LNG and Shipping in the Arctic

Final Report

Expertise for a Shared Future

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Prepared For:

Sian Prior
Clean Arctic Alliance/Seas At Risk
Rue de la Charité 22,
1210 Brussels
E: sian@cleanarctic.org

Prepared By:

Edward W. Carr, Ph.D.
James J. Winebrake, Ph.D.
Samantha J. McCabe
Maxwell Elling
Energy and Environmental Research Associates, LLC
5409 Edisto Dr.
Wilmington, NC 28403
P: (207) 751-6554
E: ecarr@energyandenvironmental.com

Acronyms and Abbreviations

AKLNG	Alaska LNG
AMAP	Arctic Monitoring & Assessment Programme
BC	British Columbia, Canada
Bcf	Billion cubic feet (/d per day)
Bcm	Billion cubic meters (/y per year)
Bio-	Derived from biological materials
Btu	British thermal unit(s)
CAA	Clean Arctic Alliance
CCUS	Carbon capture, utilization, and storage
CH_4	Methane
CO_2	Carbon dioxide
CO_2e	Carbon dioxide equivalent units
DOE	U.S. Department of Energy
DWT	Deadweight tonnage
E-	Derived from electrolysis
EIA	U.S. Energy Information Administration
EJ	Exajoule(s)
ESG	Environmental, Social, and Governance
ETS	Emissions Trading System
EU	European Union
EUR	Euro
FLNG	Floating liquefied natural gas facility
FS	Finnish-Swedish (Ice Classification System)
FSRU	Floating storage regasification unit
GEM	Global Energy Monitor
GHG(s)	Greenhouse gasses
HFO	Heavy fuel oil
IA*	Finnish-Swedish Ice Class 1A Super
IEA	International Energy Agency
IMO	International Maritime Organization
J	Joule(s)
Kg	Kilogram(s) (1,000 g)
kW	Kilowatt(s)
km	Kilometer (1,000 m)
L	Liter(s)
lb	Pound(s)
LNG	Liquefied natural gas
LNGBV(s)	Liquefied natural gas bunkering vessel(s)
LVOC	Liquefied volatile organic compounds
m^3	Cubic meters (/hr per hour)
MARPOL	International Convention for the Prevention of Pollution from Ships
MEPC	Marine Environmental Protection Committee (IMO)
MJ	Megajoule(s)
MMcf	Million cubic feet
mt	Metric tonne(s)

Mtpa	Million tonnes per annum (year)
NIS	Norwegian International Ship Register
NOK	Norwegian krone
NO_x	Nitrogen oxides
O&G	Oil & gas industry vessel
PC	Polar Class (Ice Classification System)
RoPax	Roll-on/roll-off passenger vessel
RoRo	Roll-on/roll-off cargo vessel
SEK	Swedish krona
SO_x	Sulfur oxides
Tcf	Trillion cubic feet (/d per day)
TJ	Terajoule(s)
U.S.	United States
UNSD	United Nations' Statistics Division
USA	United States of America
USD	U.S. dollar
VLSFO	Very low sulfur fuel oil
WITS	World Integrated Trade Solutions
WtW	Well-to-wake (life cycle emissions)

LNG Properties and Conversions

LNG Storage temperature	-162°C
LNG Storage pressure	1 atmospheric pressure (atm) or 15 pounds per square inch (psi)
1 cubic meter LNG (m^3)	615 cubic meter natural gas (m^3)
1 cubic meter LNG (m^3)	0.448 metric tonnes LNG (mt)
1 cubic meter LNG (m^3)	1000 liters LNG (L)
1 trillion cubic feet (Tcf)	1000 billion cubic feet (Bcf)
1 billion cubic feet (Bcf)	~ 1 billion cubic meter (Bcm) * 35.315
1 billion cubic feet per day (Bcf/d)	7.59 million tonnes per year (Mtpa)
1 million cubic feet (MMcf)	1.0551 terajoules (TJ)
1 exajoule (TJ)	1,000,000 terajoules (1e6 TJ)
1 joule (J)	0.000001 megajoules (1e-6 MJ)
1 joule (J)	1e-12 terajoules (TJ)
1 megajoule (MJ)	1e-6 terajoules (TJ)
1 liter LNG (L)	21.0 megajoules (MJ) – based on 21.0 MJ/L LHV
1 British thermal unit (Btu)	1055.06 joules (J)
1 pound LNG (lb)	0.4536 kilograms LNG (kg)
1 kilogram LNG (kg)	49.4 megajoules – based on 49.4 MJ/kg LHV

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LNG and Shipping in the Arctic

Introduction

Arctic shipping has been gradually increasing, as evolving vessel technologies have aided navigation of the environment. Concurrently, sea ice extent continues to recede and thin each year, further facilitating an upwards trajectory of maritime activity. Between 2013-2023, the number of vessels sailing the Arctic increased by 37% and their overall distances sailed increased by 111% within the region.[1]

Effective July 1st 2024, a ban on the utilization and carriage of heavy fuel oil (HFO) as a fuel source will come into force within Arctic waters as defined in the International Convention for the Prevention of Pollution from Ships (MARPOL) Annex I, administered by the International Maritime Organization (IMO).[2] In 2020, approximately 80% of marine fuel transported in Arctic waters was estimated to be HFO, with over half transported by vessels registered to non-Arctic states.[3] Full implementation of the Arctic HFO carriage ban is initially limited due to waivers and exemptions[4] that allow continued use and carriage of HFO until July 1, 2029. Additionally, IMO's Marine Environment Protection Committee (MEPC) adopted a resolution urging ship operators to voluntarily employ cleaner alternative fuels when navigating in or near the Arctic, largely due to the threats of black carbon from shipping.[5]

Regulatory measures to reduce emissions of greenhouse gasses (GHG) and minimize environmental impacts of maritime activity across the globe have increasingly led fleets away from HFO, often adopting liquefied natural gas (LNG) as an alternative fuel choice in its place. Mid-2023, IMO revised their GHG strategy with four fundamental objectives, referred to as "levels of ambition", to cut annual GHG emissions from global shipping by 20-30% by 2030 and by 70-80% by 2040, versus 2008 levels:[6]

1. Reduce the carbon-intensity and improve the efficiency of new vessels;
2. Reduce carbon dioxide (CO_2) emissions per transport work, as an average across international shipping, by at least 40% by 2030, compared to 2008;
3. Increase the uptake of zero or near-zero GHG emission technologies, **fuels** and/or energy sources to represent at least 5%, striving for 10%, of the energy used by international shipping by 2030;
4. Achieve net zero emissions from international shipping as soon as possible and align with the long-term temperature goal set out in the Paris Agreement.[7]

[1] https://hdl.handle.net/11374/2733.3
[2] Amendments to MARPOL Annex I, MEPC.329(76) / https://wwwcdn.imo.org/localresources/en/KnowledgeCentre/IndexofIMOResolutions/MEPCDocuments/MEPC.329(76).pdf
[3] https://us.eia.org/press-releases/20201120-ngos-protest-continued-pollution-of-arctic/
[4] Three forms of waivers and exemptions listed here: https://safety4sea.com/hfo-ban-in-arctic-waters-effective-from-2024/
[5] https://wwwcdn.imo.org/localresources/en/OurWork/Environment/Documents/Air%20pollution/MEPC.342%2877%29.pdf
[6]https://www.imo.org/en/OurWork/Environment/Pages/2023-IMO-Strategy-on-Reduction-of-GHG-Emissions-from-Ships.aspx
[7] Limit global warming to 1.5°C, GHGs must peak before 2025 at the latest and decline 43% by 2030 / https://unfccc.int/sites/default/files/english_paris_agreement.pdf

In 2022, global LNG trade set a record high, averaging 51.7 billion cubic feet per day (Bcf/d).[8] Concerns about high methane (CH_4) emitted throughout the natural gas life cycle are rising due to the high global warming potential[9] of CH_4, with additional consideration to its air quality and health effects. Accordingly, IMO's updated strategies now incorporate methane within its life cycle analyses to track progress towards net-zero GHG emissions. The uptake of LNG in the Arctic, a region that is warming four times as fast as the rest of the globe,[10] contributes to these concerns.

This work focuses on the following Arctic Nations and regions: Alaska (USA), Canada, Finland, Greenland, Iceland, Norway, and Sweden. This work does not include Russia. To better understand the trajectory of LNG uptake in a maritime context across the study region, this work first explores policy positions on natural gas in the study region, then describes LNG bunkering, trade, and infrastructure, and then identifies, discusses, and analyzes the Arctic-capable LNG vessel fleet.

Background

LNG is emerging as an alternative to conventional marine bunkers. LNG vessels comply with lower sulfur oxides (SO_x) regulations and LNG vessels emit less CO_2 and black carbon from their stacks than ships fuelled with oil-based fuels, but methane slip and upstream leakage contribute to a significant GHG footprint. Global fleet LNG uptake growth has been rapid. There are currently 932 active LNG powered ships operating worldwide, with 54% of these vessels registered in 2019 or after.[11]

LNG is mostly CH_4, while CH_4 has a shorter atmospheric lifetime than CO_2 and is less abundant in the atmosphere, it is a potent GHG that is 82.5 times more powerful than carbon dioxide at trapping heat in the atmosphere over a 20-year timescale.[12] Therefore, the impacts of increasing CH_4 emissions on warming are significant. CH_4 and black carbon, each with particular attention in the Arctic region, have atmospheric lifetimes less than twenty years, with methane persisting approximately 12 years.[13]

When used as a fuel, incomplete combustion leads to methane slip, where unburned methane is released in the exhaust gasses, offsetting some of the reduction in GHG emissions compared to conventional fuels. Upstream methane leaks and venting during natural gas extraction and transport contribute to higher well-to-wake (WtW) life cycle emissions, beyond stack emissions alone. Thereby, a comprehensive life cycle analysis of LNG reveals a less desirable warming potential than initially perceived.

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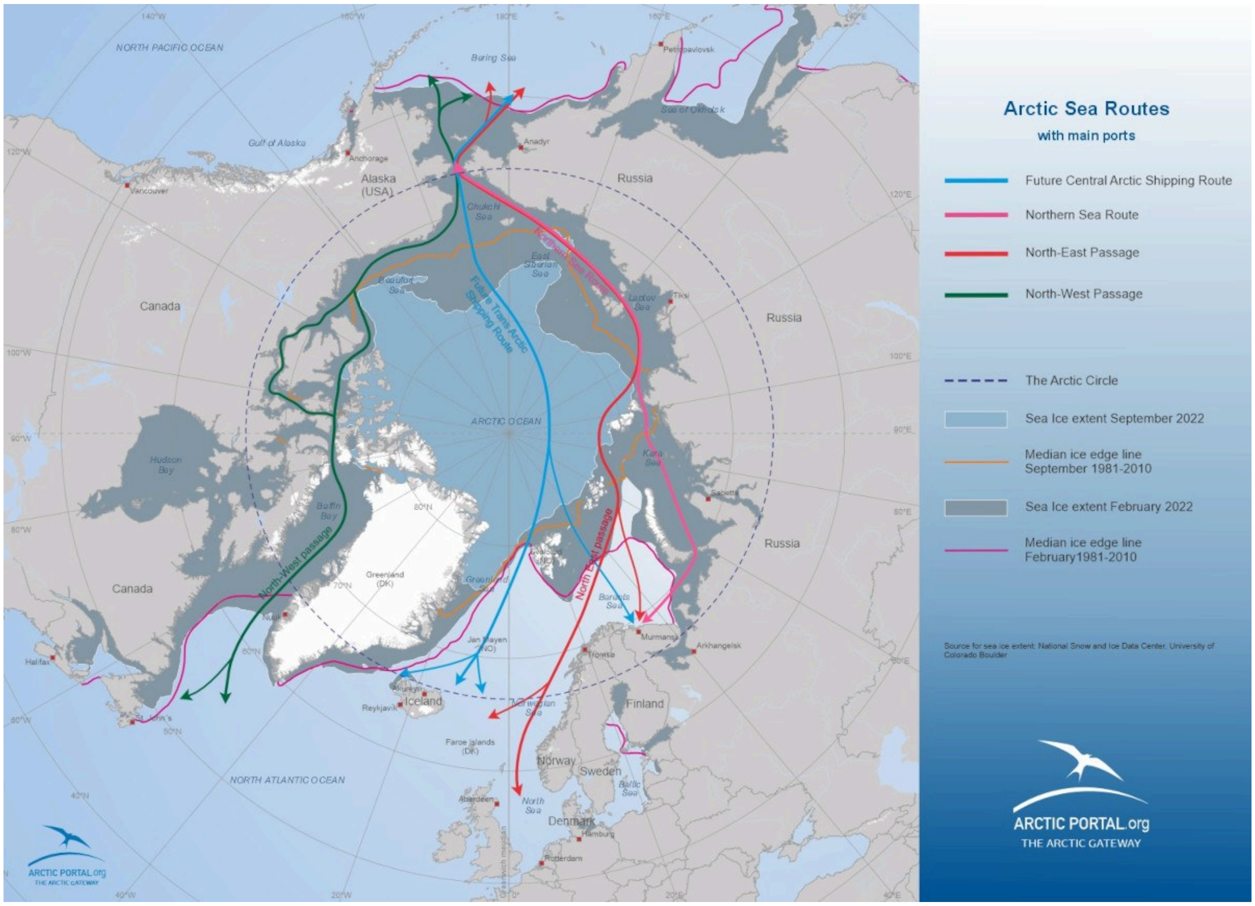
[8] https://www.eia.gov/todayinenergy/detail.php?id=57000
[9] Measure of a GHGs heat-trapping ability over a specific timeframe (20- or 100-year) compared to carbon dioxide
[10] https://doi.org/10.1038/s43247-022-00498-3
[11] "Analysis of Liquefied Natural Gas as a Marine Fuel in the United States" forthcoming EERA report for Ocean Conservancy
[12] Table 7.15, https://www.ipcc.ch/report/ar6/wg1/downloads/report/IPCC_AR6_WGI_Chapter07.pdf
[13] https://www.iea.org/reports/global-methane-tracker-2022/methane-and-climate-change

LNG fuels are not subject to the HFO carriage ban in the Arctic, prompting concerns that the carriage ban may spur development of LNG vessels in the Arctic. Though black carbon emissions (which can accelerate ice melting) from LNG are low compared to HFO, the higher WtW GHG impacts of LNG as a marine fuel can offset lower stack emissions.

Figure 1

Arctic shipping routes and main ports



Source: Arctic Portal, National Snow and Ice Data Center, University of Colorado Boulder / ArcticPortal.org

The Arctic holds approximately 30% of global undiscovered conventional natural gas resources.[14] As demand for LNG has grown in Europe and in Southeast Asia, exports of Arctic-sourced LNG are growing and exports by ship are increasing. Growing use of LNG as a marine fuel in the Arctic region will likely lead to more LNG infrastructure in the region, and increased methane emissions from LNG-fuelled ship engines. The Arctic is already warming at a rate up to four times faster than the planet as a whole, leading to concerns that Arctic shipping could replace problems with HFO with the introduction of a methane slip problem. As climate warming accelerates the depletion of sea ice, in both thickness and coverage, the region opens up to greater activity in shipping (Figure 1) and infrastructure development, with consequential increase of emissions.

[14] https://pubs.usgs.gov/fs/2008/3049/fs2008-3049.pdf

Settlements and infrastructure built to withstand Arctic conditions are at risk from environmental change. The Arctic region is particularly sensitive to climate warming, including fluctuations in sea levels and sea ice coverage; severe storms and surges; warming and thawing of near-surface permafrost, as well as freeze-thaw cycles; increasing rates of coastal and riverine erosion; increased inland flooding; and increasingly frequent and extensive wildfires.[15,16]

The Arctic region is inhabited by over forty distinct Indigenous Peoples. These peoples depend on the land, sea, sea ice, coastlines and marine wildlife for their physical sustenance and culture. As the stewards of the Arctic marine environment, they strive to ensure its long-term health and sustainability. Arctic Indigenous Peoples considerations aren't part of this technical analysis. Refer to the Arctic Council[17] and Inuit Circumpolar Council[18] for more information.

Following a study on LNG's role in decarbonizing shipping, The World Bank recommended nations refrain from enacting new public policies supporting LNG as a bunker fuel, reassess existing policy support, and implement stronger regulations to control and curb methane emissions.[19]

Observation of the present energy mix and evolving stances of Arctic governments can aid in forecasting LNG use across sectors; including in the scope of maritime shipping throughout Arctic waters, amid rising traffic and open routes. Their actions may shape years of future infrastructure use and energy dependence, and may directly or indirectly sway other stakeholders (e.g. vessel owners' assessment of fleet strategies and investments). The following sections provide insight into the current state and government perspectives to shed light on whether Arctic region nations are strengthening or scaling back their commitments to natural gas and LNG.

Alaska, USA

Alaska—the largest state in the United States (U.S.)— is the only state with land extending north of the Arctic Circle and possesses the longest coastline in the country. In the mid-2000s, the U.S. published data to support the hydrocarbon potential of oil and gas resources yet to be extracted in the Arctic, following rising global oil prices. The global response, deemed "Arctic optimism", led to greater development of oil and gas production in this region.[20]

Alaska is minimally populated across its vast land mass, with approximately half of its population concentrated within three of its cities,[21] each located below the Arctic Circle. Alaska's natural gas reserves are third largest in the U.S., totalling ~100 trillion cubic feet

[15] https://www.ipcc.ch/report/ar6/wg2/downloads/report/IPCC_AR6_WGII_CCP6.pdf
[16] https://www.arctic.gov/uploads/assets/usarc_goals_2019-2020.pdf
[17] https://arctic-council.org/explore/topics/arctic-peoples/
[18] https://www.inuitcircumpolar.com
[19] https://hdl.handle.net/10986/35437
[20] https://www.thearcticinstitute.org/pollution-arctic-oil-gas-extraction-continental-shelf-major-contributor/
[21] Anchorage, Juneau, Fairbanks

(Tcf). According to the U.S. Energy Information Administration (EIA), oil and natural gas development has been a key driver in the state's economy, where revenues largely fund the state government and pay its residents an annual share of oil royalties.[22]

In January 2024, the Biden presidential administration announced a temporary pause on *pending* decisions on LNG exports to non-free trade agreement countries until the U.S. Department of Energy (DOE) can update the underlying analyses for authorizations, including that of GHG life cycle analyses and considerations for communities adjacent to LNG operations. Active projects and approved proposals will continue. Until the DOE publishes its updated processes, the impact on future domestic investment is unclear.[23]

Alaskan government officials and members of the Biden administration have previously supported and prioritized LNG infrastructure development that would enable Alaska to export LNG overseas. A new terminal has been proposed for construction in Anchorage.[24] The facility's application for federal funds includes plans to be a launching point for low-carbon energies including hydrogen, and potentially ammonia, production.[25]

The state's lone LNG terminal, located in Kenai about 156 miles south of Anchorage, once exported LNG to Asia, but in 2017 it was sold and operations were ceased due to a drop in demand. New ownership has until the end of 2025 to convert the terminal to be functional for LNG imports under granted permits.[26,27]

Much of Alaska's oil and gas development occurs on the North Slope, in the northernmost part of the state.[28] Presently, there is no pipeline to transport natural gas withdrawals occurring in the remote-north to southern populations of the state. The majority of Alaskan natural gas withdrawals are injected into oil reservoirs to maintain crude oil production rates, with minimal amounts consumed by the population. Nevertheless, natural gas accounted for 42% of Alaska's electricity generation in 2022.[29] Alaskans' response to public polls, and some utility providers, have expressed concerns that there is an imminent shortfall in meeting the state's local natural gas demand. The utilities are seeking government subsidies to fund a pipeline for local supply, competing against the allocation of limited funds for the LNG export facility.[30]

Other utility companies and stakeholders expect local demand for natural gas to be temporary, as projects to supply power through renewable energies proliferate. As demand for natural gas declines, support grows for LNG export infrastructure, seen as a better investment with short-term demand able to be met through LNG imports (e.g.

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[22] https://www.eia.gov/state/print.php?sid=AK
[23] https://www.whitehouse.gov/briefing-room/statements-releases/2024/01/26/fact-sheet-biden-harris-administration-announces-temporary-pause-on-pending-approvals-of-liquefied-natural-gas-exports/
[24] https://alaskapublic.org/2023/09/12/amid-natural-gas-crunch-an-alaska-utility-asks-to-resurrect-in-state-gas-pipeline/
[25] https://www.hydrogenfwd.org/alaska-governor-ready-to-unlock-north-slope-natural-gas-to-power-lng-hydrogen-exports-to-asia/
[26] https://www.eia.gov/state/print.php?sid=AK
[27] https://www.gem.wiki/Kenai_LNG_Terminal
[28] https://www.eia.gov/state/analysis.php?sid=AK
[29] https://www.eia.gov/state/print.php?sid=AK
[30] https://alaskapublic.org/2023/09/12/amid-natural-gas-crunch-an-alaska-utility-asks-to-resurrect-in-state-gas-pipeline/

imports accommodated by temporarily leasing a floating storage regasification unit or completed conversion of the Kenai facility).[31]

In 2022, renewable energies accounted for a third of total state electricity generation, with approximately 90% of renewable generation powered by hydroelectricity.[32] Alaska's governor sought to address the natural gas supply shortage for southern populations with a bill proposing a portfolio standard that would require utilities to ramp up their generation capacity in renewable energies to 80% by 2040. It received strong opposition and ultimately did not pass. In the meantime, there is no clear or unanimous energy trajectory.[33]

Canada

Fossil fuels power Canada's total final energy consumption,[34] with 45.3% oil, 25.6% natural gas, and 22.2% from a fossil fuel dominant electrical grid.[35] Canada's *Energy Future 2020* "Evolving Scenario" anticipates peak natural gas production in 2040 and an increase in LNG exports until 2040. Currently, Canada's natural gas exports are dominated by pipeline transport to the United States and there is no operational infrastructure to liquefy and transport it abroad.[36] LNG Canada is set to be the nation's first operational export facility. LNG exports are anticipated to begin in 2025, although continued shelving of approved LNG projects may change timelines.

The nation seeks to leverage its domestic natural gas reserves to position itself as a global LNG supplier, while simultaneously aiming to reduce emissions from its LNG infrastructure to below the global average.[37] Canada's Methane Strategy aims to reduce domestic CH_4 emissions by over 35% by 2030, in comparison to 2020, and 75% reduction in CH_4 emissions from oil and gas operations by 2030, in comparison to 2012.[38]

British Columbia, Canada (BC) mandates new LNG proposals achieve net-zero emissions by 2030. However, their life cycle analysis does not account for downstream emissions. Consequently, the nation is being urged to pause and reevaluate LNG authorization processes, with increased pressure after the recent U.S. pause for similar action. For example, hundreds of Canadian health professionals have issued a public health advisory on the harms of natural gas production to human health, seeking to halt the government's expansion in BC.[39] However, responding statements from both the provincial and federal governments have expressed continued support for new projects, highlighting domestic

[31] https://alaskapublic.org/2023/09/12/amid-natural-gas-crunch-an-alaska-utility-asks-to-resurrect-in-state-gas-pipeline/
[32] https://www.eia.gov/state/print.php?sid=AK
[33]https://alaskapublic.org/2023/05/18/alaskas-big-shift-to-renewable-energy-appears-stalled-as-future-access-to-natural-gas-in-doubt/
[34] Final energy consumption is the total energy consumed by end users, such as households, industry and agriculture.
[35] https://iea.blob.core.windows.net/assets/7ec2467c-78b4-4c0c-a966-a42b8861ec5a/Canada2022.pdf
[36] https://iea.blob.core.windows.net/assets/7ec2467c-78b4-4c0c-a966-a42b8861ec5a/Canada2022.pdf
[37] https://iea.blob.core.windows.net/assets/7ec2467c-78b4-4c0c-a966-a42b8861ec5a/Canada2022.pdf
[38] https://www.iea.org/policies/17015-faster-and-further-canadas-methane-strategy
[39] https://cape.ca/press_release/lngharms/

climate plans and plans for a sector emissions cap as sufficient measures.[40,41] Some contend that the U.S. pause presents a chance for Canada to emerge as a worldwide supplier.[42]

Canada's Energy and Natural Resources Minister expressed concern over the risks associated with fossil fuel investments amidst the accelerating clean energy transition, underscored by forecasts from the International Energy Agency (IEA), which suggest the supply of natural gas will surpass demand within the next few years and the market for all fossil fuels will peak by the end of the decade. In Canada, LNG projects have faced many challenges, such as timeline delays and difficulty securing final investment decisions amidst rising capital costs, including the Cedar LNG, BC project. The Minister worries that upcoming projects have the potential to become stranded assets under the anticipated oversupply of natural gas in the market, and stresses the concern that facilities will not align with climate targets.[43]

Oil and natural gas production is active in 12 of 13 of the nation's provinces and territories. Alberta and British Columbia are the nation's largest natural gas producers. In 2021, 10.1 billion cubic feet (Bcf) and 5.75 Bcf were produced in these provinces, respectively.[44] Canada's emerging LNG industry has multiple proposed export terminals in various stages of development. The majority of proposed export projects are in British Columbia, on the western coast. There is a single proposed export project in Newfoundland and Labrador, the nation's eastern coast.[45]

Additional initiatives by the Canadian government support the expansion of LNG bunkering. The nation plans to utilize hydroelectricity[46] and carbon capture, utilization, and storage (CCUS) technology to power facilities across the sector to position itself as a leader in producing LNG with improved life cycle emissions. These LNG projects estimate emissions profiles 60-90% lower[47,48] than global competitors. Moreover, Canada plans to develop hydrogen production capacities utilizing its natural gas.[49]

At COP28, Canada unveiled its draft framework for limiting oil and gas emissions through a cap-and-trade system with a 2026-2030 timeline for implementation. The Canadian government introduced the framework under the context of the oil and gas industry being

[40] https://www.nationalobserver.com/2023/08/24/news/canadas-newest-health-advisory-natural-gas
[41] https://www.reuters.com/business/energy/us-pause-lng-exports-raises-pressure-canada-bc-do-same-2024-01-29/
[42] https://www.fraserinstitute.org/article/us-halt-on-lng-exports-presents-new-opportunity-for-canada
[43] https://www.nationalobserver.com/2024/02/29/news/ottawa-changing-its-tune-lng
[44] https://www.capp.ca/economy/canadas-oil-and-natural-gas-production/
[45]https://natural-resources.canada.ca/energy/energy-sources-distribution/natural-gas/canadian-liquified-natural-gas-projects/5683
[46] Hydropower is the primary source of renewable electricity generation and accounted for 14% of Canada's total final energy consumption in 2019. The total share of renewables is approximately 22%. / https://iea.blob.core.windows.net/assets/7ec2467c-78b4-4c0c-a966-a42b8861ec5a/Canada2022.pdf
[47] CCUS technologies do not address other carbon emissions (i.e. CH_4) or criteria pollutants
[48] CCUS assumptions by Canada are unclear. Real-world rates are significantly lower (<39%) compared to theoretical rates often assumed and reported (90%) / https://doi.org/10.1016/j.egyr.2023.08.021
[49] https://iea.blob.core.windows.net/assets/7ec2467c-78b4-4c0c-a966-a42b8861ec5a/Canada2022.pdf

"an economic powerhouse, proven innovator, and source of good jobs".[50] The regulations aim for a gradual reduction of emissions, but do not impede continuous fossil fuel investments.[51] Projections envision an upper emissions limit between 131-137 mtCO_2e for the oil and gas industry in 2030, which would translate to an approximate 20% reduction compared to 2019 emission levels. Projections, however, would aim for net emissions closer to 106-112 mtCO_2e through use of carbon offsets (100-year scale).[52]

Canada's plans to decarbonize maritime transport involve implementing measures from the IMO GHG strategy, as well as the Clydebank Declaration[53] for green shipping corridors signed at COP26, aiming to reduce emissions by 20-30% by 2030 and strive for net zero by 2050. This plan supports a clean fuel standard, a per-tonne price on pollution for the international shipping sector, and the allocation of $165.4 million to build cleaner ships and shore power technology. Initiatives to "advance cleaner, sustainable and renewable fuels for shipping" do not indicate a preference for which fuels align with these reduction targets, leaving uncertainty regarding the role of LNG will have in the nation's transition.[54]

Finland

Finland's total final energy consumption is largely supplied by electricity (28%), oil (26%), and bioenergies (25%), with natural gas accounting for only 3.2%.[55] Finland is a world leader in smart grid technology. Their electricity is primarily sourced (~90%) from a mix of nuclear, woody-biomass, and renewables including hydropower, wind, and solar. Finland has high energy consumption per capita, and previously relied on energy imports from Russia until severance due to the Russia-Ukraine war. Until 2017, Russia supplied 100% of Finland's natural gas energy needs, then continued to account for over two-thirds of imports. Energy trading ceased in spring and summer 2022, where terminals were not bound by contractual obligations.[56]

Finland has small-scale LNG import capacity, and thus has relied on pipelines. The absence of pipeline imports from Russia has led to Finland's investment in a floating storage regasification unit (FSRU) that began operations outside the Port of Inkoo in January 2023, under a ten-year lease. As of November 2023, there were plans to equip the FSRU "in the coming months" with equipment to load fuel into LNG bunkering vessels (LNGBVs).[57]

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[50] https://www.canada.ca/en/services/environment/weather/climatechange/climate-plan/oil-gas-emissions-cap/regulatory-framework.html
[51] Representatives of Canada at COP28 joined the call for the "phase out" of fossil fuels. Final agreement language was changed to a "just, orderly, and equitable" transition and restricts the call to "energy systems" before endorsement by 198 nations, including each of the nations in this project scope.
[52] https://www.canada.ca/en/services/environment/weather/climatechange/climate-plan/oil-gas-emissions-cap/regulatory-framework.html
[53] https://www.gov.uk/government/publications/cop-26-clydebank-declaration-for-green-shipping-corridors/cop-26-clydebank-declaration-for-green-shipping-corridors
[54] https://tc.canada.ca/en/corporate-services/transparency/briefing-documents-transport-canada/2023/current-topics/decarbonizing-transportation
[55] https://iea.blob.core.windows.net/assets/07c88e41-c17b-4ea1-b35d-85dffd665de4/Finland2023-EnergyPolicyReview.pdf
[56] https://www.trade.gov/country-commercial-guides/finland-energy
[57] https://www.offshore-energy.biz/finlands-inkoo-fsru-receives-second-lng-cargo-from-gasum-after-balticconnector-incident/

Finland has established one of the world's most ambitious climate targets, with a legal obligation to achieve carbon neutrality by 2035 and become carbon-negative after that.[58] In 1990, Finland introduced the first ever carbon tax in the world, which has gradually increased but remains focused on CO_2 and excludes other GHGs (2023 rates of 77 EUR/mtCO_2, equivalent to 83 USD/mtCO_2).[59,60,61] Around 85% of Finland's freight is transported by sea, with all of Finland's coastline in the Baltic Sea, their vessels must be built to withstand the harsh winter and ice conditions of the nation's waterways.[62] Thus, the government has not taxed commercial marine and aviation fuels to keep these modes cost-effective.[63]

In 2018, Finland's president supported LNG as the preferred marine fuel for shipping in the Arctic in replacement of the predominant use of HFO.[64] In 2022, the Finnish government secured a contract to supply LNG marine fuel to the fleets of the Finnish Transport Infrastructure Agency and the Finnish Border Guard.[65] Finland is home to several leading players in the shipbuilding industry, including Meyer Turku, Rauma Marine Constructions, and Wärtsilä. The shipbuilding industry is significant in Finland. Development plans anticipate LNG fuel to continue growing until 2035, with later transitions to low-GHG alternatives following and requiring greater build out of those networks.[66]

The Finnish Shipowners' Association argued that marine fuels should remain untaxed and/or that the additional costs due to vessels' sailing in ice conditions should be fully reimbursed under the European Union (EU) Emissions Trading System (ETS) and FuelEU Maritime Directives.[67] Their argument was based on ice class vessels being inherently more costly to manufacture and operate, with greater fuel consumption than other vessels. Therefore, imposing a carbon tax would be excessively burdensome. They did not succeed in avoiding the tax altogether. However, FuelEU Maritime, entering into force in 2025, provided a concession that allows ice class vessels to exclude the additional energy consumption from the total costs paid.[68]

In 2024, a formal partnership was established between the Port of Turku in Finland and the Ports of Stockholm, Nynäshamn and Kapellskär in Sweden, aiming to create a green shipping corridor devoid of fossil fuels by 2035. The ports are collaborating with other

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[58] https://iea.blob.core.windows.net/assets/07c88e41-c17b-4ea1-b35d-85dffd665de4/Finland2023-EnergyPolicyReview.pdf
[59] 2023 average rate of 1 EUR = 1.0813 USD
[60] https://talouspolitiikanarviointineuvosto.fi/wp-content/uploads/2023/01/Background-Report-2-Carbon-Pricing-in-Finland-Selina-Clarke.pdf
[61] https://iea.blob.core.windows.net/assets/07c88e41-c17b-4ea1-b35d-85dffd665de4/Finland2023-EnergyPolicyReview.pdf
[62] https://www.arctictoday.com/finnish-business-and-trade-unions-the-competitive-disadvantage-of-arctic-shipping-must-be-compensated/
[63] https://www.oecd.org/tax/tax-policy/taxing-energy-use-finland.pdf
[64] https://www.manifoldtimes.com/news/presidents-of-finland-russia-support-lng-as-marine-fuel-at-arctic/
[65] https://www.gasum.com/en/About-gasum/for-the-media/News/2021/gasum-wins-framework-agreement-with-the-finnish-government-for-maritime-lng-supply/
[66] https://www.maritimeeconomy.com/post-details.php?post_id=aW1rbg==&post_name=The%20Finnish%20maritime%20industry%20plans%20to%20win%20the%20race%20in%20ship%20development&segment_name=Shipyards%20%20%20Shipbuilding
[67] https://www.arctictoday.com/finnish-business-and-trade-unions-the-competitive-disadvantage-of-arctic-shipping-must-be-compensated/
[68] https://www.classnk.or.jp/hp/pdf/authentication/eumrv/fueleumaritime_faq_e.pdf

major stakeholders in the shipping sector and the Åbo Akademi University in Finland for the best approaches to phase out fossil fuels and scale alternative energies.[69]

Greenland

Greenland's Arctic climate confines its ~56,000[70] inhabitants to only 20% of its land mass, predominantly along the coast. Many stakeholders contribute to the complexity of natural gas infrastructure and development in Greenland. The nation is part of the continent of North America, however it falls under the Realm of Denmark.[71] Greenland is not directly regulated by EU law, but it is influenced by some EU regulations through its relationship with Denmark. Greenland is neither considered to be a member of the EU, nor its ports considered to be an EU port of call. However, it is labeled an overseas country/territory of the EU and its citizens are granted EU citizenship. [72,73]

The EU provides Greenland financial support for development strategies under the European Development Fund that contributes to economic, social, and/or cultural development.[74] Thus, Greenland could potentially seek EU funding to support the development of natural gas or other alternative energies. Greenland has historically leased oil and gas exploration to other nations. Due to hazardous and/or challenging environmental conditions, there have been minimal wells drilled under these leases.[75] In 2021, the government of Greenland decided to suspend all oil and natural gas extraction off its coasts, citing that it "takes the climate crisis seriously".[76] The United States' Geological Survey estimates there could be 17.5 billion barrels of oil and 148 Tcf of natural gas still unexplored off the island's coasts.[77]

Greenland's total energy supply is heavily dominated by imported oil resources. However, approximately 80% of Greenland's electric capacity is generated through renewable energies, primarily hydropower. Their fossil fuel mix is entirely sourced from oil, with minimal natural gas.[78,79] Greenland does not have supporting infrastructure for natural gas and it is unlikely that natural gas pipelines and storage infrastructure will be established in Greenland.

Greenland's renewable energy potential and proximity to Europe position it as an ideal export hub for alternative "e-fuels" crucial in the global energy transition, derived from

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[69]https://www.portofturku.fi/en/2024/02/07/green-shipping-corridor-partnership-agreement-signed-between-ports-of-stockholm-port-of-turku-and-viking-line/
[70] https://www.greenland-travel.com/inspiration/articles/facts-about-greenland/
[71] Greenland has its own extensive, autonomous government, but also two representatives in the Danish Parliament
[72] https://denmark.dk/people-and-culture/greenland
[73] https://eur-lex.europa.eu/legal-content/EN/TXT/?uri=LEGISSUM:overseas_countries_and_territories
[74]https://climate.ec.europa.eu/eu-action/transport/reducing-emissions-shipping-sector/faq-monitoring-reporting-and-verification-maritime-transport-emissions_en
[75] https://www.mondaq.com/oil-gas--electricity/366832/oil-and-gas-in-greenland--still-on-ice
[76] https://www.pbs.org/newshour/science/greenland-suspends-oil-exploration-because-of-climate-change
[77] https://www.pbs.org/newshour/science/greenland-suspends-oil-exploration-because-of-climate-change
[78]https://www.irena.org/-/media/Files/IRENA/Agency/Statistics/Statistical_Profiles/North%20America/Greenland_North%20America_RE_SP.pdf
[79] https://www.akbizmag.com/industry/oil-gas/how-eight-arctic-nations-handle-their-energy-needs/

electrolysis powered by renewables.[80] Efforts to build a green ammonia production facility for marine bunkering in Greenland, powered by domestic wind resources, are underway.[81]

Iceland

Iceland is not a member of the EU and is instead affiliated through the European Economic Area agreement. Not all EU regulations apply, but Iceland incorporates the relevant EU environment and climate laws in its legislation, which includes participation in the EU ETS.[82]

Iceland implemented a carbon tax in 2010. While fossil fuel imports and sales remain under the domestic levy, consumption emissions subject to the EU ETS are exempt to avoid double taxation (2023 rates of 35.40 EUR/mtCO_2, equivalent to 38.28 USD/mtCO_2).[83,84,85,86]

Per capita, Iceland is the top producer of electricity and green energy worldwide. Approximately 85% of Iceland's energy mix is generated from domestically produced renewable energies, primarily geothermal, making it the highest share of any nation.[87] Iceland imports 100% of the oil and coal consumed, and natural gas is nonexistent in its fossil mix.[88] The Icelandic maritime fleet includes no LNG vessels, nor is there natural gas infrastructure in Iceland.[89]

The nation's energy commitments are not likely to shift towards natural gas infrastructure investments, especially in light of climate goals. Nonetheless, leveraging ship-to-ship bunkering may allow its ports to adopt LNG operations through partnerships with energy companies or other ports. In summer 2023, the first ever LNG bunker operation occurred in Iceland through Nordic energy company *Gasum*.[90] Moreover, Iceland's capacity to channel its surplus of renewable energies into the production and export of green fuels to Mainland Europe could be a more promising investment than developing LNG infrastructure.[91]

Norway

Norway consumes very little of their natural gas resource development, representing only 4.3% of total final consumption of energy. The nation's total final consumption is largely represented by electricity (47.5%) and oil (36.1%), for which electricity generation is 98%

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[80] https://doi.org/10.1016/j.energy.2023.129605
[81] https://maritime-executive.com/article/green-ammonia-fpso-to-be-powered-by-greenland-s-first-wind-farm
[82] https://www.eeas.europa.eu/iceland/european-union-and-iceland_en?s=212
[83] Rate could not be found in local currency / 2023 average rate of 1 EUR = 1.0813 USD
[84] https://www.oecd.org/tax/tax-policy/taxing-energy-use-iceland.pdf
[85] https://taxfoundation.org/data/all/eu/carbon-taxes-in-europe-2023/
[86] https://pub.norden.org/temanord2023-520/4-iceland.html
[87] https://www.government.is/topics/business-and-industry/energy/
[88] https://aenert.com/countries/europe/energy-industry-in-iceland/
[89] https://samorka.is/wp-content/uploads/2021/12/Decarbonization-IMS_Final-Rev2.pdf
[90] https://www.offshore-energy.biz/gasum-conducts-1st-lng-bunkering-operation-in-iceland/
[91] https://doi.org/10.1016/j.ijhydene.2023.01.081

from renewable energies, primarily hydroelectricity.[92] In 2022, Norway announced an initiative to promote offshore wind power and set a target to open areas for production that will generate 30 gigawatts by 2040.[93]

Norway ranks eighth globally in natural gas production and is the fourth-largest exporter. Norway exported 122 billion cubic meters (Bcm) of natural gas in 2022, via both gas pipeline and LNG transport, replacing Russia as the largest supplier of natural gas in the European market. The nation does not have issues with resource security nor demand-side measures in the market, overall or in the context of the Russia-Ukraine war, as they are a significant international energy supplier.[94]

Norway controls the world's 4th largest merchant fleet, by value.[95] The nation began adopting non-LNG carrier, LNG-fuelled vessels more than a decade ago, with associated bunkering infrastructure,[96] including operation of the globe's first ever LNG-fuelled vessel.[97] Adoption of maritime LNG was influenced by "early mover" regulations implemented in some Baltic states, predating the IMO's establishment of limits for nitrogen oxides (NO_x) and SO_x emissions, and emission control areas. In 2008, Norway imposed a levy on NO_x emissions operating in its waters (2023 rates of 24.46 NOK/kgNO_x equivalent to 2.32 USD/kgNO_x).[98,99]

With the nation's carbon tax in place, LNG is approximately 25% more expensive than conventional fuels (2023 rates of 1.78 NOK/m^3LNG, equivalent to 0.17 USD/m^3LNG, corresponding to 761 NOK/mtCO_2e or 72 USD/mtCO_2e).[100,101,102] Furthermore, many of their vessels are subject to double taxation under additional emissions regulations of the EU,[103] as is the only national carbon tax to encompass emissions from maritime shipping under its levy.[104] Although Norway is not a member of the EU, the ETS operates in all EU countries plus Iceland, Liechtenstein and Norway under the European Economic Area agreement.[105]

The Norwegian Petroleum Directorate anticipates the nation's gas production to remain strong over the next five years before experiencing a swift decline, to align with climate targets. At COP28, Norway asserted that it will keep producing oil and gas and made claims that its domestic production has fewer emissions compared to other countries.[106]

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[92] https://iea.blob.core.windows.net/assets/de28c6a6-8240-41d9-9082-a5dd65d9f3eb/NORWAY2022.pdf
[93] https://www.trade.gov/country-commercial-guides/norway-offshore-energy-oil-gas-and-renewables
[94] https://www.trade.gov/country-commercial-guides/norway-offshore-energy-oil-gas-and-renewables
[95] https://www.trade.gov/country-commercial-guides/norway-shipping-maritime-equipment-services
[96] https://www.rivieramm.com/news-content-hub/news-content-hub/lng-fuelling-spreads-from-norwegian-waters-39785
[97] *MF Glutra,* a LNG-fueled car ferry that set sail in 2001
[98] https://www.skatteetaten.no/en/rates/nox-tax/
[99] 2023 average rate of 10.5652 NOK = 1 USD
[100] https://doi.org/10.1016/j.erss.2021.102423
[101] https://www.norskpetroleum.no/en/environment-and-technology/emissions-to-air/
[102] 2023 average rate of 10.5652 NOK = 1 USD
[103] Including but not limited to EU Emission Trading System and FuelEU Maritime Directives / https://www.sustainable-ships.org/stories/2023/overview-rules-regulations-maritime-eu
[104] https://www.itf-oecd.org/sites/default/files/docs/carbon-pricing-shipping.pdf
[105] https://www.eeas.europa.eu/norway/european-union-and-norway_en?s=174
[106] https://www.reuters.com/business/energy/leave-no-stone-unturned-gas-exploration-norway-tells-industry-2023-12-06/

Furthermore, the Norwegian government urged for increased exploration and production, including in remote regions such as the Arctic Barents Sea. The nation seeks to keep up with the growing demand, particularly in filling the gap from the global transition away from Russian gas supplies.[107]

Norway had previously begun to shift away from LNG commitments. By 2018, most of the government interventions, investments, and/or incentives to support LNG bunkering had been removed and the carbon tax exemption on LNG fuel was withdrawn. The Norwegian government argued the expansion of LNG infrastructure would overshadow investments in low- and no- GHG alternative fuels.[108] However, in light of the government's recent assertion to ramp up natural gas exploration, Norway appears to be contradicting its earlier claims and stances, and may reinstate LNG incentives. Demand has been a clear motivator, thereby an increase in global LNG bunker demand is likely to contribute to further domestic support.

As of January 2024, a decision by a Norwegian district court mandates consideration of the entire life cycle of oil and gas operations, including the downstream emissions, when awarding licenses. This ruling, which declared three petroleum production licenses invalid due to insufficient consideration of downstream emissions, may set a precedent for similar legal challenges globally, although the implications are yet to unfold.[109]

Sweden

Natural gas infrastructure was first developed in Sweden in 1982, although it has experienced limited expansion. Natural gas accounts for 2.4% of the country's total final energy consumption and is imported primarily from Denmark. Their final energy consumption is primarily from electricity (32.7%), oil (29.5%), and bioenergies (20.3%). Their electrical grid is mostly powered by nuclear (40.0%), hydro (39.7%), and wind (10.7%) energies.[110,111] Sweden does not produce any domestic natural gas and its infrastructure network is relatively small compared to other networks across Europe, with natural gas available in only 30 out of 290 of the nation's municipalities.[112]

Implemented in 1991, Sweden's carbon tax was introduced second only to Finland's, and currently ranks as the most expensive carbon rate in the world (2023 rates of 1,330 SEK/mtCO_2, equivalent to 125 USD/mtCO_2).[113,114] The Swedish tax does not include GHGs other than CO_2 and commercial fuel use for maritime or aviation purposes are exempt.

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[107] https://www.cnbc.com/2023/05/22/norway-urges-energy-giants-to-ramp-up-search-for-arctic-oil-and-gas.html
[108] https://doi.org/10.1016/j.erss.2021.102423
[109] https://www.greenpeace.org/static/planet4-sweden-stateless/2024/01/daf4fe59-oslo-tingretts-dom-og-kjennelse-18.01.2024-deepl-en.pdf
[110] https://iea.blob.core.windows.net/assets/abf9ceee-2f8f-46a0-8e3b-78fb93f602b0/Energy_Policies_of_IEA_Countries_Sweden_2019_Review.pdf
[111] https://energiforsk.se/media/29966/the-role-of-gas-and-gas-infrastructure-in-swedish-decarbonisation-pathways-energiforskrapport-2021-788.pdf
[112] https://energy.ec.europa.eu/system/files/2020-03/se_final_necp_main_en_0.pdf
[113] 2023 average rate of 10.6444 SEK = 1 USD
[114] https://www.government.se/government-policy/swedens-carbon-tax/swedens-carbon-tax/

However, these industries are now subject to the EU ETS and will soon be subject to FuelEU Maritime.[115,116]

In 2015, the Swedish Shipowners Association was among the earliest to pledge for sector net zero emissions by 2050, with a 30% reduction target by 2030, compared to 2010.[117] The same year, the federal government initiated Fossil Free Sweden, aiming to achieve climate neutrality by 2045 through the development of sector-specific roadmaps. Maritime shipping targets a 70% reduction in GHGs from domestic shipping by 2030 and net-zero by 2045.[118] In 2023, the Swedish government reduced funding for climate and environmental measures and provided tax cuts for the fossil fuel sector; Sweden is expected to miss its transport emission targets for 2030 due to these measures.[119]

Sweden is among the first countries to support and significantly uptake LNG-fuelled vessels and ship-to-ship LNGBVs; Swedish ship owners were at the forefront in introducing LNG-powered vessels across the sector. The nation has been considered progressive in its maritime decarbonization efforts due to active stakeholder participation.[120] A 2019 study found LNG to rank as the most preferred alternative fuel to HFO for Swedish ship-owners, and fuel and engine producers (whereas Swedish authorities preferred renewable hydrogen).[121]

85% of the nation's maritime bunkering demand is located in its southern region, where the ports of Stockholm, Göteborg and Donsö are located.[122] In 2016, the first LNG bunkering in Sweden took place through ship-to-ship transfer from the Coral Energy LNG bunkering vessel.[123] By 2019, IEA reported Sweden had plans for more terminals, partially with the aim to supply bunker LNG for shipping, and then recommended their government continue to consider the role of LNG in the shipping industry.[124] However, in 2020, Sweden's Ministry of Infrastructure reported no development forecasts regarding expansion of this network. Moreover, the Swedish government rejected an application for a concession to build a pipeline between the LNG terminal at Port of Gothenburg and the existing transmission network.[125]

Due to its climate goals, Sweden has been hesitant to commit to long-term LNG investment. LNG is listed on the nation's maritime industry roadmap as an alternative fuel, although there are no mentions of its expansion or support. Rather, near-term plans focus

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[115] https://taxfoundation.org/research/all/federal/carbon-tax-rankings/
[116] https://taxfoundation.org/research/all/eu/sweden-carbon-tax-revenue-greenhouse-gas-emissions/
[117] https://www.itf-oecd.org/sites/default/files/docs/decarbonising-maritime-transport-sweden.pdf
[118] https://fossilfrittsverige.se/en/roadmap/the-maritime-industry/
[119] https://www.theguardian.com/world/2023/sep/20/swedish-government-criticised-curbing-green-policies-budget
[120] https://www.itf-oecd.org/sites/default/files/docs/decarbonising-maritime-transport-sweden.pdf
[121] https://doi.org/10.1016/j.biombioe.2019.05.008
[122]https://energiforsk.se/media/29966/the-role-of-gas-and-gas-infrastructure-in-swedish-decarbonisation-pathways-energiforskrapport-2021-788.pdf
[123] https://navigatormagazine.fi/news/first-ever-lng-bunkering-in-sweden/
[124]https://iea.blob.core.windows.net/assets/abf9ceee-2f8f-46a0-8e3b-78fb93f602b0/Energy_Policies_of_IEA_Countries_Sweden_2019_Review.pdf
[125] https://energy.ec.europa.eu/system/files/2020-03/se_final_necp_main_en_0.pdf

heavily on biogas and biofuels, suggesting LNG remains only in its existing capacity for the industry and under the discussions of private shipping companies.[126]

Bunkering Locations

The immediate Arctic Circle predominantly consists of open water and/or sea ice, while its land masses are characterized by extreme terrain and climate, resulting in limited populations and infrastructure. Moreover, shipping routes that traverse through the Arctic Circle will most often start or end at points beyond its boundaries (Figure 1). The Arctic Monitoring & Assessment Programme (AMAP) and other organizations often refer to geographical coverage that includes the sub Arctic (Figure 2), as the Arctic region.[127]

The Arctic Portal, using data from the National Snow and Ice Data at the University of Colorado Boulder, highlighted the primary ports[128] for Arctic shipping routes (Table 1).[129] Only one port, Tromsø in Norway, falls inside the immediate Arctic Circle boundary. These sub Arctic ports will influence Arctic vessel navigation and logistics, particularly bunkering and trade. This section provides a comprehensive view of the LNG bunkering infrastructure within Arctic nations, with acknowledgement of LNGBVs flagged by other countries that call to these nations' ports.

Table 1

Significant Ports for Arctic Shipping Routes (excluding Russia)

Country	Port
Canada	Vancouver
Canada	Halifax
Canada	St. John's
Greenland	Nuuk
Iceland	Reykjavik
Iceland	Akureyri
Scotland	Aberdeen
Netherlands	Amsterdam / Rotterdam
Germany	Hamburg
Norway	Tromsø *
United States	Anchorage
United States	Seattle

*Port located within the Arctic Circle.

LNG bunkering locations are shown for the whole area of study in Figure 2 and, in detail, for the Northern Europe region in Figure 3. Details for these facilities are described in

[126] https://fossilfrittsverige.se/wp-content/uploads/2022/01/Roadmaps_follow_up_2021_ENG.pdf
[127] https://www.amap.no/about/geographical-coverage
[128] Identification method of "main ports" is unclear, but would likely have been identified using AIS signal or other measurement of vessel traffic movement across these Arctic Sea routes
[129] Updated August 2023 / https://arcticportal.org/maps/download/maps-shipping/3295-arctic-sea-routes-with-main-ports-and-sea-ice-extent-2022-northpolar-canada-projection

Table 3, which lists ports, status, bunkering type, and capacities for the 30 facilities identified in Canada, Finland, Iceland, Norway, and Sweden.

The primary source for this data is the SeaLNG Bunker Navigator.[130] We identified locations in the Arctic and countries in this study, extracted relevant data, and cross-referenced these data with systematic searches for publicly available supplementary information.

As shown in Figure 2, the majority of LNG bunkering ports in the area of study are located in Northern Europe and Iceland, with one bunkering location in Canada, at the Port of Vancouver's Tilbury Marine Jetty. Inferring from the national stances on natural gas, Canada and the United States have objectives to expand infrastructure and add capacities for LNG, which is likely to translate to additional port bunkering in the near-future.

Figure 3 provides a more detailed view of LNG bunkering locations in Northern Europe. It shows four facilities located within the AMAP region, with two in Norway, and two in Iceland. An additional facility, at Kristiansund in Norway, sits adjacent to the AMAP area. The remaining facilities are in the countries included in this study, but are outside the AMAP area. Norway and Sweden each have 11 LNG bunkering ports, followed by Finland (5), Canada (4), and Iceland (2).

There are 29 bunkering facilities currently operational in the study area, with two under construction and two in the proposal stage of development.

[130] https://sea-lng.org/bunker-navigator/

Figure 2

View of LNG bunkering in the Arctic region areas of this study (excluding Russia)

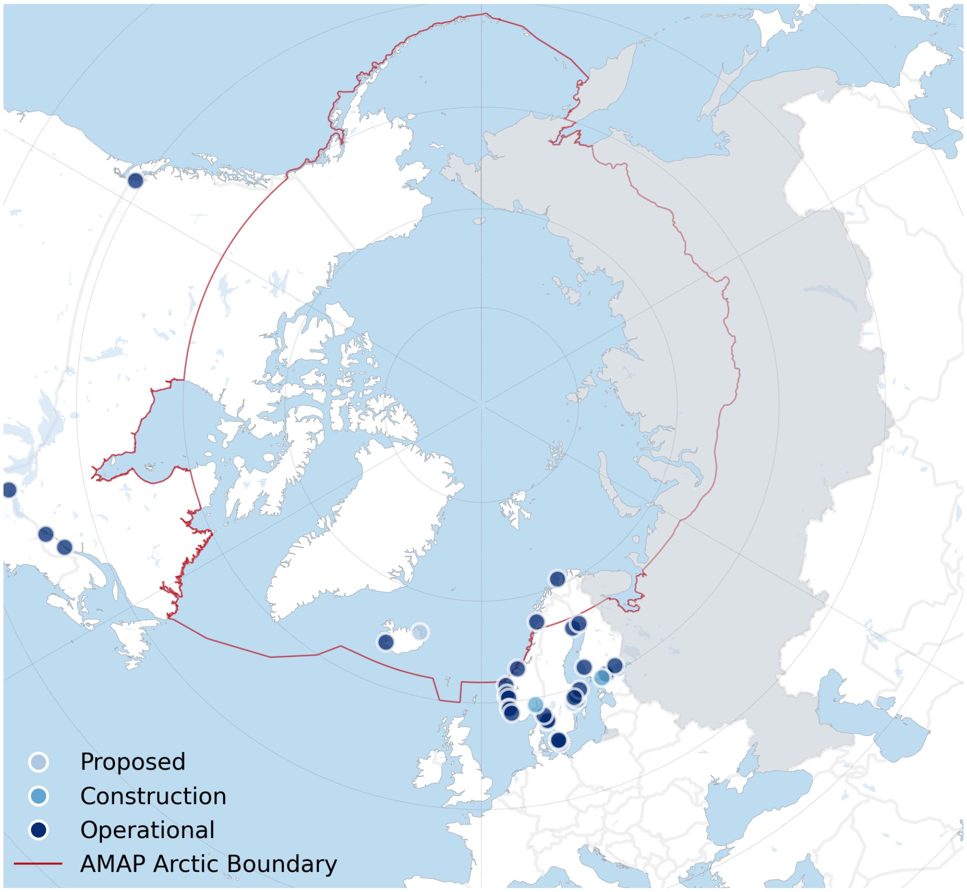
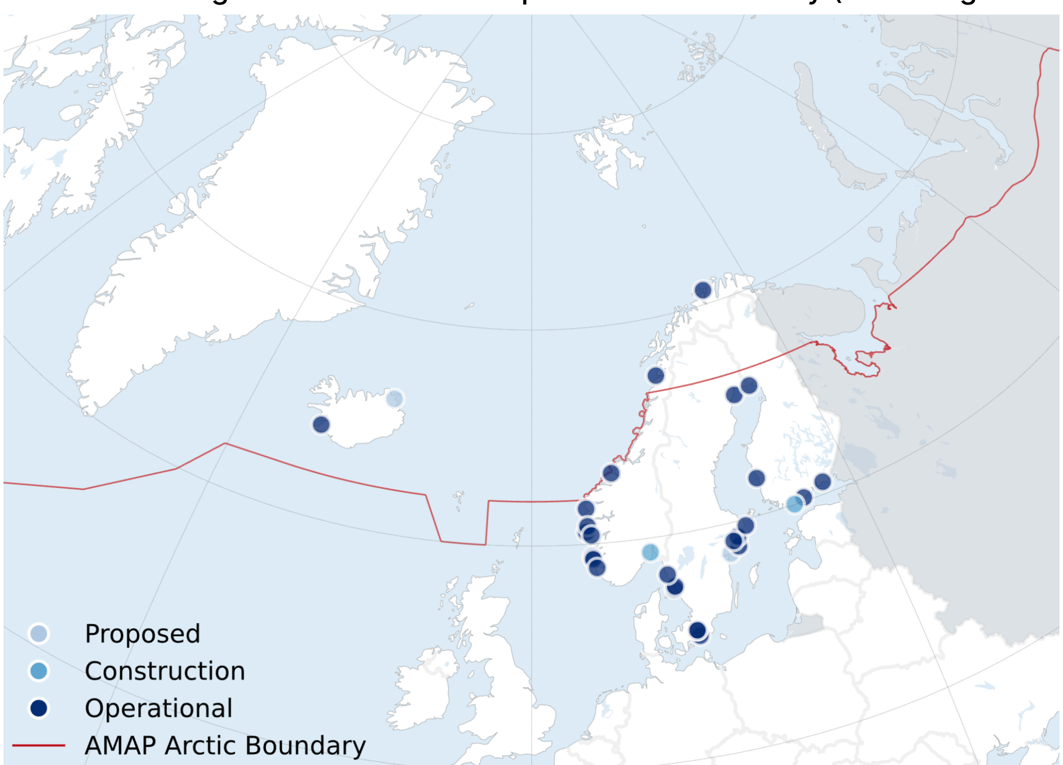


Figure 3

View of LNG bunkering in the Northern Europe areas of this study (excluding Russia)

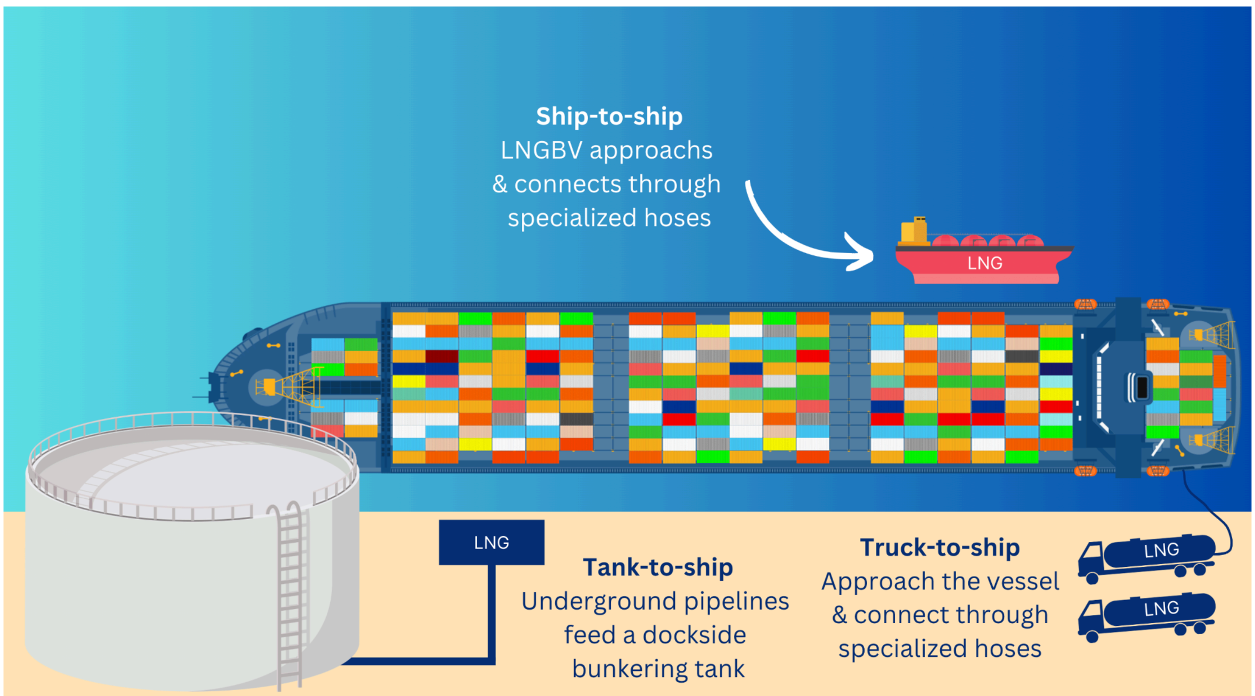


Bunkering Types

There are three major types of bunkering operations: ship-to-ship, truck-to-ship, and tank-to-ship, each playing a role in facilitating the transfer of LNG in the Arctic (Figure 4). Ship-to-ship bunkering involves transferring fuel from one ship to another, typically conducted at sea but also occurring at port. A benefit of this method is that it enables vessels to refuel without having to return to port. Truck-to-ship bunkering also provides flexibility, as trucks are not confined to refueling vessels exclusively at specific bunkering facilities. Tank-to-ship bunkering typically refers to a method of bunkering where fuel is supplied from onshore tanks. While a less versatile option, the benefits of tank-to-ship bunkering include eliminating the need for an intermediary bunkering vessel or truck, and a potential increase in storage capacity.

Figure 4

Types of LNG bunkering operations, example at port



Early bunkering operations began in 2003 at Kollsnes Port, Norway with ship-to-ship bunkering, the most popular bunkering type in this study. Truck-to-ship bunkering operations later emerged in 2013 at Lysekil Port, Sweden. The least common type of bunkering in this study, tank-to-ship, surfaced in 2015 at Port Risavika, Norway. To date, a total of 5 tank-to-ship bunkering facilities have begun operations across Canada, Finland, and Norway.

Of the 33 ports reviewed in this study, 29 are operational and 4 are proposed or under construction. Out of the 29 operational ports, 25 offer ship-to-ship bunkering[131], 19 offer

[131] The majority of these ports contract bunkering vessels from other ports, companies, and/or nations.

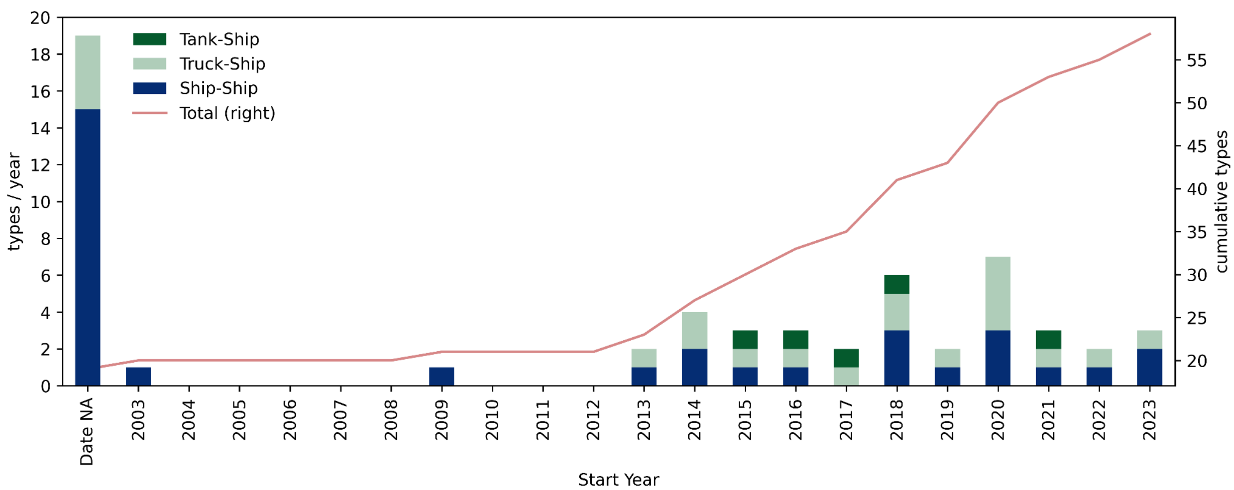
truck-to-ship bunkering, and 5 offer tank-to-ship bunkering. Many ports offer multiple types of bunkering. Under half (13) of ports offer only ship-to-ship and truck-to-ship bunkering, one port offers only ship-to-ship and tank-to-ship bunkering, and 12% (3) ports offer all three categories of bunkering. The remaining ports only have one type of bunkering option. The 2 ports currently under construction are ship-to-ship operations, managed by Gasgrid and Excelerate Energy in Finland (expected to be operational in 2023) and Kanfer Shipping AS in Norway (expected to be operational in 2024).

Bunkering locations in the Arctic began to ramp up around 2013 with the addition of several ship-to-ship and truck-to-ship operations, illustrated in Figure 5. New bunkering development peaked in 2020 with the introduction of three ship-to-ship and three truck-to-ship bunkering operations. The number of new bunkering type operations reached 45 in 2023 across 33 ports. Bunkering locations with unknown start dates are included under "Date NA."

Figure 5

Number of Arctic bunkering types by start year (excluding Russia, except LNGBVs*)

*Due to the mobility of LNGBVs, they are expected to service other neighboring countries



LNG Bunkering Vessels

Ports may engage in contractual agreements to procure LNGBVs from other ports, companies, and/or nations to enhance their bunkering capacity and capabilities. These contracts enable ports to leverage the expert crews, specialized equipment, and fuel of external entities. In some cases, these LNGBVs called to port function as the primary or sole bunkering infrastructure available. The Ports of Bergen, Stockholm, Donso, and Inkoo serve as home ports to a LNGBV, and the Port of Vancouver is anticipated to be the home port for one or more LNGBVs delivered at the start of 2024. Additional LNGBVs were identified to be contracted to bunker vessels within Arctic nation ports, traveling from other nations or sailing under other flags. These LNGBVs are highlighted in Table 2.

In general, the LNGBVs identified are smaller vessels, with capacities up to 7,600 cubic meters (m^3), though some larger vessels operate in the region, up to 15,600 m^3. The largest vessel identified, *The FSRU Exemplar*, is a floating storage and regasification unit with a capacity of 150,900 m^3.

Table 2

LNGBVs identified to provide ship-to-ship bunkering at one or more Arctic nation ports

Operational Year	Flag	IMO No.	Vessel Name	Operator	Capacity
2013	Sweden	7382691	Seagas	Gasum	167 m^3
2013	Netherlands	9617698	Coral Energy	Anthony Veder	15,600 m^3
2017	Sweden	9769128	Coralius	Gasum	5,800 m^3
2018	Cyprus	9819882	Kairos	Gasum	7,500 m^3
2020	Spain	9275074	Haugesund Knutsen	Knutsen	1,100 m^3
2021	Norway	9436159	Bergen LNG	Gasnor	850 m^3
2021	Malta	9868974	Avenir Ascension	Avenir LNG	7,500 m^3
2021	Malta	9868974	Avenir Aspiration	Avenir LNG	7,350 m^3
2021	Latvia	9870472	Optimus	Eesti Gas	6,000 m^3
2021	Russia	9888182	Dmitry Mendeleev	Gazprom Neft	5,800 m^3
2023[132]	Finland	9444649	FSRU Exemplar	Excelerate Energy	150,900 m^3
2024	Norway	–	TBD	Kanfer Shipping AS	6,000 m^3
2024	Norway	–	TBD	Kanfer Shipping AS	6,000 m^3
2024	Canada, Northwest U.S.	–	TBD	Fortis BC, Seaspan Energy	7,600 m^3
2024	Canada, Northwest U.S.	–	TBD	Fortis BC, Seaspan Energy	7,600 m^3
2024	Canada, Northwest U.S.	–	TBD	Fortis BC, Seaspan Energy	7,600 m^3

Capacity

The Port of Inkoo had the highest LNG storage capacity of the identified ports, entirely attributable to its new FSRU with 150,900m^3 of LNG storage and a significant regasification capacity. The smallest was observed at Port of Florø Fjordbase, with an LNG tank facility with approximately 500m^3 storage capacity.

Storage capacities could only be determined for 11 of the 33 ports, most often identified by the capacities of adjacent terminals. Capacities that are afforded to bunkering operations can be difficult to identify. Ports with storage capacities tied to adjacent LNG terminals will have volumes that are tied to broader trade agreements and other intended purposes.

Bunkering rates are intertwined with the bunkering type, with truck-to-ship bunkering moving volumes at a slower rate (≤80m^3/hour) than shore-to-ship (≤2,000m^3) and ship-to-ship transfers (≤1,000m^3). Higher truck-to-ship bunkering rates would utilize a Multiple Truck-To-Ship bunkering unit,[133] a Bunker Manifold,[134] or other equivalent

[132] Finland's first FSRU, (the Exemplar, went online January 2023; Bunkering capabilities are not yet online but anticipated in "the coming months" (Nov.7.2023)

[133] https://www.makeenenergy.com/cases/naturgy-spain

[134] http://www.kosancrisplant.com/lng/home/cases/quadrupled-lng-bunkering-with-on-board-truck-pumps/

technology to connect multiple trucks for simultaneous fueling. Although, these technologies are not common port infrastructure. Therefore, where exact bunkering rates could not be determined, approximate rates could be inferred based on the bunkering operations available at port.

Bio- and E-LNG

Bio- and E-LNG are alternative forms of LNG that are produced using methods that reduce total life cycle emissions, particularly for upstream[135] carbon-intensity, using biological materials (bio-) or electrolysis (e-). Ideally these production processes are powered by renewable energies in combination with CCUS technologies, however most present facilities have not yet implemented these due to limitations to their availability.

Under an ideal base-case production scenario, bio- and e-LNG are considered to be low-carbon fuels. However, due to significant methane slip throughout the remainder of its supply chain (e.g. liquefaction, distribution, consumption) the life cycle emissions of renewable LNG can still have significant radiative forcing. A three-fold increase in LNG demand by 2030, with full renewable LNG substitution, would not reduce emissions. Although production emissions would decrease relative to 2019, the utilization of LNG in marine engines would cause life cycle emissions of methane to double, thus failing to align with climate targets.[136]

A 2022 study suggested that bio-LNG (non-blended) could cover up to 3% of the total energy demand for shipping fuels in 2030 and 13% in 2050.[137] Thus, representing a minority of the shipping energy mix. The majority of ports, 21 of 33, were identified as having bio- and/or e-LNG available for bunkering.

Due to international and domestic climate goals, and regulations or levies that consider the full life cycle of a fuel, it is logical for these ports to offer a lower GHG alternative, whenever feasible. Particularly, these ports are presenting a cleaner alternative that is accessible to a greater proportion of vessels, as the fleet of LNG-capable ships is significantly larger than for other alternative fuels. It will be essential to develop infrastructure at these ports to facilitate the bunkering of other low-GHG alternative fuels to ensure a more diversified and sustainable maritime transport, aligning with climate targets.

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[135] Emissions that occur during the production, storage, and/or transportation before its intended consumption
[136] https://theicct.org/wp-content/uploads/2022/09/Renewable-LNG-Europe_report_FINAL.pdf
[137]https://sea-lng.org/wp-content/uploads/2022/10/SEA-LNG_BioLNG-Study-Key-Findings-Document_October-2022_amended.pdf

Table 3

View of proposed, under construction, and operational LNG bunkering operations in the Arctic and adjacent countries

Country	Port	Operators	Status	Start Year	Operation Year	Bio-/E-LNG	Ship-Ship	Truck-Ship	Tank-Ship	Bunker Capacity	Storage Capacity
Canada (4)	Vancouver	Fortis BC, Seaspan	Operational	2021	2024	0	1	1	1	78 m^3/hr/truck	
	Québec	Energir, Gaz Metro Transport	Operational	2018		0	0	1	0		
	Montreal	Energir, Gaz Metro Transport	Operational	2017		0	0	1	0		
	Hamilton	REV LNG	Operational	2020		0	0	1	0		
Finland (5)	Röyttä	Gasum	Operational	2018		1	1	0	1		50,000 m^3
	Pori	Gasum	Operational	2016		1	1	1	1		28,500 m^3
	Helsinki	Gasum, Eesti Gaas	Operational	2014		1	1	1	0		
	Hamina	Hamina Energy, Wärtsilä, Alexela	Operational	2022		0	1	1	0	1,000 m^3/hr	30,000 m^3
	Inkoo	Gasgrid, Excelerate Energy	Construction	2023	2023	0	1	0	0		150,900 m^3
Iceland (2)	Finnafjörður	Gasum, Bremenports	Proposed			0	0	0	0		
	Reykjavik	Gasum	Operational	2023		0	1	0	0		
Norway (11)	Hammerfest	Barents Nargass AS, Gasum	Operational	2017		1	0	0	1	90 T/hr/tank	1,250 m^3
	Bodø	Gasum	Operational			1	1	1	0		
	Vestbase Kristiansund	Gasum	Operational			1	1	1	0		
	Florø Fjordbase	Fjord Base AS, Gasum	Operational	2009		1	1	0	0		500 m^3
	Kollsnes	Gasnor	Operational	2003		1	1	0	0		
	Mongstad	Gasum	Operational			1	1	1	0		
	Bergen	Gasum, Gasnor	Operational	2020	2021	1	1	1	0		735 m^3
	Haugesund	Knutsen	Operational			0	1	0	0		
	Karmøy	Gasum	Operational			1	1	1	0		
	Risavika	Gasum	Operational	2015		1	1	1	1		30,000 m^3
		Kanfer Shipping AS	Construction		2024	0	1	0	0		
Sweden (11)	Luleå	Gasum	Operational	2023		1	1	1	0		
	Nynäshamn	Gasum, AGA, Nauticor	Operational	2020		1	1	1	0		20,000 m^3
	Stockholm[138]	Gasum, AGA, Nauticor	Operational	2013	2013	1	1	1	0		
	Kapellskär	Gasum, AGA, Nauticor	Operational			1	1	0	0		
	Södertälje	Gasum	Operational	2019		1	1	1	0		
	Donso	Gasum, Sirius Shipping	Operational		2017	0	1	0	0		
	Trelleborg	Gasum	Operational			1	1	0	0		
	Malmo	Gasum	Operational	2020		1	1	1	0		
	Gothenburg	Gasum	Operational	2018		1	1	0	0		30,000 m^3
	Lysekil	Gasum	Operational	2014		1	1	1	0		30,000 m^3
	Oxelösund	Avenir LNG, OXGAS AB	Proposed			0	0	0	0		

[138] There are three "Ports of Stockholm" in close proximity: Stockholm, Nynäshamn and Kapellskär

Introduction to the Global Natural Gas Market

Natural gas makes up a small fraction of the total energy supply for Finland (3.3%) and Sweden (1.4%), but comprises nearly a quarter of total energy supply in Norway (22.5%) and a large portion of the energy mix in Canada (40.9%) and the USA (35.3%).[139] The Arctic holds approximately 30% of global undiscovered conventional natural gas resources.[140] As explored in their respective background, these nations' governments have different stances on capitalizing on its continued extraction. Canada is actively pursuing exploration and expansion of natural gas resources, while Greenland suspended all extraction of natural gas where it was not bound by an ongoing lease. Norway continues to remain a pivotal producer and exporter of natural gas, accounting for around 3% of worldwide production.[141] Thereby, supporting its extraction and trade despite implementing legislative restrictions to prevent natural gas investments from overshadowing renewable energy development and efforts to reduce its role in their domestic energy mix.

Building upon the policy positions on natural gas for Alaska (USA), Canada, Finland, Greenland, Iceland, Norway, and Sweden explored under LNG Bunkering, this report provides projected trends in LNG growth by country in the region of study by identifying existing, under construction, and planned import and expert terminals based on Global Energy Monitor[142] (GEM) data for these Arctic nations. We describe import and export volumes, trading partners, and detail LNG trade in the Arctic region. Trajectories for the LNG market and its transport across Arctic waters are supplemented with public data and resources.

Challenges to Arctic Infrastructure

The majority of LNG terminals worldwide are situated in warm or temperate climates. Climate conditions in the Northern Arctic can be extreme and inhospitable for infrastructure and workforces. The Hammerfest LNG facility in Norway was the first of its kind built to withstand conditions north of the Arctic Circle, with its engineers developing their own project-specific liquefaction process.[143]

Climate warming causes damage to Arctic infrastructure, making it costly to maintain, repair, or replace.[144,145] The Arctic Council's AMAP identified Arctic shipping and flaring from Arctic oil and gas industries to be high-risk and high-impact sources of emissions. As the thickness and extent of sea-ice coverage decreases, activities sourcing these emissions are anticipated to significantly increase due to the eased accessibility and

139 https://www.iea.org/data-and-statistics/data-tools/energy-statistics-data-browser
140 https://pubs.usgs.gov/fs/2008/3049/fs2008-3049.pdf
141 https://www.norskpetroleum.no/en/production-and-exports/exports-of-oil-and-gas/
142 https://globalenergymonitor.org/projects/global-gas-infrastructure-tracker/
143 https://www.linde-engineering.com/en/about-linde-engineering/success-stories/lng-production-in-permafrost.html
144 https://www.arctic.gov/uploads/assets/usarc_goals_2019-2020.pdf
145 https://doi.org/10.1038/s41467-018-07557-4

opening of these waters allowing for greater frequency.[146] Although economic factors and infrastructure availability (e.g. fuel bunker) are primary drivers of shipping activity, the opening of polar seaways from shifting sea ice coverage allows previously inaccessible or economically-prohibitive routes to be traversed.[147]

The future of Arctic infrastructure is at risk, even if climate targets set by the Paris Agreement are reached. Thawing near-surface permafrost will affect 70% of all Arctic infrastructure, built atop increasingly unstable substrates.[148] Permafrost thaw has led to great volumes of frozen carbon (i.e. organic carbon and trapped gasses) being released to the atmosphere as CO_2 and CH_4. Thawing permafrost systems are releasing more GHGs, perpetuating a positive feedback loop of climate warming. The unique environmental challenges in the Arctic and their potential compounding effects have led some Arctic nations to take a cautious approach to heavy investments in natural gas infrastructure, particularly due to the CH_4 emissions associated with the industry.

Natural Gas Infrastructure

Locations of LNG import and export facilities in the Arctic region, with consideration to investment factors,[149] have geopolitical and economic implications for energy dynamics and shipping across these territories. Existing and proposed facilities and pipelines serve domestic energy requirements, but also provide connectivity with global energy networks. Beyond powering energy grids, natural gas infrastructure may support use of natural gas as a road or maritime fuel, contribute to producing alternative fuels through steam methane reforming, or potentially undergo adaptations to support the transport of other alternative energies and fuels in evolving frameworks. This section describes LNG import, export, and pipeline infrastructure in the Arctic.

Import Terminals

There are twenty import terminals located within the Arctic nations studied for this project.[150] There are no LNG terminals in Iceland or Greenland. Of these facilities, ten are inactive, seven are operational, two are proposed locations, and one is under construction (Figure 6). LNG import terminals are shown for the whole area of study in Figure 6 and, in detail, for the Northern Europe region in Figure 7.

There are no operational import terminals north of the AMAP Arctic Boundary, although the Mosjoen LNG Terminal in Norway and the Tornio Manga LNG Terminal in Finland are close to the boundary. The Alaska LNG facility proposed in Nikiski, Alaska, USA will fall north of this boundary and is anticipated to have dual import/export capabilities. Beyond these facilities, most import terminals are built along southern coastal boundaries.

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[146] https://www.amap.no/documents/download/2506/inline
[147] https://www.ipcc.ch/report/ar6/wg2/downloads/report/IPCC_AR6_WGII_CCP6.pdf
[148] https://doi.org/10.1038/s41467-018-07557-4
[149] Location and Final Investment Decision (FID) are commonly aligned with low costs and high returns, such as considering the least costs for resource extraction and transportation.
[150] Alaska (USA), Canada, Finland, Greenland, Iceland, Norway, and Sweden

Figure 6

View of inactive, proposed, under construction, and operational LNG import facilities in the Arctic region areas of this study (excluding Russia)

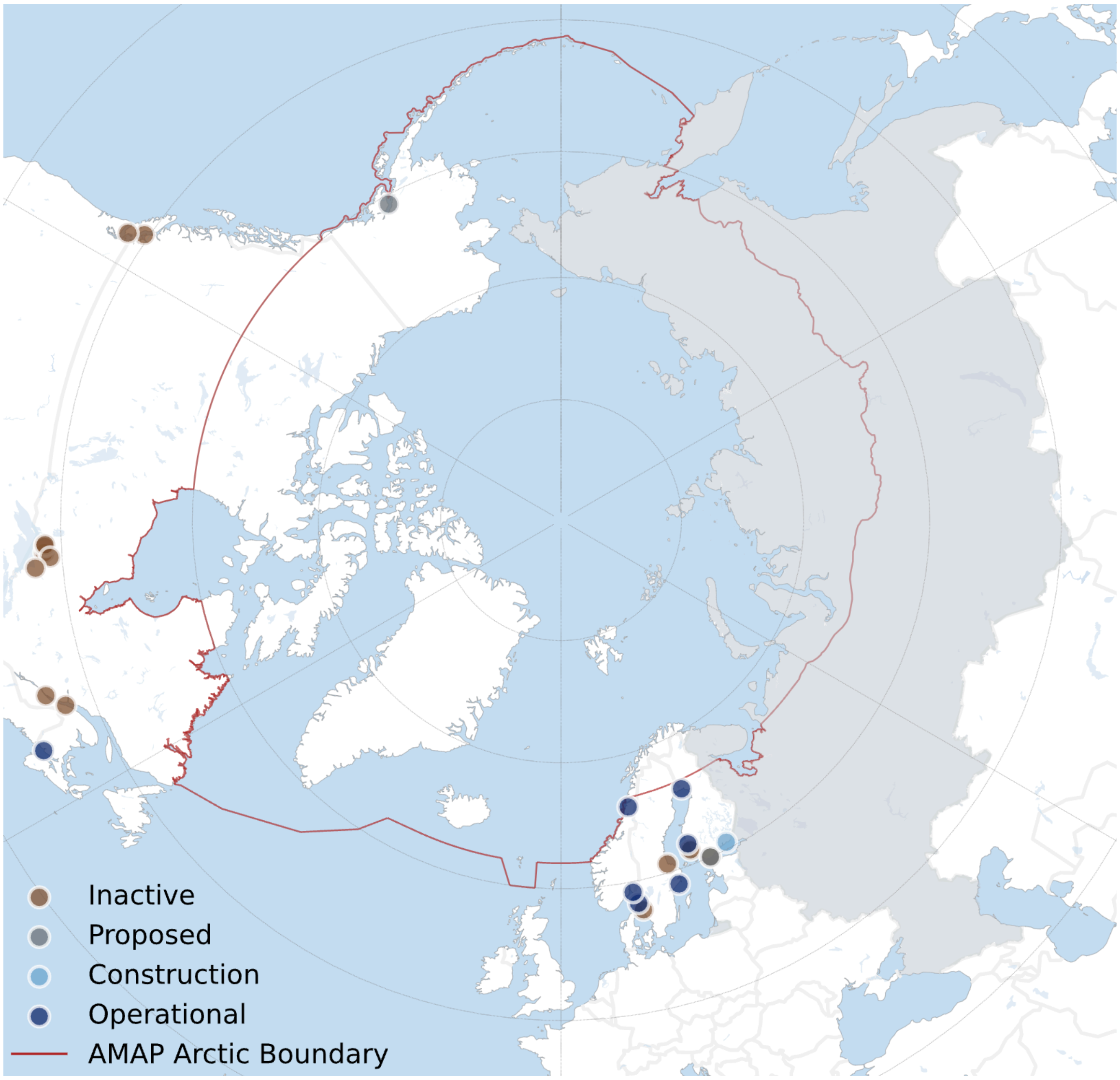


Figure 7

View of inactive, proposed, under construction, and operational LNG import facilities in the Northern Europe region areas of this study (excluding Russia)

The locations of proposed, operational and canceled LNG import terminals are shown in Table 4.[151] GEM data for Canada shows one currently operating LNG export terminal in Saint John, New Brunswick with a capacity of 7.5 million tonnes per year (Mtpa). All other facilities in the GEM dataset for Canada are canceled or shelved.

In addition to the import terminals shown, natural gas production in the Northwest Territories from the Ikhil field near the town of Inuvik provides back-up natural gas supply for imported LNG in the region.[152]

Finland shows four terminals in proposed, under construction, or operational status with a total combined import capacity of 3.88 Mtpa, including the FSRU at Inkoo Port (3.68 Mtpa). Norway and Sweden each have two operational LNG import terminals with combined capacities of 0.5 Mtpa and 0.6 Mtpa, respectively. There is a single proposed

[151] Data from Global Energy Monitor. "Global Gas Infrastructure Tracker, Global Energy Monitor, October 2023."
[152] https://www.cer-rec.gc.ca/en/data-analysis/energy-markets/provincial-territorial-energy-profiles/provincial-territorial-energy-profiles-northwest-territories.html

LNG import terminal in Kenai, Alaska which is located to the south of Anchorage, along Cook Inlet, with a capacity of 0.2 Mtpa.

The GEM data include "Canceled" and "Shelved" projects,[153] which we include to illustrate the scale of activity, not only operational, proposed, and under construction facilities.

Table 4

Arctic Nations' LNG Import Facilities, Location, Status, and Capacity.

Source: Global Energy Monitor, Global Gas Infrastructure Tracker.

Country	Terminal Name	Location	Status	Capacity (Mtpa)
Canada	Cacouna LNG Terminal	Gros Cacouna	Canceled	3.80
	Saint John LNG Terminal	Saint John	Operating	7.50
	Rabaska LNG Terminal	Lévis	Canceled	3.60
	Texada LNG Terminal	Texada Island	Canceled	3.80
	Steelhead FSRU	Bamberton	Canceled	6.00
	North Shore LNG Terminal	Manitouwadge	Shelved	--
		Marathon	Shelved	--
		Schreiber	Shelved	--
		Terrace Bay	Shelved	--
		Wawa	Shelved	--
Finland	Hamina LNG Terminal	Port of Hamina	Construction	0.10
	Pori LNG Terminal	Port of Tahkoluoto	Operating	0.10
	Tornio Manga LNG Terminal	Tornio harbour, Port of Röyttä,	Operating	--
	Rauma LNG Terminal	Rauma	Shelved	0.40
	Southern Finland LNG Terminal		Canceled	--
	Inkoo FSRU	Inkoo port	Proposed	3.68
Norway	Fredrikstad LNG Terminal	Øra	Operating	0.10
	Mosjoen LNG Terminal	Mosjoen	Operating	0.40
Sweden	Brunnsviksholme LNG Terminal	Brunnsviksholme, Nynäshamn Municipality, Stockholm County	Operating	0.40
	Gothenburg LNG Terminal	Gothenburg	Canceled	0.40
	Gävle LNG Terminal	Gävle	Canceled	0.20
	Lysekil LNG Terminal		Operating	0.20
Alaska, USA	Kenai LNG Terminal	Kenai	Proposed	0.20

Export Terminals

There are twenty-five export terminals located within the study area. There are no LNG terminals in Iceland or Greenland. Of these facilities, ten are inactive, seven are operational, seven are proposed, and one is under construction (Figure 8). LNG export terminals are shown for the whole area of study in Figure 8 and, in detail, for the Northern American region in Figure 9.

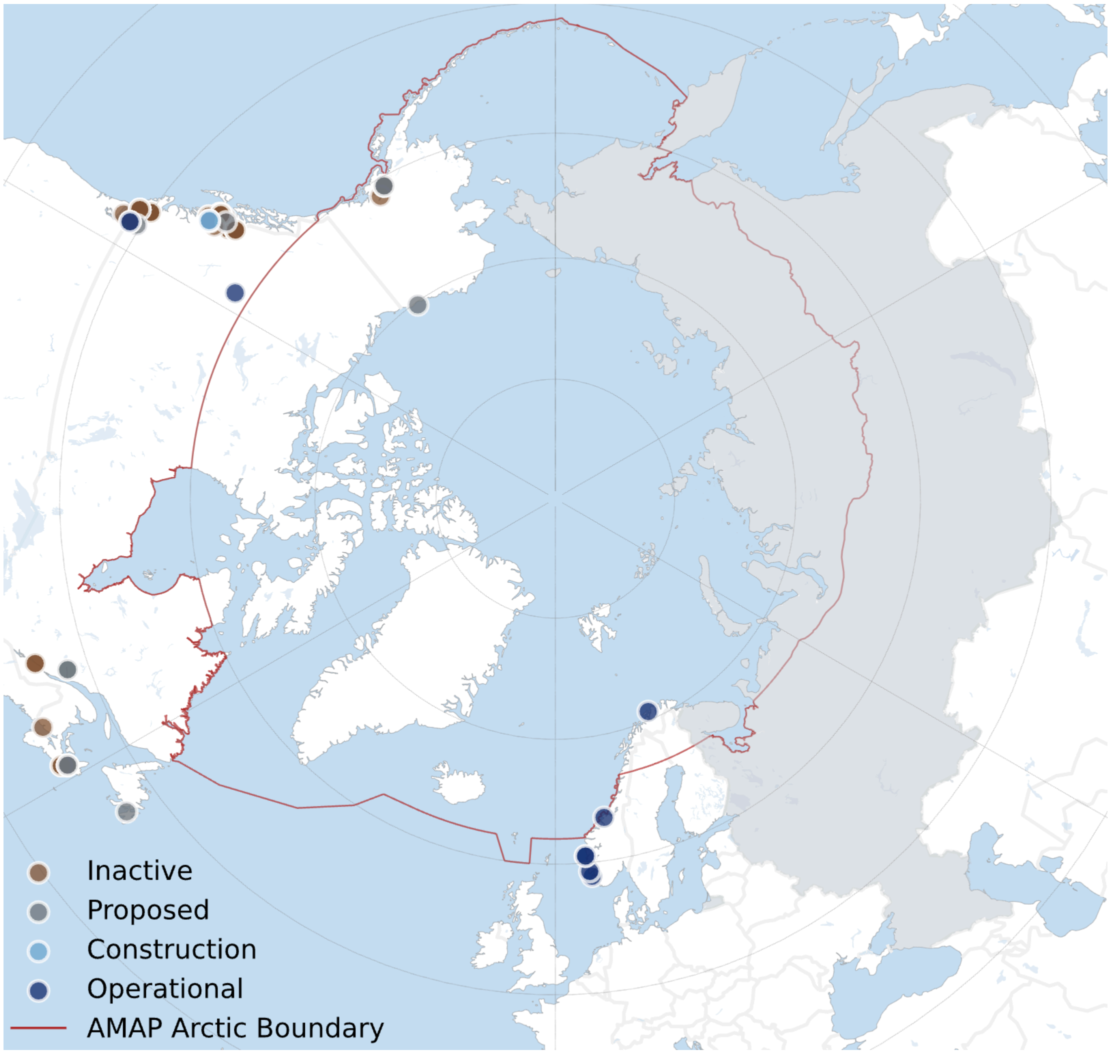
Hammerfest LNG, Norway (4.2 Mtpa) is the only operational facility north of the AMAP Arctic Boundary. There are four other LNG export facilities in Norway with a combined capacity of 0.48 Mtpa (Table 5). The inactive Kenai LNG Terminal, Alaska, USA is north of

[153] GEM assigns a status of "shelved" if no project developments in 2 years following project proposal, and a status of "cancelled [sic]" if there are no project developments in the 4 years following the project proposal.

the AMAP boundary, but has been out of commission since 2017. Two proposed Alaskan export facilities, Alaska LNG (20.10 Mtpa) in Kiniski, near Kenai on Cook Inlet, and Qilak LNG (4.00 Mtpa) on the north slope, that would be north of AMAP boundary.

Figure 8

View of inactive, proposed, under construction, and operational LNG export facilities in the Arctic region areas of this study (excluding Russia)



The Fort Nelson LNG export terminal in Fort Nelson, BC is not adjacent to a navigable waterway. The Enbridge Gas Pipeline and railways are used to transport LNG for export in proprietary train transport trailers, capable of hauling 20,000 gallons of LNG.[154] This facility primarily serves the domestic energy needs of northern Canadian communities and any exports would be minimal shipments to the U.S.[155] GEM data show 0.03 Mtpa export capacity at Tilbury Island, with an additional 3.4 Mtpa export capacity proposed at the facility, located on the Fraser River south of Vancouver, BC.

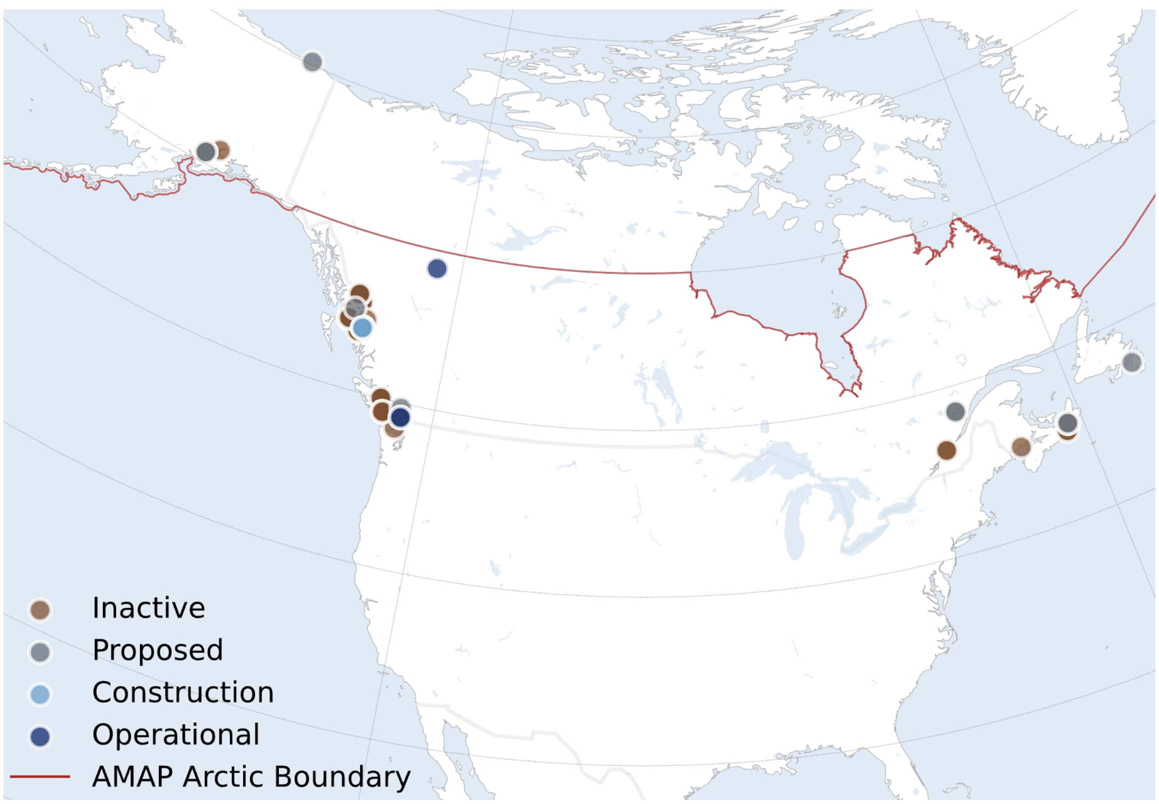
[154] https://www.offshore-energy.biz/cryopeaks-fort-nelson-lng-facility-now-in-operation/
[155] https://natural-resources.canada.ca/energy/energy-sources-distribution/natural-gas/canadian-liquified-natural-gas-projects/5683

The GEM data show significant activity in Canada around LNG export facilities, with 10 facilities or facility expansions proposed or under construction in Canada. Much of the proposed activity is found in British Columbia and Alberta, associated with the tar sands industry in Alberta and production in the Horn River, Montney, and Liard basins in British Columbia (See Figure 10). If all proposed activity comes online in Canada, it would add approximately 61.6 Mtpa in export capacity from Canada.

According to its Canadian Environmental Assessment Agency approval, the LNG Canada Terminal will achieve emissions of 0.15 mtCO2e/mtLNG, making it the lowest-emitting LNG terminal in the world. These estimates do not account for life cycle emissions, only the emissions directly emitted from the terminal. Furthermore, emissions stemming from the production and supply of gas to the LNG Canada terminal, as well as emissions generated by the terminal itself are estimated to amount to 13.0 Mtpa, surpassing the CleanBC target for all sectors of the economy set at 12.3 Mtpa by 2050. Consequently, the projected expansion of proposed and/or approved LNG capacities could result in emissions surpassing 2050 climate targets by over 200%, even if all other sectors of BC's economy achieved zero emissions by 2031.[156]

Figure 9

View of inactive, proposed, under construction, and operational LNG export facilities in the North American region areas of this study



[156]https://policyalternatives.ca/sites/default/files/uploads/publications/BC%20Office/2020/07/ccpa-bc_BCs-Carbon-Conundrum_full.pdf

Table 5

Arctic Nations' LNG Export Facilities, Location, Status, and Capacity[157]

Source: Global Energy Monitor, Global Gas Infrastructure Tracker.

Country	Terminal Name	Location	Status	Capacity (Mtpa)
Alaska, USA	Alaska Japan LNG Terminal	Port MacKenzie	Canceled	1.00
	Alaska LNG Terminal	Nikiski	Proposed	20.10
	Kenai LNG Terminal	Kenai	Mothballed	1.50
	Qilak LNG Terminal	North Slope	Proposed	4.00
Canada	Atlantic Coast LNG Terminal	Byers Cove	Canceled	16.00
	Aurora LNG Terminal	Delusion Bay	Canceled	24.00
	Bear Head LNG Terminal	Point Tupper	Proposed	12.00
	Canaport LNG Export Terminal	Saint John	Canceled	7.50
	Cedar FLNG Terminal	Kitimat	Proposed	3.00
	Discovery LNG Terminal	Campbell River	Canceled	20.00
	Douglas Channel LNG Terminal	Douglas Channel	Canceled	0.90
	Energie Saguenay LNG Terminal	Port Saguenay	Proposed	11.00
	Fort Nelson LNG Terminal	Fort Nelson	Operating	0.02
	Goldboro LNG Terminal	Goldboro	Shelved	9.60
	Grassy Point LNG Terminal	Grassy Point	Canceled	20.00
	Kitimat LNG Terminal	Port of Kitimat	Canceled	12.00
	Kitsault LNG Terminal	Kitsault	Canceled	20.00
	Ksi Lisims FLNG Terminal	Gingolx	Proposed	12.00
	Kwispaa LNG Terminal	Port Alberni	Canceled	24.00
	LNG Canada Terminal	Kitimat	Construction	14.00
	Malahat LNG Terminal	Victoria	Canceled	6.00
	New Times Energy LNG Terminal	Prince Rupert	Canceled	12.00
	Nisga'a LNG Terminal	Portland Inlet	Canceled	--
	Orca FLNG Terminal	Prince Rupert	Canceled	24.00
	Pacific Northwest LNG Terminal	Lelu Island	Canceled	18.00
	Placentia Bay FLNG Terminal	Arnold's Cove	Proposed	4.00
	Prince Rupert LNG Terminal	Ridley Island, Prince Rupert	Canceled	21.00
	Skeena LNG Terminal	Skeena	Shelved	--
	Stewart Energy LNG Terminal	Stewart	Canceled	10.00
	Stolt LNGaz Terminal	Bécancour	Canceled	0.50
	Tilbury Island LNG Terminal	Tilbury Island	Operating	0.03
	Triton LNG Export Terminal	Douglas Channel	Canceled	2.30
	Watson Island LNG Terminal	Prince Rupert	Canceled	1.00
	WCC LNG Terminal	Tuck Inlet, Prince Rupert	Canceled	30.00
	Woodfibre LNG Terminal	Squamish	Proposed	2.20
		Kitimat	Proposed	14.00
		Tilbury Island	Proposed	0.90
		Tilbury Island	Proposed	2.50
Norway	Hammerfest LNG Snøhvit Terminal	Melkoa Island	Operating	4.20
	Kollsnes LNG Terminal	Kollsnesvegen	Operating	0.12
	Risavika LNG Terminal	Port of Risavika	Operating	0.33
	Snurrevarden LNG Terminal	Snurrevarden	Operating	0.02
	Tjeldbergodden LNG Terminal	Kjørsvikbugen	Operating	0.01

157 Floating Liquefied Natural Gas facilities (FLNG) are a counterpart to FSRUs – liquefaction vs regasification capable / https://maritime-executive.com/blog/classification-of-flngs-and-fsrus-requires-flexibility

Figure 10

Proposed LNG terminals, basins, and pipelines in British Columbia, Canada

Source: Wilderness Committee.

Pipelines

There are 89 pipelines in the study area. Pipelines were included in the analysis if their starting or ending points fell within the specified bounds of the study. Of these pipelines, 15 are inactive, 63 are operational, 6 are proposed, and 5 are under construction.

The pipelines traverse through Canada, Finland, Norway, Sweden, and the U.S., with connections to some neighboring countries (e.g. Poland) that are outside of the focus area of this study. The majority of operational pipelines are located in Europe, with 39 operational pipelines, 1 proposed, 1 under construction, and 2 inactive. In North America there are 24 operational, 5 proposed, 4 under construction, and 13 inactive pipelines. The pipelines are described in Table 6.

Table 6

Arctic Nations' Gas Pipelines, Locations, Status, and Capacity

Source: Global Energy Monitor, Global Gas Infrastructure Tracker.

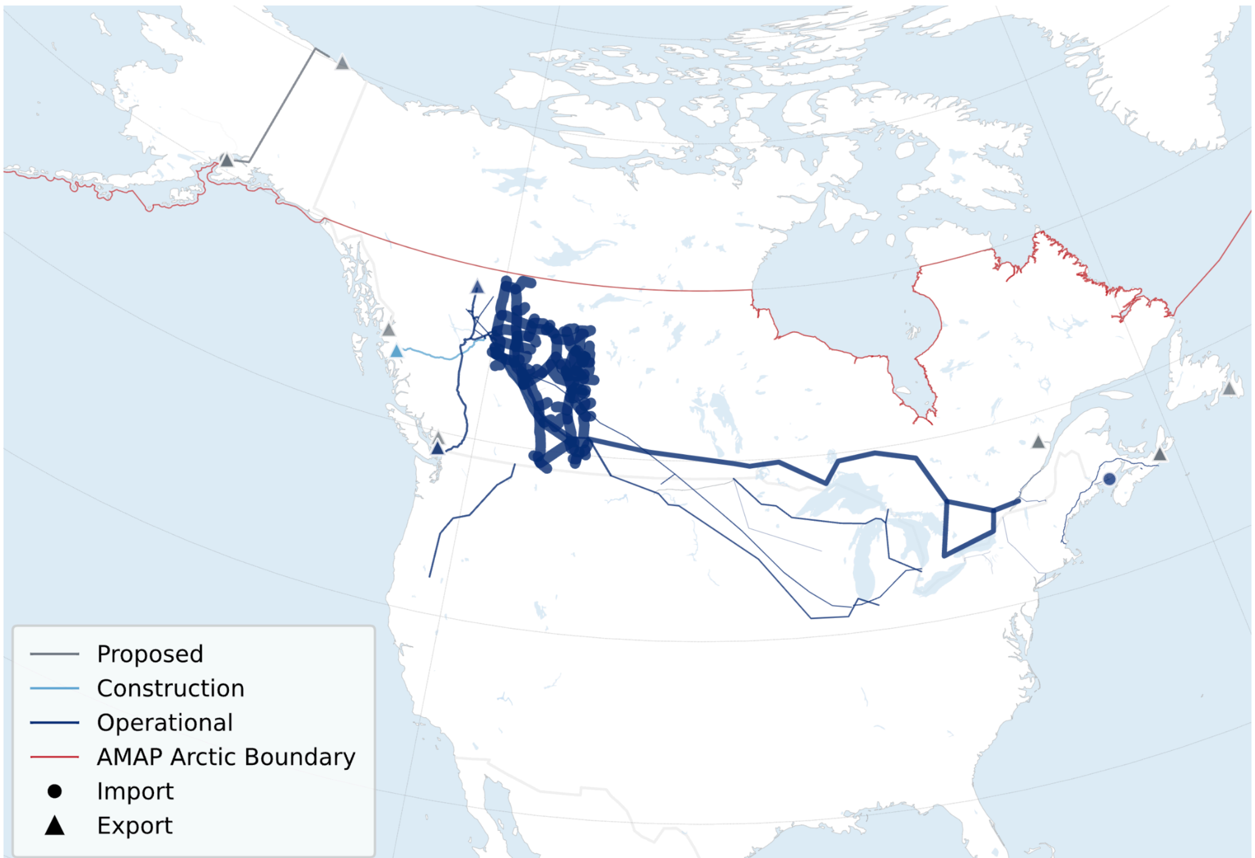
StartCountry	EndCountry	Pipeline Name	Status	Capacity (Bcm/y)
Canada	Canada	Canadian Mainline Gas Pipeline	Operating	82.74
		Coastal GasLink Pipeline	Construction	31.03
		Eagle Mountain-Woodfibre Gas Pipeline	Proposed	2.36
		Foothills System Gas Pipeline	Operating	34.13
		Horn River Gas Pipeline	Canceled	10.34
		Mackenzie Gas Pipeline Project	Canceled	19.13
		Nova Gas Transmission (NGTL) Pipeline	Operating	173.76
		Pacific Trail Gas Pipelines	Shelved	10.34
		Prince Rupert Gas Transmission Pipeline	Shelved	20.69
		Trans Québec and Maritimes (TQM) Pipeline	Operating	8.27
		Westcoast Connector Gas Transmission Project	Canceled	43.44
		Tidewater Pipeline	Shelved	3.52
		Saddle West Pipeline	Construction	3.67
		Pioneer Gas Pipeline	Operating	1.34
		BC Gas Pipeline	Construction	3.72
		BC Gas Pipeline	Operating	0.62
		BC Gas Pipeline	Operating	1.42
		BC Gas Pipeline	Operating	0.52
		Nova Gas Transmission (NGTL) Pipeline	Construction	--
		North Montney Mainline Pipeline	Operating	17.58
		North Wapiti Pipeline System	Operating	1.55
		Alton Natural Gas Pipeline	Operating	--
		Bear Paw Gas Pipeline	Proposed	--
		Energíe Saguenay Gas Pipeline	Canceled	--
		Emera Brunswick Gas Pipeline	Operating	8.48
		Pacific Trails Pipeline	Shelved	10.34
Canada	United States	Alliance Gas Pipeline	Operating	16.55
		BC Gas Pipeline	Operating	35.17
		Great Lakes Gas Transmission Pipeline	Operating	24.82
		Iroquois Gas Pipeline	Operating	5.17
		Maritimes and Northeast Gas Pipeline	Operating	14.27
		Gas Transmission Northwest	Operating	29.99
		TransGas Pipeline	Operating	0.46
		Viking Gas Transmission	Operating	5.17
		Empire Pipeline	Operating	3.1
		Northern Border Gas Pipeline	Operating	24.82
Finland	Estonia	Balticconnector Gas Pipeline	Operating	2.6
Finland	Finland	Helsinki–Siuntio Gas Pipeline	Operating	--
		Imatra–Mantsala Gas Pipeline	Operating	--
		Inkoo–Mantsala Gas Pipeline	Operating	--
		Mantsala–Hameenlinna Gas Pipeline	Operating	--
		Mantsala–Helsinki Gas Pipeline	Operating	--

StartCountry	EndCountry	Pipeline Name	Status	Capacity (Bcm/y)
		Mantsala–Kyroskoski Gas Pipeline	Operating	--
Norway	Belgium	Zeepipe Gas Pipeline	Operating	15.34
Norway	France	Franpipe Gas Pipeline	Operating	20.1
Norway	Germany	Europipe II Gas Pipeline	Operating	21
		Norpipe Gas Pipeline	Operating	16
Norway	Norway	Haltenpipe Gas Pipeline	Operating	2.2
		Polarled Gas Pipeline	Operating	25.6
		Statpipe Gas Pipeline	Operating	18.9
		Asgard Transport System	Operating	18.97
		Barents Sea Pipeline	Proposed	--
		Snohvit–Melkoya Island Pipeline	Operating	--
		Johan Sverdrup Gas Pipeline	Operating	--
		Draugen Gas Export Pipeline	Operating	1.83
		Grane Gas Pipeline	Operating	3.65
		Knarr Gas Pipeline	Operating	0.62
		Kvitebjørn Gas Pipeline	Operating	9.86
		Norne Gas Transport System Pipeline	Operating	2.56
		Oseberg Gas Transport Pipeline	Operating	12.78
		Heidrun Gas Export Pipeline	Operating	4.02
		Troll–Kollsnes I Gas Pipeline	Operating	--
		Troll–Kollsnes II Gas Pipeline	Operating	--
		Troll–Kollsnes III Gas Pipeline	Operating	--
		Ormen Lange–Nyhamna I Gas Pipeline	Operating	--
		Ormen Lange–Nyhamna II Gas Pipeline	Operating	--
		Gudrun Gas Pipeline	Operating	--
		Barents Stream Pipeline	Shelved	--
Norway	Poland	Baltic Pipe Project	Construction	10
Norway	Sweden	Skanled Gas Pipeline	Canceled	7
Norway	United Kingdom	Langeled Gas Pipeline	Operating	25.5
		Vesterled Gas Pipeline	Operating	11
		Tampen Link Gas Pipeline	Operating	5.17
		Gjøa Gas Pipeline	Operating	6.21
Sweden	Sweden	Malmoe–Stenungsund Gas Pipeline	Operating	--
		Halmstad-Gilaved Gas Pipeline	Operating	--
		Halmstad–Gilaved Gas Pipeline	Operating	--
		Malmoe–Trelleborg Gas Pipeline	Operating	--
United Kingdom	Norway	Northern Leg Gas Pipeline	Operating	3.1
United States	Canada	Alaska Gas Pipeline	Canceled	42.41
		Denali Alaskan Natural Gas Pipeline	Canceled	46.54
		Vector Gas Pipeline	Operating	18.05
		Empire Pipeline	Operating	3.1
		Empire Pipeline	Shelved	3.62
		Tioga to Emerson Pipeline	Proposed	6.21
United States	United States	Alaska LNG Pipeline (AKLNG)	Proposed	36.2
		Alaska Stand Alone Pipeline	Shelved	5.17
		Arctic Fox Pipeline	Canceled	0.54
		Donalin Gold Mine Gas Pipeline	Proposed	0.76

While there are fewer pipelines in North America, the active pipelines are larger on average (Figure 11). The average capacity of operational pipelines in North America is 22.22 billion cubic meters per year (Bcm/y) compared to the average capacity in Europe of 10.81 Bcm/y.[158] Pipelines in North America are land-based, while a majority of the operational pipelines in Europe are sea-spanning, delivering natural gas to the U.K., Germany, and other European countries, displayed in Figure 12. The average estimated length of all pipelines is about 680 kilometers (km).

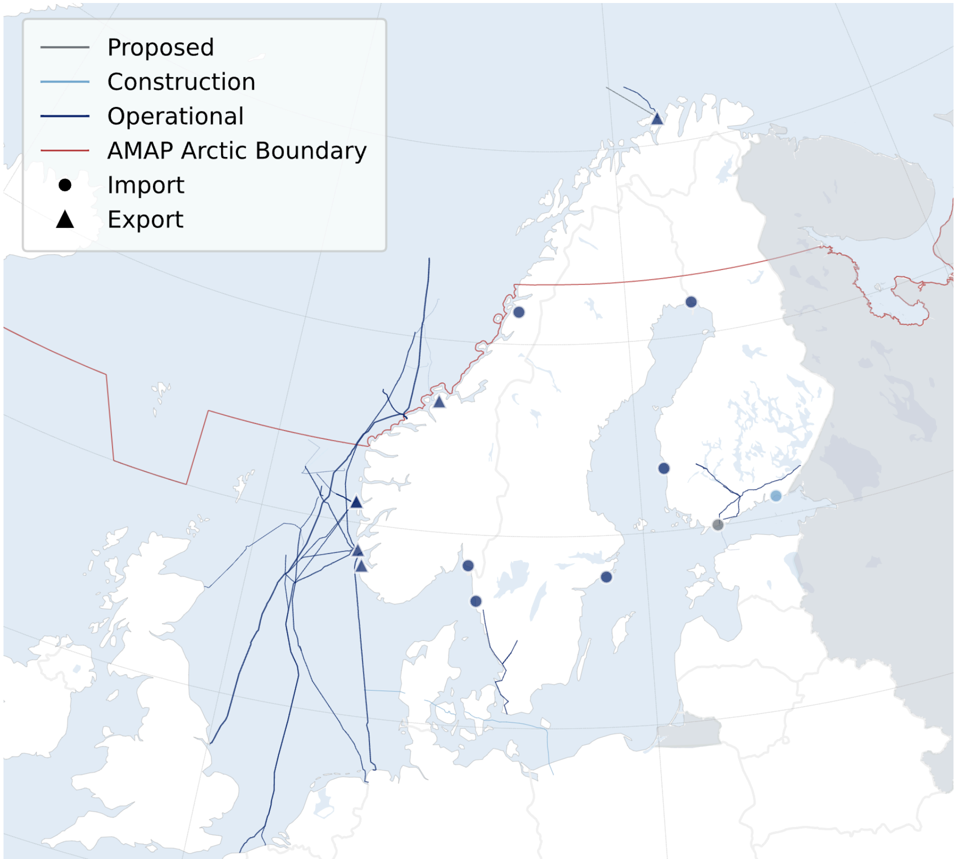
Figure 11

North American natural gas pipelines



[158] Statistics are based on available capacity information in the GEM data. There are 19 operational pipelines that do not have capacity information available (1 in North America and 18 in Europe).

Figure 12
Northern Europe natural gas pipelines



According to the GEM data, the largest operational pipeline by capacity is the Nova Gas Transmission Pipeline, which operates within Canada and has a capacity of 173.76 Bcm/y. The Nova Gas Transmission Pipeline has over double the capacity of the next largest operational pipeline in the record, the Canadian Mainline Gas Pipeline, which has a capacity of 82.74 Bcm/y. The Nova Gas Transmission Pipeline is also the longest pipeline with a total estimated length of about 9,789 km covering much of Alberta (clearly visible as the dense network of pipelines in Figure 11), which is around 5,967 km longer than the Canadian Mainline Gas Pipeline.

According to the GEM data, there are no operational natural gas pipelines in Alaska. Three projects have been canceled and one remains inactive. There are currently 2 proposed pipelines, Alaska LNG (AKLNG) pipeline and Donalin Gold Mine Gas Pipeline, with potential capacities of 36.2 Bcm/y and 0.76 Bcm/y, respectively.

Some proponents of the AKLNG pipeline, which would span almost 1,300 km within Alaska from Point Thomson to Nikiski, could become politically beneficial by delivering LNG to Japan and South Korea, reducing their reliance on natural gas from Russia. Attention to these motivations increased during the 2022 Russian invasion of Ukraine. However, due to decreasing interest in the overseas market and criticism from environmental advocates,[159] it remains uncertain whether there is sufficient interest in the project for it to be completed.[160]

Market Trends

Over the last decade there has been significant growth in utilization of natural gas in the global energy mix, with global consumption increasing by nearly 25% and an approximate 40% increase in the total primary energy supply,[161] beyond the contribution of other fuel sources.[162] The invasion of Ukraine and consequent Russo-Ukrainian War in 2022 led to global energy disruptions due to the resulting gas shortage. It provided impetus for a turning point in global gas demand, with projections it will decrease significantly by 2026, particularly for advanced economy[163] nations with accelerated demand for renewables.[164,165] Coupled with stricter standards for energy efficiency and lower emissions, the ongoing shortage of gas from Russia led to a decline of natural gas in European markets.

Record-setting LNG trade volumes occurred in 2022, with Norway solidifying their role as a global producer and exporter.[166] Although the U.S. is a significant exporter of natural gas including LNG, Alaska has not directly participated in the LNG export market due to the absence of liquefaction and export terminals. Similarly, Canada is a notable pipeline exporter of natural gas but has lacked infrastructure for liquefaction and intercontinental export of LNG. Thereby, Canada and Alaska, USA, despite possessing substantial reserves and infrastructure to extract large quantities of natural gas, are set to join the global LNG export market at the tail end of the golden decade of gas.[167]

Europe's LNG import capacity is projected to expand by over one-third (6.8 Bcf/d) by the end of 2024.[168] Import capacity of planned LNG infrastructure projects in Europe may far exceed LNG demand by 2030.[169] To reduce reliance on Russian energy, many European nations (including Sweden and Finland) greenlit construction of new terminals and FSRUs to increase LNG import volumes from overseas, with ongoing projects set to come online out to 2030 and beyond. While Norway has well-established gas infrastructure, including high pipeline density, other Arctic nations in the region have less developed natural gas infrastructure. In light of climate goals, various agencies have recommended nations take

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[159] https://www.theguardian.com/us-news/2023/apr/14/biden-alaska-lng-liquefied-natural-gas-exports
[160] https://alaskapublic.org/2023/09/15/alaska-politicians-remain-optimistic-about-ak-lng-even-as-overseas-market-cools/
[161] Total primary energy supply is the sum of production and imports, adjusted for stock changes, minus total exports and international bunker storage.
[162]https://iea.blob.core.windows.net/assets/f2cf36a9-fd9b-44e6-8659-c342027ff9ac/Medium-TermGasReport2023-IncludingtheGasMarketReportQ4-2023.pdf
[163] https://www.imf.org/en/Publications/WEO/weo-database/2023/April/groups-and-aggregates
[164]https://iea.blob.core.windows.net/assets/f2cf36a9-fd9b-44e6-8659-c342027ff9ac/Medium-TermGasReport2023-IncludingtheGasMarketReportQ4-2023.pdf
[165] Anticipated increases in natural gas demand are concentrated in Asia, Africa, and the Middle East.
[166]https://iea.blob.core.windows.net/assets/f2cf36a9-fd9b-44e6-8659-c342027ff9ac/Medium-TermGasReport2023-IncludingtheGasMarketReportQ4-2023.pdf
[167] IEA refers to the period between 2011-2021 as the golden decade for rapid growth of natural gas
[168] https://www.eia.gov/todayinenergy/detail.php?id=54780
[169] https://ieefa.org/articles/over-half-europes-lng-infrastructure-assets-could-be-left-unused-2030

a more restrained approach to these long-term fossil investments.[170,171,172]

Coming into effect mid-2024, the IMO will set a ban on the utilization and carriage of HFO fuel within Arctic waters.[173] This regulatory measure is poised to have a notable impact on the maritime industry, and some argue that it may bolster demand for LNG as an alternative fuel.[174,175] As such, there may be an incentive for the Arctic region to invest in infrastructure to position itself as a hub for the bunkering and movement of LNG through its waters. Norway and Iceland have proposed changes to HFO definitions to address concerns about spill risks associated with very low sulfur fuel oil (VLSFO) use in the Arctic, before the IMO's 10th session of the Sub-Committee on Pollution Prevention and Response in 2023, however the committee opted to revisit the issue in 2025.[176]

Full implementation of the Arctic HFO carriage ban is initially limited due to waivers and exemptions[177] that allow continued use and carriage of HFO until July 1, 2029. Canada, Finland and Russia initially opted to postpone the approval of the ban amendments.[178] Russia has not updated its stance. In 2023, Canada backed the ban on HFO and launched an emissions control program to promote cleaner fuel adoption in Arctic waters as a component of its Oceans Protection Plan, in accordance with IMO regulations by 2029.[179] In March 2024, IMO approved the creation of an emissions control area in Canadian Arctic waters, requiring ships to use fuels with <0.1% sulfur and setting limits for NO_x and particulate matter. It is expected to take effect 16 months after receiving final approval, anticipated to occur at the next MEPC meeting in the fall, indicating it would likely enter force around August 2025.[180]

The LNG-fuelled fleet has experienced rapid expansion, with over 90% of its vessels constructed in or after 2010 and more than half (54%) of the IMO numbers in the active fleet being registered in or after 2019. LNG tankers represent the largest fraction of vessels in both the active and ordered LNG-fuelled fleet at 45.5% and 37.5% respectively. Containerships accounted for only 6.4% of the active fleet but 22.9% of the LNG orderbook.[181]

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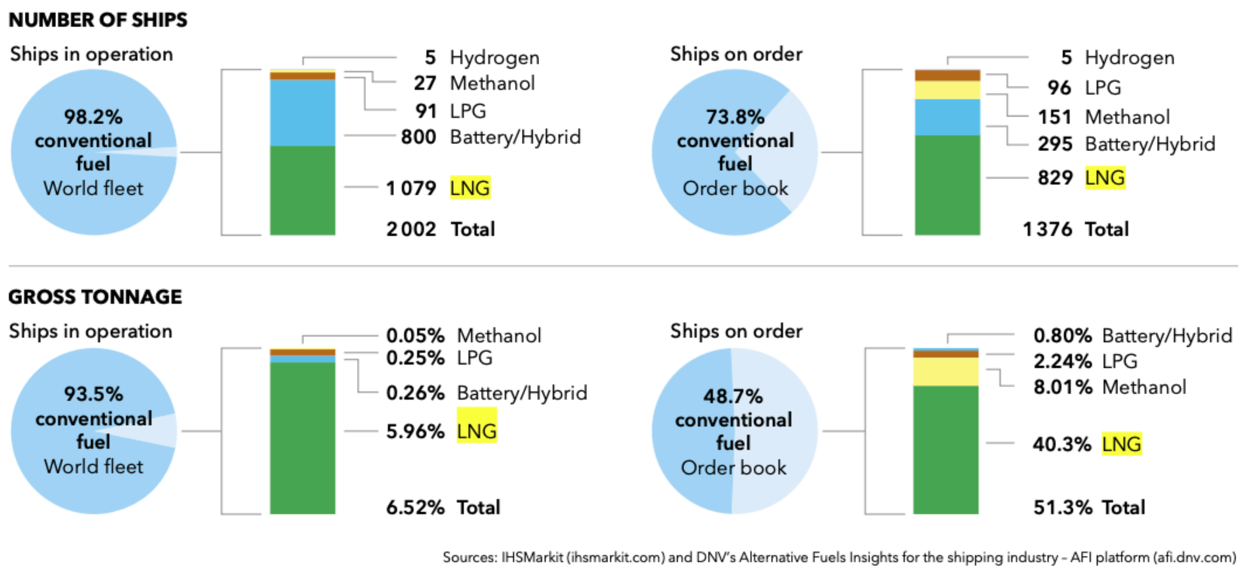
170 https://cleanarctic.org/campaigns/the-arctic-climate-crisis/lng-the-threat-to-the-arctic-from-liquified-natural-gas-as-a-shipping-fuel/
171 https://www.iea.org/reports/net-zero-by-2050
172 https://hdl.handle.net/10986/35437
173 Amendments to MARPOL Annex I, MEPC.329(76) / https://wwwcdn.imo.org/localresources/en/KnowledgeCentre/IndexofIMOResolutions/MEPCDocuments/MEPC.329(76).pdf
174 https://cngva.org/wp-content/uploads/2022/10/2022-Clear-Seas-Investigating-LNG-as-a-Marine-Fuel-for-the-Canadian-Arctic.pdf
175 https://pame.is/document-library/pame-reports-new/pame-ministerial-deliverables/2019-11th-arctic-council-ministerial-meeting-rovaniemi-finland/428-report-on-the-environmental-economic-technical-and-practical-aspects-of-the-use-by-ships-in-the-arctic-of-alternative-fuels/file
176 https://ibia.net/ppr-10-discusses-whether-hfo-ban-will-prevent-vlsfo-spills-in-the-arctic/
177 Three forms of waivers and exemptions listed here: https://safety4sea.com/hfo-ban-in-arctic-waters-effective-from-2024/
178 https://cleanarctic.org/2022/11/17/clean-arctic-alliance-responds-to-russian-opt-out-from-heavy-fuel-oil-ban-raises-concerns-over-canadas-implementation/
179 https://tc.canada.ca/sites/default/files/2024-01/tc-taking-action-envinronment-e-acc.pdf
180 https://www.notllocal.com/national-news/maritime-body-approves-new-environmental-protections-for-shipping-in-canadian-arctic-8497253
181 "Analysis of Liquefied Natural Gas as a Marine Fuel in the United States" forthcoming EERA report for Ocean Conservancy

LNG remained the most prominent alternative maritime fuel choice in 2023, often in dual fuel applications. Of the alternative fuel vessels on the orderbook (Figure 13), non-carrier LNG-fuelled vessels accounted for 38%, with an additional 22% represented by LNG-fuelled LNG-carriers. The gross tonnage of LNG-fuelled vessels, excluding carriers, on the orderbook is more than double that of the existing fleet. Currently there are 45 LNGBVs in operation to serve this fleet, with 11 additional LNGBVs set to be delivered in the next few years.[182]

Figure 13

DNV's alternative fuel uptake in the world fleet in number of ships (top) and gross tonnage (bottom), as of July 2023



Global LNG supply is anticipated to expand to 2026 by ~25%, with increasingly flexible and interconnected markets. North America and Qatar will drive this growth, accounting for 80% of incremental LNG supply from 2023 to 2026, with the U.S. alone contributing to 50% of this worldwide supply. Some market predictions suggest a "third big wave in LNG" in which the gas industry could develop capacities that initially took 60 years to build in only six. While some agencies predict demand could be outpaced as soon as next year, others estimate LNG demand won't peak until 2045.[183,184]

Europe's LNG imports are projected to maintain an average of 165-185 bcm over this period, a minimal decrease compared to 2022.[185] The expansion of global biomethane production is expected to increase over 65% in the same period to 2026.[186] Moreover, the

[182] https://www.dnv.com/maritime/publications/maritime-forecast-2023/index.html
[183] https://www.bloomberg.com/news/features/2024-01-11/natural-gas-boom-to-hit-warming-world-trying-to-quit-fossil-fuels
[184] https://www.woodmac.com/news/opinion/third-wave-us-lng-part-two/
[185] https://iea.blob.core.windows.net/assets/f2cf36a9-fd9b-44e6-8659-c342027ff9ac/Medium-TermGasReport2023-IncludingtheGasMarketReportQ4-2023.pdf
[186] https://iea.blob.core.windows.net/assets/f2cf36a9-fd9b-44e6-8659-c342027ff9ac/Medium-TermGasReport2023-IncludingtheGasMarketReportQ4-2023.pdf

2022 REPowerEU plan has set a target for 35 bcm of biomethane production by 2030 in the EU.[187]

Global biogas and biomethane production grew to more than 1.6 million terajoules in 2022, with the majority generated in Europe.[188] Biogas and biomethane often incur higher production costs than natural gas, but are considered to be more resilient to price volatility, as evidenced by its lower valuation during the gas shortage in Europe and Asia. Over the last two years, there has been increasing policy support for the production of biogas and biomethane worldwide. Although primarily promoted for electricity generation, its growth as a fuel is accelerating, with biomethane utilized by 20% of gas-fuelled vehicles.[189] However, there are challenges to sourcing sustainable feedstocks to develop bio- fuels to scale, particularly as a bunker fuel against competitive use in other sectors.

Bio-LNG and e-LNG can utilize existing LNG infrastructure. In earlier discussion of bunkering infrastructure, renewable LNG was demonstrated to be offered by Arctic nations whenever feasible. Moreover, there is an increasing role of third-party certifications regarding the performance of natural gas production against environmental, social, and governance (ESG) metrics and ambitious targets to reduce the emissions intensity of production operations, particularly limiting flaring and methane emission. The successful management of life cycle LNG emissions, particularly the challenges of methane slip, will influence its long-term market beyond 2026 and inline with decarbonization targets.

Natural Gas and LNG Trade

The movement and trade of natural gas and LNG originating in the Arctic region encapsulates an interplay of infrastructure and geopolitical factors. This relationship is reflected by the network of pipelines, import and export facilities previously discussed. In navigating natural gas trade, it is evident that being a major exporter of natural gas does not necessarily translate into being a prominent LNG exporter due to the presence or absence of liquefaction and export terminals for waterborne transport, which influences the intercontinental trade dynamics.

Natural Gas Trade

This section delves into the intricacies of natural gas trade and its movement across Arctic territories, including but not limited to that of LNG. The primary source of data for Arctic nations comes from the United Nations' Statistics Division[190] (UNSD) reported in terajoules of natural gas, including LNG. Data was provided from 1990 to 2021, with the complete set of trade quantities available in the Appendix (Table A1). Norway is the only primary exporter in the past decade with increasing net exports, while Canada has decreased their export trade while importing greater quantities. Information on Alaska,

[187] https://iea.blob.core.windows.net/assets/96d66a8b-d502-476b-ba94-54ffda84cf72/Renewables_2023.pdf
[188] https://iea.blob.core.windows.net/assets/96d66a8b-d502-476b-ba94-54ffda84cf72/Renewables_2023.pdf
[189] https://iea.blob.core.windows.net/assets/96d66a8b-d502-476b-ba94-54ffda84cf72/Renewables_2023.pdf
[190] https://data.un.org/Data.aspx?q=natural+gas&d=EDATA&f=cmID%3aNG

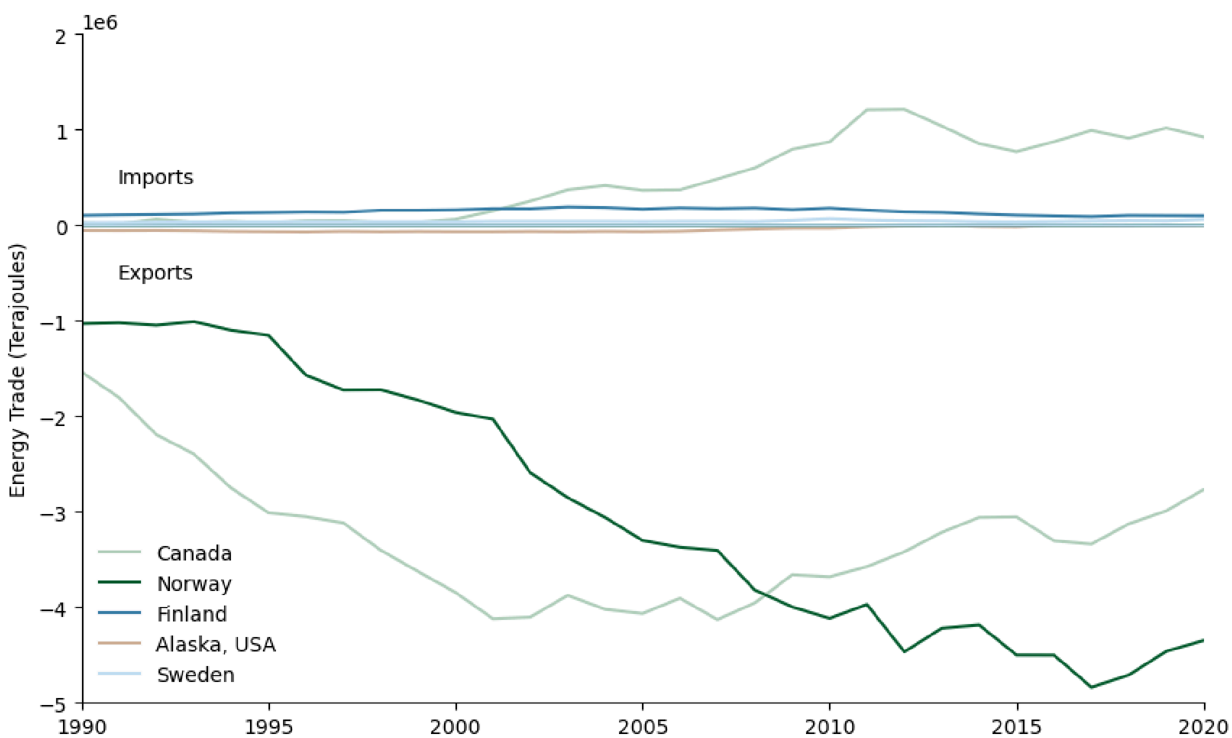
USA was sourced from the U.S. Energy Information Administration[191] (EIA) reported in million cubic feet (MMcf) and converted to terajoules.[192]

Figure 14 shows imports and exports of natural gas, including LNG, by Arctic region. Norway is the only Arctic area with a consistent, positive trendline for exports of natural gas and handled the largest quantities of natural gas trade over this timeline. While most Arctic areas are predominantly either importers or exporters of natural gas, Canada had a smaller disparity in scale between the two. Considering that data includes LNG, with Canada's lack of liquefaction infrastructure it is probable that exports include limited LNG volumes. Explored in the next section, Canadian LNG exports were less than 0.1% of total natural gas export quantities.

Norway is the only primary exporter for Arctic areas in the past decade, with increasing net exports. Canada has decreased their export trade while importing greater quantities. Vastly different quantities of trade are represented for these areas, stemming from the different energy demands and demographic sizes for these nations. Norway and Canada trade dominates over other Arctic areas, which show comparatively low imports and exports. Visualization and data for the Arctic nations are available in the Appendix (Figure A1)

Figure 14

Natural Gas Trade, including LNG, from Arctic nations (TJ)[193]



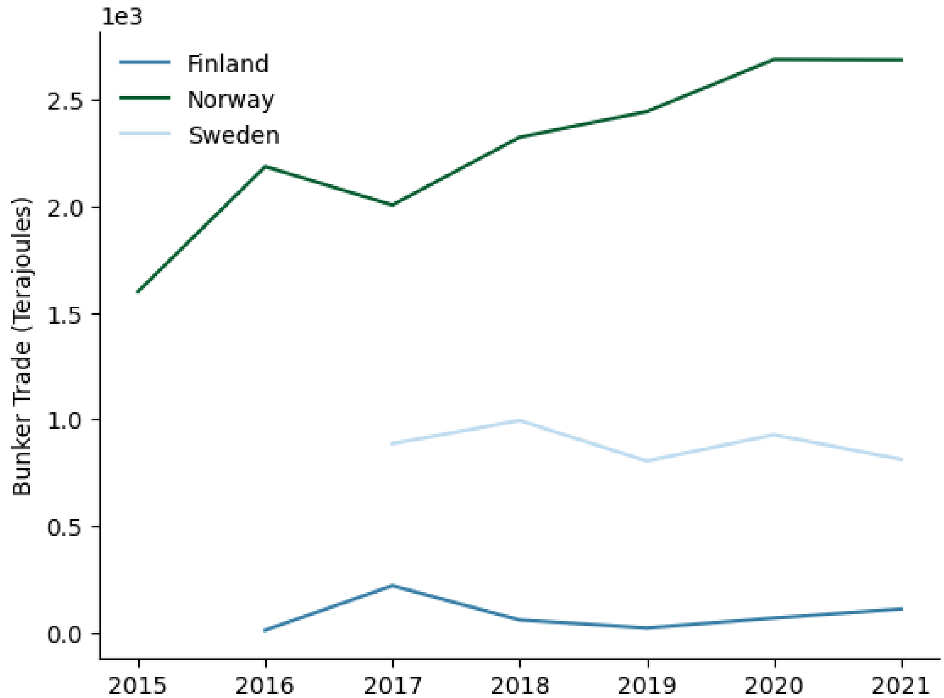
[191] https://www.eia.gov/dnav/ng/ng_move_state_dcu_SAK_a.htm
[192] 1 MMcf = 1.0551 TJ
[193] A scale of 1e6 can be directly interpreted in exajoules (EJ), where 1e6 TJ = 1 EJ

LNG Marine Bunkers

The UNSD dataset includes international marine bunkers in terajoules of LNG, as available. Data was available for Norway, Finland, and Sweden, with varying start dates reported for each nation (Figure 15). Bunkering volumes may occur in other nations of this project scope, but were not available in the UNSD dataset. Norway has shown increasing demand for LNG marine bunkering since 2015, whereas Finland and Sweden have had relatively flat demand since 2016 and 2017, respectively. Additional data are available in the Appendix (Table A2).

Figure 15

International Marine Bunkers of LNG in Arctic Areas (TJ)



LNG Trade

This section discusses the dynamics of LNG trade across Arctic territories, drawing data from the World Integrated Trade Solution[194] (WITS). WITS is a collaborative organization that includes the UNSD, thereby the datasets from each section share a common foundation and the information from each provide a cohesive and comprehensive total perspective of natural gas and LNG trade in the Arctic. WITS data are reported in kilograms, converted to terajoules in this report.[195]

The WITS data include the entire United States and do not differentiate for data from Alaska. Data include natural gas produced in Alaska, but trade does not originate or

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[194] https://wits.worldbank.org/trade/comtrade/en/country/ALL/year/2022/tradeflow/Exports/partner/WLD/product/271111

[195] Conversion of WITS data from kilograms or liters to terajoules based on LNG lower heating values of 49.4 MJ/kg and 21 MJ/L

terminate within Alaska itself due to the current absence of active infrastructure for LNG imports and exports in the region.

The U.S. was one of the top three LNG exporting nations in 2022 and was the largest global LNG exporter in 2023.[196,197] U.S. trade has recently dominated LNG trade from other Arctic nations. In 2012, Norway's total exports were 4.5x larger than the U.S. but by 2022 the U.S. exports were 13x greater than Norway (Table 7).

The WITS data spans two decades of LNG-specific import and export trade (Table 7), though there are temporal and geographic gaps in the WITS dataset. WITS data are limited for Greenland, with sporadic data availability over the time series. The data show Greenland received imports from Denmark in 1997, 2006, 2007, & 2018. Iceland's data are less limited, but with negligible quantities reported for most years; their import data extend across 1995, 2002, 2004, 2008-2022 from a mix of export nations. These quantities are very small compared to other nations, available in the Appendix (Table A3).

Table 7

LNG Trade 1992 vs 2022 (TJ)

	Total Imports (TJ)			Total Exports (TJ)		
	1992	2012	2022	1992	2012	2022
United States	<0	75,107	48,240	51	38,928	1,470,663
Canada	16	19,960	32,537	<0	--	26
Norway	--	22	2,465	--	173,963	110,793
Sweden	<0	936	11,800	<0	25	1,336
Finland	1	--	6,146	--	2	1,736
Iceland	--	<0	<0	--	--	--
Greenland	--	--	--	--	--	--

-- no data <0 indicates negligible value

Sankey Diagrams in Figure 16 show the dynamics of global LNG trade, particularly when comparing the increasing complexity and trading partners between 2012 and 2022. The following diagrams present individual visualizations and their scales are not comparable across figures.

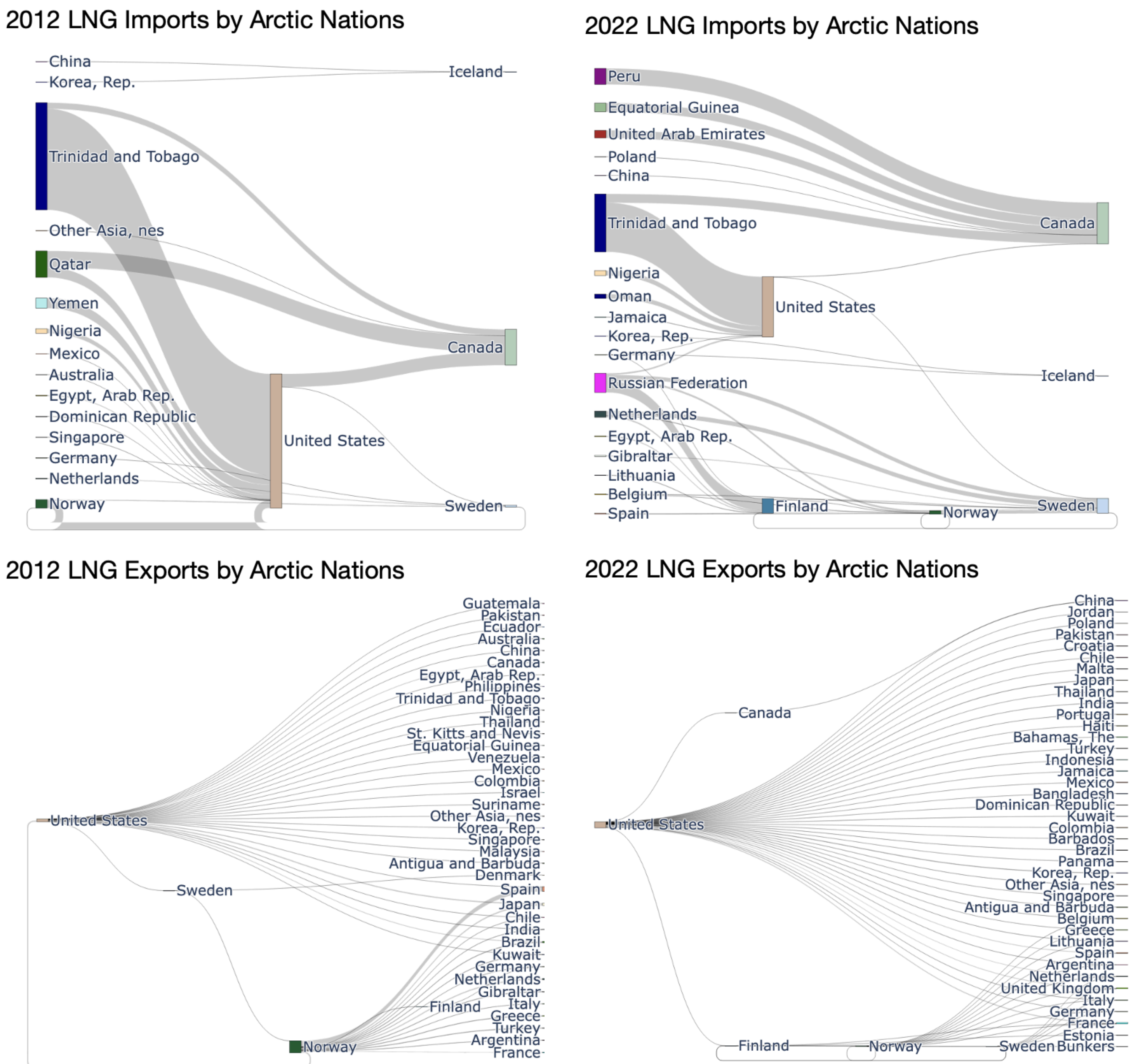
In 2012, Norway dominated the region as an LNG export nation, however by 2022 the U.S. emerged as a globally dominant force. While Qatar is a major trading nation on the worldwide LNG market, the Arctic region did not import from Qatar in 2022. Russia was also absent from import and export trade with Arctic nations in 2012, likely due to Russian government restrictions that did not allow the export of natural gas from companies other than Gazprom until 2013.[198] Although most gas trade in the region from Russia ceased in

[196] https://www.eia.gov/outlooks/steo/report/BTL/2023/07-LNG/article.php
[197] https://www.reuters.com/business/energy/us-was-top-lng-exporter-2023-hit-record-levels-2024-01-02/
[198] On Dec. 1st 2023, a law on LNG export liberalization came into force / https://www.ifri.org/sites/default/files/atoms/files/defifrimitrovalngengdecember2013.pdf

2022 due to Russian energy embargoes, some deliveries remain under long-term contracts held by these Arctic nations.[199]

Figure 16

2022 LNG Trade Origin-Destination Sankey Diagrams[200]



[199] https://www.cedigaz.org/wp-content/uploads/20231114-EU-Russian-gas-contracts-FINAL.pdf

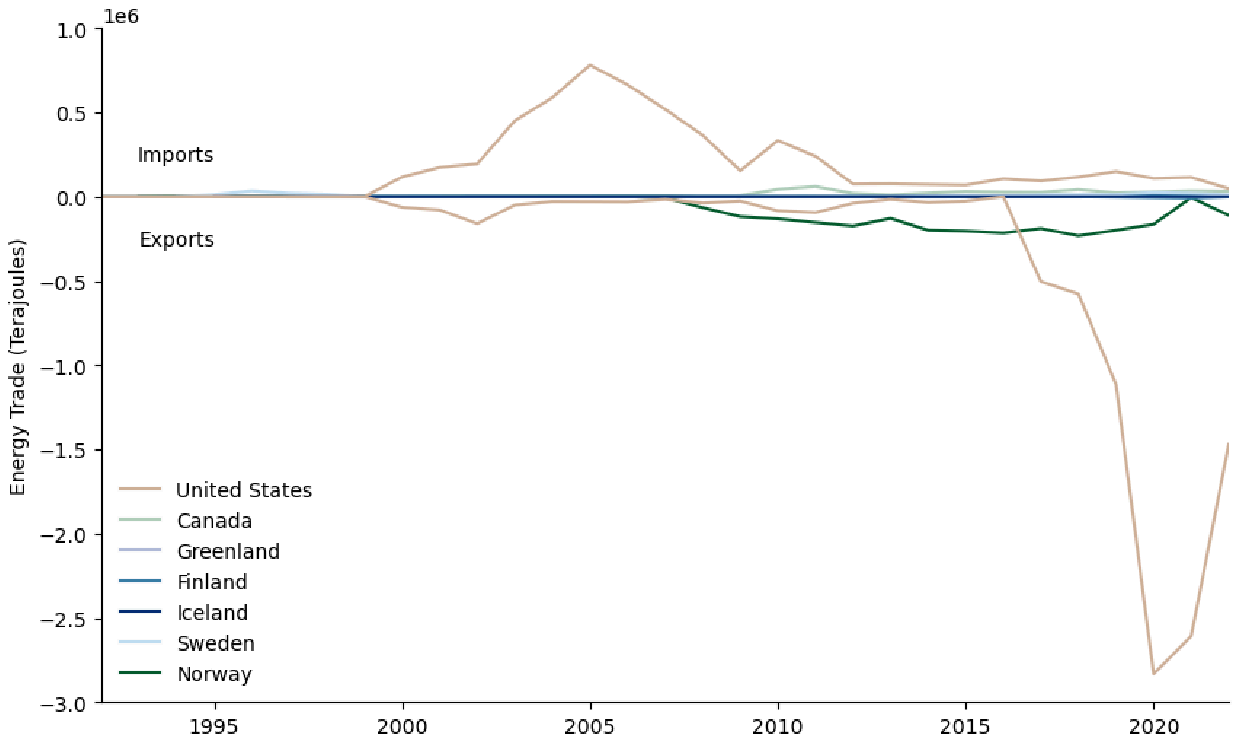
[200] Caution is advised when interpreting the width of the flows between years or trade, as each diagram represents a distinct data set.

The LNG trends show higher volatility than natural gas trading. For most nations, there is no consistent growth over the two decades reported. Apart from the globally significant LNG exporters, like the U.S. and Norway, the Arctic nations are primarily importers of LNG.

Iceland data show two spikes in LNG imports, in 2002 and 2020, while LNG import quantities were otherwise low. These two spikes are related to imports from Sweden, though no indicative national events were found that explain these peaks. Finland's primary partners for LNG export were Norway and Sweden. Finland also imported from these nations the same years, thereby this export movement may be due to excess quantities sold back and/or the movement of Russian gas entering through Finland before reaching its final destination (Figure 16).

Figure 17

Total LNG Trade from Arctic Nations (TJ)[201]



LNG Shipping in the Arctic

Navigating Arctic waters presents unique challenges for maritime vessels, creating greater hazards for crew, cargo, and the ship, necessitating stringent safety measures and specialized vessel designs to mitigate risk. Icebreakers and ice class vessels are constructed to operate in these conditions, designed with reinforced hulls, strengthened propellers, and often a high power output to break through ice. When transporting hazardous fuels, environmental challenges in the Arctic may lead to greater risk of

[201] A scale of 1e6 can be directly interpreted in exajoules (EJ), where 1e6 TJ = 1 EJ

ecological damage in the event of accidents or spills in the remote and sensitive environment. The IMO's International Code for Ships Operating in Polar Waters (or Polar Code) covers the range of vessel design and construction matters, and operational and safety measures for ships operating in the waters of the poles.[202]

As global demand for LNG grows alongside diminishing ice coverage, LNG carriers and tankers may capitalize on the potential for shorter distances and cost-savings by navigating open passages in the Arctic. Those vessels will be required to adopt specialized designs and technology in line with the Polar Code to navigate these waters safely and minimize the risk of fuel spills.

LNG spills on water do not inflict direct ecological harm to the waterways and its life. Instead, LNG vaporizes upon contact, forming a vapor cloud that is at risk of ignition in the presence of an ignition source. In the absence of a spark, LNG dissipates, releasing substantial quantities of methane and exacerbating climate warming, and thereby, harming the ecosystem through indirect pathways.

This section identifies and analyzes the fleet of vessels that are capable of LNG operations in the Arctic. These vessels fall under the following categories:

- LNG carriers flagged in the study area countries (including boil off gas)
- LNG carriers identified as built to ice class[203] specifications
- Ice Class LNG vessels flagged in the study area countries
- LNG vessels flagged in the study area countries

In practice, while there may be Ice Class vessels operating LNG in southern waters, the majority of ice-class LNG vessels will be designed to service northern regions, due to the density of populations and oil and gas activity. LNG-fuelled and/or carrying vessels were identified for home-ported, flagged, or ice/polar class vessels in IHS-Seaweb.[204] Vessel characteristics are presented, including trends in size, gas capacity, ice class, and year of build. Analysis of the orderbook presents Polar capabilities and identifies current trends and developments.

Active Arctic-Capable LNG Fleet

IHS-Seaweb yielded 277 vessels in the Arctic-capable LNG fleet, with 222 active/in service vessels (80% of the active fleet + orderbook). This section provides an examination of active, operational vessels, including trends in vessel size and operating capacity. Vessels on the orderbook (e.g. keel laid, under construction) are discussed in the next section.

Vessels with LNG listed as the primary fuel and method of propulsion were analyzed. No queried vessels in our Arctic-capable scope were identified as having LNG as a secondary

[202] https://www.imo.org/en/ourwork/safety/pages/polar-code.aspx
[203] Polar Ice Class, FS Ice Class, Super, Ice Strengthened, Ice Breaking
[204] https://maritime.ihs.com/Areas/Seaweb

fuel, and a minimal number were found to list a secondary fuel alongside LNG. One vessel, registered in Finland, listed liquefied biogas as a secondary fuel to LNG. Eight vessels flagged on the Norwegian International Ship Register (NIS), listed liquefied volatile organic compounds[205] (LVOC) as a secondary fuel to LNG, each identified as shuttle tankers, classified under the broader categorization of oil and gas (O&G) vessels.

Trends in Vessel Size and Capacity

Deadweight tonnage (DWT), gas capacity (if applicable), and main engine power are compared over time and across different ship types. There are 222 active vessels, distributed across ten ship categories (Table 8).

Table 8

Ship Categorization of the Arctic-capable LNG Fleet

February 2024	Built	Orderbook	Total
Cargo ship	9	0	9
Chemical/Products tanker	20	20	40
Containers ship	10	3	13
Fishing	7	2	9
LNG Tanker	62	1	63
LNGBV	1	3	4
O&G Vessel	43	4	47
RoPax/Passenger	46	0	46
RoRo	12	20	32
Service	12	2	14

1. **Cargo ship:** merchant vessels that transport a variety of goods
2. **Chemical/Products tanker:** tanker ships transporting non-fuel goods in bulk (e.g. asphalt, fertilizer, etc.)
3. **Container ship:** merchant vessels designed to transport goods in intermodal twenty-foot equivalent containers
4. **Fishing:** commercial vessels involved in the catch and/or transport of fish and seafood
5. **LNG tanker:** tanker ships transporting liquefied natural gas in cryogenic storage
6. **LNGBV:** smaller tanker ships designed and equipped to provide bunkering services, including the transport and transfer of LNG to refuel other vessels
7. **O&G vessel:** vessels involved in various oil and gas industry operations, including CO_2 tankers, well stimulation and gas processing vessels, platform supply ships, and more.
8. **RoPax/Passenger:** Roll-on/Roll-off passenger (RoPax) and other passenger vessels, including ferries and cruises
9. **RoRo:** Roll-on/Roll-off (RoRo) merchant vessels designed to transport wheeled cargo
10. **Service:** vessels whose principal function is to provide a support or service to another vessel (e.g. tug/tow, patrol, icebreakers[206], etc.)

[205] New technology allows released crude oil vapors, also known as volatile organic compounds, to be recovered and consumed as a supplementary fuel for O&G tankers / https://www.wartsila.com/docs/default-source/product-files/ogi/recovery/brochure-o-ogi-recovery-voc-system.pdf
[206] Special-purpose service vessel designed to move and navigate through ice-covered waters ahead of another vessel (typically non-ice class) to provide safeway for those other vessels

The average deadweight of active ships is about 34,530 DWT, with the highest recorded at 129,734 tons (Table 9), held by Norwegian shuttle tanker *Rainbow Spirit*. LNG tanker *Christophe De Margerie*, flagged in Panama, records the highest total power output of the main engine at 64,350 kilowatts (kW), about 360% of the average output of approximately 17,100 kW. The only vessel types that have a gas capacity greater than zero are LNG tankers, LNGBVs, and O&G vessels. The average gas capacity of vessels with a capacity greater than zero is 146,102 m^3, with Norwegian LNG tanker *Trainano Knutsen* recording the highest gas capacity of 176,381 m^3.

Table 9

Main engine output, gas capacity, & deadweight summary statistics for active vessels[207]

Ship Type	Deadweight Mean	Deadweight Median	Deadweight Max	Gas Capacity Mean (m^3)	Gas Capacity Median (m^3)	Gas Capacity Max (m^3)	Total Engine Output Mean (kW)	Total Engine Output Median (kW)	Total Engine Output Max (kW)
Cargo ship	8,685	3,850	25,532	--	--	--	3,366	2,430	6,000
Chemical/Products tanker	15,631	17,671	22,554	--	--	--	4,817	4,500	6,300
Container ship	39,831	43,448	51,737	--	--	--	29,186	28,080	42,700
Fishing	5,410	5,898	8,650	--	--	--	5,178	5,500	7,560
LNG tanker	83,069	91,554	96,958	147,754	167,156	176,381	37,524	34,280	64,350
LNGBV	3,077	3,077	3,077	5,781	5,781	5,781	3,000	3,000	3,000
O&G vessel	33,886	5,500	129,734	158,724	167,042	167,042	11,540	8,040	39,900
RoPax/Passenger	1,507	1,025	6,107	--	--	--	10,044	7,778	46,800
RoRo	11,396	5,375	27,000	--	--	--	16,438	9,270	52,200
Service	1,846	1,784	5,307	--	--	--	6,731	5,000	21,000

LNG tankers account for 27.9% of the active fleet. O&G vessels account for 21.2% and RoPax/Passenger vessels account for 20.7% of the LNG Arctic fleet. RoRo (5.4%), container ships (4.5%), and cargo ships (4.1%) collectively constitute a smaller portion of the active LNG Arctic fleet. However, RoRo vessels have a notable uptick on the orderbook, indicating potential growth of Arctic shipping in the near future (Figure 18).

The IHS-Seaweb queries returned fewer LNGBVs than identified in our earlier examination of bunkering locations in the Arctic, as the earlier examination included non-Arctic flagged vessels that were found to service Arctic region ports. Only one LNGBV is flagged in an Arctic nation, the Swedish-flagged LNGBV *Coralius*. Additional LNGBVs on the orderbook are anticipated to enter service in 2024.

[207] These statistics only take into account vessels that have non-zero values in each respective category, which may cause small n issues. For example, there are only three active O&G vessels with non-zero gas capacity information and two of these vessels have the same gas capacity. This results in the median and maximum gas capacity values being equivalent.

Figure 18

Arctic-capable LNG Vessels by Ship Type from 1980-2030

277 total LNG-Fuelled Vessels by 2028

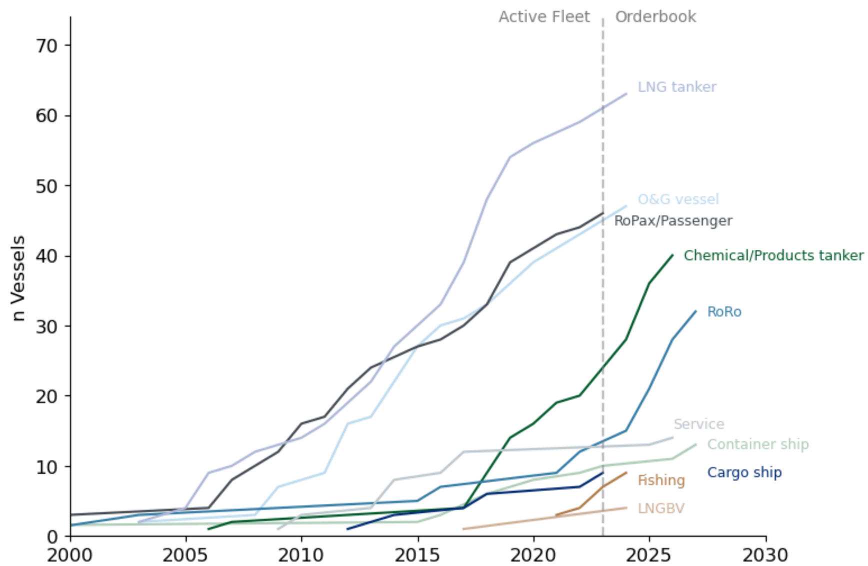


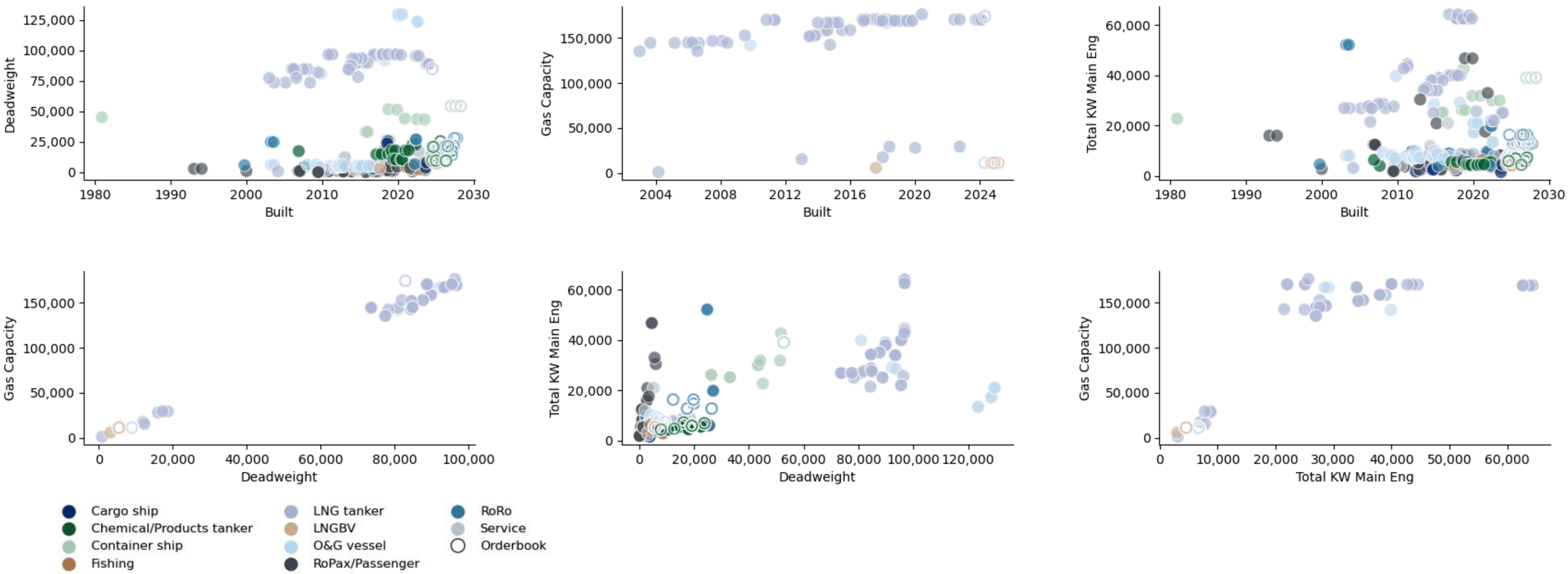
Figure 19 shows the relationships between deadweight tonnage, gas capacity, main engine size in kW, and the year of build for Arctic fleet LNG vessels. Trends in deadweight and gas capacity (for LNGBVs and LNG Tankers only) show a general trend toward increasing size over time, consistent with similar trends observed in other sectors of the maritime industry. As shown in the left-most panels of Figure 19, there is a bifurcation in the LNGBV and LNG tanker fleets, with a group of larger, more powerful, and higher capacity vessels and another group of smaller, lower-powered vessels. The larger vessels likely correspond to those serving primary transit routes between major import and export hubs, while the smaller vessels are feeders servicing smaller gas volumes at smaller terminals and individual vessels. The relationship between gas capacity and deadweight is linear, regardless of vessel size.

Excluding LNGBVs and LNG tankers, most vessels in the fleet studied are less than 60,000 DWT. Container ships range from 26,300 DWT to 51,700 DWT, but otherwise all other vessel types are smaller than 27,000 DWT. Service vessels, chemical/products tankers, fishing vessels, cargo ships, and LNGBVs are consistently both small (<15,000 DWT) and low powered, generally less than 12,000 kW installed. RoPax ferry power scales linearly with deadweight, up to 50,000 kW, with a general trend towards more powerful vessels in recent years.

Service vessels, RoRo, container, and LNG tankers have all generally gotten more powerful over time, though RoPax and LNG tankers do show some stratification indicating size and power are being tailored to specific routes or vessel applications in those sectors.

Figure 19

Deadweight, gas capacity, main engine size, and year of build of the Arctic-capable LNG Fleet[208]



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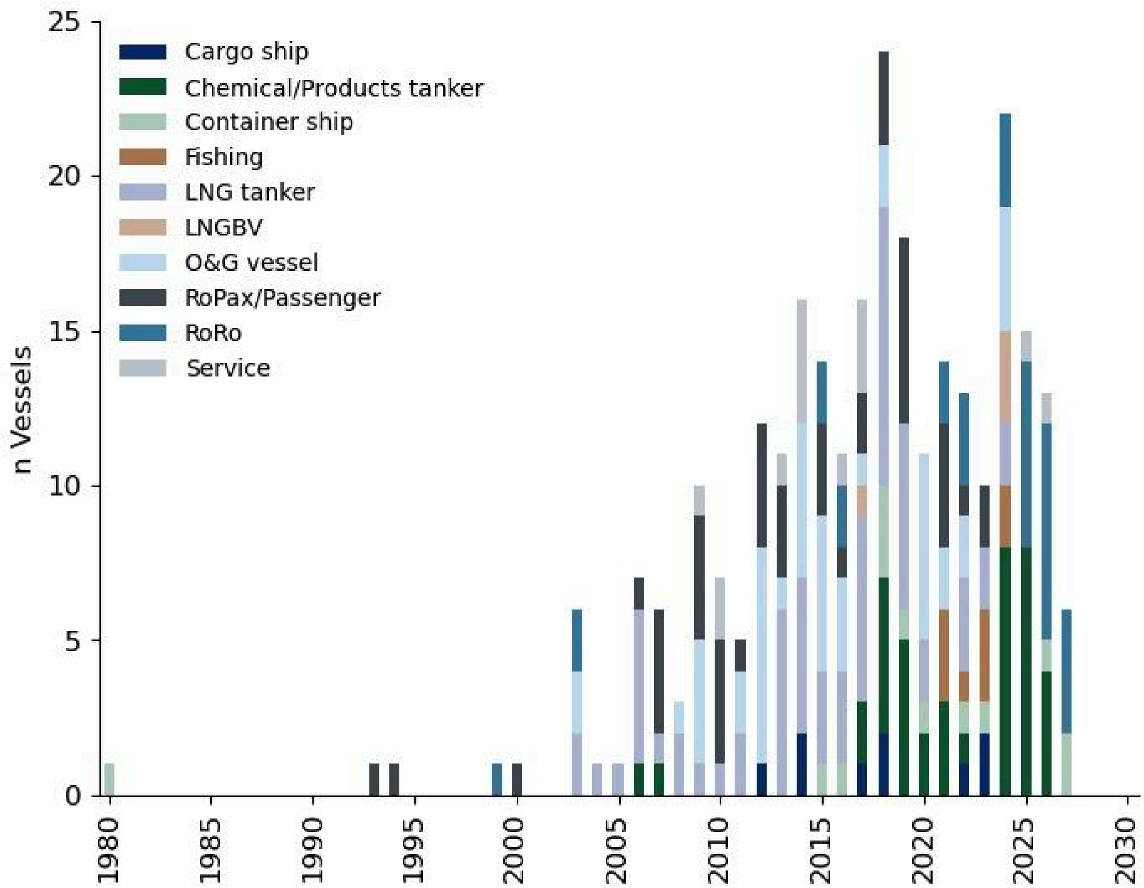
208 The solid circles represent active vessels and the open circles represent vessels on the orderbook.

Few fishing vessels are LNG-fuelled at present, with 12 LNG-fuelled fishing vessels globally, 10 of which are flagged in Norway or NIS. Fisheries are important economic and social activities in the Arctic and sub-Arctic region, which host some of the world's largest fish stocks and fisheries along their boundaries.[209,210,211]

Figure 20 illustrates the growth of the Arctic-capable LNG fleet by build year, denoting when each vessel became active. It reveals that the fleet has not seen more than 24 vessels enter service in any single build year thus far. Besides observing market trends and demand, the build year can provide information about the technological standards and efficiencies of the fleet. The oldest active vessel is a containership built in 1980, whereas the newest addition to the Arctic-capable LNG fleet is a LNG Tanker built at the start of 2024. The average vessel in the active fleet was built in 2016 (Table 10).

Figure 20

Arctic-capable LNG Fleet by Build Year & Ship Type from 1980-2030



[209] https://www.thearcticinstitute.org/climate-change-factor-impacting-current-future-commercial-fisheries-arctic-region/
[210] https://arcticportal.org/fishing-portlet/arctic-fisheries
[211] https://www.fisheries.noaa.gov/insight/changing-arctic

Table 10

Additions to the Arctic-capable LNG Fleet by Build Year & Ship Type from 1980-2030

Ship Type (active)	mean	min	med	max
Cargo ship	2018	2012	2018	2023
Chemical/Products tanker	2018	2006	2019	2022
Container ship	2015	1980	2018	2023
Fishing	2022	2021	2022	2023
LNG tanker	2015	2003	2016	2024
LNGBV	2017	2017	2017	2017
O&G vessel	2014	2003	2014	2022
RoPax/Passenger	2013	1993	2013	2023
RoRo	2015	1999	2016	2022
Service	2014	2009	2014	2017

Norway is ranked as the world's 4th largest merchant fleet, by value.[212] Norway has two ship registers, national and NIS. The NIS was created to compete with flag of convenience registers.[213] The NIS is open to owners of all nationalities, but has trade restrictions for Norwegian ports and along the Norwegian continental shelf.[214] As observed in Figure 21, Norway dominates the operational Arctic-capable LNG fleet through both its national and NIS registry.

Figure 21

Active Arctic-capable LNG fleet by flag nation

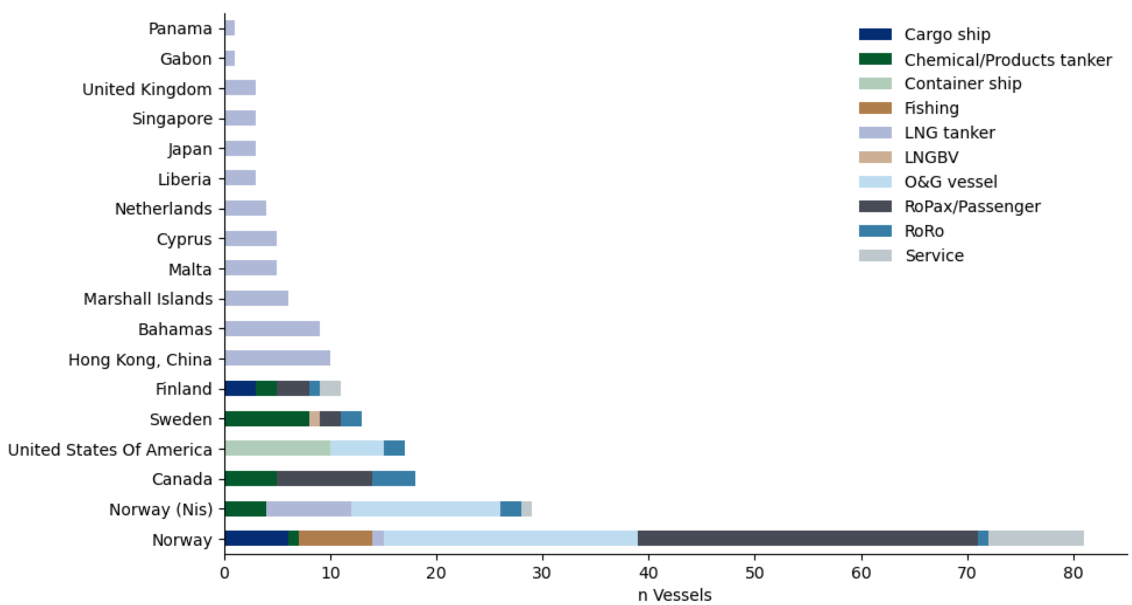


Figure 21 includes all LNG-fuelled vessels flagged in Arctic nations plus ice class LNG vessels from other flags. Flag nations' LNG fleets navigating Arctic waterways have grown at vastly different rates. As an early adopter of LNG-fuelled vessels, Norway's fleet has

[212] https://www.trade.gov/country-commercial-guides/norway-shipping-maritime-equipment-services
[213] The practice wherein a shipowner registers a vessel in a country different from their own, typically in a jurisdiction known for its lenient regulations, lower taxes, and reduced operational costs (e.g. Panama, Malta, Marshall Islands, and more).
[214] https://www.sdir.no/en/shipping/registration-of-commercial-vessels-in-nisnor/what-distinguishes-nis-from-nor/

experienced rapid growth over the years, whereas other nations have experienced slower growth. Faster growth for these flags is observed after 2015 (Figure 22).

Ice Class Vessels

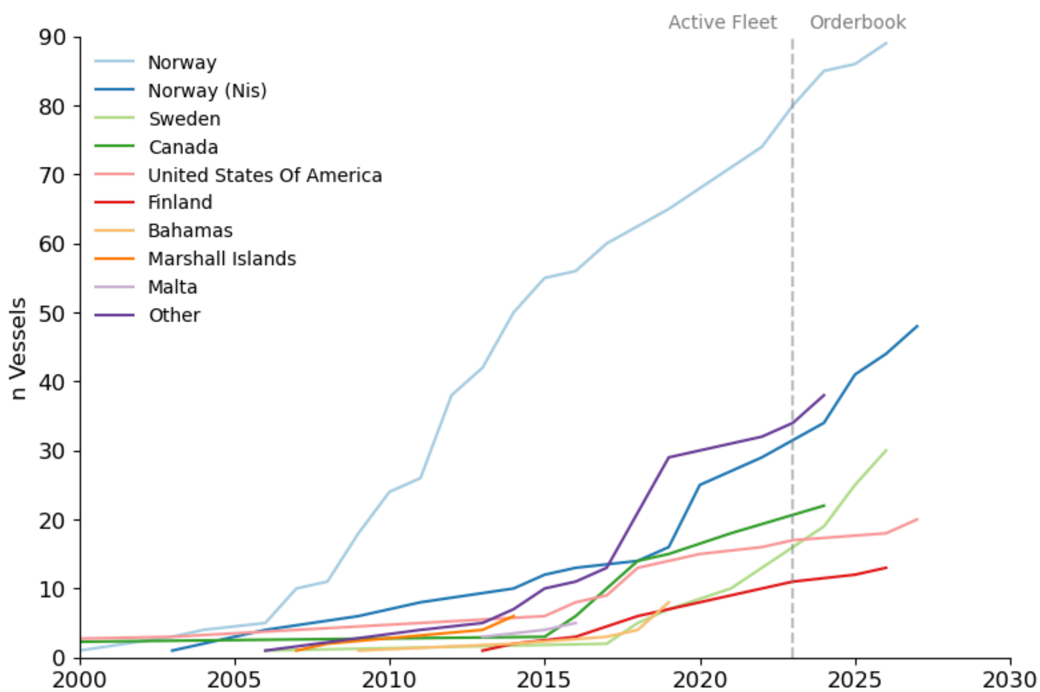
Ice class vessels are classified by their design characteristics and ice navigation capabilities through either the International Association of Classification Societies' Polar Class (PC) system,[215] complementing IMO guidelines,[216] or the Finish-Swedish (FS) Ice Class system[217] which regulates traffic in the Baltic Sea during winter months (Table 11).

Vessels can be assigned one of seven Polar Class numbers (PC 1-7) denoting the seasonal capabilities of its build, for which 1 indicates capable of year-round operation in all Arctic ice conditions and 7 is capable of summer and early fall operation only. Vessels may also or instead receive a FS ranking issued by the Swedish Maritime Administration and the Finnish Transport and Communications Agency. The highest ranked FS classification, 1A Super (IA*), is equivalent to the lowest two Polar Class ranks, PC 6 & 7. The notation "icebreaker" for a vessel can be assigned to any vessel ranking between PC 1-6.[218]

Figure 22

Growth of Arctic-capable LNG Fleet by Flag Nation from 1980-2030

277 LNG-Fuelled Vessels by 2028



[215]https://webcitation.org/query?url=http%3A%2F%2Fwww.iacs.org.uk%2Fdocument%2Fpublic%2FPublications%2FUnified_requirements%2FPDF%2FUR_I_pdf410.pdf&date=2012-09-11

[216] https://www.gc.noaa.gov/documents/gcil_1056-MEPC-Circ399.pdf

[217] https://www.sjofartsverket.se/globalassets/isbrytning/pdf-regelverk/finnish-swedish_iceclass_rules.pdf

[218] http://www.arctis-search.com/Technical+Requirements+for+Ships+Operating+in+the+Arctic

Table 11

Summary of Ice Class Vessel Classification Systems

		Polar Class		Baltic FS
PC1	Year-round	All Polar waters	**ICE 1A Super / IA***	1.0m first-year ice
PC2	Year-round	Moderate multi-year ice	**ICE 1A / IA**	0.8m first-year ice
PC3	Year-round	Second-year ice#	**ICE 1B / IB**	0.6m first-year ice
PC4	Year-round	Thick first-year ice#	**ICE 1C / IB**	0.4m first-year ice
PC5	Year-round	Medium first-year ice#	**ICE 2 / ICE II**	Steel-hulled, no ice strengthening
PC6	Summer/autumn	Medium first-year ice#	**ICE 3 / ICE III**	No class characteristics, wooden
PC7	Summer/autumn	Thin first-year ice#		

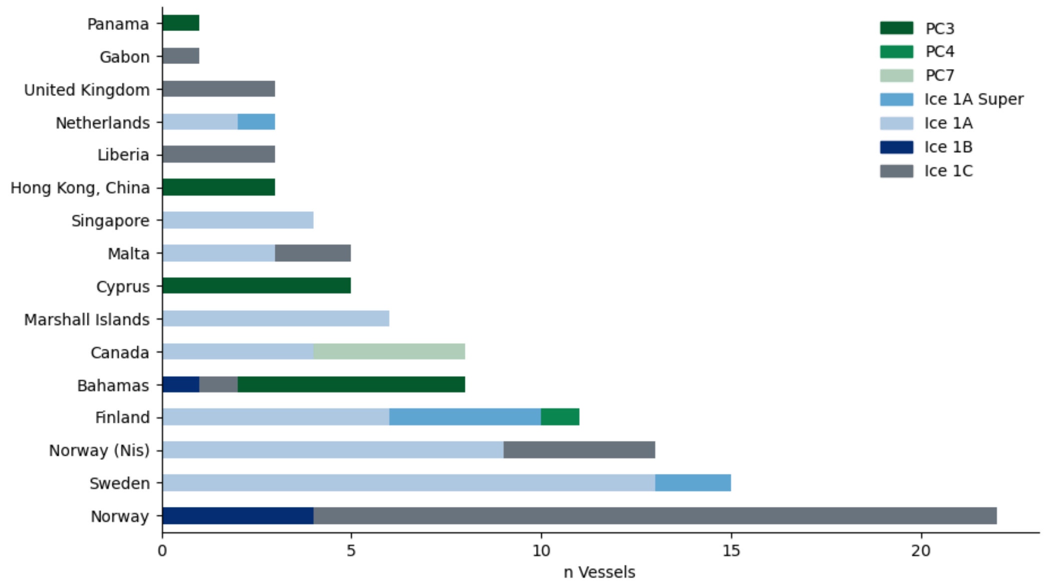
which may include multi-year inclusions

Ice-class vessels are registered to Arctic nations or sailing under other flags. The most numerous ice class group in this dataset, PC3, was flagged in Panama, Cyprus, Bahamas, and China. Of the Arctic nations, Norway boasts the largest ice class fleet with 22 vessels, followed by Sweden with 15, Finland with 11, and Canada with 8. Despite the considerable size of Norway's fleet, its vessels are classified as 1B or 1C, whereas all of Sweden's ice-class fleet holds 1A or 1A* classifications. All ice-class vessels in Finland and Canada's fleets are ranked 1A* or higher (Figure 23).

Figure 23

Active & Orderbook Ice Class LNG Vessels by Flag Nation

Legend ordered from most to least ice capable



LNG Fleet on the Orderbook

There are 55 vessels on the orderbook that fall into eight vessel categories: Chemical/Products tanker, Container ship, Fishing, LNG tanker, LNGBV, O&G vessel, RoRo, and Service. There are no RoPax/Passenger or cargo ship vessels on the orderbook. A summary of the orderbook can be observed in Figure 24 and among Table 12 below.

The majority (93%) of vessels in the orderbook have estimated deadweight information available. The average deadweight of these vessels is 18,743 tons, which is nearly half the average capacity of active vessels. *North Wind*, flagged in Singapore, is the largest vessel on the orderbook with a deadweight of 82,000 tons. The vessel *PHILLY 040*, which will be flagged in the US, has the highest total power output of the main engine in the orderbook, standing at 37,740 kW. The main engine output of *PHILLY 040* is approximately 380% of the orderbook average. *North Wind*, the largest vessel in the orderbook by deadweight, also claims the largest gas capacity, estimated at 170,520 m^3. Among the vessels in the orderbook with gas capacity information, only six others are listed, all having a capacity of around 7,500 m^3.

Figure 24

Orderbook Additions by Ship Type

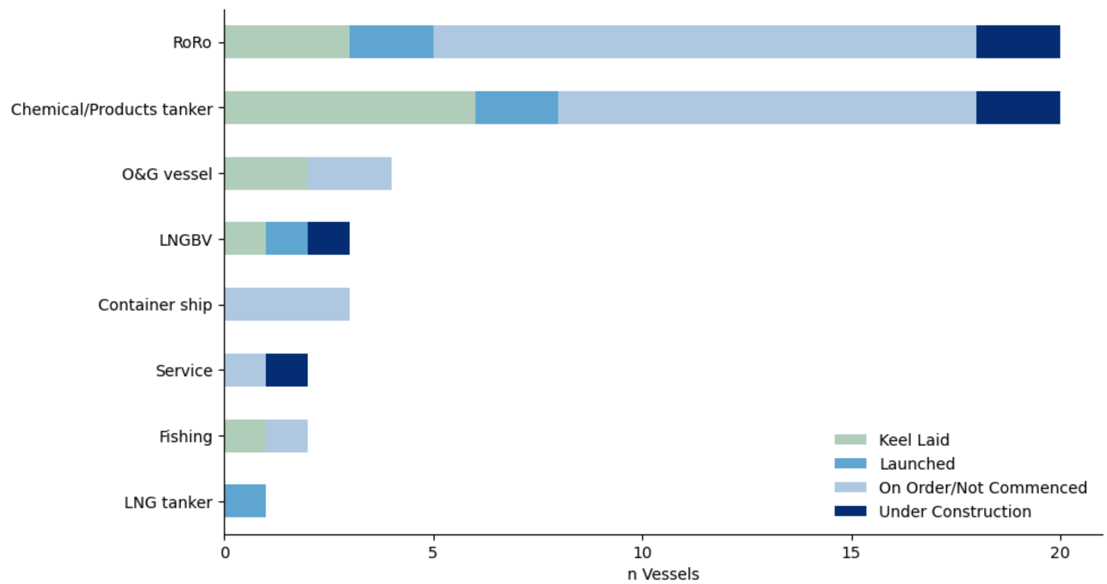


Table 12

Main engine output, gas capacity, and deadweight summary statistics for orderbook

Ship Type	Deadweight Mean	Deadweight Median	Deadweight Max	Gas Capacity Mean (m^3)	Gas Capacity Median (m^3)	Gas Capacity Max (m^3)	Total Engine Output Mean (kW)	Total Engine Output Median (kW)	Total Engine Output Max (kW)
Chemical/Products tanker	15,575	17,999	22,554	--	--	--	4,619	4,500	5,850
Container ship	51,500	51,500	51,500	--	--	--	37,740	37,740	37,740
Fishing				--	--	--	2,880	2,880	2,880
LNG tanker	82,000	82,000	82,000	170,520	170,520	170,520	--	--	--
LNGBV	4,500	4,500	4,500	7,448	7,448	7,448	3,960	3,960	3,960
O&G vessel	7,375	8,000	8,000	7,500	7,500	7,500	6,498	6,090	7,720
RoRo	18,245	17,425	25,200	--	--	--	12,452	11,340	14,940
Service	--	--	--	--	--	--	12,000	12,000	12,000

Conclusion

With Arctic maritime activity anticipated to increase amidst diminishing sea ice coverage, the impending ban on HFO in Arctic waters presents an opportunity to transition towards cleaner alternative fuels. The global LNG market has experienced significant growth over the last two decades, including growth as a marine fuel. LNG is bunkered, consumed, and transported by over 930 vessels globally, including those on order. Currently the LNG-fueled fleet exceeds that of other alternative fuels in both the active worldwide fleet and on the orderbook.

LNG has a lower carbon content than conventional marine bunkers, and so LNG combustion emits less CO_2. Accordingly, LNG has been marketed as a low emissions fuel when only considering combustion emissions. However, life cycle analysis has demonstrated significant GHG emissions associated with LNG throughout the supply chain, and during on-board storage and combustion, which offset lower combustion emissions. Furthermore, methane's attention in maritime policy is recent, particularly when evaluating a fuel's WtW life cycle emissions and global warming potentials. This has highlighted the radiative forcing of an LNG transition.

LNG operations can leak methane throughout each activity, including offshore extraction, bunkering, storage, and transportation, exacerbating climate warming. Concerns have been raised about the potential risks associated with LNG fuel, particularly when traversing the sensitive Arctic region, which may experience amplified effects (e.g. feedback loop of permafrost thaw). This can include but is not limited to further recession of sea ice coverage, intensified storms, and thaw of permafrost, and have far-reaching consequences beyond the Arctic.

LNG Bunkering in the Arctic is currently mainly limited to the Scandinavian nations, with limited LNG bunkering in Canada. Ship-to-ship bunkering is the most commonly available form of LNG bunkering, enabling flexible delivery of LNG to vessels where they need it. Overall, LNG bunkering in the Arctic has grown from a handful in 2010 to around 33 operational and proposed facilities.

Finland and Sweden committed larger investments in LNG bunkering than other Arctic nations studied, excluding Norway. These nations appear to have more hesitant approaches to expanding natural gas trade in their energy mixes, but have been supportive of its advantages as an alternative maritime fuel.

Nations economically benefiting from substantial global exports and/or reserves of natural gas, including the United States, Canada, and Norway, have shown greater reluctance to transition away from it. These nations continue to propose additions to LNG bunkering, trade, and fleets. While these nations seek to reduce sector emissions and align with climate pledges, agreements, and international frameworks, their investments in natural gas present a challenge to transition away from it.

Natural gas extraction, processing, and LNG trade in the Arctic nations studied has grown significantly. There are seven active LNG import terminals and seven active LNG export terminals in the region. Three more import and 11 export terminals are proposed. Pipelines connect much of the oil and gas extraction infrastructure in the region, with dense networks of pipelines in sub-Arctic Canada and the North Sea.

Expansion and growth of oil and gas infrastructure has led to large volumes of LNG trade in the region. Globally, record LNG volumes were traded in 2022, and while much of that trade was via pipeline, growth in LNG carriers and tankers facilitated increased maritime trade. Over 90% of the global LNG-fuelled fleet was constructed after 2010, and more than half of vessels are around 4 years old or younger.

Norway and Canada are the largest net exporters of natural gas among the countries studied (not including U.S. trade outside of Alaska). Canada is also a major natural gas importer. LNG trade networks are complex, but in the study region imports are dominated by trade from Trinidad and Tobago, Qatar, the U.S., Norway and Canada. Exports are dominated by trade from the U.S. (including the continental U.S.), followed by Norway.

On the vessel side, while initial growth of the Arctic-capable fleet was dominated by LNG tankers, oil and gas vessels, and RoPax vessels, recent years have also seen growth in other shipping sectors, including chemical tankers, RoRos, service vessels, and container ships. Norway has the largest fleet of register for Ice Class LNG vessels in the region (including the state register and NIS), followed by Sweden and Finland. Norway also has 8 LNG-fueled fishing vessels, with two on order. The orderbook shows around 55 Arctic-capable LNG vessels, mostly RoRos (20 vessels), and chemical/products tankers (20 vessels).

The Arctic is a sensitive region, rich in natural resources, including oil and gas. Continued economic and regulatory commitments to natural gas development by Arctic nations will likely further spur development of infrastructure and maritime activity. Furthermore, life cycle analyses indicate that ongoing reliance on natural gas is unlikely to align with domestic or international climate targets. Political intervention to enhance regulation on methane emissions, but also to support the research and development of near-zero and zero-GHG fuels, is imperative to protect Arctic ecosystems and align with climate timelines set for 2030 and 2050.

Appendix

Table A1

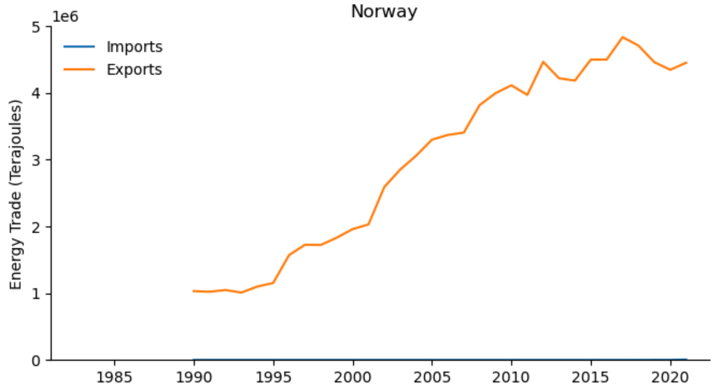
Natural Gas Trade (including LNG) by Arctic Areas (TJ)

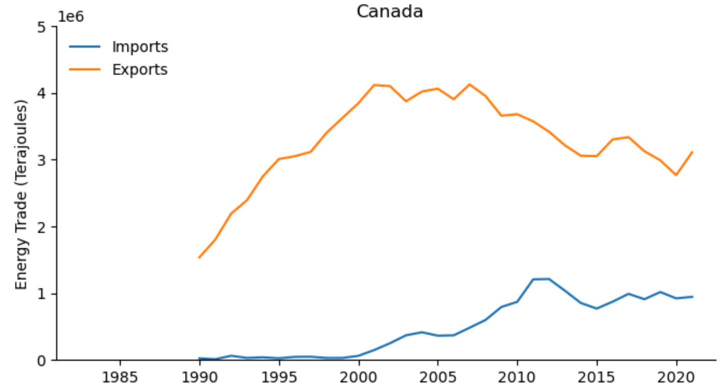
	Alaska, USA		Canada		Finland		Norway		Sweden	
Date	Imports	Exports	Imports	Exports	Imports	Exports	Imports	Exports	Imports	Exports
1990	--	55,441.0	24,220.0	1,537,221.0	101,546.0	--	--	1,031,422.0	26,840.0	--
1991	--	56,981.0	12,070.0	1,804,035.0	107,331.0	--	--	1,022,434.0	28,675.0	--
1992	--	55,427.0	62,838.0	2,193,148.0	111,241.0	--	--	1,047,700.0	32,366.0	--
1993	--	59,074.0	30,895.0	2,395,257.0	115,511.0	--	--	1,009,981.0	35,323.0	--
1994	--	66,136.0	40,031.0	2,752,595.0	127,720.0	--	--	1,099,747.0	35,067.0	--
1995	--	68,880.0	25,670.0	3,011,066.0	132,093.0	--	--	1,153,541.0	35,102.0	--
1996	--	71,375.0	46,389.0	3,052,458.0	138,037.0	--	--	1,571,375.0	37,613.0	--
1997	--	65,614.0	48,394.0	3,118,037.0	135,221.0	--	--	1,725,755.0	37,155.0	--
1998	--	69,585.0	30,226.0	3,403,358.0	155,171.0	--	--	1,723,495.0	36,826.0	--
1999	--	67,112.0	30,658.0	3,626,971.0	155,283.0	--	--	1,832,004.0	36,905.0	--
2000	--	69,225.0	61,823.0	3,846,343.0	159,584.0	--	--	1,960,233.0	36,092.0	--
2001	--	69,376.0	148,953.0	4,120,413.0	172,861.0	--	--	2,031,451.0	40,720.0	--
2002	--	66,934.0	251,548.0	4,103,366.0	171,783.0	--	--	2,592,486.0	41,439.0	--
2003	--	69,318.0	369,794.0	3,876,239.0	190,461.0	--	--	2,853,413.0	41,322.0	--
2004	--	65,521.0	414,979.0	4,022,042.0	184,222.0	--	--	3,061,008.0	41,142.0	--
2005	--	68,712.0	364,396.0	4,065,940.0	167,783.0	--	--	3,301,480.0	39,199.0	--
2006	--	64,113.0	369,343.0	3,906,419.0	180,742.0	--	--	3,372,193.0	41,024.0	--
2007	--	51,063.0	482,801.0	4,129,114.0	173,583.0	--	--	3,406,124.0	42,358.0	--
2008	--	41,322.0	599,227.0	3,956,242.0	179,672.0	--	--	3,819,976.0	38,450.0	--
2009	--	32,219.0	793,925.0	3,660,092.0	162,064.0	--	--	3,997,352.0	50,684.0	--
2010	--	31,759.0	871,342.0	3,682,104.0	178,502.0	--	237.0	4,116,121.0	68,195.0	--
2011	--	17,302.0	1,208,000.0	3,575,422.0	156,304.0	--	54.0	3,972,086.0	53,900.0	--
2012	--	9,857.0	1,213,086.0	3,420,358.0	139,799.0	2.0	24.0	4,467,345.0	46,827.0	--
2013	--	--	1,037,235.0	3,216,135.0	132,901.0	20.0	--	4,220,664.0	44,440.0	--
2014	--	14,043.0	853,770.0	3,060,563.0	116,925.0	11.0	--	4,186,783.0	36,939.0	--
2015	--	17,429.0	770,134.0	3,054,761.0	104,042.0	11.0	--	4,500,753.0	33,662.0	--
2016	--	--	873,403.0	3,305,089.0	95,787.0	15.0	--	4,501,580.0	38,064.0	--
2017	--	--	990,926.0	3,338,603.0	89,099.0	--	--	4,837,764.0	43,870.0	205.0
2018	1.0	--	910,408.0	3,128,354.0	101,361.0	--	360.5	4,710,680.6	48,205.0	661.0
2019	6.0	--	1,017,915.0	2,991,778.0	99,553.0	--	1,057.3	4,462,084.7	45,694.7	1,039.0
2020	1.0	--	923,050.0	2,769,347.0	98,580.0	--	1,325.9	4,348,404.0	60,377.9	1,161.9
2021	--	--	946,099.0	311,2118.0	98,144.0	--	6294.7	4,454,252.1	56,017.3	2,263.1

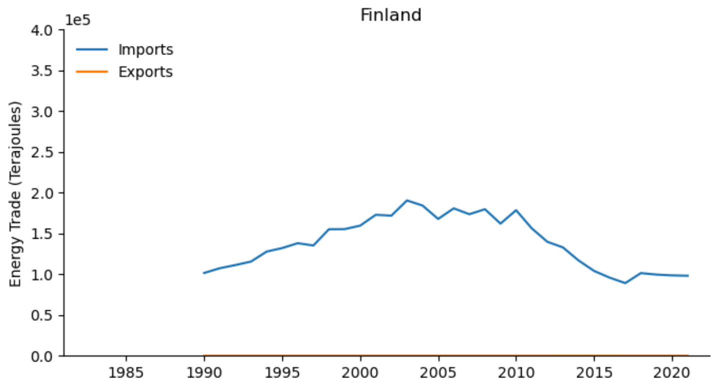
-- no data

Figure A1

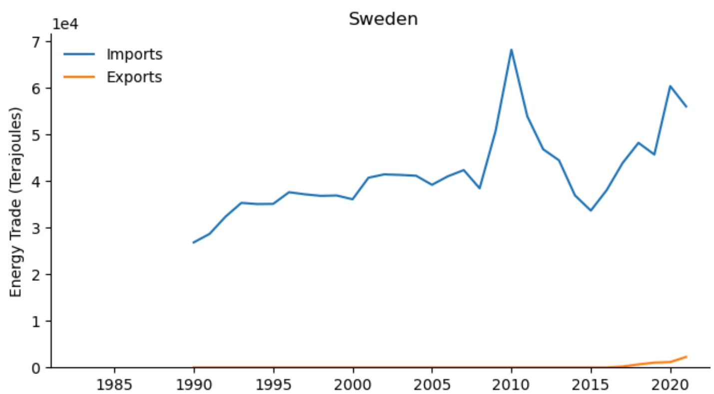
Natural Gas Trade (including LNG) by Arctic Areas (TJ)







The large differences in trade volumes for these areas is notable, stemming from the different energy demands and demographics for these nations. Note the axis scales when comparing nations (1e6 to 1e5 to 1e4).



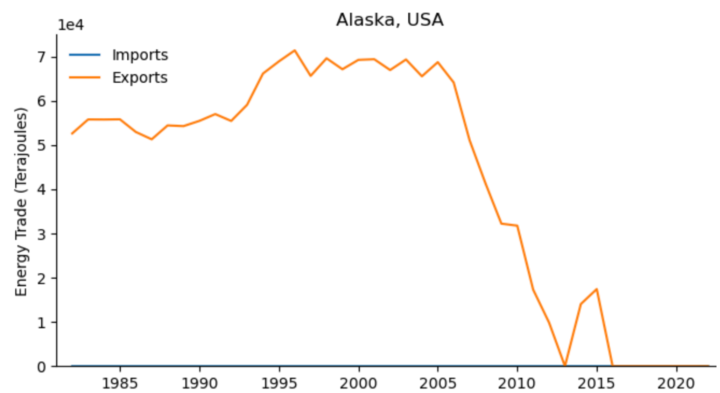


Table A2

International Marine Bunkers of LNG in Arctic Areas (TJ)

Date	Norway	Sweden	Finland	Canada	Alaska, USA
2015	1,601	0	0	0	0
2016	2,188	0	10	0	0
2017	2,007	886	219	0	0
2018	2,326	995	58	0	0
2019	2,446	804	20	0	0
2020	2,691	928	67	0	0
2021	2,689	812	110	0	0

Table A3

LNG Trade by Arctic Areas (TJ)

	Canada		Finland		Greenland		Iceland		Norway		Sweden		United States	
Date	Imports	Exports	Imports	Exports	Imports	Exports	Imports	Exports	Imports	Exports	Imports	Exports	Imports	Exports
1992	16.2	0.1	1.4	--	--	--	--	--	--	--	0.2	--	0.1	50.6
1993	177.4	0.9	2.2	--	--	--	--	--	1,320.0	22.9	3.2	--	6.4	56.8
1994	94.9	--	1.8	0.0	--	--	--	--	4,281.8	--	8.8	1.2	11.5	161.1
1995	0.0	--	6.0	--	--	--	0.0	--	4,075.3	0.0	12,364.4	0.6	614.1	18.0
1996	0.0	--	1.2	11.1	--	--	--	--	3,532.5	--	34,719.5	3.5	123.0	133.1
1997	0.0	--	--	17.6	0.0	--	--	--	3,047.1	--	20,701.3	0.6	504.7	1,053.9
1998	0.0	--	--	7.7	--	--	--	--	1,179.0	1.2	14,108.0	0.1	477.7	1,230.5
1999	0.0	--	--	2.3	--	--	--	--	658.0	6.6	6.5	1.2	935.2	497.6
2000	7.8	1.4	--	10.9	--	--	--	--	35.1	11.7	12.0	1.2	116,718.8	63,294.1
2001	1,167.6	--	--	--	--	--	--	--	--	9.7	7.2	1.0	173,235.7	79,173.1
2002	2,947.0	--	0.6	13.4	--	--	2.1	--	--	1.6	1.9	0.1	194,057.3	159,960.7
2003	118.1	--	0.6	18.3	--	--	--	--	--	1.7	1.9	0.0	450,430.2	49,622.1
2004	1,876.1	0.0	--	13.6	--	--	0.0	--	--	3.9	6.9	0.8	588,028.1	29,253.8
2005	635.0	7.7	--	16.2	--	--	--	--	--	5.8	3.0	0.1	781,313.2	29,942.6
2006	246.9	--	0.6	--	0.0	--	--	--	--	28.8	19.4	0.2	664,107.8	31,093.5
2007	157.6	--	--	60.1	0.0	--	--	--	5,828.9	6,645.9	91.8	1.5	518,918.0	16,413.2
2008	496.0	0.0	--	70.5	--	--	0.0	--	21.9	65,177.2	97.5	--	364,287.5	37,942.6
2009	6,808.7	0.1	--	224.2	--	--	0.0	--	11.4	118,790.2	260.6	0.1	153,514.9	26,673.0
2010	43,800.7	--	26.4	448.3	--	--	0.0	--	216.1	131,562.9	533.2	1.0	333,246.6	83,755.1
2011	60,340.3	0.1	5.5	233.2	--	--	0.0	--	49.6	153,041.3	647.2	61.8	239,964.6	94,493.9
2012	19,959.5	--	--	1.7	--	--	0.0	--	21.8	173,961.8	936.4	24.5	75,107.2	38,927.6
2013	10,596.8	--	--	1.7	--	--	0.0	--	--	128,984.4	1,047.4	661.1	76,231.6	16,374.5
2014	22,294.3	2,268.4	--	--	--	--	0.1	--	--	199,145.8	5,371.9	885.2	72,613.4	34,691.5
2015	31,593.0	--	--	--	--	--	0.0	--	--	204,147.2	8,095.8	949.2	69,153.7	27,324.1
2016	27,704.3	--	646.4	10.4	--	--	0.2	--	--	215,497.8	6,724.0	882.5	106,186.9	199.7
2017	26,786.7	58.5	2,589.0	927.5	--	--	0.0	--	--	188,663.3	11,390.6	993.5	93,261.9	504,212.7
2018	42,633.4	166.4	2,621.7	646.0	0.0	--	--	--	--	232,343.5	12,395.3	1,354.0	116,317.4	577,592.8
2019	23,598.9	542.5	8,188.9	2,858.0	--	--	0.1	--	--	199,138.7	13,962.9	1,665.8	149,322.0	1,114,454.9
2020	28,128.9	583.8	8,825.0	6,184.2	--	--	2.2	--	1,222.2	163,946.5	25,409.0	1,705.1	108,400.3	2,832,880.2
2021	34,991.8	123.7	9,620.0	9,180.2	--	--	0.0	--	5,780.9	5,686.6	20,259.9	1,995.1	114,407.0	2,609,455.4
2022	32,537.4	25.7	6,146.2	1,736.0	--	--	0.0	--	2,464.9	110,793.2	11,800.1	1,335.5	48,240.1	1,470,663.4

-- no data

0.0 indicates negligible values at scale