regulators have limited ability to assess the effectiveness of regulations.

In their comments on the proposed framework, a group of environmental non-governmental organizations that advocate for strong methane regulations identified the need to strengthen regulatory requirements for measurement, monitoring and verification.[27] They also advocated for the federal government to improve the inventory by investing in measurement and data initiatives, and focusing the proposed centre for global excellence on methane detection and elimination's mandate on these issues. Enhanced efforts to detect methane using hybrid methods (45) and to move to continuous measurement show promise in advancing leak detection and repair. Current regulations mainly address equipment that emits by design (e.g., pneumatics, surface casing vents, flares), and known events (e.g., intentional releases like blowdowns or leaks from specific pieces of equipment that can be detected with frequent surveys). The challenge will be in designing regulations suited to addressing both known methane emissions from intentional releases and accidental releases that likely characterize the majority of methane emissions (34, 46).

One of Canada's leading experts in emissions from the oil and gas sector, Matthew Johnson at Carleton University, commented to the CBC: "You can't reduce what you can't measure. And if we're talking about 45 per cent in a near term ... and net-zero by 2050, we better be measuring how our progress is going or we won't make it." (47) Tyner and Johnson (40) also noted that in addition to the technical limitations inherent in monitoring and repairing methane leaks using frequent ground-based surveys (48, 49), leak events are often misclassified using optical gas imaging, and this can lead to major discrepancies in how leaks are quantified (50). This is highly material to regulating methane emissions from the oil and gas sector, "because current policy and regulation have been developed using insights based on current inventories, these issues have serious consequences for the effectiveness of regulations and the likelihood of meeting methane reduction targets." (40)

> **You can't reduce what you can't measure. And if we're talking about 45 per cent in a near term ... and net-zero by 2050, we better be measuring how our progress is going or we won't make it.**
>
> *– Matthew Johnson, professor of mechanical and aerospace engineering,*
> *former Canada Research Professor in Energy and Combustion Generated Pollutant Emissions,*
> *Carleton University*

[27] Pembina, David Suzuki Foundation, Environmental Defense Fund and Clean Air Task Force 2022. Coalition comments on proposed regulatory framework for methane emissions

In 2022, 12 of the larger global oil and gas companies announced through their Oil and Gas Climate Initiative, the *Aiming for zero methane emissions initiative,* ambition to "reach near zero methane emissions from our operated oil and gas assets by 2030,"[28] indicating the industry is confident that the technology is mature, commercially available and currently being successfully deployed. Indeed, as the IEA has documented, much of the methane mitigation opportunity in oil and gas can be implemented at no net cost, since conserved methane is a valuable commodity.[29] While new methane regulations, as outlined in greater detail in Canada's *Faster and Further* plan,[30] are a significant gesture toward addressing sources of methane losses throughout the oil and gas supply chain, how these policies will be implemented will determine how effective they will be. Large amounts of uncertainty still surround how leak monitoring will be improved.

It is outside the scope of this report to assess how effective new methane regulations and the forthcoming B.C. and federal oil and gas emissions cap will be. Major improvements in methane emissions mitigation practices should be pursued; however, any relative climate benefit such regulations would give Canadian gas over its competitors is not yet realized and remains hypothetical. With this in mind, we will address below how even fully capturing methane losses would be insufficient to make Canadian LNG compatible with a Paris-compliant energy transition. But first, we will review the emissions from LNG terminals and upstream processes, and how they compare with B.C.'s climate goals.

2.1.4 CARBON INTENSITY LIMITS FOR B.C. LNG FACILITIES AND ELECTRIC VERSUS GAS-DRIVE COMPRESSION

The B.C. environmental assessment of Canada's first LNG export facility under construction, LNG Canada, found that the facility, with both phases built, would emit roughly four $MtCO_2e$ per year, yielding an emissions intensity of 0.15 tCO_2e/t LNG at a rate of 26 million million tonnes per annum of LNG production.[31] This is below the threshold of 0.16 tCO_2e/t LNG imposed by the B.C. government; however, since LNG facilities are exempted from the regulations under the *Clean Energy Act*, which would have required 93 per cent of their electricity to come from hydroelectric or renewable energy sources, there is no regulatory requirement for LNG Canada to reduce these on-site emissions. B.C. also announced in March 2023 that it is moving to an output-based pricing system for large emitters, including LNG facilities, though final details have yet to be confirmed. The combined effect of the carbon price rising to $170/tonne by 2030, as well as the new cap on oil and gas sector emissions, could incentivize LNG Canada do electrify its export terminal or to implement other measures to reduce its on-site emissions.

Due largely to a lack of available transmission infrastructure and electricity, current indications are that gas compressors in Phase 2 of LNG Canada will be powered by gas, not electricity.[32] The company's CEO, Jason Klein, has indicated that if Phase 2 is built, it will likely use gas to power the compressors, at least initially (51). The B.C. and federal governments have already fully approved both Phase 1 and 2 of the project, meaning there is no regulatory obligation for LNG Canada to electrify Phase 2. Given the increased costs and attendant lack of investor support, it appears unlikely that LNG Canada will voluntarily retrofit its facility. This would reduce the likelihood of liquefaction emissions being reduced substantially through facility electrification.

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[28] https://www.ogci.com/ogci-members-aim-to-eliminate-methane-emissions-from-oil-and-gas-operations-around-2030/

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

[30] https://www.canada.ca/en/services/environment/weather/climatechange/climate-plan/reducing-methane-emissions/faster-further-strategy.html

[31] https://projects.eao.gov.bc.ca/api/public/document/58869063e036fb0105768ad7/download/Part%20B_05.03_Greenhouse%20Gas%20Management.pdf

[32] Like phase 1, phase 2 will be powered partially by electricity. Phase 1 plans to use grid electricity to power its non-compression load and gas turbines for its compression load. The latter is responsible for liquefying the terminal's gas into LNG, and comprises the majority of its energy needs. The "non-compression load" refers to auxiliary power needs.

Woodfibre LNG and Cedar LNG, which have both received environmental assessment approval, have been proposed with fully electric liquefaction. However, there are still residual emissions from other processes, mostly from the thermal oxidizer used to limit air pollution from the facility. Cedar's on-site emissions would be 0.08 tCO_2e/t LNG, but these residual emissions would need to be reduced to net-zero by 2050, as one of the 16 conditions included in the Environmental Assessment Certificate. To abide by the requirement to become emissions-neutral by 2050, Cedar LNG's submission to the environmental assessment process proposed purchasing carbon offset credits to achieve net-zero on-site emissions. However, purchasing offsets to achieve net-zero goals lacks credibility, as available offset regimes are largely unreliable and such a strategy would not be scalable to all similar infrastructure projects. Furthermore, according to the newly announced Energy Framework, "all proposed LNG facilities in or entering the environmental assessment (EA) process to pass an emissions test with a credible plan to be net zero by 2030."[33] Such cumulative impacts should also be considered under the federal government's Strategic Assessment of Climate Change, which Cedar LNG and future LNG export terminals are also subject to (52, 53).The SACC also requires that all domestic emissions associated with any project be reduced to net-zero by mid-century, which would require all upstream emissions to be mitigated or offset.

2.1.5 EMISSIONS INTENSITY OF CANADIAN LNG VERSUS OTHER SUPPLIERS

LNG terminals typically use gas power to liquefy gas. Associated emissions are predominantly from gas combustion (excluding venting and leaking of gas). Emissions from liquefaction of fossil gas make up approximately five to eight per cent of the total life cycle emissions of gas production and consumption (54 SI).[34] This means that electrification of gas liquefaction, as proposed by many B.C. producers, could reduce total life cycle emissions of gas used in power generation by up to eight per cent if all GHG emissions associated with liquefaction were avoided. For comparison, an increase or decrease in fugitive emissions of one per cent can cause a 9.4 per cent change in total life cycle emissions (54 SI). Likewise, uncertainty in fugitive emissions affects total life cycle emissions more than the difference in emissions from liquefaction electrification.

By this same logic, there are limits to how much life cycle emissions can be reduced through proposed revisions to methane regulations. When using the fugitive emissions rate derived from Chan and colleagues' survey of Western Canadian oil and gas operators of 4.3 per cent (Section 2.1.1), reducing methane emissions from Canada's oil and gas sector by 75 per cent would reduce total life cycle emissions by 30 per cent.[35] The reduction in life cycle emissions would be smaller when using a lower fugitive emissions rate baseline like those in use by government and industry. Whether such reductions are achievable is uncertain given the current approach to monitoring and mitigating methane (Section 2.1.3).

In addition to emissions reductions made through liquefaction electrification, electrifying upstream processes like gas extraction and processing could substantially reduce life cycle emissions of Canadian gas. However, how much of upstream processes could be electrified is limited by available energy. Even electrifying LNG projects and associated gas production currently under development (partial electrification of LNG Canada Phase 1 and full electrification Woodfibre LNG) would require 2.4 times that generated by B.C.'s Site C

[33] https://news.gov.bc.ca/releases/2023PREM0018-000326

[34] Using estimates for U.S. LNG from Abrahams and colleagues (54), which surveyed 13 studies for liquefaction emissions, total life cycle emissions of LNG used for power generation are 655 gCO_2e/kWh using GWP 100, and 900 gCO_2e /kWh using GWP 20. For industrial heating, total lifecycle emissions are 104 gCO_2e/MJ using GWP100 and 143 gCO_2e/MJ using GWP20 for industrial heating. Liquefaction emissions over both time horizons are 49 gCO_2e/kWh or 8 gCO_2e/MJ.

[35] Using the above-cited sensitivity to fugitive emissions of 9.4 per cent change in total life cycle (i.e., well to end user) emissions for a one per cent change in fugitive emissions (methane loss), a 75 per cent reduction of 4.3 per cent methane loss would yield a reduction of 3.2 per cent lost product and a 30 per cent reduction in life cycle emissions.

hydroelectric dam.[36] Diverting electricity to gas production would come at the opportunity cost of using it to decarbonize the B.C. economy, especially for energy-intensive natural resource industries like mining, which the province also intends to electrify (55). Setting aside the question of how the clean electricity to electrify upstream emissions will be generated, the impact on LNG's life cycle carbon intensity would be up to roughly a third of emissions from well to regasification (56).

2.1.6 DOES EXPANDING GAS PRODUCTION AND LNG EXPORT ALLOW B.C. TO MEET ITS CLIMATE TARGETS?

British Columbia has also set an industry sector target for oil and gas to reduce emissions to 33 per cent to 38 per cent of 2007 levels by 2030 and the newly announced emissions cap is intended to ensure this target is met. Recent analysis from the Pembina Institute also shows that even under highly optimistic assumptions where Canadian producers meet methane reduction targets, GHG emissions from LNG terminals under development (LNG Canada Phase 1 and Woodfibre LNG) and gas production needed to feed these terminals would exceed the B.C. sectoral target, reaching almost twice the level of the 2030 target.[37] If all LNG projects were approved and deployed, sectoral emissions would grow to almost three times the 2030 target. These findings add to earlier work showing how forecasted gas and LNG production would occupy enough of B.C.'s emissions to render meeting its provincial targets virtually impossible (57).

2.1.7 DOWNSTREAM METHANE LOSSES

2.1.7.1 METHANE EMISSIONS DURING SHIPPING

Liquefied natural gas carriers are powered by either steam turbines or slow-speed diesel engines. The choice of power source is based on a number of factors, such as size of the vessel, required speed and efficiency of the engine. LNG carriers that operate on long-haul routes often use steam turbines (like those that would service Canadian LNG terminals), as they are more fuel-efficient and can reach higher speeds. These ships typically use boil-off gas (BOG), which is the gas that is naturally released from the LNG cargo due to pressure and temperature changes, as fuel for their turbines. Methane loss from engines is common and referred to as "methane slip." The latest research suggests methane slip to be 6.9 g CH_4 per kWh, which is equivalent to a methane loss rate of 4.6 per cent (58). This same research finds slip rates under low performance operating conditions, like while driving at slow speeds in ports and while carrying loads under ship capacity, to be much higher, with a slip value of 10 g CH_4 per kWh, equivalent to a methane loss rate of about 6.7 per cent. These loss rates are much higher than previously reported and add substantial GHG emissions to the life cycle of Canadian LNG.

2.1.7.2 METHANE REGULATIONS AND EMISSIONS IN ASIA

It is beyond the scope of this paper to review methane regulations, measurement, detection and enforcement in receiving markets in Asia for Canadian LNG. However, we note that at present, indications are that much effort needs to be taken to address the issue of methane. Methane losses downstream of regasification, like leaks from local distribution networks, could add substantially to the life cycle emissions of Canadian LNG, especially when exported to regions with high loss rates in long distance and local distribution. Recent research has discovered that local distribution losses in U.S. networks are approximately five times greater than reported (59). Studies of specific cities in the U.S. and Canada suggest there is a wide variability in performance, with methane loss rates in some U.S. cities as high as two to three per cent (60–62). These

[36] Gorski, J. and Lam, J. 2023. *Squaring the Circle: Reconciling LNG expansion with B.C.'s climate goals.* The Pembina Institute.

[37] *ibid.*

losses include pre- and post-metering emissions, where prominent sources of fugitive emissions originate from gas meters, furnaces, boilers and hot water heaters. Poorer countries may have higher loss rates due to worse infrastructure and laxer regulations. For example, Pakistan, which is highly dependent on imported gas, has much higher methane loss rates than wealthier nations, with 12 to 17 per cent of gas lost during distribution (63). Other target countries, such as China and Japan, likely perform better than Pakistan, but are probably still on par with the U.S. and other developed countries. Recent research estimates local distribution losses to be around 2.7 per cent in China and 3.4 per cent in northeastern China, where gas use has grown considerably in recent years (64).

2.1.8 METHANE "BREAK-EVEN RATE" NEEDED FOR GAS TO OUTPERFORM COAL AND OIL

On a one-to-one basis, gas can outperform coal and oil for certain end uses when gas has lower life cycle emissions than other fossil fuels. However, methane losses throughout the oil and gas supply chain must be kept low enough. The methane loss rate at which gas has lower life cycle emissions is referred to as a "break-even rate" or "crossover point." Break-even rates can be quantified for all end uses and vary with time frame, technology switching scenario (e.g., lifetime emissions treated as a single GHG pulse at time of switch,or gradual transition following retirement and replacement), the efficiency of end-use process, the carbon dioxide and methane content of coal and other fuels gas is being compared to, and the radiative forcing of the GHGs themselves.

Alvarez and colleagues (65) used a method that integrates radiative forcing of GHGs over time to assess the relative benefits of (1) gas over coal power, (2) gas for light ground transport over gasoline engines and (3) gas for heavy transport over diesel engines. They found that the immediate climate impact (and equivalently, the climate impact over all time) for gas over coal power to be negated when greater than 3.2 per cent of gas is lost to the atmosphere before being combusted, and analogous break-even rates of 1.6 per cent and one per cent and for light- and heavy-duty vehicles, respectively. Howarth (31) updates the radiative forcing factor to use the latest research at the time[38] to find a break-even point for coal-to-gas switching of 2.8 per cent. Similar work by Schwietzke and colleagues (66) found that the coal-to-gas power break-even loss rate would be 3.4 per cent and 8.6 per cent using global warming potential to combine GHGs over a 20- and 100-year time horizon, respectively. Note that Alvarez and colleagues' emissions pulse method is equivalent to using GWP at the 20- and 100-year mark. For the pulse method, they reported break-even rates of 4.4 per cent for power generation, 2.1 per cent for light duty vehicles and 1.2 per cent for heavy-duty vehicles at 20 years, and 11.7 per cent for power generation, 4.9 per cent for light duty vehicles, and 2.4 per cent for heavy-duty vehicles at 100 years (Table 2). Note that the pulse method does not reflect actual switching dynamics when, for example, coal power plants are retired and replaced with gas power plants at the end of their lifetime, which is more representative of real-world practices. This is why Alvarez and colleagues developed their new metric for comparing the climate impacts of fossil fuel infrastructure to account for the timing dynamics of an actual substitution campaign. Accounting for the delay in switching lowers the break-even rates for power and transport gas conversion; i.e., climate benefits associated with converting to gas power generation and transport are less pronounced than otherwise portrayed and would be negated at lower methane loss rates.

[38] Updating radiative forcing values from the Intergovernmental Panel on Climate Change's fourth to fifth assessment report.

TIME (YEARS)	COAL TO GAS POWER GENERATION			GASOLINE TO GAS LIGHT-DUTY TRANSPORT			DIESEL TO GAS HEAVY-DUTY TRANSPORT		
	FLEET CONVERSION	SERVICE LIFE	PULSE	FLEET CONVERSION	SERVICE LIFE	PULSE	FLEET CONVERSION	SERVICE LIFE	PULSE
0.1	3.3	3.3	3.3	1.6	1.6	1.6	1.0	1.0	1.0
20	3.8	3.8	4.4	1.8	1.8	2.1	1.1	1.1	1.2
100	7.6	9.5	11.7	3.3	4.7	4.9	1.7	2.3	2.4

Table 2. Break-even methane loss rates (%). "Fleet conversion" replaces existing fleet with gas alternative as existing units are retired, "service life" represents the difference between new gas-powered units and their alternatives, used over their full lifetime, and "pulse" represents an immediate replacement; e.g., the difference between driving a gas-powered and gasoline-powered car for a day. The shortest time horizon (0.1 years) can be used to assess whether there is an immediate climate benefit, while times of 20 and 100 years are for comparison with commonly used GWP20 and GWP100 break-even rates. Pulse break-even rates for 20 and 100 years are equivalent to those calculated with GWP20 and GWP100. Data from Ref. (65).

Here we address common arguments by proponents that gas has significant climate advantages over coal and oil. First, we have established above that methane loss rates are systematically underestimated and underreported, eroding the climate advantage of current gas production. Regulations and efforts by industry can help reduce these emission rates, so it may be that the carbon intensity of gas exported from Canada will substantially improve as new rules apply. However the onus remains on government to devise and implement these regulations effectively. Methane loss rates must be kept very low — lower than what they likely are in reality at present — for gas to even have a relative advantage on a one-to-one basis over coal or oil for power and transport.

2.1.9 THE RELEVANT TIME FRAME FOR CLIMATE ACTION REQUIRES ASSESSMENT OF THE CLIMATE IMPACT OF GAS OVER DECADAL TIMESCALES

There is one final aspect crucial in the debate over the climate merits of switching to gas from other fossil fuel: the sensitivity of gas's climate impact to time scale. As discussed above, gas has a much higher warming effect than carbon dioxide, and its global warming potential is much higher in the near term than long term. Proponents of coal or oil to gas switching usually quote break-even rates over long-term time scales (typically using a GWP100 break-even rate). This downplays the nearer-term climate impacts of gas. The window needed to limit warming to 1.5 C or well below 2 C is rapidly closing, and the time frame to align emissions with pathways consistent with the Paris goals are the coming years and decades (Section 1.2). Decisions to switch from coal to gas power, even temporarily, which may appear advantageous over 100-year time scales, could result in an emissions increase and overshoot of 1.5 C (67). Failure to limit warming to within the limits of the Paris Agreement increases the risk of reaching climate tipping points, which could lead to abrupt and irreversible runaway climate change as early as the next decade (11, 12). This is why the climate impact of gas over the following decades should be assessed, and why we include a sample of break-even rates over these relevant timescales.

We now turn to the more fundamental reason that throws gas as a "bridge fuel" into doubt: even if fugitive emissions could be totally contained — i.e., methane loss rates were reduced to near zero — there is still no room in a Paris-compliant energy transition for more gas production or consumption or sustained high levels.

2.2 MORE GAS BREAKS THE CARBON BUDGET

As discussed above, setting the world on a GHG emissions trajectory aligned with the goals of the Paris Agreement necessitates a rapid transition of the global energy system from fossil fuels to renewable energy and other low-carbon or carbon-free energy sources. In other words, it will be impossible to achieve the deep and rapid emissions mitigation needed without the near-total decarbonization of the energy system. The role of gas during such a transition appears increasingly immaterial, as marginal reductions in GHG emissions when switching to gas from coal or oil are now insufficient to reduce emissions at the rate required to limit warming to 1.5 C or well below 2 C. This would remain true even if leakage rates were reduced to zero (which is practically impossible). Here we review research that focuses only on the carbon dioxide emissions from gas and other fossil fuels, ignoring the contributions of methane to warming, to show why even totally eliminating fugitive emissions cannot make gas compatible with climate stabilization.

Stabilizing temperatures requires carbon dioxide to fall to near-zero levels (68). The climate also responds to cumulative carbon dioxide emissions equally, with every tonne of carbon dioxide raising Earth's global average temperature an equal amount (69). In other words, each additional tonne of fossil fuels humanity burns will make the impacts of climate change worse, and there is no "safe" amount of emissions. Likewise, there is a finite amount of remaining carbon dioxide that can be emitted under a given temperature increase, which is referred to as the remaining carbon budget (70–72). Studies have shown how existing fossil fuel infrastructure already commits us to around 1.5 C of global warming, and that if planned infrastructure were also constructed and fully utilized, these committed emissions would very likely exhaust the RCB for 1.5 C and use most of what remains under a 2 C temperature limit (73, 74).

New research has also shown that if burned, developed fossil fuel reserves (i.e., all coal, oil and gas production from operational and planned extraction projects) would exhaust the remaining 1.5 C RCB, and also warm the world to nearly 2 C (75). This analysis showed that to limit global temperature rise to 1.5 C, 40 per cent of developed reserves would have to remain unexploited. Developed oil (323.0 $GtCO_2$) and gas (165.4 $GtCO_2$) reserves alone would use up 84 per cent of the 1.5 C (50 per cent probability) RCB (580 $GtCO_2$) (Figure 2). All slated fossil fuel extraction would use up 95 per cent of the "well below" 2 C RCB (here, a 2 C RCB with 83 per cent probability) (Figure 2). This means that any new gas (or oil and coal) extraction projects further endanger our ability to limit warming to the goals of the Paris Agreement. Canada has 2.2 trillion cubic metres of developed gas reserves, which amount to committed emissions of 4.2 $GtCO_2$. Note that this study does not include carbon dioxide emissions from cement production or land use. Cement emissions are hard to abate and would reduce the space in the RCB for additional fossil fuels, while land use[39] will likely also increase emissions and further reduce this space.

Carbon dioxide removal technologies may add room for additional fossil fuels but are unproven at scale and likewise endanger the success of mitigation efforts when relied upon (76–79). The primary technology, carbon capture and storage, is heavily relied upon in many energy transition scenarios, but attempts to deploy CCS over three decades have largely failed (80).

[39] Land Use, Land-Use Change and Forestry

As introduced above, decarbonization efforts required under the Paris Agreement necessitate deep and rapid emissions mitigation beginning immediately. Plans to expand or continue gas production at current or marginally lower levels, as Canadian producers foresee, are also at odds with global climate goals, and endanger the achievement of current domestic (federal [77] and B.C. [53]) emissions reduction pledges.

PARIS-ALIGNED ENERGY FUTURES

The International Energy Agency, one of the leading authorities on the global energy system, produced a "Net Zero Emissions by 2050" (NZE) scenario for 1.5 C and a detailed analysis of what a global energy transition would entail for the energy system and fossil fuel production under this pathway (82). It found that no new fossil fuel extraction projects were required to satisfy demand under 1.5 C. More recently, researchers from the International Institute for Sustainable Development, a top global think tank dedicated to policy-relevant energy and climate research, published a first-of-its-kind meta-analysis of a large set of climate and energy pathways needed to limit global warming to 1.5 C from those reviewed by the IPCC, those produced by intergovernmental organizations such as the IEA and the International Renewable Energy Agency and by the private sector (83). They identified a high level of agreement between 1.5 C scenarios, confirming that no new oil and gas extraction is needed under a 1.5 C global energy transition. Taking the median of selected IPCC scenarios and the IEA's NZE scenario, they found that oil and gas production should decline respectively by 15 per cent and 30 per cent by 2030, and by 65 per cent by 2050, compared to 2020 levels (Figure 3). This also means that any new oil and gas fields would either become stranded assets or push the world beyond the 1.5 C target, unless existing oil and gas production is curtailed to make room for new projects. Also, recall that new research shows gas phase-out rates to be underestimated, due to an overreliance on coal phase-outs in 1.5 C pathways (17).

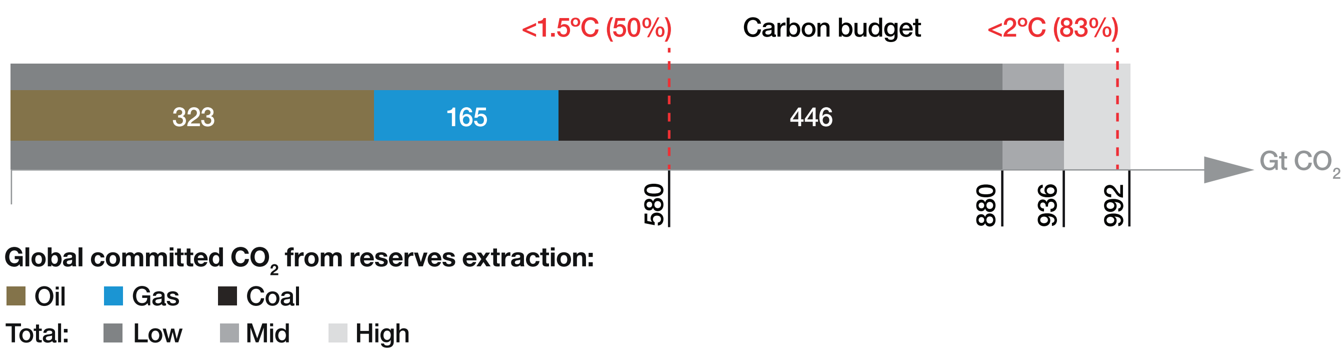

Figure 2. Distribution of committed CO_2 emissions from developed fossil fuel reserves. Estimate of total global committed CO_2 by fuel compared to remaining 1.5 C and 2 C carbon budgets for given probabilities as of the start of 2018. The low-to-high uncertainty range displayed is the 90 per cent confidence interval. Reproduced from Ref. (75).

BOX 1

WHY QUEBEC REJECTED AN LNG EXPORT TERMINAL: NOT A CLIMATE SOLUTION

...the commission considers that the implementation of new LNG export infrastructure could hinder the energy transition in the markets targeted by the project. Long-term integration in this supply chain, following the GNLQ business model, would have the effect of locking in the energy choices of client countries and, consequently, the GHG emissions associated with the combustion of the natural gas that would be delivered to them. This could delay the transition of these countries to a low-carbon economy.

The Panel notes that the use of electricity would reduce the footprint of GNL Quebec liquefaction activities, but the GHG emissions associated with the upstream supply of natural gas and the uncertain substitution for more polluting energy sources downstream do not allow the Panel to confirm the positive impacts of the project as put forward by the proponent. The Panel believes that the government cannot expect net global GHG reductions. The baseline value associated with the project that should be used for government decision-making would be a net addition of GHG emissions, although the Panel is unable to establish this precisely.

- Bureau d'audiences publiques sur l'environnement, March 2021 (Excerpt translated from French)

IISD's conclusion was robust for gas even in light of the near-term spike in demand caused by the reduction in Russian supply, where it found that "Europe's existing gas import capacities are sufficient to meet the continent's 1.5 C-compatible energy demand from 2024 onward." Other analysis by the Pacific Northwest–based Sightline Institute found that Canadian LNG exported via B.C. will arrive on the market too late to offset Russian gas supply, and will not be needed in the longer term as Europe continues to reduce its demand for gas in line with its full decarbonization agenda (Figure 4) (84). Relatedly, Quebec's environmental consultation agency, the *Bureau d'audiences publiques sur l'environnement* (BAPE), concluded that the proposed GNL Québec LNG terminal should not proceed because it would undermine the province and Canada's ability to respect the goals of the Paris Agreement. After assessing the BAPE's recommendation, the Quebec government decided to shelve the project (see Box 1).

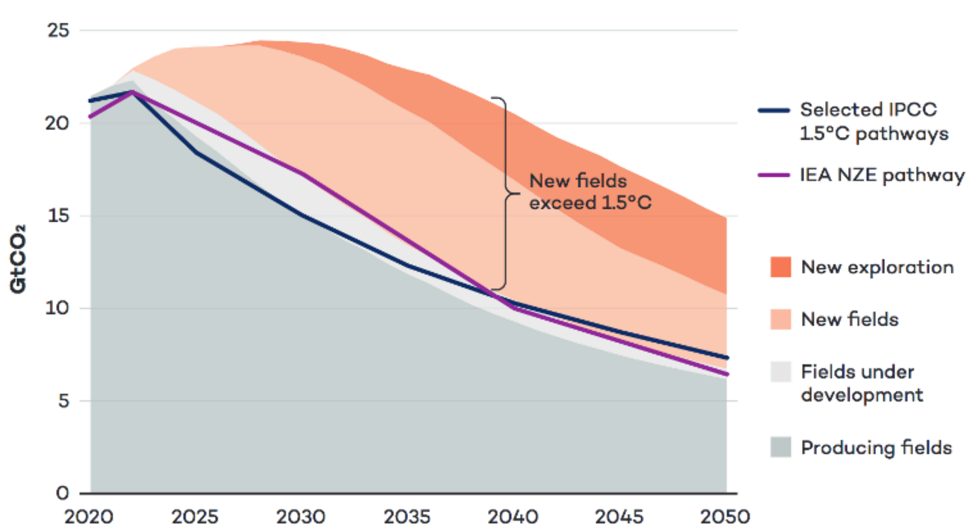

Figure 3. Global oil and gas production, based on selected IPCC and IEA 1.5 C pathways. Reproduced from Ref.(83) NZE, Net Zero Emissions by 2050.

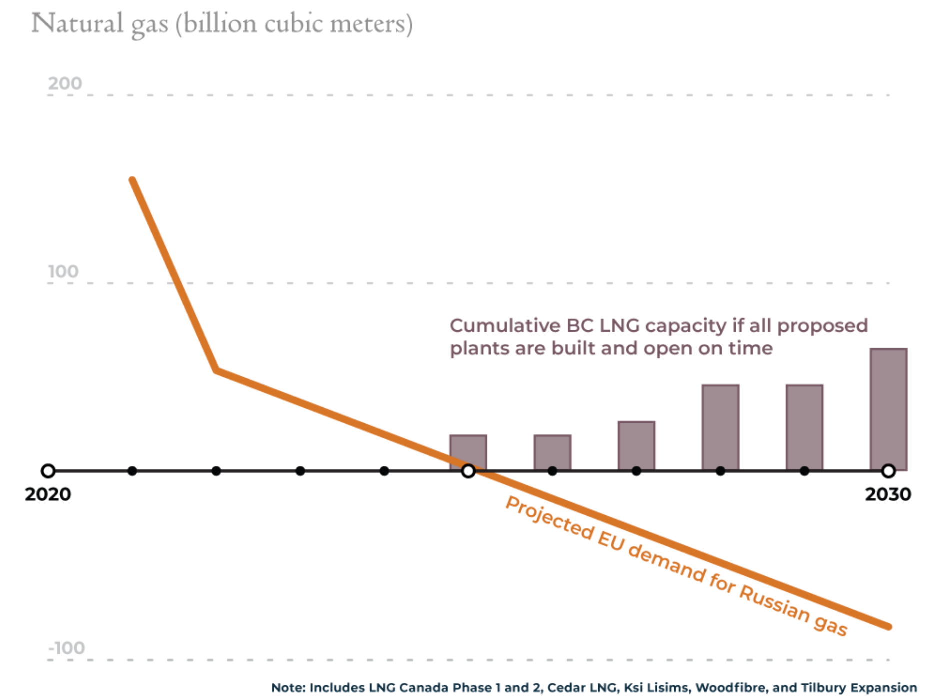

Figure 4. The EU will be off Russian gas by the time B.C. LNG projects come online. Source data: RePowerEU. Reproduced from Ref.(84).

The IEA also recently released its latest flagship report, the "World Energy Outlook 2022" (WEO2022), which provides detailed analysis of gas and LNG trends, both in light of the recent surge in demand due to Russia's invasion of Ukraine, and long-term outlooks based on NZE scenario for 1.5 C, Announced Pledges Scenario (APS) and Stated Policies Scenario (STEPS) (85). APS and STEPS limit global warming to about 1.7 C and 2.5 C, respectively. The IEA found that the Russia-Ukraine war has spurred a long-term commitment to shifting off gas around the world, as gas prices surged and countries are concerned about the long-term price volatility and competitiveness of gas versus renewables. All IEA scenarios now expect there to be no increase in global gas demand over the long term (85). The WEO2022 also found that new LNG capacity is not needed in either the NZE or APS scenarios. As countries strengthen climate efforts, LNG demand will likely peak by the end of the decade, and much of existing and under-construction capacity will exceed what is needed under a 1.5 C scenario (Figure 5). Even in the absence of any increase in policy ambition, existing and under-construction LNG capacity would be sufficient until 2035 (as represented in STEPS). Likewise, only in a scenario in which countries fail to limit warming to 2 C can producers expect demand for additional LNG export. New Canadian LNG terminals, such as LNG Canada Phase 2 and Cedar LNG, are among those that will become superfluous in a Paris-compliant global energy transition.

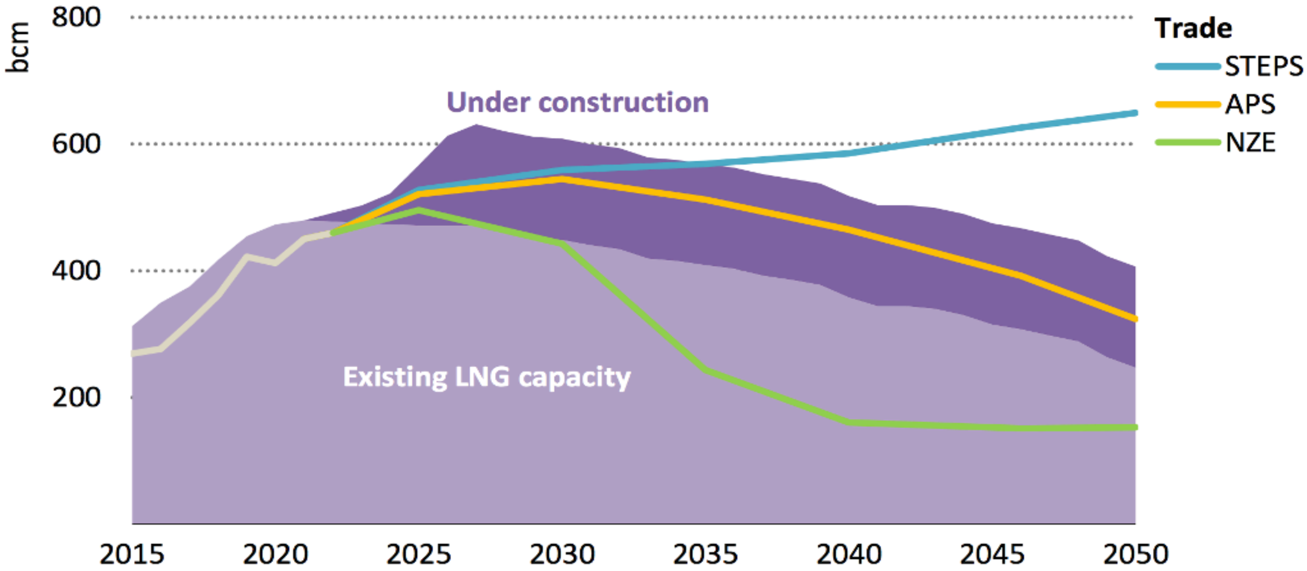

Figure 5. Existing and under-construction LNG capacity and total interregional LNG trade by scenario, 2015-2050, in billion cubic metres (bcm). Reproduced from World Energy Outlook 2022 (85). STEPS, Stated Policies Scenario; APS, Announced Pledges Scenario; NZE, Net Zero Emissions by 2050.

THE IMPACT OF THE COVID-19 PANDEMIC AND THE RUSSIA-UKRAINE WAR ON THE LONG-TERM FUTURE OF GAS

Before the pandemic struck, the world was on a strong upward trend in oil and gas consumption, where growing LNG exports from Australia and the U.S. had lowered gas prices in Asia and increased the global availability of gas (86). While the widespread pandemic lockdowns did cause a marked drop in oil and gas consumption and emissions, this was only temporary. Carbon dioxide emissions have already rebounded to their pre-COVID levels (87) and have now reached a record high of 36.6 $GtCO_2$ (3). How emissions trends proceed post-pandemic depends on long-term energy decisions we make now.

Russia's invasion of Ukraine and protracted conflict has caused gas prices to soar to record highs; however, this price environment is also likely temporary. LNG prices will decline as more supply becomes available from the U.S. and Gulf States in the coming years, and as demand declines.[40] There is growing optimism that the Russia-Ukraine invasion has actually sparked an accelerated turn toward renewables. Although it has caused a temporary return to coal in the short term, Europe's plans for transitioning off coal and gas power to renewables have been pushed up and intensified (88).[41] The WEO2022 report also notes that some Asian countries have decided to transition directly from coal to renewables due to gas price volatility (85). Price volatility due to the Russia-Ukraine war especially harms poorer countries that lack long-standing gas-purchasing agreements. New agreements and spot prices will adjust to the new price environment, though long-term plans that formerly favoured gas as a bridge fuel, even anticipating an eventual return to pre-war prices, have been irrevocably changed.

In contrast with price shocks of the past, oil and gas companies have not reacted by investing heavily in

[40] Rystad Energy (2023). Gas Market Cube and US Gas Market Fundamentals Dashboard. Available with subscription only.

[41] For more details, see Europe's RePowerEU plan here: https://commission.europa.eu/strategy-and-policy/priorities-2019-2024/european-green-deal/repowereu-affordable-secure-and-sustainable-energy-europe_en

increasing expansion. Instead of investing in more production or a transition to renewable energy, fossil majors have been using their record cash flows for stock buybacks, inflating their company values while waiting to see which way the wind blows on energy trends. One of the industry's most trusted sources of energy analysis, Rystad Energy, has been providing long-term outlooks for gas power. They showed that with recent high gas prices, it would be 10 times more expensive to operate gas-fired power plants in the long term than to build new solar PV capacity in Europe (89). They do not expect prices to remain at such high levels over the medium to long term, but even if gas prices fall back to pre-war levels, gas will struggle to remain competitive in Europe's power mix.

A similar logic applies to Asia. For instance, an April 2022 report by Carbon Tracker found that in the case of South Korea, "within just five years firm renewables will outcompete all future gas plant projects on cost in South Korea. … our analysis shows under a NZE2050 scenario there will be limited time to operate the gas units before they are retired implying the opportunity for gas as a transition fuel will be very short-lived."[42] While some Asian countries may look for substitutes for Russian gas in the short term, long-term plans to decarbonize mean that B.C. LNG will arrive too late to be a stopgap for Russian supply. If Asian countries fail to shift to renewables and continue to rely on gas, switching to B.C. LNG would only displace Russian gas, not coal, ruling out any climate benefit of coal-to-gas switching (90). Furthermore, Japan is expected to reduce its demand for gas by 38 per cent by 2030 relative to 2021 in a business-as-usual scenario (as represented by WEO2022's STEPS) and by 58 per cent by 2030 and 83 per cent by 2050 if implementing its Green Transformation plan, which the Japanese cabinet has recently approved (as represented by WEO2022's APS). This calls into serious question the long-term viability of Canadian LNG for Japanese energy, even without additional ambition required to align Japan's energy future with a 1.5 C world. The other largest Asian target market is China, which has no qualms about purchasing Russian gas and may do so at a discount as long as other countries that previously relied on Russian gas imports turn to other suppliers (91). Hence it seems unlikely that Canada will find demand for Canadian LNG in China, even in absence of enhanced domestic climate ambition.

[42] Carbon Tracker 2022, Stop Fuelling Uncertainty: Why Asia should avoid the LNG trap." https://carbontracker.org/reports/stop-fuelling-uncertainty-why-asia-should-avoid-the-lng-trap/

2.3 HOW GAS IMPEDES THE ENERGY TRANSITION

The role of gas in a global energy transition consistent with the goals of the Paris Agreement has been a topic of considerable research and debate. Gas is a fossil fuel and is combusted to release its energy, which produces radically more GHG emissions than non-fossil sources of energy, such as solar and wind power. But in some limited circumstances — where gas production has low enough methane loss rates, and when comparing gas with other fossil fuels over longer time scales — gas can emit fewer GHG emissions than other fossil fuels, such as coal or oil. However, when researchers weigh both possibilities against each other, they consistently find that expanding gas supply, especially from North America, offers little help in reducing GHG emissions or avoiding climate change (31, 92–94).[43] As summarized in the most complete study to look at this question, "increases in global supplies of unconventional natural gas do not discernibly reduce the trajectory of GHG emissions or climate forcing." (94) In other words, efforts to expand the supply of fracked gas do little, if anything, to reduce GHG emissions. This is because expanding gas supply delays decarbonization of the energy system — a greater supply of gas increases overall energy consumption[44] and postpones the adoption of low-carbon energy.

> **Efforts to expand the supply of fracked gas do little, if anything, to reduce GHG emissions. This is because expanding gas supply delays decarbonization of the energy system — a greater supply of gas increases overall energy consumption and postpones the adoption of low-carbon energy.**

The latter effect is often referred to as carbon "lock-in," which in this context refers to the inertia related to construction of carbon-intensive infrastructure that keeps lower-carbon alternatives from being built (96–99). Carbon lock-in is especially pernicious for coal and gas power plants, since they have such large upfront capital costs but relatively low operating costs and long lifetimes (100). The same is true of LNG terminals, which have not become a major source of capital expenditure. For example, the first major LNG export terminal under construction in Canada, LNG Canada, is the largest private investment ($40 billion) in Canadian history (101). The risk for lock-in is especially pertinent for these major projects, since they will continue to operate at a loss as long as they can at least recoup some of their lost capital. This is known as "infrastructure lock-in," which is an especially material risk for the fossil fuel industry where the bulk of investment capital is sunk in the project's first years to build needed structures and facilities. Once infrastructure is in place, "producers will ignore sunk costs and continue to produce as long as the market price is sufficient to cover the marginal cost (but not the average cost) of production (102)." In other words, as long as overhead costs are less than revenue, even when revenue isn't enough to make up capital expenditures producers will continue operating to recoup as much of their sunk costs as they can. Investment in new gas extraction, transport (e.g., LNG export and import terminals) and end-use infrastructure also crowds out much needed investments in renewable energy infrastructure.

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[43] For more recent studies showing how gas impedes an energy transition, see: K. Gillingham, P. Huang, Is Abundant Natural Gas a Bridge to a Low-carbon Future or a Dead-end? *The Energy Journal*. 40 (2019), doi:10.5547/01956574.40.2.kgil; C. Gürsan, V. de Gooyert, The systemic impact of a transition fuel: Does natural gas help or hinder the energy transition? *Renewable and Sustainable Energy Reviews*. 138, 110552 (2021).; C. Shearer, J. Bistline, M. Inman, S. J. Davis, The effect of natural gas supply on US renewable energy and CO2 emissions. Environ. Res. Lett. 9, 094008 (2014); J. Woollacott, A bridge too far? The role of natural gas electricity generation in US climate policy. *Energy Policy*. 147, 111867 (2020).

[44] This is often referred to as the "rebound" or "scale" effect. The rebound effect is one aspect of the Jevons paradox. Improvements in efficiency tend to lead to an overall increase in scale. See, for example (95), for a detailed account of the Jevons paradox and its implications is achieving economic sustainability.

Furthermore, there is no way to guarantee that gas exported as LNG will displace coal, since it could equally add to existing energy supply to meet rising demand, or displace renewables, with both outcomes resulting in a net increase in global GHG emissions (103–105). This remains true even in cases where contracts are signed, since the overall effect could be rebounded energy demand and increases in gas consumption elsewhere in the world, since gas has become a globally traded commodity like oil in the LNG spot market. A comprehensive study of scenarios where U.S. LNG is shipped to Asian markets found that "emissions are not likely to decrease and may increase significantly due to greater global energy consumption, higher emissions in the US, and methane leakage." (104) There is no reason to believe that outcomes would differ for Canadian LNG exports to Asia, which has similar rates of upstream methane loss (section 2.1). Another recent study has shown that LNG and renewable energy do compete with each other, and that imported LNG displaces renewable energy (105). Based on econometric analysis of LNG trade over the past 30 years, this study concluded that LNG has impeded a transition to renewable energy in importer countries and that stronger decarbonization policies will reduce demand for LNG.

Even if gas were to reliably displace coal, it would not be enough. In instances where gas does displace coal or higher GHG emissions energy, a net decrease in global GHG emissions will still be insufficient to be justified as compatible with the Paris goals to limit warming to 1.5 C or well below 2 C. Recent research has shown that there is simply not enough coal capacity to displace to make a meaningful contribution to achieving a Paris-compliant 1.5 C or 2 C energy transition, and that countries like Canada are adding unneeded gas production and LNG export capacity, since LNG already under development exceeds what is needed under Paris-compliant pathways (106).

Credit: Citizen Monitoring Group

BOX 2

CANADA CANNOT CLAIM EMISSIONS REDUCTIONS ABROAD FOR SUPPLYING OTHER COUNTRIES WITH LNG

Federal Minister of Natural Resources Amarjeet Sohi has argued that Canada could get credit under Article 6 of the Paris Agreement for lowering emissions by replacing coal used in Asia to generate electricity, through the use of internationally transferred mitigation outcomes (ITMOs). The *Globe and Mail* quoted Sohi as saying, "We feel that by supplying clean energy — such as LNG that allows other countries to reduce emissions in diesel and coal — it will not only allow us to play a leadership role in making the world cleaner and less polluting, but at the same time get credit toward our emission reductions."[45]

While this may appear plausible, IMTOs are reserved strictly for measures that would not occur otherwise and must be negotiated as voluntary measures between countries. Commercial exchange, like the sale of LNG, is something that profits Canadian producers and might occur regardless of a climate incentive. As Jason Dion from the Canadian Climate Institute explains:

> When a business or utility in another country buys Canadian LNG, it does so because it wants energy that is cheaper or less GHG-intensive (or both) than other options. On the sellers' side, Canadian companies sell LNG because they want the revenue from the sale. If the sale results in a net reduction of emissions (which will not always be the case), that benefit goes to the host country. (107)

Rather, if a country like Canada uses finances or expertise to assist another country to build a wind farm that would otherwise build a coal or gas plant, it may negotiate an IMTO with this country so that it can claim some or all of the emissions reductions associated with the project. In contrast, planned LNG exports that occur as business transactions, which is how all future LNG trade is currently envisioned, will not be eligible for IMTOs, and Canada will not be able to count any incremental reduction in downstream emissions in other countries resulting from coal-to-gas switching in its own GHG emissions inventory.

2.4 THE FUTURE OF CANADIAN GAS PRODUCTION IN A CLIMATE-SAFE WORLD

Canada could use the global trajectory of the descent in gas production under a Paris-compliant transition as a rule of thumb; however, there are compelling reasons why Canada should reduce its gas production faster than the global average. In general, the geographical distribution of remaining fossil fuel production will likely not be, nor should be, uniform. Rather, which countries get to produce the last burnable fuels will be affected by market forces (108), including a potential race by low-cost producers to get their reserves to market before they become unburnable. The impacts of gas exports on aggregate global emissions (e.g., carbon intensity of fuels, economic dynamics of global energy markets) and equity should also be considered Regulations can also play a determining role in which producers contribute more or less to remaining fossil fuel supply (109).

[45] https://www.theglobeandmail.com/business/article-canada-touts-lng-exports-as-opportunity-to-reduce-emissions-in-asia/

2.4.1 GAS REMAINING UNDER COST-OPTIMAL GLOBAL ENERGY TRANSITION

Under a 2 C cost-optimal global transition, Canada had 0.95 trillion cubic metres of burnable gas reserves as of 2010 (110). This gas was already produced as of 2016.[46] Under a 1.5 C cost-optimal global transition, Canada had 0.4 Tcm of burnable gas reserves as of 2020 (111), which was also already fully produced during 2022. While Canada will continue to produce gas during a global energy transition, these studies have concluded that Canadian gas will be in excess of what is needed to satisfy global demand during a phase-out of global supply in which gas is purchased in order of least to greater cost, which is increasingly true as more of the market is traded based on spot pricing and contracts for fixed prices become scarcer. At present, the long-term price outlook for gas suggests a return to pre-Ukraine invasion prices, whereby firms operating in Canada will be uncompetitive and as a late entrant,[47] less likely to secure contracts, meaning that some Canadian gas may end up being sold at a loss and will contribute to oversupply and price depression (112, 113). This would encourage more gas consumption around the world, hindering a global energy transition. Continued rising construction prices for LNG terminals and gas pipelines, as well as a new royalty regime, are also making Canadian LNG increasingly uncompetitive (114).

In sum, plans for continued gas production in Canada presume that demand for Canadian gas will be greater than what is needed under a 1.5 to 2 C world, and signal to the world that Canada and its gas producers do not believe that global efforts to decarbonize in line with the Paris Agreement's goals will succeed. In other words, when betting on a long-term market share, Canadian gas producers imply that they believe the world will fail to reduce its dependency on gas needed to avert catastrophic levels of warming. Alternatively, Canadian producers may believe that they are immune to market economics of the global gas trade. But as spot traded gas occupies an ever-larger share of the global LNG market and countries act to reduce their long-term dependence on gas, Canadian LNG producers will likely be priced out of this shrinking market by abundant cheaper supply.

A push to overbuild LNG capacity in B.C. may just become another manifestation of the "green paradox" (115), where fossil fuel producers are motivated to produce as much as they can before regulations prevent them from exploiting reserves. Short-term thinking to exploit as much B.C. gas as possible would have long-term consequences, since megaprojects like gas pipelines and LNG terminals cost billions and can take decades to recoup capital costs. In a world pursuing decarbonization aligned with the goals of the Paris Agreement, Canadian LNG will likely become superfluous, and Canadian LNG terminals, which include some of the most capital-intensive private business ventures in history, will become major stranded assets (106, 113).

2.4.2 GAS REMAINING UNDER AN EQUITABLE GLOBAL ENERGY TRANSITION

As a signatory to the Paris Agreement, Canada has committed to pursuing decarbonization efforts in an equitable manner, which has been codified in the Paris Agreement and preceding climate treaties as the principle of "common but differentiated responsibilities and respective capabilities." This principle was initially in reference to the onus for wealthy countries to phase down their domestic emissions faster than poorer countries. There is also a strong practical and ethical onus on wealthy fossil fuel–producing countries such as Canada, which have relatively diversified economies and can more easily do without revenues from fossil fuel production, to phase down production at relatively faster rates than developing nations more economically reliant on fossil fuel production (116, 117). While there may not be a strong case for incentivizing extraction in developing countries that do not already have established industries or viable reserves, there are strong developmental

[46] Author's calculation using Canada Energy Regulator statistics.

[47] EEFA 2023. Global LNG Outlook 2023-27: High Prices Create New Risks to Demand Growth. https://ieefa.org/media/3619/download?attachment

co-benefits for rich countries to cede marginal reserves to poorer ones with higher quality ones (118). For example, cheaper conventional fuels in poorer nations could replace high-cost unconventional oil and gas in Canada, thereby improving the overall economic and carbon efficiency and equity of the energy transition. New analysis published by the Tyndall Centre shows that to have a 50 per cent chance of not exceeding 1.5 C of warming, while pursuing decarbonization in an equitable way, wealthy nations like Canada need to end all oil and gas production by 2034, while extraction could continue in poorer nations up to 2050 (119).

2.4.3 INDUSTRY PLANS FOR FUTURE GAS EXPORTS

In stark contrast to a Paris-compliant gas phase-down, Canadian producers are planning to expand or maintain high levels of production. The Canada Energy Regulator forecasts that in absence of global climate action, Canadian gas production will steadily ramp up, reaching production levels of 229 billion cubic metres per year by 2050 (growth of 41 per cent relative to 2022 levels), or that production levels will decline to 136 bcm by 2050 (decline of 17 per cent relative to 2022 levels) in its evolving policies scenario, which assumes that unabated fossil fuel use (i.e., fossil fuel use without CCS) will decrease by 62 per cent globally between 2021 and 2025 (120). Under the evolving policies scenario, about 40 per cent of Canadian gas production would be exported as LNG. The CER acknowledges that this scenario would lead to domestic emissions that could make achieving Canada's long-term emissions reduction goal impossible, stating that "[i]n the Evolving Policies Scenario ... ambitious goals such as net-zero by 2050 are unlikely to be met."[48] In 2022, the CER was instructed by the minister of natural resources to prepare a 1.5 C-compliant scenario for its upcoming CEF report, now delayed until spring 2023. This may entail substantial revisions of the CER's projections for Canadian gas production and exports.

Exported oil and gas also contribute significantly to global emissions. The downstream emissions alone from oil and gas extracted by 2050 under the CER evolving scenario (60.5 billion barrels of oil and 5.3 trillion cubic metres of gas) would produce 36.2 billion tonnes (Gt) of CO_2 when combusted, using up 16 per cent of the carbon budget remaining with a 67 per cent chance of limiting warming to 1.5 C (121). Cumulative downstream CO_2 emissions from gas would be about 10 $GtCO_2$ between 2021 and 2050, or about six per cent of the remaining carbon budget under 1.5 C (>67 per cent) (81).[49]

Credit: Joachim Kohler Bremen

[48] Canada's Energy Future: Scenarios and Assumptions (2021). Available from: https://www.cer-rec.gc.ca/en/data-analysis/canada-energy-future/2021/scenarios-and-assumptions.html

[49] Author's calculation using Canada Energy Regulator statistics and carbon dioxide-only emissions factor from Environment and Climate Change Canada.

3. Why renewables are the only "bridge" we need

3.1 RENEWABLES ARE READY AND ABLE TO FULLY DECARBONIZE ENERGY PRODUCTION

Wind and solar energy technologies are ready for immediate and rapid deployment. Looking into the future, models used by the IEA and IPCC have consistently underestimated their rate of adoption and level of penetration, and have overestimated their future prices (122–124). This is because energy-economy-environment models are inherently conservative, built to predict futures similar to our present, and cannot anticipate paradigmatic shifts such as a global energy transition, even when technological learning is modelled endogenously (125). More recently, the IEA has acknowledged that there has been a phase shift in renewable deployment and much greater appreciation of how renewables can increase energy security by reducing the exposure of importing countries to disruptions in world energy markets. Illustrating this effect, IEA's December 2022 forecast for the rate of renewable deployment was increased by 30 per cent from the previous year's forecast.

> **First, high fossil fuel and electricity prices resulting from the global energy crisis have made renewable power technologies much more economically attractive, and second, Russia's invasion of Ukraine has caused fossil fuel importers, especially in Europe, to increasingly value the energy security benefits of renewable energy.**
>
> *- IEA December 2022, Note (50)*

Proponents of gas as a "bridge fuel" often downplay the readiness of renewables, and paint gas as a safe "middle ground" to use as we transition off of coal and oil while renewables reach maturity. The evidence shows that renewables are already mature enough to be deployed at industrial scales for similar or lower costs than fossil fuels with similar applications (Section 3.2).

The main intended use for gas is power generation. There is growing consensus that no insurmountable technical barriers remain to achieving a 100 per cent renewable energy system (126). The IPCC's WGIII has concluded that full decarbonization of electricity production using renewables is fully achievable and cost-effective (18). Prominent energy transition researcher Mark Z. Jacobson of Stanford University has detailed the most comprehensive road map to date for meeting 100 per cent of the world's energy needs using renewable sources (specifically, wind, solar and hydro) by 2050 (127, 128). A recent study found that 72 to 91

[50] https://www.iea.org/reports/renewables-2022/renewable-electricity

per cent of hours of electricity demand could be met with wind and solar with existing technologies without any storage. With 12 hours of energy storage, this energy demand can be met 83 to 94 per cent of the time (129). Linking regional transmission networks, additional storage, improved energy efficiency and managed demand response would further help reach an all-renewable power system. Recent research has also shown that extrapolating historical trends in renewable energy costs paired with adequate carbon pricing could result in up to three-quarters of global energy needs being met through carbon-free electricity by 2050 (130). This includes hard-to-decarbonize industries like steel production, though scaling up these solutions will require major investments and supporting policies like carbon pricing.

Since the Paris Agreement was signed, major advancements have been made in hard-to-decarbonize heavy industries such as steel and cement production, where emissions can be drastically lowered using a variety of new options, like demand management, materials efficiency and direct and green hydrogen–based electrification of primary materials production, facilitated by the falling cost of renewable electricity (131). Heavy industry can also concentrate energy-intensive production facilities in locations where cheap and abundant renewable energy already exists. Aluminum production in Quebec is a prime example of that already taking place, where bauxite is imported to its Côte-Nord region to make use of vast hydroelectric capacity for electrified smelting.

The last holdouts for decarbonization might be aviation and other forms of heavy machinery that require energy-dense fuels. In the case of aviation, current technologies require liquid fuels, so gas has limited relevance as a substitute to jet fuel. LNG proponents suggest gas with carbon capture and storage can play a role in these applications, by producing low-carbon fuels such as ammonia and hydrogen ("blue hydrogen"), though cost-effective scaling of gas to hydrogen production with high rates of CCS (e.g., >95 per cent capture) remains a major challenge and is prohibitively costly (132). Emissions from blue hydrogen also rarely factor in fugitive emissions. Because of this, even with CCS, blue hydrogen can have very high levels of life cycle emissions (132). Burning gas directly could even have lower life cycle emissions than blue hydrogen (133). Furthermore, electrolysis with renewable energy ("green hydrogen") could become cheaper than fossil fuels with CCS (132).

These final applications can also be solved by converting to fuel cells that use green hydrogen produced by renewable energy during times of surplus. Growth in green hydrogen and its derivatives (ammonia, methanol) will also add to the suite of energy storage options that have been rapidly advancing and proliferating. In many instances, hydroelectric infrastructure can be cost-effectively converted to act as pumped storage facilities, and lithium ion battery storage or evolving battery chemistries or storage technologies such as advanced compressed air are likely the most promising options for regions where hydro infrastructure does not exist. One recent study has shown that electric vehicle batteries alone would be sufficient for short-term storage needs as early as 2030 (134). Other viable longer-term storage options include high-intensity pumped storage that can be used in locations with modest elevation and gentler gradient than when using water (135). Storage technologies are rapidly evolving and improving, and costs will continue to fall as these technologies further mature.

3.2 ENERGY COSTS BENEFIT RENEWABLES AND INVESTMENT TRENDS SIGNAL THAT THE TRANSITION IS UNDERWAY

IPCC WGIII also found that wind and solar energy offer cost-effective ways to mitigate ~4.5GtCO_2eq/yr, and their remaining mitigation potential is far cheaper than fossil fuels with CCS (14). Over the past decade, wind and solar have become the cheapest form of new power in many countries, including India and China (136). The LCOE from solar and wind continue to beat out gas and other fossil fuels for uses with similar generation profiles. Solar photovoltaic is cheaper than gas peaker and wind cheaper than combined-cycle gas for an increasing number of countries, including the U.S., Australia, Brazil, India, South Africa, Japan and Europe (137). LCOE estimates have yet to be updated to account for the spikes in gas prices following the Russia-Ukraine war, which would substantially increase the cost competitiveness of renewables over gas.

> **We cannot afford to ignore either today's global energy crisis or the climate crisis, but the good news is that we do not need to choose between them — we can tackle both at the same time.**
>
> *–Fatih Birol, executive director, International Energy Agency (138)*

While renewable energy investments are still not on track to meet the joint challenge of the climate crisis and energy security, and while investments in fossil fuel production and infrastructure are above levels that are 1.5 C- or even 2 C-compliant, shifts in investments have begun to exhibit trends more in line with climate targets. Clean energy investment grew by only two per cent a year in the five years after the Paris Agreement was signed in 2015, but the pace of growth has accelerated significantly to 12 per cent since 2020 (139). The IEA also reported that renewables, grids and storage now account for more than 80 per cent of total power sector investment, and that spending on solar PV, batteries and electric vehicles is now growing at rates consistent with reaching global net zero emissions by 2050. While investments are still falling short of what's needed to achieve full decarbonization, IISD found that the amount now being invested in fossil fuel production (US$570 billion annually) could fill the annual investment gap in renewable energy needed to align with a 1.5 C pathway (US$450 billion until 2030): "Planned investments for new oil and gas to 2030 could fully finance the scale-up of wind and solar energy needed to limit global warming to 1.5 C." (83) Lastly, energy megaprojects like pipelines and LNG terminals tend to have big cost overruns, in part due to their inherent complexity (140, 141). In contrast, renewable energy can be deployed in smaller, more manageable projects, where costs are less likely to exceed budgets.

4. Synthesis and conclusions

This report has reviewed the latest literature on climate science, energy transitions, the role of renewables and the interplay of B.C. and federal GHG emissions policies. After assessing the merits of gas as a "bridge fuel" according the latest literature, and after considering policies by the federal and British Columbia governments that are intended to lower the carbon intensity of LNG exported from B.C.'s coast, it becomes clear that gas has an increasingly constrained role in a Paris-compliant energy transition, and that additional gas infrastructure such as new LNG export terminals in B.C. cannot be seen as advancing a climate-safe future. Instead, the focus must be on significant increases in investments in renewable energy as the clear way forward to both safely and securely meet our energy needs while averting catastrophic levels of global warming. There are many reasons why gas obstructs the energy transition we need:

1 Methane losses throughout the oil and gas supply chain are underreported and, at present, these "fugitive emissions" substantially increase the climate impact of gas.

2 If proposed changes to regulations designed to limit methane emissions from Canada's oil and gas sector succeed in reducing emissions by over 75 per cent by 2030, total life cycle emissions (i.e., well to end user) would be reduced by at most 30 per cent.

3 The possible emissions savings from LNG terminal electrification are up to eight per cent of total LNG life cycle emissions, if all emissions associated with liquefaction were mitigated.

4 Incremental reductions in life cycle emissions from LNG export terminal electrification or reductions in upstream methane emissions are not sufficient contributions to the level of mitigation needed to align global emissions with the Paris goals.

5 Even though B.C. requires that LNG export terminals stay below an emissions intensity of 0.16 tonnes CO_2e per tonne of LNG, and despite this level being lower than many exporting competitors, this still allows for substantial direct, upstream and downstream emissions associated with B.C. LNG.

6 There is an important opportunity cost to using B.C.'s clean electricity to power the liquefaction process at LNG export terminals since this implies less electricity will be available to support the decarbonization of B.C.'s economy without substantial increases in renewable generation. Thus, beyond the emissions associated with gas production and the terminals themselves, B.C.'s LNG exports are likely to further compromise the province's ability to achieve climate targets.

7 Increasing supply makes gas cheaper in receiving markets and incentivizes its consumption, and this rebound in demand can negate any marginal benefit of coal-to-gas switching.

8	Gas infrastructure such as power plants and LNG export terminals lock in long-living high emissions infrastructure that add to a fleet that already commits the world to enough emissions to exhaust the remaining Paris carbon budget.
9	Likewise, investing in and building gas infrastructure draws capital away from and locks out the renewable energy infrastructure needed for the Paris-compliant energy transition.
10	There is already enough gas and LNG under production to meet energy needs as we transition to a Paris-compliant world.
11	Incremental reductions in CO_2 emissions from switching to gas are not enough to make gas part of a clean energy transition (and are a dangerous distraction from the need to switch directly to renewables and other low-carbon forms of energy).
12	Renewables are ready to deploy, and in many countries, including those in target markets for B.C. LNG, are already or soon will be competitive or cheaper than fossil alternatives.
13	Deploying renewables can help countries reduce their exposure to the volatility of energy markets and improve their energy security.

As explored throughout this report, a growing body of research shows the need for an immediate transition away from gas that does not allow for expanded LNG export capacity. This disqualifies Canadian LNG as a part of a credible energy transition, regardless of any marginal improvements in emissions intensity gained through terminal electrification, which play a negligible role compared to emissions growth from expanding gas production, and whether LNG displaces coal or renewables. Likewise, B.C.'s emissions intensity target, while allowing for gas-powered liquefaction and still performing better than many LNG facilities in the U.S. and other competing exporters, does not lower life cycle emissions sufficiently for Canadian LNG to be advantageous over LNG from other sources.

In light of the overwhelming evidence, there is no reason that gas should be granted a special privilege in the energy transition. It remains a fossil fuel with unacceptable climate impacts, and its continued production will delay and impede the transition to GHG emissions–free sources of energy. Renewable energy like solar PV and wind power, combined with enabling technologies such as transmission and storage, can be deployed rapidly to meet much of the energy needs in countries that would import Canadian LNG.

While hard-to-abate industries will take more time to decarbonize, solutions are already emerging, including increased use of electricity and replacing gas with hydrogen produced with renewable power.

Drilling and fracking more gas wells, expanding the network of pipelines and building more LNG terminals and increasing the number of trans-Pacific LNG cargo voyages are dangerous distractions from the direct route to a carbon-free energy system. Indigenous nations risk being left with fossil gas infrastructure on their territories that will require decommissioning, and the companies that owned them may not have the financial resources to do so.

There should be no further delay in wholeheartedly pursuing a transition off fossil fuels. This means that no further expansion of Canadian gas production should occur. Federal and provincial governments should not provide public financing, infrastructure or other supports to enable such projects. Indigenous nations should take a hard look at projects on their territories or for which they have an ownership stake. If the B.C., federal and Indigenous governments and investors decide to expand Canada's LNG export capacity, they should not hide behind claims that gas is a bridge fuel and that they are enabling a climate solution in the form of reduced global emissions. As this report has carefully documented, the science is unequivocal: LNG is a fossil fuel and producing it in Canada and shipping it abroad for combustion — even if it replaces coal — will increase the likelihood of missed emissions targets while exacerbating the climate crisis at home and around the world. There are some bridges that should not be crossed.

Credit: Citizen Monitoring Group

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BURNING BRIDGE:

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By Daniel Horen Greenford
Commissioned by the David Suzuki Foundation

May 2023

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