LNG Supply Chains: a supplier-specific life cycle assessment for improved emissions accounting

ACS Sustainable Chemistry & Engineering

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Built for the Challenge

Building a company that can help meet the world’s energy needs while integrating sustainability into our business

February
- Cargo Emissions Tags
  - Cheniere to provide estimated greenhouse gas emissions data associated with each LNG cargo to customers in 2022

March
- Climate Scenario Analysis
  - Analyzed long-term resilience of Cheniere’s business in various future climate scenarios through 2040

April
- Shipping Emissions Study
  - First study to directly measure methane emissions from an LNG carrier completed

May
- QMRV Collaboration
  - Collaboration with natural gas suppliers and academic institutions to quantify, monitor, report, and verify GHG emissions at natural gas production sites

June
- 2020 CR Report
  - Published 2020 Corporate Responsibility report which highlights Cheniere’s resiliency, responsible operations and response to COVID-19

July
- Life Cycle Assessment
  - First-of-its-kind peer-reviewed, LNG life cycle assessment published in the American Chemical Society Sustainable Chemistry & Engineering Journal

August
Framework for customized life cycle GHG assessments for LNG supplies

LNG Supply Chains: A Supplier-Specific Life-Cycle Assessment for Improved Emission Accounting

Selina A. Roman-White, James A. Littlefield, Kaitlyn G. Fleury, David T. Allen, Paul Balcombe, Katherine E. Konschnik, Jackson Ewing, Gregory B. Ross, and Fiji George*
Key study findings

National or regional average supply chains do not accurately represent unique supply chains
  • Individual supplier GHG performance varies significantly
  • Our supply-chain specific GHG is 30-43% lower than other studies employing average values to estimate U.S. LNG emissions

Supply chain emissions upstream of end use are significant
  • Upstream (prior to power plant) GHG emissions are > 30% of total GHG emissions on a CO₂e basis
  • Methane emissions matter: ~ 8-18% of the total GHG emissions (100-yr to 20-yr basis)

Coal supply chains are also variable due to upstream methane emissions
  • Characterizing this variability is important for quantifying the benefits of coal to gas switching

Characterizing the GHG intensity of specific gas supplies via LCAs is critical for informing differentiated gas supply, as well as informing policy and decision makers looking to develop climate strategies
  • Ex: a 50% reduction in methane emissions results in 14-24% reduction in lifecycle emissions from production through liquefaction
LCA model concept

LCA modeling consistent with ISO 14040, 14044, and 14067
Built from the NETL LCA Model Framework and employs life cycle principles, not a simple aggregation of individual supplier inventories
1. National Energy Technology Laboratory (NETL) Lifecycle Model for upstream natural gas emissions. Model is data driven, highly parameterized, and open source. Includes emissions for production, gathering & boosting, processing, and transmission.

2. Includes CO2 vented from the AGRUs that is not currently reported under the GHGRP program. Also includes electricity purchases where applicable.

LCA model structure

- Cheniere Lifecycle Analysis Model (CLAM)
  - Published Upstream NETL Model
  - Upstream Emissions & Losses
  - Cheniere Liquefaction Unit Process
  - SPL & CCL Specific Liquefaction Data
  - EPA GHGRP Data
  - EPA GHGI Data
  - Published Literature
  - Cheniere Data
  - Supplier Self-Reported Data

- Shipping Unit Process
  - EPA GHGRP Data
  - EPA GHGI Data
  - Published Literature

LCA Results
- Detailed Characterization Of GHG Emissions Intensity
- Lifecycle Emissions Intensity (Tonne CO2e/Tonne LNG)

1. National Energy Technology Laboratory (NETL) Lifecycle Model for upstream natural gas emissions. Model is data driven, highly parameterized, and open source. Includes emissions for production, gathering & boosting, processing, and transmission. Includes CO2 vented from the AGRUs that is not currently reported under the GHGRP program. Also includes electricity purchases where applicable.
<table>
<thead>
<tr>
<th>Key differences between this study and NETL LNG Report</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Upstream Supply Chain</strong></td>
</tr>
<tr>
<td>Our study represents Cheniere’s 2018 supply chain, and includes modeling updates to the latest state of the science, namely for gas flaring and transmission compression operations</td>
</tr>
<tr>
<td><strong>Liquefaction</strong></td>
</tr>
<tr>
<td>Our study models Sabine Pass Liquefaction operations, utilizing actual plant data and emissions reporting</td>
</tr>
<tr>
<td><strong>Ocean Transport</strong></td>
</tr>
<tr>
<td>Our study employs a first of its kind customized ocean transport model that uses actual fuel consumption data supplemented with proprietary data sources, characterizing every cargo loaded at SPL in 2018</td>
</tr>
<tr>
<td><strong>Power Generation</strong></td>
</tr>
<tr>
<td>Our study employs market-specific natural gas power plant efficiencies calculated based on IEA reports, as well as includes the transmission pipeline between regasification and the power plant</td>
</tr>
</tbody>
</table>
Supply chain accounting matters: production to regasification

- We compare our study to two other LNG studies that examined U.S. LNG exported to China.
- We estimate a GHG intensity 30-43% lower than Gan et al. and NETL studies (100-yr to 20-yr GWP basis).
- Gan et al. and NETL employ national and regional average estimates to represent the supply chain. We find these estimates to not be representative of specific supply chains.
- Key drivers of differences in GHG intensity are the production, G&B, transmission, and ocean transport stages.
Methane vs. carbon dioxide across the supply chain

100-year CO₂ vs. CH₄ Life Cycle Emissions of Cheniere LNG Delivered to China (through busbar)

20-year CO₂ vs. CH₄ Life Cycle Emissions of Cheniere LNG Delivered to China (through busbar)

Production through Liquefaction CH₄ Emission Rate: 0.65%
Production through Shipping CH₄ Emission Rate: 0.90%
We estimate the average GHG intensity on a DES basis (production through ocean transport) for each market served in 2018:

- We model a round trip voyage (laden and ballast)

Within a market, there is variability between the GHG intensity of individual cargoes due to voyage duration and differences in vessel performance:

- Neighboring countries have different profiles – voyage duration alone cannot explain this
- The differences in ocean transport intensity are driven by a combination of voyage distance and propulsion system of the LNG carrier (performance)
Vessel choice: case study

- The importance of vessel choice is magnified over longer distances.
- For the UK, the difference between DFDE/TFDE cargoes (high slip, lower efficiency) and XDF cargoes (lower slip, higher efficiency) is only 5%.
- For China, the difference is a 14% lower GHG intensity on a DES basis.
- Additional work is necessary to better understand methane slip rates in main propulsion and auxiliary engines.
Methane emissions intensity

LNG Exported to China: CH₄ Emission Rate

LNG Exported to UK: CH₄ Emission Rate

Total CH₄ emission rate:
- China: 0.90%
- UK: 0.74%
Quantifying coal to gas switching benefits: China case study

- We used the latest published science to estimate the GHG intensity of coal-fired power generation in China.
- Recent studies have shown that coal mine methane may be much more significant than previously thought, and highly variable.
- Quantifying CMM emissions for specific coal supply chains will be important for understanding the benefits of coal to gas switching.
- We estimate Cheniere’s LNG exported to China for power generation to be 47-57% less GHG intense than coal power generation on an equivalent MWh basis (100-yr and 20-yr GWP basis).
Sensitivity to methane emission rate

- Cheniere’s 2018 SPL baseline methane emission rate is 0.65% (production through liquefaction).
- We conducted a sensitivity analysis to measure the impact of upstream (production through transmission) methane emission reduction on the overall profile.
- The sensitivity was technology agnostic.
- We estimate that a 50% reduction in upstream methane would result in a 14% reduction in 100-yr GHG CO₂e intensity, and a 24% reduction on a 20-yr GWP basis.

![Graph showing sensitivity to methane emission rate](image-url)
Sensitivity to underreporting in the GHGRP Inventory

- We estimated the impact of certain modeling decisions on the LCA result, using the UK and China as case studies.
- We use recent work by Lyon et al. and Rutherford et al. to look at Permian flaring efficiency, Production and G&B fugitive emissions, and Production and G&B tanks.
- On a cradle through regas basis, the impact ranges from less than 1% to 37% from the baseline depending on parameter.
- These sensitivity results do not impact the fundamental conclusions of this study, the modeling framework is data agnostic and still valid for customized LCA of LNG supply chains.
Policy implications

Customized LCA models are needed to assess the intensities of different gas supplies for policy and commercial considerations

• There are wide variations in emission intensities across different supply chains
• Use of generic or regional emissions data, or simply an aggregation of inventory estimates in each segment does not provide an accurate representation of emissions
• All relevant emission sources and segments of the supply chain should be considered
• Our LCA model provides a framework for improved GHG accounting

CO₂ is the dominant GHG source from “cradle to busbar” but CH₄ matters

• Key segments: production, gathering & boosting, transmission and shipping segments

LCA modeling provides customers and policymakers the information to integrate climate and trade/commercial policies
Thank you

Questions?
Appendix
**Methods and data sources**

**Cheniere Supplier Data (Production Through Pipeline)**
- GHGRP Facility Reports
- Producer Self-Reported non-GHGRP facilities
- Cheniere Gas Supply Purchasing Records
- Cheniere Pipeline Deliveries

**Data Collection and Verification**

**Data Processing and Parameter Creation**

**Published NETL Upstream Model**

**Cheniere Lifecycle Analysis Model (CLAM)**

**LCA Results**

**Cheniere Liquefaction Unit Process**
- GHGRP Facility Reports
- Pipeline Deliveries
- Operations Data
- Composition Data

**Cheniere Shipping Unit Process**

**LNG Ocean Transport Data**
- Cheniere Voyage Data
- Kpler
- Form B “Particulars of the Vessel”
- Engine Manufacturer Specifications

**Total Life Cycle GHG Intensity, Cradle through X, tonne CO2e/tonne NG**

**GHG Contribution of Each Emission Source, Normalized to Functional Unit**
### Baseline Production through Liquefaction Results, tonne CO$_2$e/tonne LNG

<table>
<thead>
<tr>
<th>Stage</th>
<th>100-yr GWP</th>
<th>20-yr GWP</th>
</tr>
</thead>
<tbody>
<tr>
<td>Production</td>
<td>0.13</td>
<td>0.26</td>
</tr>
<tr>
<td>Gathering &amp; Boosting</td>
<td>0.10</td>
<td>0.16</td>
</tr>
<tr>
<td>Processing</td>
<td>0.16</td>
<td>0.21</td>
</tr>
<tr>
<td>Transmission Compressor Stations</td>
<td>0.15</td>
<td>0.21</td>
</tr>
<tr>
<td>Transmission Storage</td>
<td>0.01</td>
<td>0.02</td>
</tr>
<tr>
<td>Transmission Pipeline</td>
<td>0.01</td>
<td>0.03</td>
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<tr>
<td>Liquefaction</td>
<td>0.26</td>
<td>0.26</td>
</tr>
<tr>
<td>Total</td>
<td>0.82</td>
<td>1.15</td>
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<tr>
<td>P2.5</td>
<td>0.63</td>
<td>0.86</td>
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<tr>
<td>P97.5</td>
<td>1.05</td>
<td>1.51</td>
</tr>
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</table>
### Backup slides – detailed results tables

**Baseline Production through Regasification Results, tonne CO₂e/tonne natural gas regasified**

<table>
<thead>
<tr>
<th>Stage</th>
<th>United Kingdom</th>
<th>China</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>100-yr GWP</td>
<td>20-yr GWP</td>
</tr>
<tr>
<td>Production</td>
<td>0.13</td>
<td>0.27</td>
</tr>
<tr>
<td>Gathering &amp; Boosting</td>
<td>0.11</td>
<td>0.16</td>
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<tr>
<td>Processing</td>
<td>0.17</td>
<td>0.22</td>
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<tr>
<td>Transmission Compression</td>
<td>0.15</td>
<td>0.21</td>
</tr>
<tr>
<td>Transmission Storage</td>
<td>0.01</td>
<td>0.02</td>
</tr>
<tr>
<td>Transmission Pipeline</td>
<td>0.01</td>
<td>0.03</td>
</tr>
<tr>
<td>Liquefaction</td>
<td>0.27</td>
<td>0.27</td>
</tr>
<tr>
<td>Ocean Transport</td>
<td>0.13</td>
<td>0.17</td>
</tr>
<tr>
<td>Regasification</td>
<td>0.01</td>
<td>0.01</td>
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<tr>
<td>Total</td>
<td>0.98</td>
<td>1.36</td>
</tr>
<tr>
<td>P2.5</td>
<td>0.78</td>
<td>1.05</td>
</tr>
<tr>
<td>P97.5</td>
<td>1.25</td>
<td>1.77</td>
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</table>
## Baseline Production through Power Generation Results, kg CO₂e/MWh (busbar)

<table>
<thead>
<tr>
<th>Stage</th>
<th>United Kingdom</th>
<th>China</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>100-yr GWP</td>
<td>20-yr GWP</td>
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<tr>
<td>Production</td>
<td>18.4</td>
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<td>Gathering &amp; Boosting</td>
<td>14.9</td>
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<tr>
<td>Processing</td>
<td>23.7</td>
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<td>Transmission Compression</td>
<td>21.4</td>
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<td>Transmission Storage</td>
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<td>Transmission Pipeline</td>
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<tr>
<td>Liquefaction</td>
<td>37.3</td>
<td>37.7</td>
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<tr>
<td>Ocean Transport</td>
<td>17.9</td>
<td>23.5</td>
</tr>
<tr>
<td>Regasification</td>
<td>1.4</td>
<td>1.4</td>
</tr>
<tr>
<td>Foreign Transmission</td>
<td>2.8</td>
<td>3.3</td>
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<tr>
<td>Power Generation</td>
<td>384.7</td>
<td>384.9</td>
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<tr>
<td>Total</td>
<td>525.7</td>
<td>580.0</td>
</tr>
<tr>
<td>P2.5</td>
<td>492.5</td>
<td>531.3</td>
</tr>
<tr>
<td>P97.5</td>
<td>567.6</td>
<td>642.3</td>
</tr>
</tbody>
</table>
Backup slides - drilldowns
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Production through Regas GHG Emissions

(tCO2e/t NG, 100-yr GWP)

Cumulative Contribution to Total Life Cycle Production through Regasification

Production through Regasification

Composition:
- CO2
- CH4
- N2O

Cumulative Contribution

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