LNG as a Marine Fuel in the United States

EEA
Energy & Environmental Research Associates

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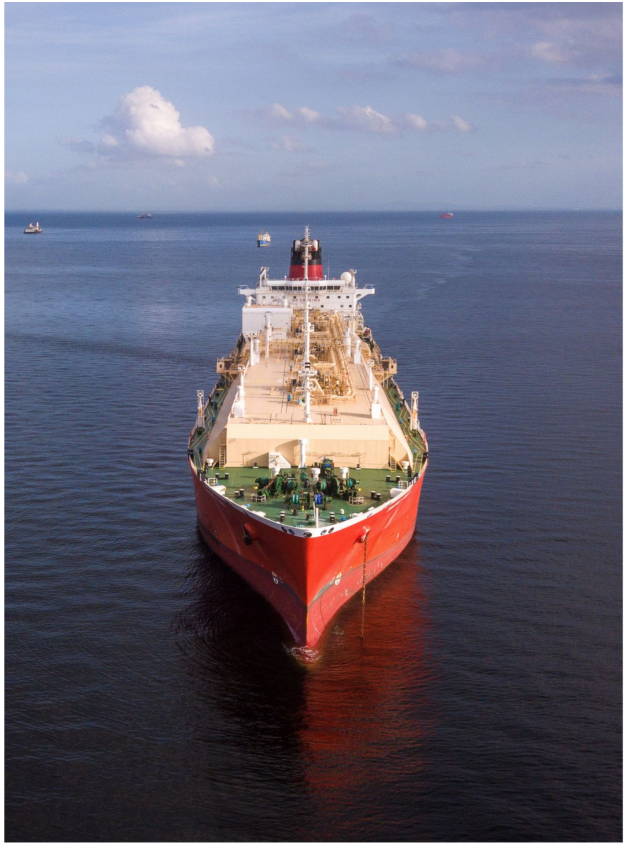
Introduction

- International and domestic shipping emit over **1 billion** metric tonnes of carbon dioxide (CO_2) each year
- IMO net-zero goal by 2050
- Liquefied natural gas (LNG) is a growing choice for shippers
  - Low sulfur oxide (SOx) emissions
  - Lower exhaust CO_2 emissions than conventional marine fuels
- LNG is primarily methane (CH_4) and is <u>not</u> a low GHG fuel
  - 27-30x more potent a GHG than CO_2 over 100-years
  - 82.5x more potent over a 20-year time period
- Unburned CH_4 from ships + supply chain CH_4 emissions have significant implications for climate change, human health, and environmental justice



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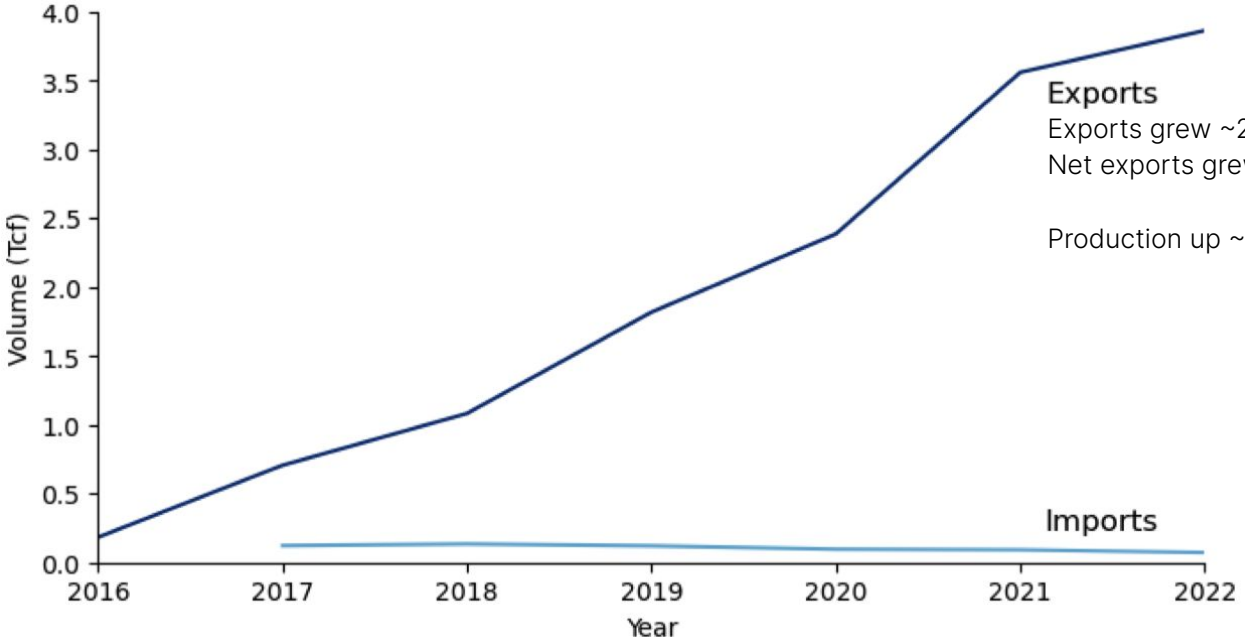
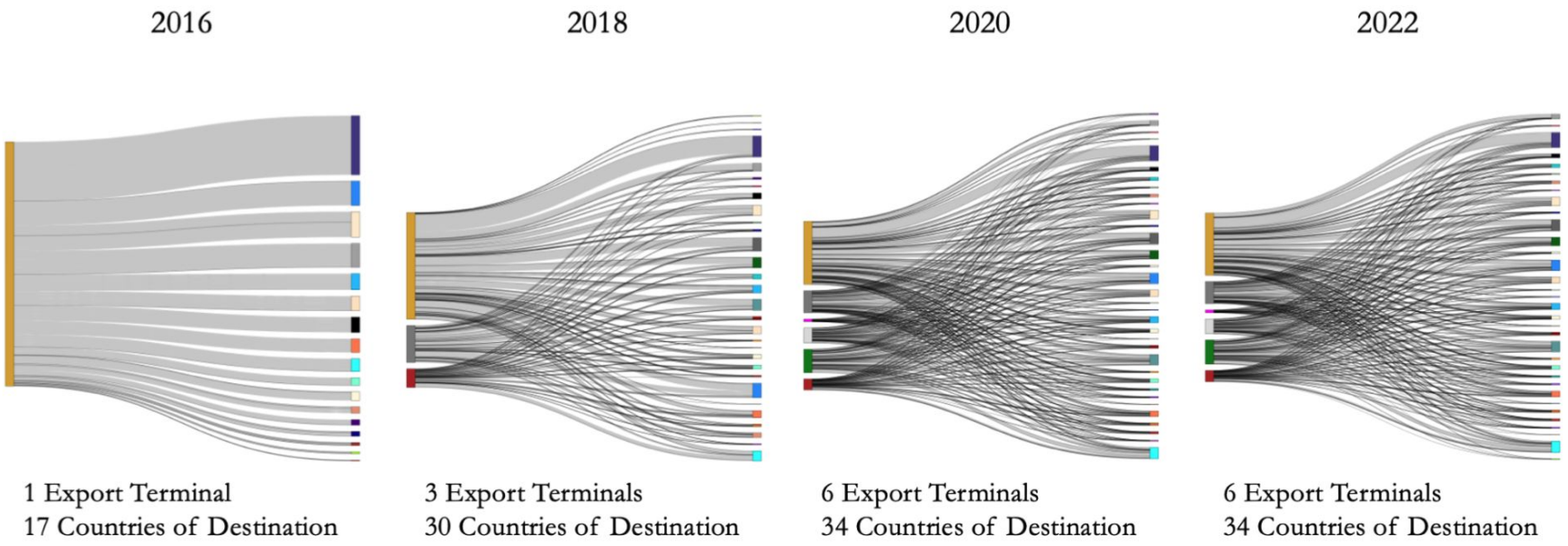
U.S. LNG Imports and Exports



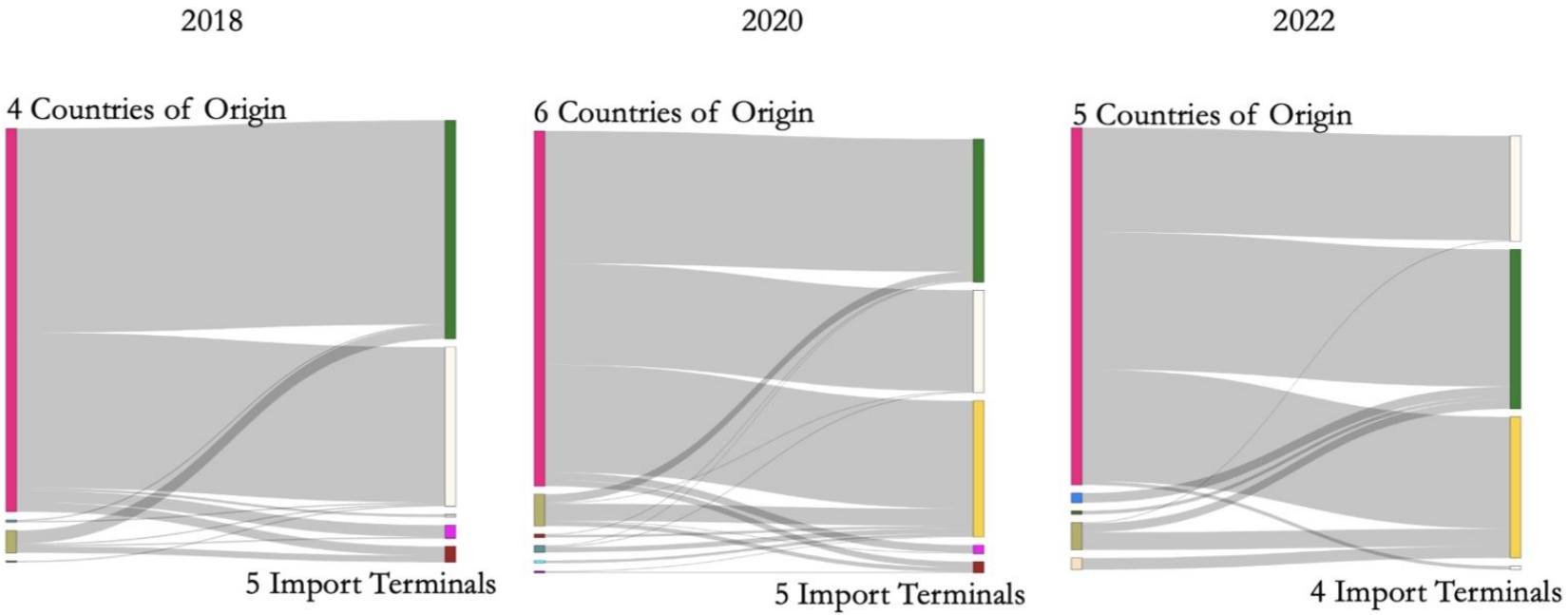
Exports grew ~21x from 2016 to 2022
Net exports grew ~6.5x from 2017 to 2022

Production up ~1.45x

U.S. LNG Export Partners



U.S. LNG Import Partners



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LNG Supply Chain

> 99.9% of U.S. Exports are by vessel

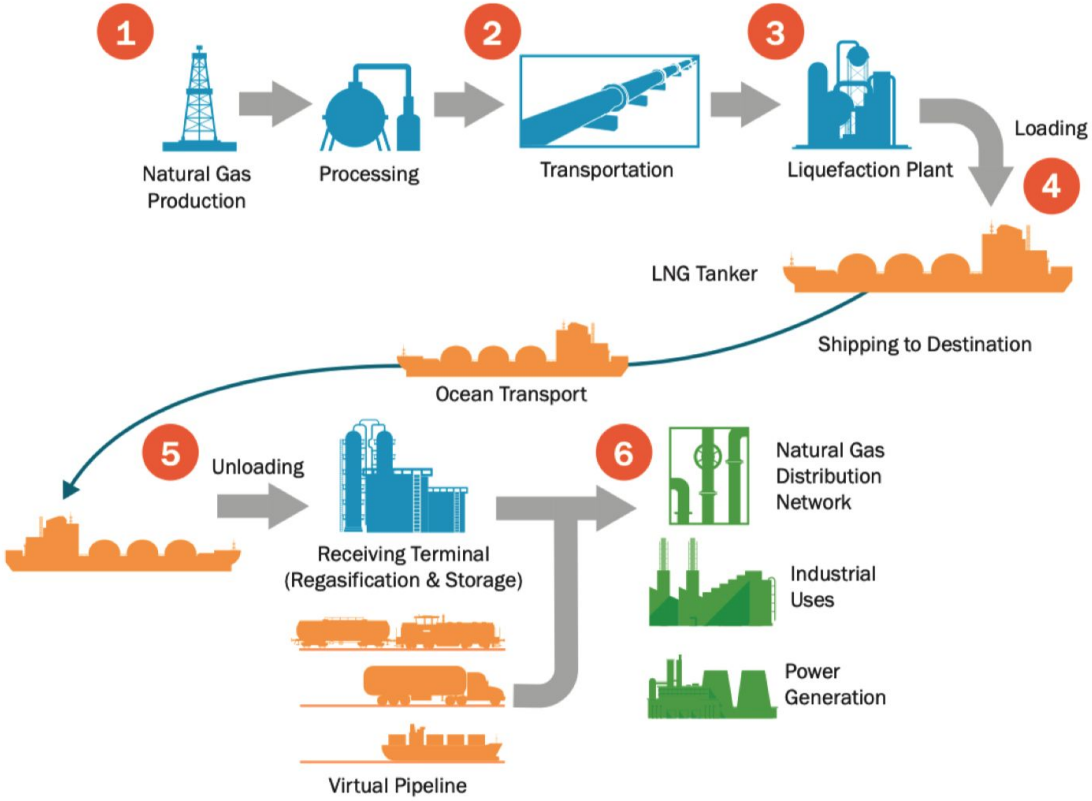


Diagram of the LNG value chain from production to end-use (Office of Fossil Energy, 2020).

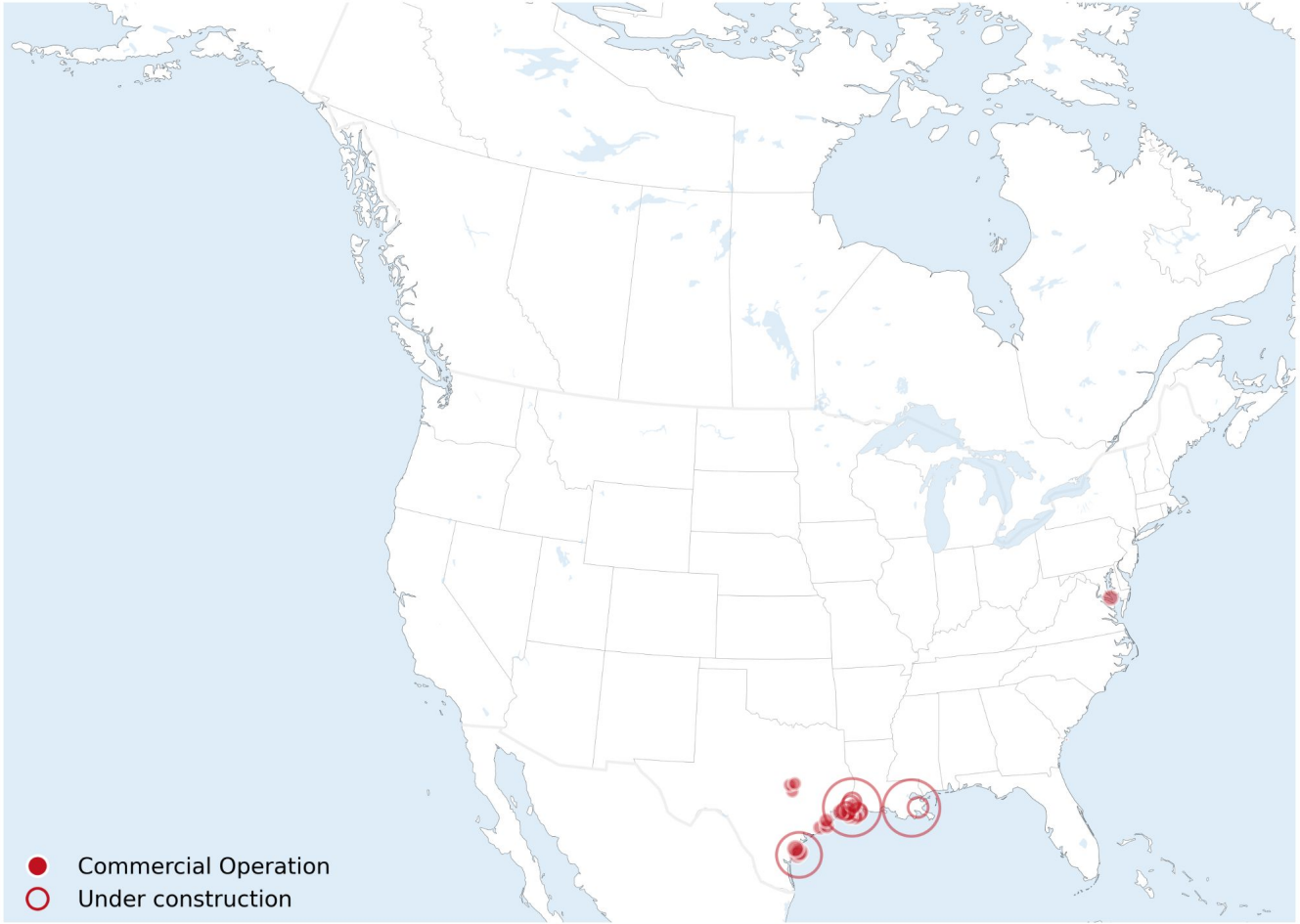
Liquefaction

28 Projects

20 Operational
8 Under construction

~10.8/~13.0 Bcf/d
Baseload/Peak Capacity

~18.7/~22.1 Bcf/d
Baseload/Peak Capacity (Projected)



Bunkering

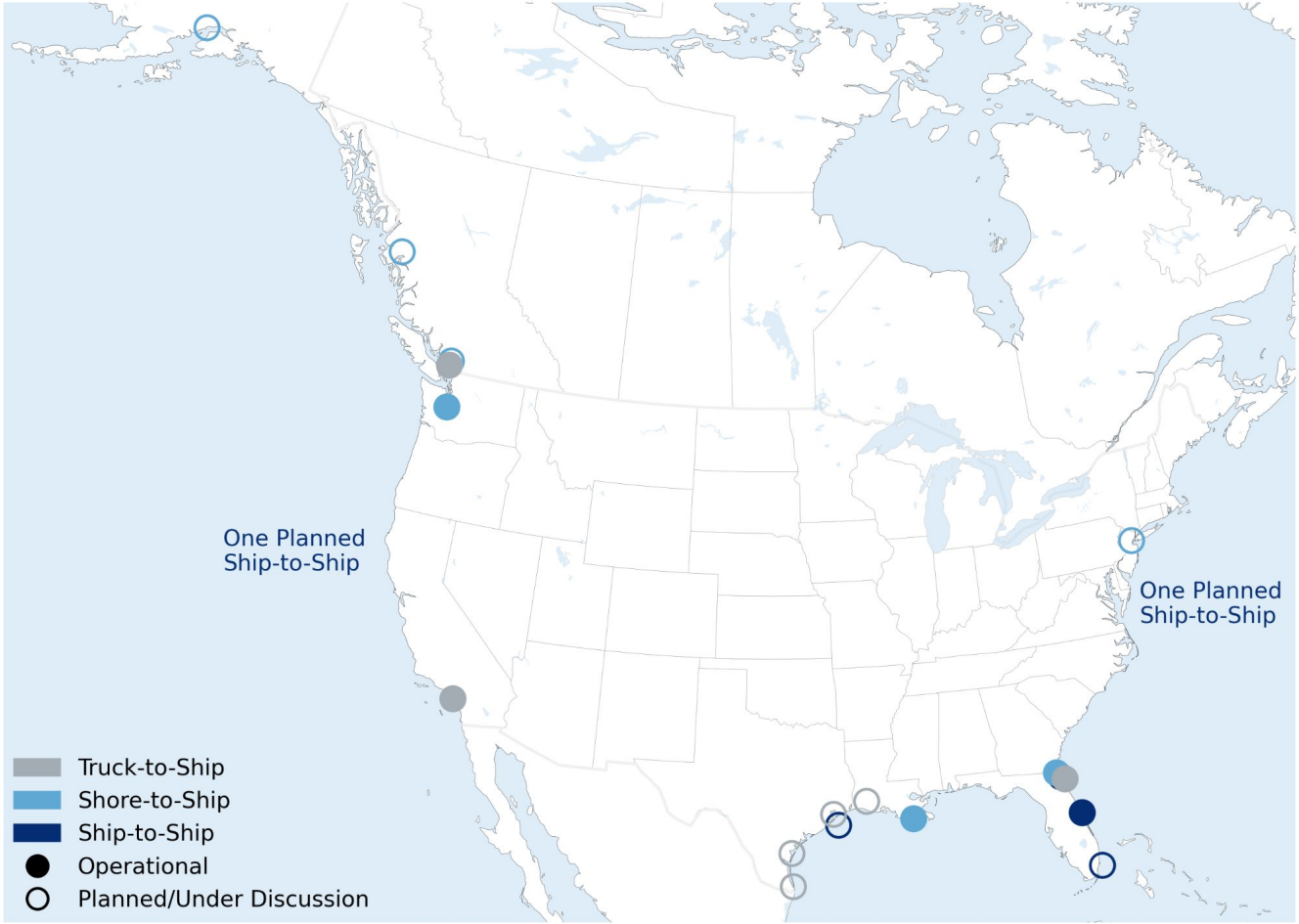
Truck-to-Ship
- **3** Existing / 4 Planned

Shore-to-Ship
- **3** Existing / 1 Planned

Ship-to-Ship
- **3** Existing / 5 Planned

31 LNGBVs globally
15 on order

4 Jones Act LNGBVs
4 on order



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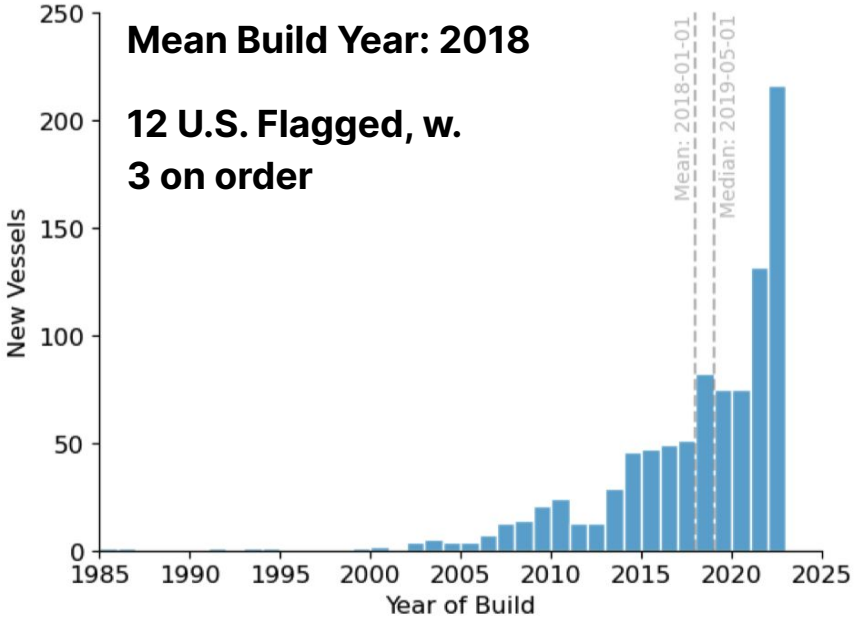
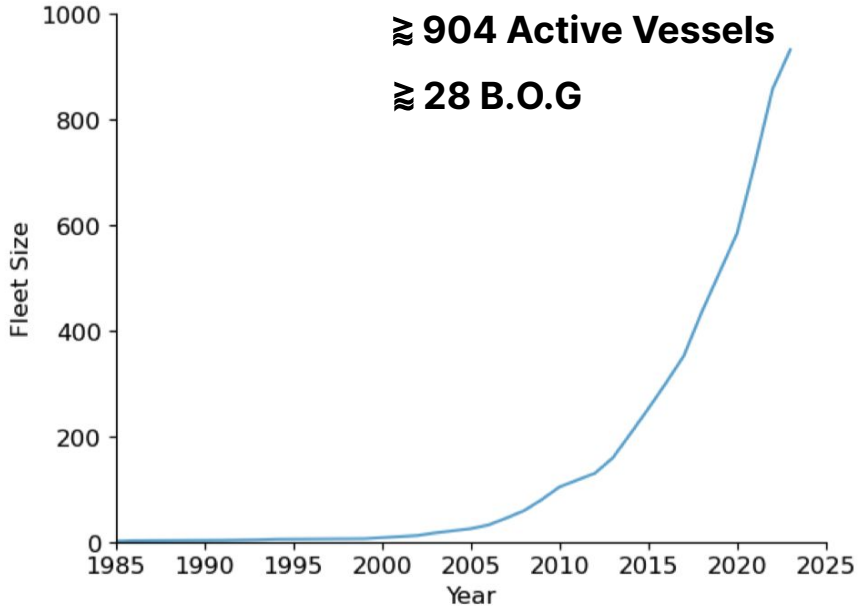
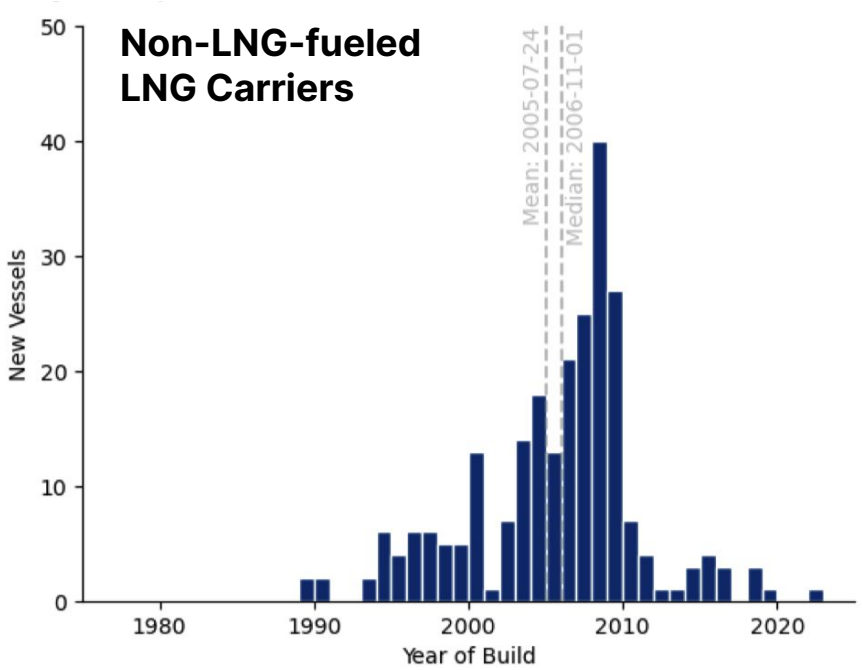
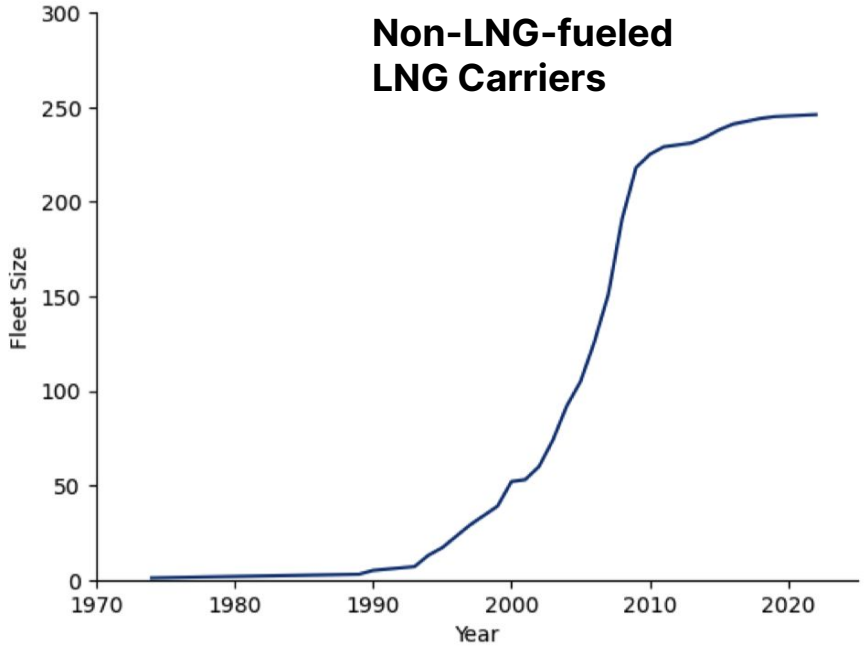
Global LNG-Fueled Fleet



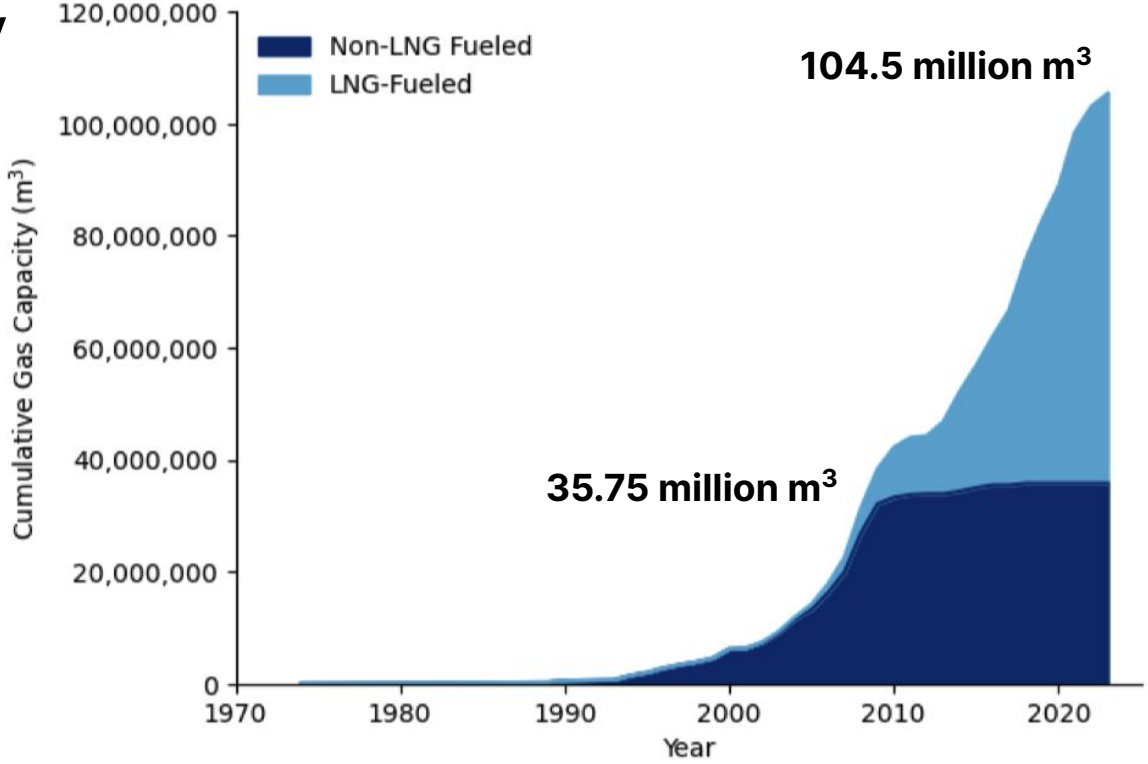


Global LNG-Carrying Fleet





Global Gas Capacity



Orderbook

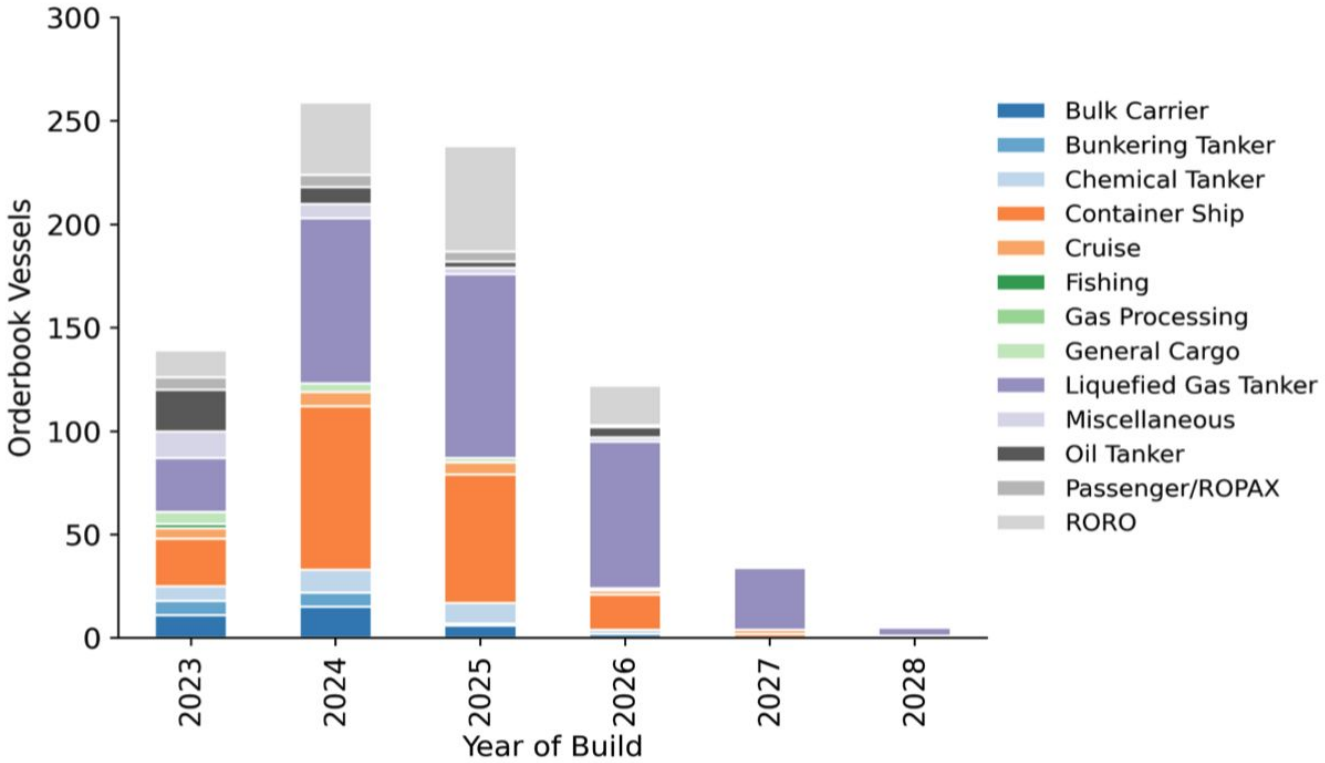
567 order/not commenced

97 keel laid

84 under construction

77 launched

as of Q4 2023



Orderbook Statistics as of Q4 2023

Ship Type	Count	Mean DWT	Std.	Min. DWT	25%	50%	75%	Max. DWT
Bulk Carrier	34	185,492	55,933	5,560	207,000	209,800	210,000	210,000
Bunkering Tanker	15	5,751	2,744	1,500	4,000	5,300	7,450	12,351
Chemical Tanker	30	19,213	12,306	6,600	9,000	17,999	22,554	50,000
Container Ship	183	120,493	54,293	21,023	82,000	131,000	160,000	230,000
Cruise	23	10,486	5,402	1,000	6,250	10,509	13,500	19,750
Fishing	2	8,650	-	8,650	8,650	8,650	8,650	8,650
Gas Processing	1	95,000	-	95,000	95,000	95,000	95,000	95,000
General Cargo	12	26,533	27,185	7,800	8,700	17,500	26,000	82,000
Liquefied Gas Tanker	300	86,500	14,427	1,280	81,000	92,312	93,000	128,845
Miscellaneous	25	903	2,580	-	-	-	351	12,000
Oil Tanker	36	152,712	102,409	4,998	112,820	114,000	300,000	320,000
Passenger/ROPAX	19	5,687	3,262	600	3,448	5,805	8,475	11,742
RORO	119	18,124	2,676	5,385	18,000	18,600	19,000	23,942

Orderbook Gas Capacity

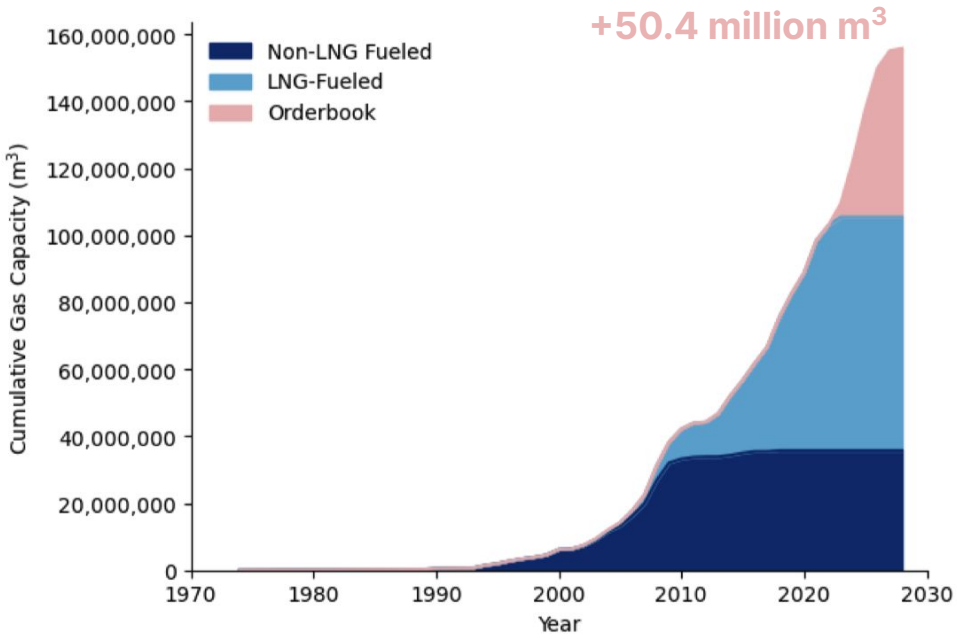
316 vessels w. gas carrying capacity

294 LNG tankers

12 LNG bunkering tankers

10 Miscellaneous, LPG, CO_2 etc.

as of Q4 2023



LNG Trade

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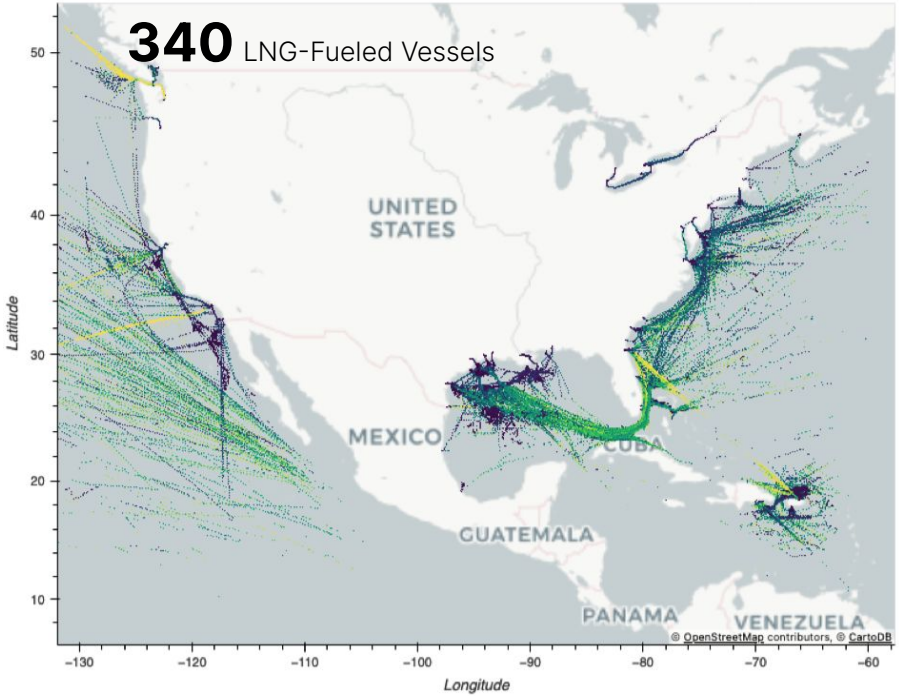
LNG Vessels

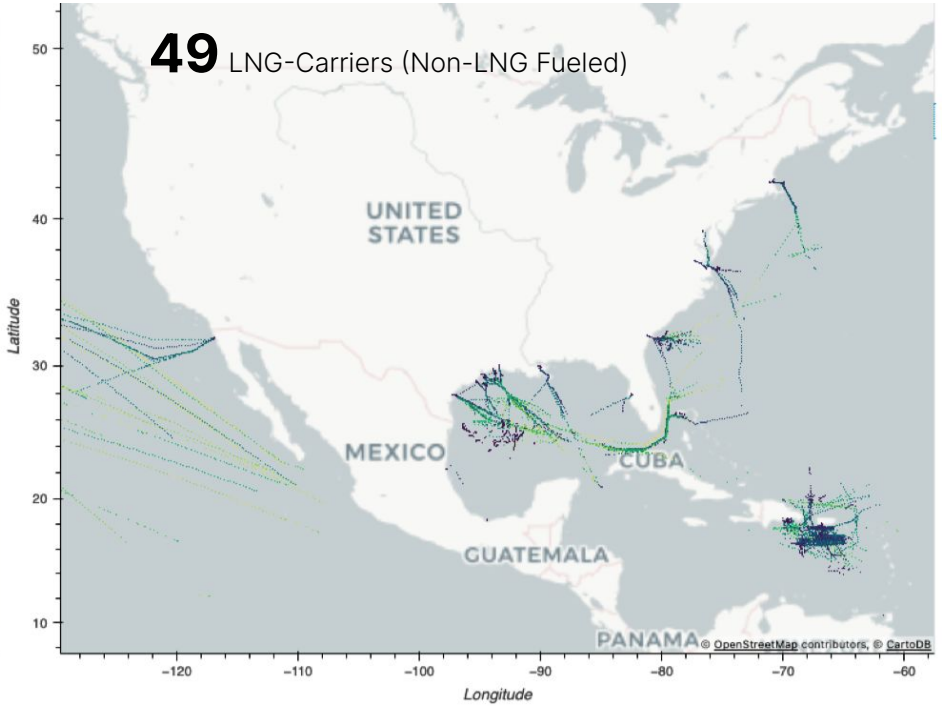
Vessel Movements

Engine Emissions

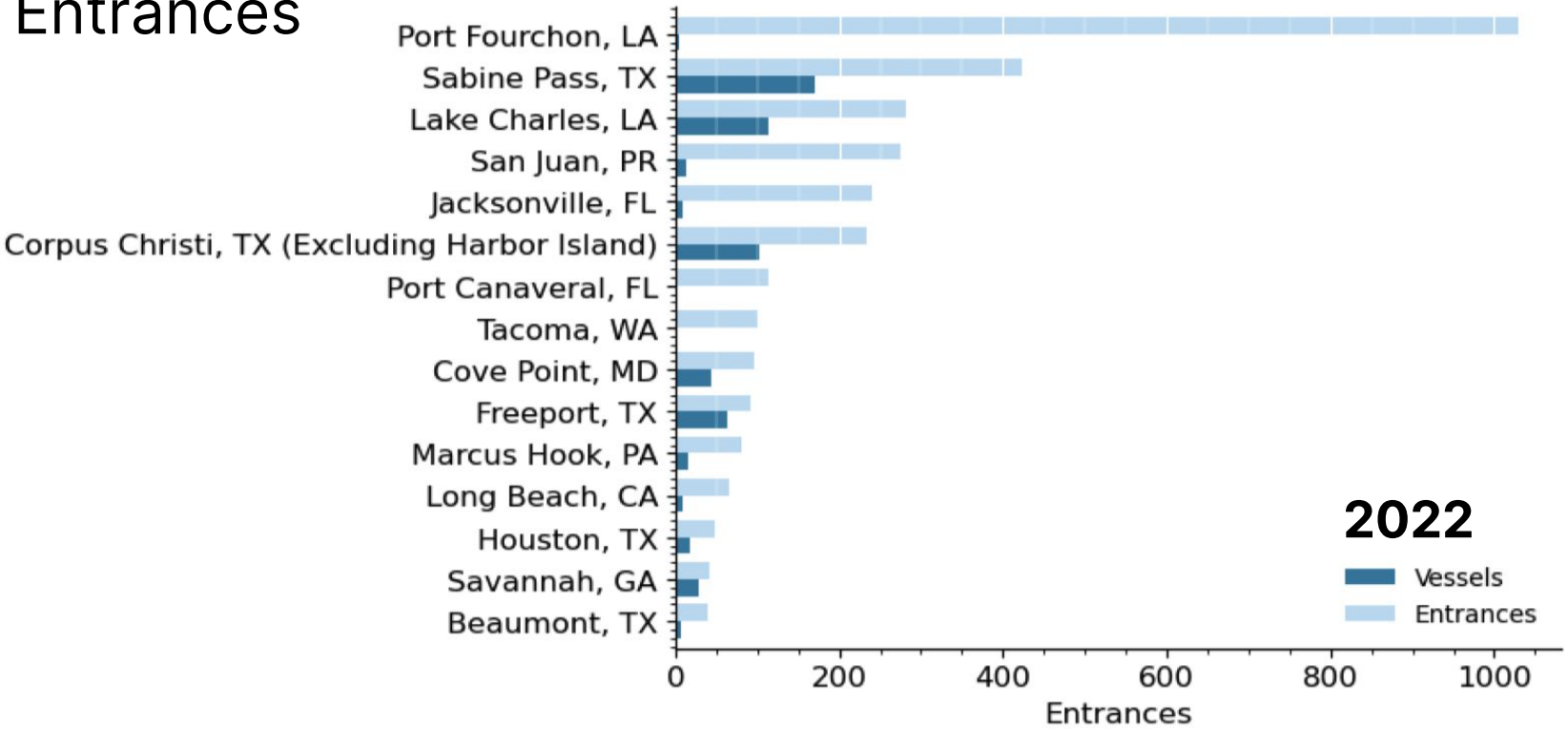
Health and Equity

AIS Movements in 2022





Port Entrances



Vessel Calls

Port Entrances

2022

Port A		Port B	Voyages	Entrance ΔT (h)
Port Fourchon, LA		Port Fourchon, LA	995	18
Jacksonville, FL		**San Juan, PR**	202	80
San Juan, PR		Jacksonville, FL	202	88
Sabine Pass, TX	→ ? →	**Sabine Pass, TX**	197	1,000
Lake Charles, LA	→ ? →	Lake Charles, LA	126	1,062
Tacoma, WA		Tacoma, WA	97	168
Corpus Christi, TX	→ ? →	**Corpus Christi, TX**	93	812
Port Canaveral, FL		Port Canaveral, FL	89	96
Marcus Hook, PA	→ ? →	Marcus Hook, PA	50	692
Corpus Christi, TX	→ ? →	**Sabine Pass, TX**	47	1,036
San Juan, PR		**San Juan, PR**	46	235
Sabine Pass, TX	→ ? →	Lake Charles, LA	45	1,100
Sabine Pass, TX	→ ? →	**Corpus Christi, TX**	44	1,007
Lake Charles, LA	→ ? →	**Sabine Pass, TX**	40	1,098
Long Beach, CA		Honolulu, HI	39	151
Oakland, CA		Long Beach, CA	38	50
Honolulu, HI		Oakland, CA	35	137
Corpus Christi, TX	→ ? →	Lake Charles, LA	30	931
Cove Point, MD	→ ? →	**Cove Point, MD**	28	1,285

Bold ports with import/export terminals
Blue different consecutive ports

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LNG Engines

Engine Type	Lean-Burn Spark Ignition (LBSI)	Low-Pressure Dual Fuel (LPDF)		High-Pressure Dual Fuel (HPDF)
Power Stroke	Four-stroke		Two-stroke	
Power Range	Medium- & High-speed 0.5-8 MW	Medium-speed 1-18 MW	Slow-speed 5-63 MW	Slow-speed >2.5 MW
Fuel Cycle(s)*	Otto	Otto (gas mode) & Diesel (diesel mode)		Diesel
Ignition Process	Spark plug ignition of air-gas mixture	Constant volume homogeneous air-gas mixture		High-pressure compression-ignition
Pilot Fuel	No	Yes		
Nitrogen Oxides Performance	Tier III			Tier II

*Diesel-cycle systems inject fuel at high pressures, for which heat is generated in the charge to ignite the fuel. Otto-cycle uses constant volume combustion of an air-fuel mixture at low pressures, with use of a spark plug or pilot fuel ignition.

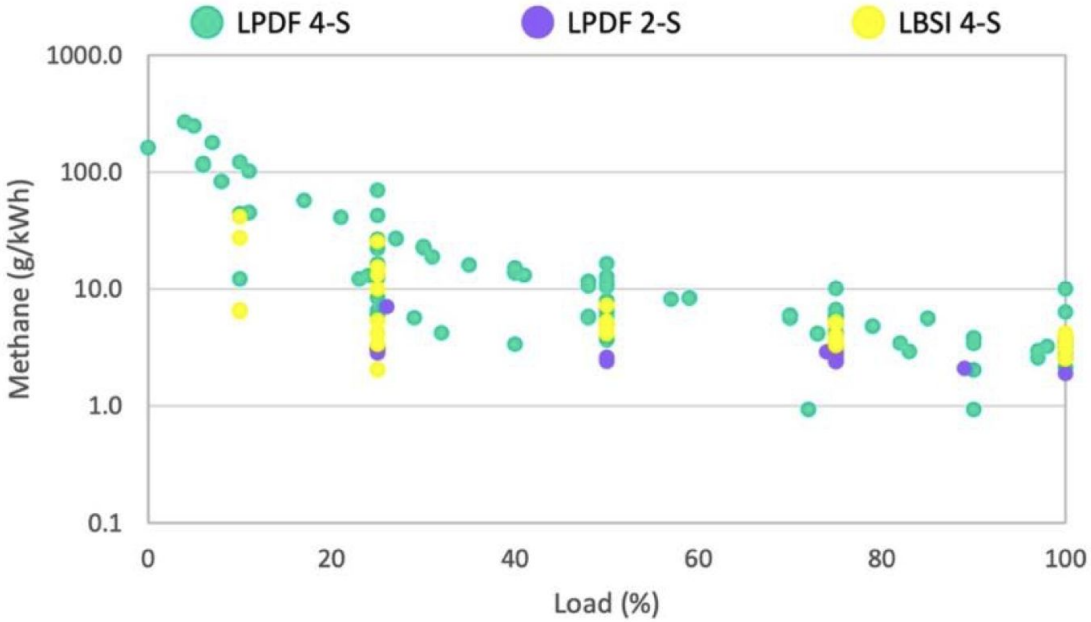
LNG Engine Emissions

Engine Type	LBSI 4-S	LPDF 4-S	LPDF 2-S	HPDF 2-S
% of Fleet	< 2%	~54%	~25%	15%
E2/E3 CH_4 Slip (gCH_4/kWh)	2.0 - 5.5	2.0 - 13.5	2.1 - 3.5	0.2 - 0.3
<25% Load CH_4 Slip (gCH_4/kWh)	6.4 - 42.5	6.1 - 123.5	2.8 - 7.2	NA

29.8 (GWP_{100})
82.5 (GWP_{20})

LNG Engine Emissions

The Green Ray Project: "Methane emission factors as a function of engine load for all engine types" (p.18)



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LNG, Health, and Equity

- Atmospheric CH_4 linked with ground-level Ozone formation
- Combustion criteria pollutants are low compared to conventional fuels, but upstream emissions from extraction, processing, and liquefaction can potentially impact air and water quality of nearby communities
- Extraction of unconventional natural gas, which accounted for 89% of U.S. production in 2022 and includes fracking, can lead to negative impacts on public health, increased air pollution, and water contamination.
- “Boomtowns” built around extraction can provide economic opportunities during expansion, but contractions can lead to increased social vulnerabilities for low-income groups and women, and increased crime and drug-use.
- LNG infrastructure is often co-located with areas with environmental justice concerns and high social vulnerability
    - Flaring and energy intensive operations increase local criteria pollution emissions

Analytical Conclusions

1. U.S. LNG trade has grown > 20x since 2016. Production up 1.4x.
2. > 99.9% of U.S. LNG exports by vessel.
3. U.S. liquefaction capacity set to grow by ~1.7x.
4. U.S. bunkering locations set increase from 9 to 19 locations.
5. Global orderbook to add upwards of 50.4 million m^3 gas capacity.
6. LNG vessel entrances highest in the Gulf Coast region, Florida, and Puget Sound.

Policy Relevance

1. Huge growth in trade and infrastructure in the U.S.
2. More than a thousand LNG vessels operating and on order → long operational life
3. Engines can have a NOx - CH_4 tradeoff
4. CH_4 slip and upstream well-to-tank emissions can increase LNG life cycle emissions relative to conventional fuels
5. Policy are frameworks beginning to address CH_4 emissions - need to include WTW
6. LNG as a marine fuel does not meet stated climate goals and can result in disproportionate impacts to socially vulnerable and environmental justice communities

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