The New Gas Boom

TRACKING GLOBAL LNG INFRASTRUCTURE

Ted Nace, Lydia Plante, and James Browning

ABOUT THE COVER

LNG tanker Energy Progress taking on cargo at Darwin LNG Terminal, Northern Territory, Australia, in March 2016.

ABOUT GLOBAL ENERGY MONITOR

Global Energy Monitor (formerly CoalSwarm) is a network of researchers developing collaborative informational resources on fossil fuels and alternatives. Current projects include the Global Coal Plant Tracker, the Global Fossil Infrastructure Tracker, the CoalWire newsletter, and the CoalSwarm and FrackSwarm wiki portals.

ABOUT THE GLOBAL FOSSIL INFRASTRUCTURE TRACKER

The Global Fossil Infrastructure Tracker is an online database that identifies, maps, describes, and categorizes oil and gas pipelines and oil, gas, and coal terminals. Developed by Global Energy Monitor, the tracker uses footnoted wiki pages to document each plant. For further details, see "Methodology" at http://ggon.org/fossil-tracker/

AUTHORS

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FURTHER RESOURCES

For additional data on proposed and existing pipelines, Summary Data at http://ggon.org/fossil-tracker/ provides over 50 tables compiled from the Global Fossil Infrastructure Tracker (GFIT), broken down by nation and region. To obtain primary data from the GFIT, contact Ted Nace (ted@tednace.com).

Global Energy Monitor

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EXECUTIVE SUMMARY

Through a massive increase in portside infrastructure, floating offshore terminals, and oceangoing LNG vessels, the natural gas industry is seeking to restructure itself from a collection of regional markets into a wider and more integrated global system. If successful, this transformation would lock in much higher levels of natural gas production through mid-century—a seeming win for the industry—except that the falling cost of renewable alternatives will make many of these projects unprofitable in the long term and put much of the $1.3 trillion being invested in this global gas expansion at risk. Such an expansion is also incompatible with the IPCC's warning that, in order to limit warming to 1.5°C above pre-industrial levels, gas use must decline 15% by 2030 and 43% by 2050, relative to 2020.

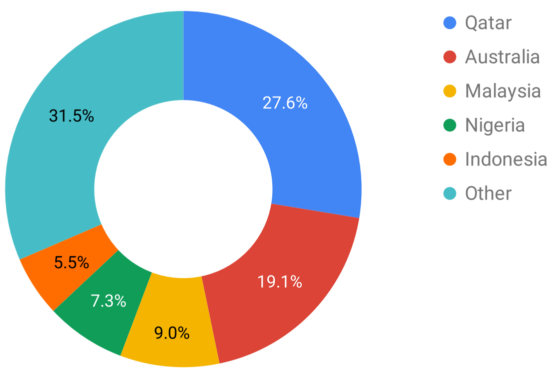
This report provides the results of a worldwide survey of LNG terminals completed by the Global Fossil Infrastructure Tracker. The report includes the following highlights:

- Methane, the chief component in natural gas, is responsible for 25% of global warming to date.
- Measured by global warming impacts, the scale of the LNG expansion under development is as large or greater than the expansion of coal-fired power plants, posing a direct challenge to Paris climate goals.
- Due to falling costs of renewable alternatives, the expansion of LNG infrastructure faces questions of long-term financial viability and stranded asset risk. However, since only 8% of terminal capacity under development has entered construction, there is still time to avoid overbuilding.
- At least 202 LNG terminal projects are in development worldwide, including 116 export terminals and 86 import terminals.
- LNG export terminals are under development in 20 countries, of which Canada and the U.S. account for 74% of proposed new capacity. If built, LNG terminals in pre-construction and construction would increase current global export capacity threefold.
- LNG import terminals are in development in 42 countries, of which 22 have no current import capacity. Capacity expansion is focused on the Asia Pacific Region.
- Overall, LNG terminals in development represent capital outlays of $1.3 trillion, of which 70% is for North American export terminals and 6% is for Asia Pacific import terminals. In terms of capital outlays for import and export terminals combined, the top ten countries are United States ($507 billion), Canada ($410 billion), Russia ($86 billion), Australia ($38 billion), Tanzania ($25 billion), China ($24 billion), Indonesia ($24 billion), Mozambique ($23 billion), Iran ($21 billion), and Papua New Guinea ($17 billion).

THE GROWING ROLE OF LNG IN NATURAL GAS MARKETS

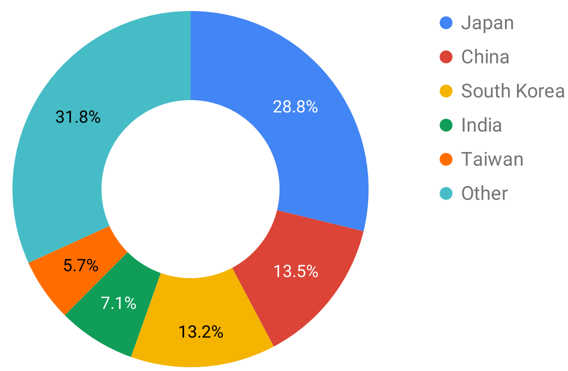
Historically, most natural gas was transported by pipeline within regions, with a small fraction (5.5% in 2000) transported by ship as liquified natural gas (LNG), mainly from a handful of producing countries (led by Qatar and Australia) to a handful of importing countries (led by Japan, China, and South Korea). In the case of both imports and exports, just five exporting and five importing countries accounted for two-thirds of the global LNG trade in 2017, as shown in Figures 1 and 2. Since 2000, the share of LNG in the global system has doubled to 11%, with 432 billion cubic meters of LNG in 2018 out of total global natural gas production of 3,940 bcm (IEA 2019).

Figure 1. Shares of LNG Exports for Top Five Countries, 2017



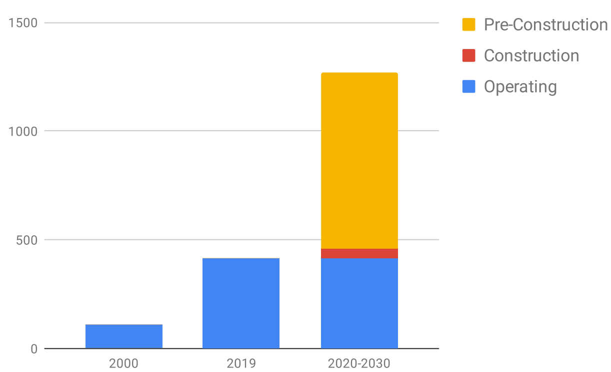
Source: International Gas Union, 2018

Figure 2. Shares of LNG Imports for Top Five Countries, 2017



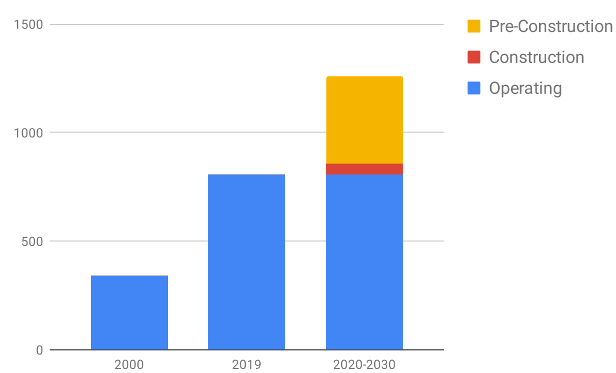
Source: International Gas Union, 2018

Figure 3. LNG Export Capacity in 2000, 2019, and in Development



Source: Global Fossil Infrastructure Tracker, April 2019

Figure 4. LNG Import Capacity in 2000, 2019, and in Development



Source: Global Fossil Infrastructure Tracker, April 2019

TOWARD A NORTH AMERICA–CENTERED, GLOBALLY INTEGRATED NATURAL GAS SYSTEM

As shown in Figure 3, projects currently under construction or in pre-construction would more than triple global export capacity. If fully implemented, current proposals will raise the share of LNG in overall gas production to 20% by 2030, assuming sector growth in line with the IEA New Policies Scenario (IEA 2018).

Besides growing in market share, LNG is also growing in geographic scope to include more producing and recipient countries. Together, the two developments are shifting the global gas system to a more globally integrated system connected by shipborne LNG cargoes.

Although some new LNG export capacity is under development in 20 countries, as shown in Table 2, the vast majority is concentrated in North America, including 352.7 million tonnes per annum (MTPA) under development in the U.S. and 281.6 MTPA under development in Canada, or 74% of all export capacity in development globally.

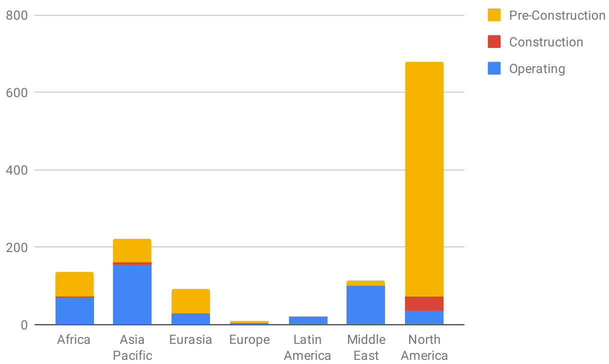
As shown in Figure 4 and Table 1, expansion of LNG import capacity is more widely distributed, including 65.6 million tonnes per annum of new capacity in 22 countries that currently have no import capacity. Overall, projects under development would increase the number of countries with LNG import capacity from 40 to 62.

Table 1. LNG Importing Countries, 2000, 2019, and 2030 (projects in development shown in red)

Year	Countries
2000	Belgium, France, Greece, Italy, Japan, South Korea, Spain, Taiwan, Turkey, USA
2019	Argentina, Bangladesh, Belgium, Brazil, Canada, Chile, China, Colombia, Dominican Republic, Finland, France, Greece, India, Indonesia, Israel, Italy, Jamaica, Japan, Jordan, Kuwait, Lithuania, Malaysia, Malta, Mexico, Netherlands, Pakistan, Panama, Poland, Portugal, Russia, Singapore, South Korea, Spain, Sweden, Taiwan, Thailand, Turkey, United Arab Emirates, United Kingdom, USA
2030	Argentina, **Australia**, **Bahrain**, Bangladesh, Belgium, Brazil, Canada, Chile, China, Colombia, **Croatia**, **Cyprus**, Dominican Republic, Finland, **Egypt**, **Estonia**, France, **Germany**, **Ghana**, Greece, **Haiti**, India, Indonesia, **Ireland**, Israel, Italy, Jamaica, Japan, Jordan, **Kenya**, Kuwait, Lithuania, Malaysia, Malta, Mexico, **Morocco**, **Myanmar**, **Namibia**, Netherlands, **Nigeria**, Pakistan, Panama, **Philippines**, Poland, Portugal, **Romania**, Russia, Singapore, **South Africa**, South Korea, Spain, **Sri Lanka**, Sweden, Taiwan, Thailand, Turkey, United Arab Emirates, **Ukraine**, United Kingdom, USA, **Uruguay**, **Vietnam**

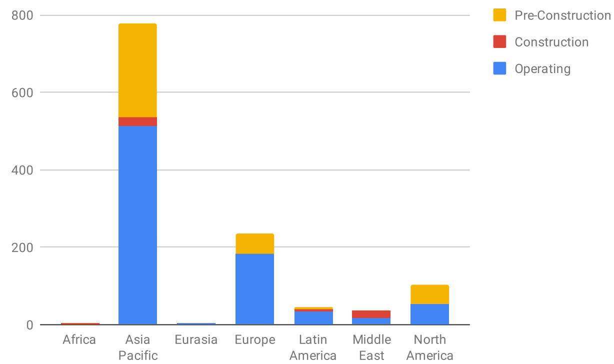
Source: Global Fossil Infrastructure Tracker, April 2019

Figure 5. LNG Export Capacity by Region and Developmental Status, 2019 (million tonnes per annum)



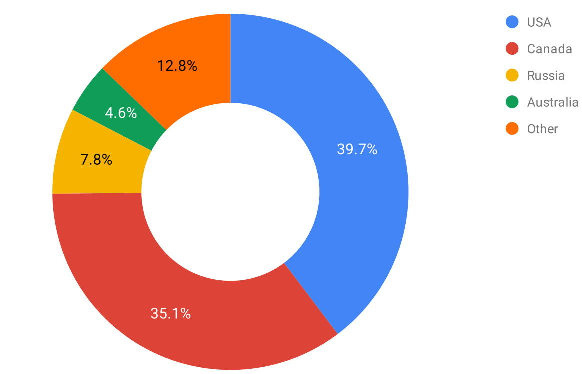
Source: Global Fossil Infrastructure Tracker, April 2019

Figure 6. LNG Import Capacity by Region and Developmental Status, 2019 (million tonnes per annum)



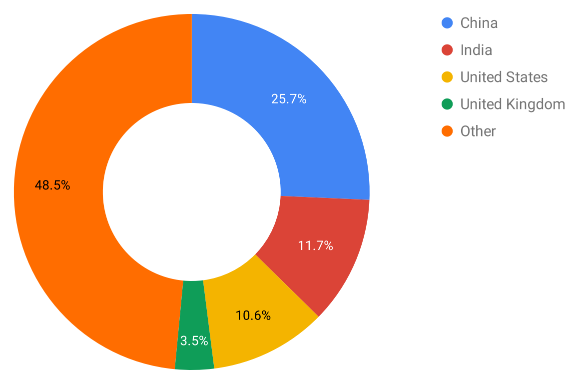
Source: Global Fossil Infrastructure Tracker, April 2019

Figure 7. LNG Export Capacity in Development (Pre-Construction and Construction), 2019, Top Four Countries



Source: Global Fossil Infrastructure Tracker, April 2019

Figure 8. LNG Import Capacity in Development (Pre-Construction and Construction), 2019, Top Four Countries



Source: Global Fossil Infrastructure Tracker, April 2019

Table 2. LNG Export (Liquefaction) and Import (Regasification) Capacity by Country and Developmental Status (million tonnes per annum), 2019

	Export Terminals			Import Terminals		
Country	Operating	Construction	Pre-Construction	Operating	Construction	Pre-Construction
Algeria	25.3	0.0	4.0	0.0	0.0	0.0
Angola	5.2	0.0	0.0	0.0	0.0	0.0
Argentina	0.0	0.0	0.0	7.8	0.0	0.0
Australia	83.2	0.0	36.7	0.0	0.0	5.2
Bahrain	0.0	0.0	0.0	0.0	6.1	0.0
Bangladesh	0.0	0.0	0.0	5.0	3.5	7.5
Belgium	0.0	0.0	0.0	9.0	0.0	0.0
Brazil	0.0	0.0	0.0	8.9	3.6	0.0
Brunei	7.2	0.0	0.0	0.0	0.0	0.0
Cameroon	2.4	0.0	0.0	0.0	0.0	0.0
Canada	0.0	0.0	281.6	21.2	0.0	11.0
Chile	0.0	0.0	0.0	5.3	3.3	1.4
China	0.0	0.0	0.0	73.2	8.6	78.5
Colombia	0.0	0.0	0.0	3.0	0.0	0.0
Croatia	0.0	0.0	0.0	0.0	0.0	1.5
Cyprus	0.0	0.0	5.0	0.0	0.0	1.3
Dominican Republic	0.0	0.0	0.0	1.9	0.0	0.0
Egypt	12.2	0.0	0.0	0.0	0.0	0.0
Equatorial Guinea	3.7	0.0	8.8	0.0	0.0	0.0
Estonia	0.0	0.0	0.0	0.0	0.0	4.5
Finland	0.0	0.0	0.0	1.6	0.1	0.0
France	0.0	0.0	0.0	27.8	0.0	0.0
Germany	0.0	0.0	0.0	0.0	0.0	11.0
Ghana	0.0	0.0	0.0	0.0	3.4	0.0
Greece	0.0	0.0	0.0	7.7	0.0	0.0
India	0.0	0.0	0.0	49.0	10.0	29.5
Indonesia	26.5	4.3	11.0	8.9	0.0	7.8
Iran	0.0	0.0	13.3	0.0	0.0	0.0
Ireland	0.0	0.0	0.0	0.0	0.0	2.0
Israel	0.0	0.0	0.0	3.7	0.0	0.0
Italy	0.0	0.0	0.0	11.7	0.0	3.5
Jamaica	0.0	0.0	0.0	4.8	0.0	2.5
Japan	0.0	0.0	0.0	219.7	0.0	11.7
Jordan	0.0	0.0	0.0	5.5	0.0	0.0
Kenya	0.0	0.0	0.0	0.0	0.0	0.3
Kuwait	0.0	0.0	0.0	9.6	11.3	0.0
Lithuania	0.0	0.0	0.0	2.2	0.0	0.0
Malaysia	30.5	1.5	0.0	7.3	0.0	0.0

Table 2 (continued)

	Export Terminals			Import Terminals		
Country	Operating	Construction	Pre-Construction	Operating	Construction	Pre-Construction
Malta	0.0	0.0	0.0	0.4	0.0	0.0
Mexico	0.0	0.0	7.0	16.1	0.0	0.0
Mozambique	0.0	3.4	12.0	0.0	0.0	0.0
Myanmar	0.0	0.0	0.0	0.0	0.0	4.0
Netherlands	0.0	0.0	0.0	9.0	0.0	0.0
Nigeria	21.9	0.0	10.0	0.0	0.0	0.0
Norway	4.5	0.0	0.0	0.0	0.0	0.0
Oman	10.8	0.0	0.0	0.0	0.0	0.0
Pakistan	0.0	0.0	0.0	14.5	0.0	4.5
Panama	0.0	0.0	0.0	1.5	0.0	0.0
Papua New Guinea	6.9	0.0	14.0	0.0	0.0	0.0
Peru	4.5	0.0	0.0	0.0	0.0	0.0
Philippines	0.0	0.0	0.0	0.0	1.5	0.0
Poland	0.0	0.0	0.0	3.7	0.0	1.8
Portugal	0.0	0.0	0.0	6.0	0.0	0.0
Qatar	77.0	0.0	0.0	0.0	0.0	0.0
Romania	0.0	0.0	0.0	0.0	0.0	6.0
Russia	28.0	2.0	62.6	2.7	0.0	0.0
Senegal	0.0	0.0	2.5	0.0	0.0	0.0
Singapore	0.0	0.0	0.0	11.0	0.0	5.3
South Africa	0.0	0.0	0.0	0.0	0.0	1.6
South Korea	0.0	0.0	0.0	101.8	0.0	3.6
Spain	0.0	0.0	0.0	46.0	0.0	2.0
Sri Lanka	0.0	0.0	0.0	0.0	0.0	2.7
Sweden	0.0	0.0	0.0	0.4	0.0	0.0
Taiwan	0.0	0.0	0.0	12.0	0.0	7.8
Tanzania	0.0	0.0	20.0	0.0	0.0	0.0
Thailand	0.0	0.0	0.0	10.0	0.0	9.0
Trinidad and Tobago	15.5	0.0	0.0	0.0	0.0	0.0
Turkey	0.0	0.0	0.0	19.4	0.0	0.0
Ukraine	0.0	0.0	0.0	0.0	0.0	7.3
United Arab Emirates	5.8	0.0	0.0	4.0	0.0	0.0
United Kingdom	0.0	0.0	0.0	35.0	0.0	12.0
Uruguay	0.0	0.0	0.0	0.0	0.0	0.1
USA	37.3	34.3	318.4	17.6	0.0	36.0
Vietnam	0.0	0.0	0.0	0.0	0.0	4.6
Yemen	7.2	0.0	0.0	0.0	0.0	0.0
Total	**415.5**	**45.5**	**806.9**	**805.9**	**51.4**	**287.5**

Source: Global Fossil Infrastructure Tracker, April 2019.

EXPORT INFRASTRUCTURE IS THE FOCUS OF THE EXPANSION

Global LNG export capacity is smaller than global LNG import capacity, and utilization rates are higher than for LNG import terminals. This means that LNG export capacity is the limiting factor in the growth of global LNG usage, particularly from North American fracked gas production. In 2018, average utilization rates were 79% for export terminals and 40% for import terminals. Since existing export capacity is rarely idle, significant growth in LNG exports will not be possible without building new LNG export terminal capacity.

As shown in Table 3, import terminal capacity under development is heavily concentrated in the Asia Pacific region, led by China with 87.1 million tonnes per annum (MTPA) and India with 39.5 MTPA, as shown in Table 2. The leading importer, Japan, has comparatively modest expansion plans, with only 11.7 MTPA in development.

CAPITAL COSTS: $1.3 TRILLION

The capital expenditures required for LNG terminals in development amount to $1.3 trillion globally and are overwhelmingly concentrated in North America, where $914.5 billion in export terminals are development, representing 70% of the global total. As shown in Table 3, export terminals dominate proposed expenditures, for two reasons. First, a larger amount of export capacity is currently under development globally. Second, on a tonne-for-tonne basis, the liquefaction process at export terminals is more expensive than the regasification process at import terminals, due to the massive cooling and pressurization processes required for liquefaction. The International Gas Union estimates capital costs for export terminals at $1,501 per tonne of annual capacity for greenfield projects and $458 per tonne for brownfield projects; IGU estimates capital costs for import terminals projects at $274 per tonne (IGU 2018).

Table 3. Capital Investments for LNG Export (Liquefaction) and Import (Regasification) Terminals Under Development (Billion US$)

Region	Export	Import	Total
Africa	85.0	1.4	86.5
Asia Pacific	75.5	73.2	148.7
Eurasia	85.6	0.0	85.6
Europe	7.5	14.2	21.7
Latin America	0.0	3.0	3.0
Middle East	21.0	4.8	25.8
North America	914.5	12.9	927.4
Total	**1,189.2**	**109.4**	**1,298.6**

Sources: Capacity estimates from Global Fossil Infrastructure Tracker, April 2019; Capital costs from IGU 2018.

STRANDED ASSET RISK

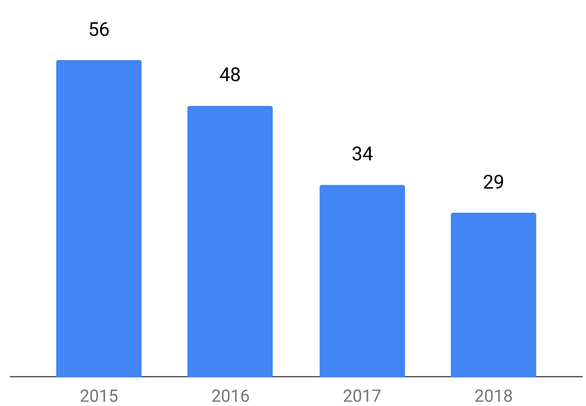
Despite its price tag ($1.3 trillion) and its role in the climate crisis, the expansion of LNG infrastructure has received relatively little scrutiny in terms of stranded asset risk. But attention to stranded asset issues is rising due to increased cost pressure on natural gas by renewable alternatives. In its 12th annual levelized cost of energy study, Lazard Bank reported that unsubsidized solar PV is now cheaper or comparable in cost to natural gas peaking power in all economies studied, including the U.S., Australia, Brazil, India, South Africa, Japan, and Northern Europe. Similarly, wind power is now cheaper or comparable in cost to combined cycle gas turbines across the same set of countries (Lazard 2018). A 2018 study by Rocky Mountain Institute concluded that U.S. power system portfolios built around renewables and distributed energy resources will offer the same grid reliability at lower cost as gas generators by 2026 at gas prices of $5 per million Btu, or by 2040 at $3 per million Btu. Such a shift would place hundreds of billions of dollars of relatively new gas plants in jeopardy of becoming stranded assets (Dyson 2018). To the extent that new LNG terminals are relying on power sector demand, that infrastructure is also at risk of underutilization.

As an example of how competitive renewables are fundamentally changing the power industry, falling orders for natural gas turbines have dramatically impacted the market value of power equipment manufacturer General Electric, which has declined in value from over $350 billion in 2007 to under $90 billion in 2019, including a $23 billion write-down on its investment in the power and grid division of Alstom. According to one analysis, "While financial leverage drove the collapse of GE's value over 2016–2018, the trigger was the halving of global thermal power sector demand." (Buckley 2019a) Figure 10 shows the decline in worldwide orders for gas turbines that drove the fall in GE's market value.

The financial shocks now being experienced in the natural gas sector are reminiscent of similar patterns in the coal sector, where euphoric forecasts of growth based on East Asian demand a decade ago led to overexpansion and financial collapse. In 2010, Peabody Energy Chairman Gregory Boyce predicted that rising demand in China and China's neighboring economies would create "a long-term super-cycle for coal." (Schmidt 2010.) Yet in a relatively short time span, 2011 to 2016, falling coal prices and competitive alternatives forced Peabody Energy along with most other major American coal companies to file for Chapter 11 protection (Nace 2019).

The sort of instability that has afflicted the coal sector similarly threatens the long-term financial viability of fracked gas. As with coal, capital investments in the gas sector must be made under conditions of inherent uncertainty about key factors such as the rate of decline in the cost of renewables and the level of climate regulation a decade in the future. For natural gas, the fact that fracking remains a relatively new practice whose long-term economics are still not well understood adds yet another dimension of risk. After a cross-section of 29 fracking-focused companies found more than $2.5 billion in negative free cash flows in the first quarter of 2019, raising the aggregate negative cash flow from fracking to $184 billion since 2010, analysts at Sightline Institute and the Institute for Energy Economics and Financial Analysis concluded that negative cash flows appeared to be chronic and "should be of grave concern to investors." The analysts wrote, "Until fracking companies can demonstrate that they

Figure 9. Gas Turbine Industry Orders (gigawatts)



Source: GE 2018 Annual Report. Includes turbines 30 megawatts and larger.

can produce cash as well as hydrocarbons, cautious investors would be wise to view the fracking sector as a speculative enterprise with a weak outlook and an unproven business model." (Williams-Derry, 2019.)

Compounding questions of financial risk are widening concerns about the impact of natural gas on global warming. As detailed in the sidebar "Hero to Villain," the perception of gas, especially when produced by fracking and shipped as LNG, has shifted in recent years due to several new findings:

- Estimates of the level of fugitive emissions have risen.
- Estimates of the potency of methane as a global warming gas have also risen.
- Fracked gas, with approximately 50% higher fugitive emissions than conventional natural gas, now dominates the production mix in North America.
- Due to the additional energy demands and opportunities for fugitive emissions involved in liquefaction, shipborne transport, and regasification, LNG is seen as particularly damaging to climate stability.
- In its most recent reports, the IPCC has called for near-term reduction in natural gas production of 15% by 2030 and 43% by 2050, relative to 2020 (see Table 5). Such reductions are not compatible with expansion of the current natural gas system, including the building of new LNG capacity.

METHANE AS A GLOBAL WARMING GAS: 7 KEY NUMBERS

As described in the sidebar, "Hero to Villain: Changing View of Natural Gas," the perception of the benefit or harm of natural gas in a climate-constrained energy system has shifted over the past decade from positive to negative, as climate scientists measure with increasing accuracy the level of leakage throughout the natural gas supply and delivery system and the potency of methane as a global warming gas. While carbon dioxide plays a larger role than methane in global warming, a number of recent findings indicate that the role of methane is larger than previously thought. Seven key numbers illustrate the shift in understanding.

Table 4. Seven Key Methane Numbers

700	In the pre-industrial era, the level of gas was about 700 parts per billion (NASA 2016).
1,850	In 2018, climate scientists reported that atmospheric methane had risen from 1,775 parts per billion in 2006 to 1,850 ppb in 2017 and was growing at an accelerating rate. The rapid growth, which had not been expected, "is sufficient to challenge the Paris Agreement." (Nisbet 2017)
25%	The percentage of global warming to date caused by methane (Myhre 2014).
2.3%	In 2018, a major peer-reviewed study estimated that the leakage rate for the U.S. gas system was 2.3%. The estimate was 60% higher than the figure previously used by the U.S. government in major assessments of natural gas (Alvarez 2018).
86	Compared to carbon dioxide (CO_2), methane (CH_4) is a relatively short-lived but highly potent global warming gas, which remains in the atmosphere for only a decade but during that time has more than 100 times as much effect on global warming as carbon dioxide. Considered over a 20-year horizon, methane's global warming impact is 86 times that of carbon dioxide, according to the most recent IPCC assessment (Myhre 2014).
34	Considered over a 100-year horizon, methane's global warming impact is 34 times that of carbon dioxide, according to the most recent IPCC assessment (Myhre 2014).
25%	In 2016 the authors of the IPCC's 2014 assessment concluded that methane's impact on global warming is about 25% higher than previously estimated, further raising concerns (Etminan 2016).

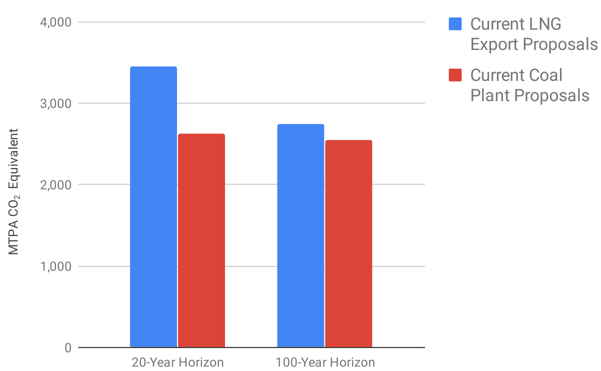
WORSE THAN THE COAL BOOM: MEASURING THE CARBON FOOTPRINT OF THE LNG BOOM

To assess the global warming footprint of the LNG terminal boom, we can compare it to another boom: the expansion of global coal-fired generating capacity. Both expansions involve the construction of massive new facilities with life expectancies of four decades or more.

Currently, over 579 gigawatts (GW) of coal power capacity is under construction or in pre-construction (Shearer 2019). In order to compare that to the 856 million tonnes per year of LNG export capacity under construction or in pre-construction, we need to examine both expansions on the basis of lifecycle emissions for both CO_2 and methane, including all stages from mining or drilling through final consumption. That analysis is detailed in Appendix B. It uses a common basis for comparison known as "CO_2 equivalency" or CO_2e. Since methane (CH_4) in natural gas lasts for only about a decade, but during time has over 100 times the global warming potency of CO_2, determining CO_2e requires that the analysis specify the time horizon over which the global warming averages are being averaged. Analyses of methane typically use two alternative comparisons, one over a 20-year period, the other over a 100-year period. The 20-year horizon is relevant for understanding how greatly methane emissions will affect the climate in the short term; the 100-year horizon is relevant for understanding the long-term effect on climate.

The results of the lifecycle comparison, including fugitive methane emissions, show that current proposals for new LNG terminal capacity, if fully developed, would lock in global warming impacts that are roughly equivalent, when considered on a 100-year horizon, to those of current proposals for new coal-fired power plants. These proposals amount to 574 GW of new coal-fired generating capacity, or 1,214 generating units (Global Coal Plant Tracker, January 2019). When considered on a 20-year horizon, the global warming impact of current proposals for new LNG terminals exceed current proposals for new coal-fired plants by 25%.

Figure 10. Comparing the Life Cycle Global Warming Footprint of Proposed Expansion of LNG-Transported Natural Gas (856.4 MTPA) to the Life Cycle Global Warming Footprint of Proposed Coal Plants, (574 GW). Both Life Cycle estimates in Million Tonnes Per Annum CO_2 Equivalent.



Based on Global Coal Plant Tracker (January 2019) and Global Fossil Infrastructure Tracker (April 2019). For details, see Appendix A.

HERO TO VILLAIN: CHANGING VIEWS OF NATURAL GAS

"With the move to natural gas, it's as if we proudly announced we kicked our Oxycotin habit by taking up heroin instead." —Bill McKibben

Because power plant combustion of natural gas produces about 40% less carbon dioxide than combustion of coal, proponents of natural gas have characterized it as a "bridge" from coal to renewables (Oil Change International 2017, Sightline 2019). However, a full life cycle comparison of both natural gas and coal requires also including the effect of leakages in natural gas production and transportation, since methane (CH_4), the main component of natural gas, is a far more powerful global warming gas than carbon dioxide.

Early life cycle comparisons favor gas. A milestone in addressing the full life cycle impacts of natural gas was the U.S. Department of Energy's 2014 report "Life Cycle Greenhouse Gas Perspectives on Exporting Liquefied Natural Gas from the United States." That report showed lower life cycle greenhouse gas impacts from exporting LNG to overseas power plants than from burning domestic coal (U.S. Department of Energy, 2014).

Updated leakage estimates alter the assessment. The 2014 DOE report was based on the assumption that methane leakage was 1.3% for conventional onshore gas and 1.4% for fracked gas. In 2018, a comprehensive reassessment of methane emissions in the U.S. oil and gas supply chain, based on facility-scale measurements and validated with aircraft observations in areas accounting for about 30% of U.S. gas production, concluded that the overall leakage rate for natural gas was 2.3% of gross U.S. gas production, a figure 60% higher than the U.S. Environmental Protection Agency inventory estimate (Alvarez 2018). At the higher leakage rate, the advantage to using coal disappears. Multiple studies estimate the overall leakage rates even higher than the 2.3% Alvarez estimate, due to the fact that the Alvarez study did not include "downstream" leaks in the distribution of gas. Such leaks account for an additional 2.7 ± 0.6%, according to a study of Boston (McKain 2015).

Fracked gas versus conventional gas. Side-by-side comparisons of conventionally produced gas and gas produced by fracking indicate that fracked gas, also known as "unconventional" gas, is associated with approximately 50% great leakages than conventional gas (Brandt 2014). From 2000 to 2015, the share of fracked gas in U.S. production went from less than 5% to 67%, and continues to rise (US EIA 2016). With the greater share of fracked gas in the overall mix, the relative level of fugitive emissions has correspondingly risen.

Adding shortwave effects shows even more harm from methane. More recently, the authors of the IPCC findings issued a significant revision in their estimate of the relative ratios that incorporated new findings based on the inclusion of shortwave climate forcing. The new findings raise estimates of methane's climate impact relative to carbon dioxide by about 25% (Etminan 2016).

20-Year or 100-Year? Methane has a residence time in the atmosphere of only a decade, but while present its greenhouse warming effect is more than 100 times that of carbon dioxide, on a mass-to-mass basis (Howarth 2015). Averaged over a 20-year time period, the ratio between methane and carbon dioxide, including climate-carbon feedbacks, is 86:1; over a 100-year time period the ratio including climate-carbon feedbacks is 34:1, according to the Intergovernmental Panel on Climate Change (IPCC 2014).

Additional considerations. Increasingly, climate advocates have pointed out that the debate over whether coal or gas is worse from a climate perspective misses a larger point, namely, that according to the most findings of the IPCC, the entire global system must decarbonize by 2050 (Stockman 2019). Replacing old coal infrastructure with new gas infrastructure will lock in a fossil-based system, effectively resetting the clock on system transformation by another 40 or more years. Such a result is incompatible with the mandate that fossil emissions be phased out by mid-century.

IPCC 1.5° findings. The October 2018 report of the IPCC, "Global Warming of 1.5°C," brought new urgency to the need for fossil fuel reductions. As shown in Table 5, which is based on pathways that would allow a 1-in-2 to 2-in-3 chance of limiting global warming to 1.5°C above pre-industrial levels, gas must decline 15% by 2030 and 43% by 2050, relative to 2020.

Table 5. Median primary energy supply (Exajoules) for below IPCC 1.5°C pathways with low overshoot.

	2020	2030	2050
Gas	132.95	112.51	76.03

Source: IPCC, "Global Warming of 1.5°C," Table 2.6, October 2018

CONCLUSION: A MORATORIUM IS NEEDED ON NEW LNG CONSTRUCTION

As shown in Table 2, plans for LNG export terminals includes 45.5 MTPA in projects under construction and 806.9 MTPA in pre-construction projects; for LNG import terminals, plans include 51.4 MTPA in projects under construction and 349.3 MTPA in pre-construction projects. As shown in Table 6, which reflects only projects with known dates and does not account for schedule slippage, a large amount of capacity has announced dates prior to 2026 and may be close to entering construction. Given the climate mandate that natural gas be scaled back over the next decade, not to mention the risk to investors of stranded assets and financial losses from overbuilding, a sensible approach to the question of LNG terminal expansion would be a moratorium on further construction.

Table 6. LNG Terminal Projects in Pre-Construction, including Export and Import, by Announced Start Year (million tonnes per annum)

Start Year	MTPA
2019	99
2020	71
2021	69
2022	162
2023	63
2024	58
2025	112
2026	37
2027	21
2028	0
2029	0
2030	20
Total	**712**

Source: Global Fossil Infrastructure Tracker, April 2019

APPENDIX A. THE COAL MINING EQUITIES CRASH

On April 13, 2016, the largest U.S. coal company, Peabody Energy, declared bankruptcy. By that point four other major companies had already filed for Chapter 11 protection: Arch Coal, ANR, Patriot Coal, and Walter Energy. One analyst called it "the day coal died in the United States."

What's striking is how fast the coal industry went from boom to bust. In 2010, forecasts about the future of global coal demand closely resembled today's optimistic forecasts about growing global demand for natural gas. Those optimistic expectations were reinforced by a strong upward trend in coal prices, with benchmark coal prices increasing from $100 per tonne in January 2010 to $140 per tonne in January 2011. In early 2011, coal mining company stocks hit an all-time high, as promoters predicted a "super cycle" of growth based on China's domestic consumption. In its *World Energy Outlook 2010*, the IEA projected that the coal mining industry would see continued growth, including a 38% increase in Chinese production from 2008 to 2015, supporting coal-supply infrastructure investment of $720 billion in the period 2010–2035.

Figure 11. Peabody Energy stock chart, 2011–2016

Based on the confluence of indicators pointing safely toward an ongoing boom, coal mining companies took on increased debt as they undertook aggressive ramp-ups in new acquisitions of mines and investments in new mines.

In retrospect, the warning signs were clear, and the parallels with today's gas boom particularly striking:

- Mining companies were convinced that coal, long touted as the cheapest fuel, would maintain that advantage into the future. Similarly, today's boom in North American LNG terminals is based on a belief that the fracking boom has given North American producers a long-term advantage in global markets. But just as the fracking revolution enabled natural gas to push coal out of North American power markets, today plunging solar and wind cost structures threaten to similarly drive the displacement of natural gas.
- Mining companies, along with their political allies in Washington, D.C., and other capitals, failed to factor growing global concern over carbon pollution and other environmental impacts into their growth calculations. Yet as of early 2019, over 24 governments had committed to phasing out coal and over 100 banks and other financial lenders had instituted restrictions on coal financing.

APPENDIX B. METHODOLOGY

The Global Fossil Infrastructure Tracker uses a two-level system for organizing information. Summary data is maintained in Google sheets, with each spreadsheet row linked to a page on the SourceWatch wiki. Each wiki page functions as a footnoted fact sheet, containing project parameters, background, and mapping coordinates. Each worksheet row tracks an individual LNG plant unit. Under standard wiki convention, each piece of information is linked to a published reference, such as a news article, company report, or regulatory permit. In order to ensure data integrity in the open-access wiki environment, Global Energy Monitor researchers review all edits of project wiki pages by unknown editors. For each project, one of the following status categories is assigned and reviewed on a rolling basis:

- **Proposed:** Projects that have appeared in corporate or government plans in either pre-permit or permitted stages.
- **Construction:** Site preparation and other development and construction activities are underway.
- **Shelved:** In the absence of an announcement that the sponsor is putting its plans on hold, a project is considered "shelved" if there are reports of activity over a period of two years.
- **Cancelled:** In some cases a sponsor announces that it has cancelled a project. More often a project fails to advance and then quietly disappears from company documents. A project that was previously in an active category is moved to "Cancelled" if it disappears from company documents, even if no announcement is made. In the absence of a cancellation announcement, a project is considered "cancelled" if there are no reports of activity over a period of four years.
- **Operating:** The plant has been formally commissioned or has entered commercial operation.
- **Mothballed:** Previously operating projects that are not operating but maintained for potential restart.
- **Retired:** Permanently closed projects.

To allow easy public access to the results, Global Energy Monitor worked with GreenInfo Network to develop a map-based and table-based interface using the Leaflet Open-Source JavaScript library. The public view of the Global Fossil Infrastructure Tracker can be accessed at http://ggon.org/fossil-tracker/.

APPENDIX C. LIFE CYCLE GREENHOUSE GAS COMPARISON OF GLOBAL COAL PLANT DEVELOPMENT AND GLOBAL LNG TERMINAL DEVELOPMENT

To compare the impacts of the two fossil fuel categories—increased production and consumption associated with LNG terminals and increased coal production and consumption associated with new coal-fired power plants—we consider the full life cycle impacts from wellhead or coal mine through combustion. The results are shown in Table 7.

For coal, greenhouse gas impacts are mainly in the form of the carbon dioxide produced by coal-fired power plants. Additional global warming impacts result from the venting and leaking of methane from coal mines, and from releases of carbon dioxide by trains and ships.

The comparison between coal and gas requires converting any impacts from fugitive methane emissions into the atmosphere into a CO_2 equivalent. For natural gas, fugitive emissions occur throughout the production cycle, including well site, processing, transmission, storage, liquefaction, and distribution. Some methane "boils off" during ocean transit but is recaptured and burned by ship engines; methane is also combusted to fuel the liquefaction process and by end-use applications such as industrial heating or power generation.

Coal mining produces significant amounts of methane due to outgassing of coal seams. Such emissions are dramatically higher in underground mines. This analysis assumes that approximately equal shares of coal are produced globally by underground and surface mining. The analysis does not include combustion emissions resulting from the powering of natural gas wellhead or coal mining operations.

Table 7. Comparison between the greenhouse gas emissions enabled by pre-construction and in-construction coal plants (573 gigawatts) and the pre-construction and in-construction LNG export terminals (772 million tonnes per annum), based on 2018 utilization rates. Emissions in million tonnes CO_2 equivalent per annum.

Source of Emissions	Natural gas (20-year Horizon)	Coal (20-year Horizon)
Supply Chain Fugitive Methane	1,339	335
LNG Liquefaction	237	
LNG Transport	130	
LNG Regasification	8	
Coal Transport (ship)		11
Coal Transport (rail)		40
Combustion	1,733	2,361
Total	**3,446**	**2,747**

Source of Emissions	Natural gas (100-year Horizon)	Coal (100-year Horizon)
Supply Chain Fugitive Methane	529	133
LNG Liquefaction	221	
LNG Transport	130	
LNG Regasification	8	
Coal Transport (ship)		10
Coal Transport (rail)		40
Combustion	1,733	2,361
Total	**2,621**	**2,544**

Coal emissions are based on coal plants in pre-construction or construction as estimated by the Global Coal Plant Tracker, January 2019, in "Coal Plants by Country: Annual CO_2 (Million Tonnes) at http://bit.ly/31yblfC. For natural gas, emissions are based on LNG export terminals in pre-construction or construction as reported in Table 6 of this report, assuming the 2018 average global utilization rate of 79.04%. Supply chain methane leakage is assumed to be 2.3% (Alvarez 2018). Liquefaction, transport, regasification emissions are based on estimates by Pace Global (Pace 2015). In addition to the carbon dioxide emissions from coal, the estimate includes methane leakage from coal mines based on the assumption that half of thermal coal comes from surface mines, with an average of 8 cubic feet of methane released per short ton of coal, and half comes from underground mines, with an average of 360 cubic feet per short ton of coal (US DOE 2014). Coal shipping emissions are based on 2015 global CO_2 emissions for bulk shipping estimated by the International Council on Clean Transportation (Olmer 2017) of which 18.75% is thermal coal (Open Seas 2019). Coal rail emissions are based on 51.5 million tonnes per year CO_2 from total rail transport in the U.S. (Association of American Railroads 2008), of which 13% was coal (AARC 2016), scaled globally based on U.S. share of global thermal coal production (WEO 2018).

For additional methodology notes, see: Comparison of GHG Emissions for Proposed Terminals and Coal Plants, SourceWatch. http://bit.ly/2KKz5Y8

APPENDIX D: CAPITAL EXPENDITURES BY COUNTRY

The table below (Table 8) provides estimates by country for LNG projects (both export and import) in pre-construction and construction stages. Costs are based on International Gas Union estimates of $1,501 per tonne of annual capacity for greenfield export (i.e. liquefaction) projects, $458 per tonne for brownfield export projects, and $274 per tonne for greenfield and brownfield import (i.e. regasification) projects (IGU 2018).

Table 8. Capital Investments for LNG Terminals Under Development by Top 20 Countries (Billion US$)

Country	Pre-Construction	Construction	Total
USA	469.4	37.4	506.8
Canada	410.1	0.0	410.1
Russia	82.6	3.0	85.6
Australia	37.5	0.0	37.5
Tanzania	24.8	0.0	24.8
China	21.5	2.4	23.9
Indonesia	17.1	6.5	23.5
Mozambique	18.0	5.1	23.1
Iran	21.0	0.0	21.0
Papua New Guinea	17.3	0.0	17.3
Nigeria	15.0	0.0	15.0
India	8.1	2.7	10.8
Mexico	10.5	0.0	10.5
Cyprus	7.9	0.0	7.9
Equatorial Guinea	6.3	0.0	6.3
Algeria	6.0	0.0	6.0
Senegal	3.8	0.0	3.8
United Kingdom	3.3	0.0	3.3
Japan	3.2	0.0	3.2
Kuwait	0.0	3.1	3.1
Other	48.6	9.6	58.1
Total	**1,231.9**	**69.8**	**1,301.6**

Sources: Capacity estimates from Global Fossil Infrastructure Tracker, April 2019; Capital costs from IGU 2018.

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