



ICF Methane Emissions Estimator Documentation

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ICF Methane Emissions Estimator Documentation

Introduction

Overview/Purpose

The methane emissions estimator is a tool that allows an informed analyst to estimate the life-cycle methane emissions for gas delivered to a specific gas local distribution company (LDC). The tool is an Excel spreadsheet with tabs for each segment of the natural gas value chain – production, gathering, processing, transmission and storage, and distribution. The tool provides several different potential values for each segment and allows the user to select which one to use. The tool shows emissions in pounds of methane or as pounds of CO₂ equivalent (CO₂e) based on a global warming potential (GWP) selected by the user.

The tool relies on two primary data sources:

- Inventory of U.S. Greenhouse Gas Emissions and Sinks¹ – This is the U.S. EPA’s annual official report on U.S. greenhouse gas (GHG) emissions to the UN Framework Convention on Climate Change (UNFCCC). It is the most detailed and comprehensive estimate of U.S. GHG emissions but it is based on emission factors and is not a unit-by-unit inventory and has limited regional detail.
- Greenhouse Gas Reporting Rule² – This is a U.S. EPA program that requires reporting from entities that emit more than 25,000 tons per year of GHG. It includes data from specific companies at specific locations but does not include all emitters or all emissions due to the size threshold.

Both of these sources are updated annually and are subject to variability, especially the individual company values in the GHGRP. Thus we have one comprehensive data source with limited detail and one more detailed source with limited coverage. The data are converted to emissions per 1,000 cubic feet (Mcf) of throughput in order to provide consistency and easier manipulation of the results. The results are presented both as kg/Mcf and ktonnes/year.

The tool also incorporates an adjustment factor based on studies coordinated by the Environmental Defense Fund (EDF). EDF organized a series of methane measurement studies in the oil and gas industries. A final integrating study applied statistical analysis to account for intermittent occurrences and “super-emitter” events.³ This study was compared to the 2016 EPA inventory. ICF has attempted to disaggregate this comparison analysis to provide an adjustment factor for each industry segment (except distribution, which was not included in the EDF analysis). For each segment in this tool, there is a value based on the U.S. inventory and a second factor scaled by the adjustment in the EDF study. The publicly released EDF analysis does not provide regional detail.

¹ <https://www.epa.gov/ghgemissions/inventory-us-greenhouse-gas-emissions-and-sinks>

² <https://www.epa.gov/ghgreporting>

³ Assessment of methane emissions from the U.S. oil and gas supply chain.
<http://science.sciencemag.org/content/361/6398/186>.

The remainder of this document provides a user guide and additional documentation of the data sources and processing.

User Guide

Instructions

The emissions estimator is an Excel spreadsheet. There are several tabs with data that do not require any interaction from users but could be used in the future to update the data or as a reference for those interested in the data sources. (See section on data sources.) For regular users of the tool, the tabs of interest are the Case Definition/Results tab and a tab for each segment of the natural gas value chain – Distribution, Transmission and Storage, Processing, Gathering, and Production. Each of these is described below.

Case Definition and Results

This tab is the location for the primary user inputs.

Primary Input Table

User Inputs in Blue	Recommended Values	User-Defined Value (if applicable)
Demand Location Methodology	By LDC	
LDC Annual Deliveries Methodology	GHGRP	
LDC Name	Brooklyn Union Gas Co	
City	Brooklyn	
State	NY	
GHGRP Annual Deliveries (Mcf)	184,283,034	
GWP Methodology	100 Year w/Oxidation	
GWP Value	36	

- Demand Location Methodology – The user specifies whether they would like to choose a specific LDC or a State/Region.
- LDC Annual Deliveries Methodology – If the user chooses “By LDC” as the demand location methodology, then they can choose between three methodologies for providing the annual gas deliveries. If the user chooses “GHGRP” or “EIA/State PUC”, then it will be automatically populated. If the user chooses “User-Defined” or if no internal data available, then they can fill in the annual deliveries in the blue box that appears to the right.
- LDC Name – This is the name of the LDC of interest to the user. There is a drop-down list of 1,220 LDCs that are in the GHGRP and the Energy Information Administration (EIA) databases. If the desired LDC is not on the list, the user can specify “By State/Region” in the “Demand Location Methodology” section and then provide a location in the “State” drop-down and annual deliveries in the blue box below it.
- City and State – These fields specify the location of the selected LDC. If the LDC is selected from the drop-down list, this information is automatically supplied. If the user specifies a State/Region, the state must be supplied by the user.
- Annual gas deliveries – The annual quantity of natural gas delivered by the LDC in 1,000 cubic feet (Mcf). If the LDC is selected from the drop-down list, this information is automatically supplied. If the user specifies a state/region or chooses an LDC Annual

Deliveries Methodology of “User-Defined”, this information must be supplied by the user. The user can also choose to supply a value to override the value supplied by the model.

- Global Warming Potential (GWP) methodology – The GWP is a factor that converts from units of methane to CO₂e. The available values are listed in the adjacent table. The values vary widely depending on whether the factor is evaluated over a 20 year or 100 year lifetime. (See appendix for discussion.)
- Supply Definition – The user must specify the sources of gas distributed by the LDC. The user can specify up to eight supply basins with an associated percentage of the LDC supply portfolio. There is a drop-down list of supply basins defined in the GHGRP. The share percentage of the selected basins must total to 100%. The distance from each basin to the LDC is calculated automatically.

Global Warming Potential Values		
	20 Year	100 Year
Without Feedback	84	28
With Feedback	86	34
With Oxidation	87	36

Map of Available Supply Basins



Map Source: ABB Velocity Suite

The remainder of this tab displays the results of the calculations. The results are summarized in a tabular format with all of the results for each segment shown in a table. In addition, the user can add a user-defined value for each segment in the last column on the right. There is a drop-down list for each segment that allows the user to select which calculated result to use.

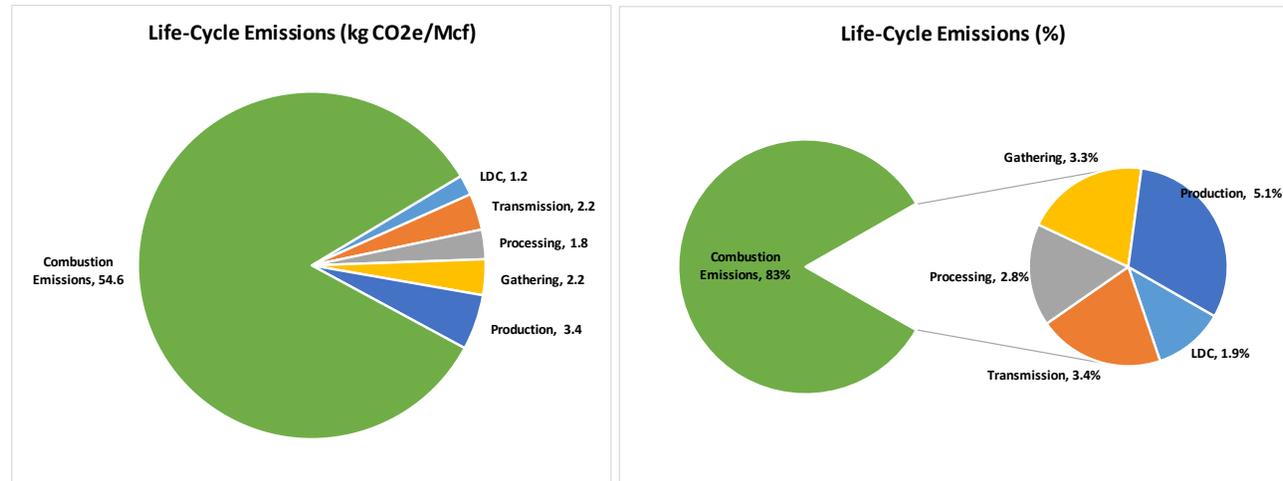
Results Summary/Selection Table

	Emissions Factor Data Source (Pick One)	kg CH4/Mcf				
		GHGRP	Inventory Average	Local data	EDF Adjustment	User-Defined
LDC	Inventory Average	0.050	0.035	0.03	N/A	0.040
Transmission	GHGRP	0.062	0.052	N/A	0.069	0.050
Processing	User-Defined	0.002	0.022	N/A	0.036	0.050
Gathering	Inventory Average	0.028	0.060	N/A	0.079	0.050
Production	EDF Adjustment	0.046	0.072	N/A	0.093	0.050

The selected values for each segment are then shown in the final summary table as kTonnes and kg/Mcf of methane and of CO₂e based on the selected GWP. The result is also compared to the emissions from the end use combustion of the gas – 54.6 kg CO₂/Mcf. The results are also shown in graphical form.

Final Results Summary

Final Results (Emissions)						
Final Results	CH4			CO ₂ e		
	kTon/yr	kg/Mcf	kTon/yr	kg/Mcf	Proportion	
LDC	6,378.51	0.03	229,626.36	1.25	12%	
Transmission	11,333.71	0.06	408,013.59	2.21	21%	
Processing	9,214.15	0.05	331,709.46	1.80	17%	
Gathering	11,115.77	0.06	400,167.64	2.17	20%	
Production	17,189.38	0.09	618,817.56	3.36	31%	
Total Methane	55,231.5	0.30	1,988,335	10.8		
Combustion Emissions				54.6		



LDC Tab

The LDC tab displays the results calculated for the selected LDC and allows the user to supply alternative information. The LDC emissions are those related to the local gas supply mains and service lines, customer meters, regulators, valves, etc. There are two results that are calculated automatically. The first is based on the U.S. Inventory average emission rate for LDCs. It is the total LDC emissions in 2016 from the national inventory (480 kt) divided by total U.S. LDC deliveries as reported by the U.S. EIA (13.9 Tcf). That value is 0.03 kg methane/Mcf and is multiplied by the selected LDC throughput to calculate a total kTonnes/year value. The second calculated value is the emissions in kg methane/Mcf reported to the GHGRP by the selected utility divided by the quantity of gas reported by that reporter.

For LDCs the user can also calculate a site-specific value based on local characteristics and emission factors used in the EPA inventory e.g. the “Source Specific Method Using EPA Factors” or “Local Data”. To do this, the user can fill in the blue boxes in the “U.S. GHG Inventory Source Specific Methodology Intermediate Calculations” section at the bottom of the LDC tab. In this case, the user must obtain characteristics such as miles of different kinds of mains, numbers of customer meters, etc. Local users might be able to obtain these characteristics directly from the utility. Many of the pipeline mileage, leaks, and maintenance numbers can be obtained for larger utilities by searching the PHMSA database. All of the results are carried over to the results tab. There is no EDF-adjusted factor for LDCs. All results are carried over to the results tab.

Transmission and Storage Tab

The transmission tab displays the results calculated for the pipelines that would deliver gas from each of the selected supply areas to the selected LDC. These are primarily interstate pipelines though it includes intrastate pipelines in some states, especially California and Texas. The emissions are largely from the compressor stations, including pneumatic controls, venting from seals, blowdowns, etc. It also includes emissions from the pipelines, including blowdowns.

The first value calculated is the national average value based on the U.S. inventory estimate in 2016 for transmission and storage (1,311 Ktonnes) divided by the total volume of gas delivered to customers (25.2 Tcf), as depicted by EIA. Dividing the emissions by throughput yields an emission factor of 0.05 kg methane/Mcf. That value is multiplied by the LDC deliveries to calculate the total kTonnes per year. The second value calculated is based on data as reported in GHGRP. This value is a function of both compressor stations and pipeline systems and accounts for gas transmission emissions. For compressor stations, the emission factor was calculated in kg methane/Mcf gas transferred using GHGRP emissions and gas throughputs from PointLogic. PointLogic maintains a database of reported throughputs from compressor stations that are located on interstate natural gas pipelines. PointLogic sources the throughputs from the pipeline informational bulletin boards, which are publicly available. The compressor stations for which emissions data was available in the GHGRP database and throughput data was available in the PointLogic database were mapped to each other so that emissions factors for each compressor station could be calculated. For pipeline systems, a more involved process was used to determine a factor that accounts for the states in which the gas must travel based on the supply region. This generic pipeline pathway was defined for each city/basin pair and the emission rates for each state were calculated and added to estimate pipeline emissions. A more detailed discussion of this process is included in the segment documentation. There is also a value that incorporates the EDF adjustment factor of 1.33 times the U.S. inventory national average value.

The storage emissions were included as part of the total value and implicitly prorated across all transmission operations. Because storage is used differently by different companies and in different years, it was not possible to directly calculate storage-related emissions for each LDC. All results are carried over to the results tab.

Processing Tab

This tab calculates emissions from gas processing plants. These plants remove impurities, natural gas liquids, and non-hydrocarbon gases (including CO₂) from the raw gas. However, some gas is

clean enough to be used without processing and does not need to be processed. For this reason, the tool estimates how much of the gas in each supply basin must be processed, which is used to prorate the applicable emission factor. Once again, two emission factors are calculated. The first is the national average based on the national inventory estimate of emissions for processing in 2016 (448 kt CH₄) divided by the total amount of gas processed according to EIA (20.4 Tcf). This average factor is 0.02 kg methane/Mcf and is applied to the gas deliveries for the selected LDC. The second factor is based on GHGRP data for processing in each of the selected supply basins for the selected LDC. Emissions were considered from GHGRP reporting at the processing plant level, and mapped to relevant EIA gas processing volumes to determine a factor in kg methane/Mcf. These values were then aggregated at the basin level, which were then applied to delivered LDC volumes based on the specified supply basins. There is also a value that incorporates the EDF adjustment factor of 1.62 times the U.S. inventory national average value. All results are carried over to the results tab.

Gathering Tab

Gathering systems include the short-distance pipes that bring gas to a processing plant or a pipeline hub where the gas enters a transmission system. They also include dehydrators and other equipment that performs initial gas clean-up and liquids removal. The gathering tab calculates a national average emission value based on the U.S. inventory and a regional value based on GHGRP reporting by basin. The national average emissions value is based on the national inventory estimate of emissions for gathering in 2016 (1,966 kt CH₄) divided by the total amount of gas produced according to EIA (32.6 Tcf). This average factor is 0.06 kg methane/Mcf and is applied to the gas deliveries for the selected LDC. The regional values for the specified supply basins are combined on a weighted basis. There is also a value that incorporates the EDF adjustment factor of 1.31 times the inventory national average value. All results are carried over to the results tab.

Production Tab

The production tab estimates emissions from exploration, completion, and continuing gas production at the gas wellhead. The production tab calculates a national average emission value based on the U.S. inventory and a regional value based on GHGRP reporting by basin. The national average emissions value is based on the national inventory estimate of emissions for production in 2016 (2,336 kt CH₄) divided by the total amount of gas produced according to EIA (32.6 Tcf). This average factor is 0.07 kg methane/Mcf and is applied to the gas deliveries for the selected LDC. The regional GHGRP values for the specified supply basins are combined on a weighted basis. There is also a value that incorporates the EDF adjustment factor of 1.3 times the inventory national average value. All results are carried over to the results tab.

Industry Segment Documentation

Applicable Data Sources

U.S. EPA Inventory

Annually, the United States Environmental Protection Agency generates estimates for greenhouse gas emissions from natural gas sources as part of the national inventory process.⁴ The inventory estimates individual emission sources using emission factors (emissions per piece of equipment or throughput) and activity factors (e.g. counts of equipment or throughput) and then multiplies these to get total emissions by emission source. These emission sources are aggregated for the various natural gas segments including exploration, production and gathering, processing, transmission and distribution which were incorporated into the tool.

EDF

The Environmental Defense Fund coordinated a series of emissions measurement and analysis studies to estimate methane emissions across the U.S. oil and natural gas supply chain. The results were integrated and summarized in “Assessment of methane emissions from the U.S. oil and gas supply chain”.⁵ The study included statistical adjustments to account for intermittent emission events and super-emitters. The resulting estimate was compared to the 2016 EPA inventory and found to be 60% higher for all oil and gas operations. The emission estimator model estimates the implications of the EDF study by deriving adjustment factors from the EDF analysis relative to each of the gas industry segments (there was no factor for LDCs). For each segment then, a value is calculated equal to the U.S. inventory value scaled by the EDF generated emissions values for 2015 divided by the U.S. inventory values in 2015.

GHGRP

The EPA Greenhouse Gas Reporting Program (GHGRP)⁶ is a federal regulation that requires various types of industrial facilities to submit annual reports. Facilities must comply with these federal regulations when it is determined the facility emits greater than 25,000 metric tons CO₂e per year. These annual reports contain relevant emission volumes (either facility-wide or source-specific) and in some cases also contain certain operational parameters for the reporting facility based on specified requirements. For the purposes of this tool, ICF relied on Petroleum and Natural Gas Systems sector reporting data and relevant methane emission volumes.

PointLogic

PointLogic maintains a private database of quantities of gas transported at various supply points (gathering systems & processing plants), demand points (power plants, gas utilities, & industrial facilities), and throughput points (compressor stations & border crossings) that are located on interstate natural gas pipelines. PointLogic sources its data from the pipeline informational bulletin boards which are publicly available and updated daily.

⁴ EPA’s Natural Gas and Petroleum Systems. Accessed at: <https://www.epa.gov/ghgemissions/natural-gas-and-petroleum-systems>

⁵ Assessment of methane emissions from the U.S. oil and gas supply chain. Accessed at: <http://science.sciencemag.org/content/361/6398/186>.

⁶ EPA Greenhouse Gas Reporting Program (GHGRP). Accessed at: <https://www.epa.gov/ghgreporting>

ABB Velocity Suite

ABB Velocity Suite maintains a private database with information on the energy industry in North America including commodity pricing, resource extraction, electricity production, geographic details and forecasts. Velocity Suite's data on annual LDC throughputs (sourced from the EIA and reporting to State Public Utility Commissions) and its geographic mapping capabilities were used in developing this tool.

EIA

EIA data was used to provide nationwide natural gas throughput values. EIA's Natural Gas Annual contains national volumes of natural gas produced, processed, and delivered to customers. Additionally, EIA's Form 176, provided estimates for LDC deliveries. These two sources were utilized to derive the national emission factors. Furthermore, EIA's Form 757 provided volumes of natural gas processed by processing plant.

Table 1: EIA Natural Gas Annual Figures^{7,8}

Applicable Gas Segment(s)	Description	2016 Volumes (Tcf)
Production, Gathering	Natural Gas Gross Withdrawals	32.6
Processing	Natural Gas Processed ⁹	20.4
Transmission	Natural Gas Delivered to Customers	25.2
Distribution	Natural Gas Delivered to Customers from LDCs	13.9

Model Assumptions

Gas Production

U.S. Inventory

Estimated emissions from gas production were 2,336 kt CH₄ in 2016 which accounts for all voluntary emission reduction measures reported by companies within production. The emissions value was divided by the total amount of gas produced in 2016 of 32.6 Tcf as reported to EIA's Natural Gas Annual for gross withdrawals. This results in the average emission factor of 0.07 kg methane/Mcf which is then applied to the gas deliveries volume for the selected LDC.

EDF estimated the production and gathering and boosting emissions as 7,600 kt CH₄ in 2015. After accounting for the 2,600 kt CH₄ in gathering and boosting and then apportioning the production emissions between oil production and gas production using the same ratio as the U.S. inventory, the gas production from EDF accounts for 2,969 kt CH₄ in 2015. The U.S. inventory estimates emissions in production at 2,281 kt CH₄ in the same year. Therefore, the EDF adjustment factor was 1.3 for production.

GHGRP

⁷ EIA's Natural Gas Summary. Accessed at: https://www.eia.gov/dnav/ng/ng_sum_lsum_dcu_nus_a.htm

⁸ EIA Form 176. Accessed at:

<https://www.eia.gov/naturalgas/ngqs/#?report=RP4&year1=2016&year2=2016&company=Name>

⁹ Note: Also used EIA's state by state volumes of natural gas processed. Accessed by:

https://www.eia.gov/dnav/ng/ng_prod_pp_a_epg0_ygp_mmcf_a.htm

For this segment, ICF used 2016 facility level emission estimates and the 2016 volume of gas produced for sales from “Facility Overview” data in the GHGRP to generate emission factors in kg methane/Mcf. Using the associated basin according to GHGRP reporting, production volumes and emissions were aggregated at the basin level and then used to determine an average basin level factor. These basin level factors were then used in combination with the delivered LDC volume and the specified supply area basin factors respectively to determine a total emission estimate.

When generating emission factors at the basin level, significant variability was seen between basins based on reported data. This variability can sometimes occur as a result of inconsistent data reporting from certain reporters. To help address this, emission factors were first generated at the reporter level using respective emissions and volumes of gas produced for sales. Calculated emission factors were then compared between reporters at the associated basin level using standard deviation. If an emission factor at the basin level was determined to be more than one standard deviation out of expectation, than that operator was considered inconsistent and their reported data an outlier. In these cases, additional yearly data for that reporter was then reviewed to see if 2015 or 2017 reported volumes were more consistent using a similar process. If so, those production volumes and emissions were substituted for 2016 values for that reporter in overall basin level estimates with 2017 as priority. If no value is found to be consistent, that reporter’s data was excluded. This process ensures that production and emission volumes that produce unreliable emission factors are not included in basin level estimates.

After following the above methodology to remove outliers, there were remaining instances where certain basin level factors still seemed beyond a reasonable range (with one gross outlier). In these cases, the calculated factor sometimes pertained to only a small number of reporters. A standard deviation methodology is not reliable for data vetting in this case because the population of data is too small. To address this issue, either 2015 or 2017 basin level data was first reviewed for consistency. If either year’s data produced a factor in line with an expected value, that year’s factor was substituted for 2016, with 2017 data taking priority where both apply. If neither 2015 nor 2017 data seemed to represent a realistic factor, a similar basin level factor was then substituted for the unrealistic factor based on geographic characteristics and location per ICF judgement. Note that these instances do not represent predominant basins based on production volume.

Gathering and Boosting

U.S. Inventory

The inventory was used to estimate *national* gathering and boosting emissions of 1,966 kt CH₄ in 2016. The inventory estimate represents the total emissions from gathering and boosting sources as calculated by the inventory minus voluntary emission reduction measures reported by companies for pipeline leaks, gas engines, compressor starts and dehydrator vents. The U.S inventory emissions value was divided by the total amount of gas produced in 2016 of 32.6 Tcf as reported to EIA’s Natural Gas Annual for gross withdrawals which was used to approximate the gas that would go through gathering and boosting stations. This results in the average emission factor of 0.06 kg methane/Mcf which is then applied to the gas deliveries volume for the selected LDC.

EDF

The EDF study estimated gathering emissions as 2,600 kt CH₄ nationwide in 2015 compared with the U.S. inventory emissions of 1,982 kt CH₄ in the same year. After dividing these two values, the resulting EDF adjustment factor was 1.31 for gathering and boosting.

GHGRP

For this segment, ICF used 2016 facility level emission estimates and the 2016 volume of gas transported by gathering/boosting stations from “Facility Overview” data in the GHGRP to generate emission factors in kg methane/Mcf. Using the associated basin according to GHGRP reporting, transported volumes and relevant emissions were aggregated at the basin level and then used to determine an average basin level factor. These basin level factors were then used in combination with the delivered LDC volume and the specified supply area basin factors respectively to determine a total emission estimate. In a few minor cases, a similar basin level substitution process was followed to that of Gas Production to avoid emission factor outliers at the basin level.

Gas Processing

U.S. Inventory

The Inventory estimated national processing emissions of 448 kt CH₄ in 2016 which was divided by the total amount of gas processed according to EIA of 20.4 Tcf. This average emission factor of 0.02 kg methane/Mcf was then applied to the gas deliveries for the selected LDC.

EDF estimated national processing emissions to be 720 kt CH₄ in 2015 compared with the U.S. inventory emissions of 445 kt CH₄ in the same year. After dividing these two values, the resulting EDF adjustment factor was 1.62 for processing.

GHGRP

For evaluating processing emissions, ICF used the 2014 facility level processing emission estimates from the Greenhouse Gas Reporting Rule 40 CFR Subpart W-Petroleum and Natural Gas Systems. The tool utilized data located under the “Emissions Sources” categorization from 2014 in order to match the emissions data to existing EIA Form 757 data. EIA’s Form 757 provides the volume of gas processed at processing plants in 2014.¹⁰ After completing the mapping for all facilities that matched across the datasets, approximately 54% of reported emissions and 75% of the processed gas volumes had been accounted for.¹¹ For these mapped facilities the emissions were aggregated by basin and divided by the aggregated processing volumes. This yielded an average basin level emission factor in kg methane/Mcf. For basins where there were no facilities mapped between the GHGRP and 757 data, a nearby basin’s emission factor was utilized.

Next, an average weighted emission factor based on the locations the LDC supplied gas from was determined by multiplying the individual basin level emission factors by the percent of gas processed in the basin’s state by the percent of gas supplied from each basin. This weighted emission factor was then used in combination with the delivered LDC volume to determine a total emission estimate.

¹⁰ EIA Form 757’s latest available data was 2014 at the time of this study.

¹¹ GHGRP is a company-reported dataset and some of the reported data labeled as processing included other segment data for compressor stations, production fields, and others. This contributed to capturing a smaller portion of the emissions than processed volumes.

Gas Transmission

U.S. Inventory

The inventory estimated national transmission and storage emissions to be 1,311 kt CH₄ in 2016, which accounts for voluntary emission reduction measures reported by companies as stated in the U.S. Inventory. The national emissions value was then divided by the gas delivered to customers according to EIA of 25.2 Tcf yielding an average emission factor of 0.05 kg methane/Mcf. The average emission factor was then applied to the gas deliveries for the selected LDC.

EDF

The EDF analysis estimated transmission and storage emissions of 1,800 kt CH₄ in 2015 compared with the U.S. inventory emissions of 1,349 kt CH₄ in the same year. After dividing these two values, the resulting EDF adjustment factor was 1.33 for transmission.

GHGRP

For this segment, ICF considered facility level reported emissions for both compressor stations and pipeline systems. These sources were handled in two separate ways. First, GHGRP data was used to determine emissions by compressor station and state. The compressor stations for which emissions data was available in the GHGRP database and throughput data was available in the PointLogic database were mapped to each other so that emission factors for each compressor station could be calculated.

To calculate emission factors for transmission pipeline systems on a gas throughput basis, pipeline mileage and gas transferred volumes were pulled from “Facility Overview” data in the GHGRP. While volumes are not available at a state level, the overall volume a system transports is reported. Additionally, GHGRP data provides applicable state mileage for each pipeline system that reports. Using the above data, a factor was calculated using the total emissions for the system, the total amount of gas transferred by the system, and the total pipeline system mileage. This system level factor is represented as kg methane/Mcf gas transferred–mileage. An average state level factor was then determined by using these system-level factors, which were averaged for each state where there exists reported mileage for that system in that state.

To determine an emission factor per gas throughput, the amount of distance the gas travels by pipeline within each state on its route to its final destination was determined using calculations based on the specified supply regions. First, the states that the gas must pass through in order to travel between the supply region and the demand area were determined for each possible route in the U.S. and Canada. Second, the average distance that gas must travel in each state was determined using the ratio of the square mileage of each state to the total distance that the gas travels for each possible route. Next, those ratios for each state were multiplied by each route’s total distance to determine the mileage within each state. The average state level factor determined above was then multiplied by the mileage within each applicable state, given the route the gas must travel to the selected LDC. This returns a factor in terms of kg methane/Mcf gas transferred for each state, which were then combined to give a representative factor for that supply area distance. For the overall emission estimate, these representative factors are determined for each specified supply area, and weighted using the amount of gas supplied from each region. This

overall emission factor is then used in combination with the delivered LDC volume to determine a total emission estimate for pipeline systems.

Gas Distribution

US Inventory

The Inventory estimated national distribution emissions to be 480 kt CH₄ in 2016. The national emissions value was then divided by the gas delivered to customers by LDCs according to EIA of 13.9 Tcf yielding an average emission factor of 0.03 kg methane/Mcf. The average emission factor was then applied to the gas deliveries for the selected LDC.

GHGRP

For this segment, ICF used facility level emission estimates and the quantity of gas delivered from “Facility Overview” data in the GHGRP to generate emission factors per gas throughput for each reporting LDC.

Updating Emissions Data

Both the U.S. Inventory of GHG Emissions and the Greenhouse Gas Reporting Rule data are updated annually. Users can potentially update the data in the estimator tool. The model uses emission factors in pounds of methane per Mcf of gas throughput, thus both an emission value and throughput value must be used to calculate the factor and update the model. Some of the categories are relatively easy to update, others are much more complicated. Any user who updates the information will then take on responsibility for the accuracy and validity of the results based on those updates. The following sections address the updating process.

U.S. Inventory of GHG Emissions

The U.S. Inventory is updated annually and typically released in April. The methane emissions estimates for natural gas systems are listed in Table 3.6-1 of the inventory report¹². The associated gas throughput values and where they are located are shown in the table below.

Applicable Gas Segment(s)	Description	Data Location
Production, Gathering	Natural Gas Gross Withdrawals	EIA Natural Gas Annual ¹³
Processing	Natural Gas Processed ¹⁴	EIA Natural Gas Annual ¹⁵
Transmission	Natural Gas Delivered to Customers	EIA Natural Gas Annual
Distribution	Natural Gas Delivered to Customers from LDCs	EIA Form 176

¹² EPA’s Natural Gas and Petroleum Systems. Accessed at: <https://www.epa.gov/ghgemissions/natural-gas-and-petroleum-systems>

¹³ EIA’s Natural Gas Summary. Accessed at: https://www.eia.gov/dnav/ng/ng_sum_lsum_dcu_nus_a.htm

¹⁴ Note: Also used EIA’s state by state volumes of natural gas processed. Accessed by: https://www.eia.gov/dnav/ng/ng_prod_pp_a_epg0_ygp_mmcf_a.htm

¹⁵ EIA Form 176. Accessed at: <https://www.eia.gov/naturalgas/nggs/#?report=RP4&year1=2016&year2=2016&company=Name>



The emissions and throughput values should be entered in the “U.S. GHG and EDF Inputs” tab in the spreadsheet by updating columns C and D. The factors will then be calculated and linked to the appropriate cells in the calculator.

EDF Factors

The EDF adjustment factors were developed based on the EDF analysis for 2015 data compared to the 2015 Inventory. There is no new EDF analysis to compare to more recent Inventory data. To the extent that the Inventory changes over time, the 2015 adjustment factors may become less accurate or relevant. There is no systematic way to update these adjustments without an updated analysis program, which is unlikely to take place. It is up to the user to determine whether the EDF factors will still be relevant depending on how much the inventory values change over time.

Greenhouse Gas Reporting Rule

The GHGRP data are updated each year based on new data received from affected companies. The data typically are released in the fall and can be found at the GHGRP website.¹⁶ The raw data files must be downloaded and manipulated to develop the required emissions data. Due to the large number of reporters, the GHGRP data are more complicated to update than the Inventory data. In addition, sectors report only emissions data so the throughput data must be found from other sources, which can be difficult. Each sector is addressed below.

Production

The production emissions are reported and used in the model by basin. The data include both emissions and throughput (production) data. For this segment, ICF used facility level emission estimates and the volume of gas produced for sales from “Facility Overview” data in the GHGRP to generate emission factors in kg methane/Mcf. Using the associated basin according to GHGRP reporting, production volumes and emissions were aggregated at the basin level and then used to determine an average basin level factor. As noted in the earlier discussion, some reporters were found to be outliers and were either discarded or replaced with data from a different year that was more plausible. Updated data should be loaded into the “GHGRP Production” tab in the model.

Gathering

For this segment, ICF used facility level emission estimates and the volume of gas transported by gathering/boosting stations from “Facility Overview” data in the GHGRP to generate emission factors in kg methane/Mcf. Using the associated basin according to GHGRP reporting, transported volumes and relevant emissions were aggregated at the basin level and then used to determine an average basin level factor. In a few minor cases, data from a similar basin was used to avoid emission factor outliers at the basin level. Updated factors should be entered into the “GHGRP GB” tab in the model.

Gas Processing

¹⁶ EPA Greenhouse Gas Reporting Program; <https://www.epa.gov/ghgreporting>

The GHGRP does not provide throughput data for gas processing plants so the emissions data must be manually matched to another source for the throughput data. EIA's Form 757 provides the volume of gas processed at processing plants in 2014 and this report comes out every few years.¹⁷ This data can be updated only in years where the EIA Form 757 data is available. Identification information including the processing plant names and locations under the "Emissions Sources" categorization from the 2014 GHGRP was used to manually match the emissions data to throughput data from the EIA Form 757 data. After completing the mapping for all facilities that matched across the datasets,¹⁸ the emissions for these mapped facilities were aggregated by basin and divided by the aggregated processing volumes. This yielded an average basin level emission factor in kg methane/Mcf. For basins where there were no facilities mapped between the GHGRP and 757 data, a nearby basin's emission factor was utilized. Updated emission factors should be entered in the "Processing Emission Factors" tab in Column D in the model.

Transmission and Storage

The GHGRP does not include throughput data for all portions of this segment. There are also three GHGRP reporting categories associated with this segment – pipelines, compressors, and storage.

For compressors, GHGRP data was used to calculate emissions by compressor station and state. The throughput for the stations must be determined from another source. ICF used the PointLogic database, which is a private, subscription service. Users who do not have access to this service might be able to find alternative sources. Compressor stations for which emissions data was available in the GHGRP database and throughput data was available in the PointLogic database were mapped to each other so that emission factors for each compressor station could be calculated. Updated compressor station level emission factors should be entered in the "GHGRP Compression" tab in the model.

To calculate emission factors for transmission pipeline systems on a gas throughput basis, pipeline mileage and gas transferred volumes were pulled from "Facility Overview" data in the GHGRP. While volumes are not available at a state level, the overall volume a system transports is reported. Additionally, GHGRP data provides applicable state mileage for each pipeline system that reports. Using the above data, a factor was calculated using the total emissions for the system, the total amount of gas transferred by the system, and the total pipeline system mileage. This system level factor is represented as kg methane/Mcf gas transferred–mileage. An average state level factor was then determined by using these system-level factors, which were averaged for each state where there exists reported mileage for that system in that state. Updated average state level pipeline system emission factor values should be entered in the "GHGRP Pipeline" tab.

To determine an emission factor per gas throughput, the amount of distance the gas travels by pipeline within each state on its route to its final destination was determined using calculations based on the specified supply regions. This routing is unlikely to change from year-to-year and it is not recommended that this be routinely updated. The procedure is outlined here for reference.

¹⁷ EIA Form 757's latest available data was 2014 at the time of this study.

¹⁸ GHGRP is a company-reported dataset and some of the reported data labeled as processing included other segment data for compressor stations, production fields, and others. This contributed to capturing a smaller portion of the emissions than processed volumes.

First, the states that the gas must pass through in order to travel between the supply region and the demand area were determined for each possible route in the U.S. and Canada. Second, the average distance that gas must travel in each state was determined using the ratio of the square mileage of each state to the total distance that the gas travels for each possible route. Next, those ratios for each state were multiplied by each route's total distance to determine the mileage within each state. The average state level factor determined above was then multiplied by the mileage within each applicable state, given the route the gas must travel to the selected LDC. This returns a factor in terms of kg methane/Mcf gas transferred for each state, which were then combined to give a representative factor for that supply area distance. For the overall emission estimate, these representative factors are determined for each specified supply area, and weighted using the amount of gas supplied from each region. This overall emission factor is then used in combination with the delivered LDC volume to determine a total emission estimate for pipeline systems.

Because storage is used differently by different companies and in different years, it was not possible to directly calculate storage-related emissions for each LDC from GHGRP data.

Gas Distribution

For this segment, ICF used facility level emission estimates and the quantity of gas delivered from "Facility Overview" data in the GHGRP to generate emission factors per gas throughput for each reporting LDC. Updated data should be entered in the "GHGRP Distribution" tab of the model.

Global Warming Potential¹⁹

Greenhouse gases absorb and re-emit solar radiation, trapping heat in the earth's atmosphere and resulting in an overall warming effect. Different gases have different warming effects and different lifetimes in the atmosphere, making it difficult to compare their effects on a consistent basis. A factor called global warming potential (GWP) is often used for this purpose. GWP can be defined as the amount of total energy added to the climate by a gas relative to the impact of the baseline gas, CO₂, which is assigned a GWP of 1. The GHG emissions weighted by the GWP are expressed as CO₂ equivalent (CO₂e).

The science and policy communities have historically looked to the U.N. Intergovernmental Panel on Climate Change (IPCC) assessment reports as the authoritative basis for GWP values. The IPCC is the chief international organization for climate change issues, and was established in 1988 by the United Nations Environmental Programme (UNEP) and the World Meteorological Organization (WMO). Governments, organizations, and climate experts from all around the world voluntarily contribute to these reports. Five Assessment reports have been published:

- IPCC First Assessment Report 1990 (FAR)

- IPCC Second Assessment Report 1995 (SAR)

- IPCC Third Assessment Report 2001 (TAR)

- IPCC Fourth Assessment Report 2007 (AR-4)

- IPCC Fifth Assessment Report 2014 (AR-5)

Two key factors in determining the effect of a GHG are its warming effect and the length of time that it remains active in the atmosphere. CO₂ is the least potent of the GHGs but it remains in the atmosphere for thousands of years and moves between different parts of the air-ocean-land system. Even though it is the least potent, CO₂ is the largest GHG source, especially from large users of fossil fuels, and thus it has been a focal point for initiatives to regulate GHG emissions. On the other hand, methane has a stronger warming effect than CO₂, but its lifetime in the atmosphere is only about 12 years. Other GHGs have much greater warming effect than methane and may have longer or shorter lifetimes. **Error! Reference source not found.** was developed by the U.S. EPA²⁰ to describe the characteristics and lifetimes of major greenhouse gases based on the IPCC's Fifth Assessment Report.

The IPCC calculates the GWP based on a 100 year and a 20 year lifetime to provide alternative bases for analyzing emission impacts. Depending on the lifetime of the individual gas, the 20 year GWP can be higher or lower than the 100 year GWP. Both of these values are correct but they reflect a different snapshot of the warming effect of the subject gases. While there is no scientific imperative for selecting one or the other GWP life, the GWP for a time horizon of 100 years was adopted as a metric to implement the multi-gas approach embedded in the United Nations

¹⁹ From "Finding the Facts on Methane Emissions: A Guide to the Literature", April 2016. ICF for the Natural Gas Council.

²⁰ EPA website. Glossary of Climate Change Terms. Accessed at: <http://www.epa.gov/climatechange/glossary.html>

Framework Convention on Climate Change (UNFCCC) and was made operational in the 1997 Kyoto Protocol. The 100 year GWP is also the standard for reporting national emissions to the UNFCCC and is the standard used in most national GHG reporting and regulatory programs.

Greenhouse Gas GWPs and Lifetime

Greenhouse Gas	How It's Produced	Average Lifetime in the Atmosphere	100-Year GWP
Carbon Dioxide	Produced mainly by the burning of fossil fuels (oil, natural gas, and coal), solid waste, and trees and wood products. Land-use changes, deforestation, and soil degradation also contribute to its production.	Carbon dioxide's lifetime is not defined because it continues to move between different parts of the ocean-atmosphere-land system instead of being destroyed.	1
Methane	Emitted during the production and transport of coal, natural gas, and oil, as well as from livestock, agricultural practices, and the anaerobic decay of organic waste in solid waste landfills.	12 years	28
Nitrous Oxide	Produced during agricultural and industrial activities, and during the combustion of fossil fuels and solid waste.	121 years	265
Fluorinated Gases	Synthetic gases containing fluorine, such as hydrofluorocarbons, perfluorocarbons, and sulfur hexafluoride. They are emitted from various industrial processes and commercial and household uses.	A few weeks to thousands of years	Varies (Sulfur hexafluoride is the highest at 23,500)

Source: <http://www.epa.gov/climatechange/glossary.html>

Most countries and international agencies (including the U.S. EPA) follow inventory protocols set by the IPCC, which still use the AR-4 100 year GWP of 25. That said, the AR-5 is the most recent assessment and includes some changes in the treatment of the methane GWP. The first major change in AR-5 is fully including carbon cycle feedback in calculating the GWP. As the temperature increases, the biosphere retains less CO₂, which enters the atmosphere and causes further warming. This feedback was included for CO₂ (the denominator in the GWP) in earlier reports but not for the other gases. Including it for the other gases increases the calculated GWP for each GHG.

The second change is specific to methane. When methane oxidizes in the atmosphere, it creates CO₂, which has an additional warming effect. Thus methane emissions have a direct and then an indirect effect on the Earth's climate due to the CO₂ that is created. The primary GWP values for methane listed in the AR-5 are for biogenic methane, for which the CO₂ is assumed to have been absorbed from the biosphere and therefore the oxidation does not constitute a net increase. For

fossil methane, however, the methane oxidation effect adds 1 to the 20 year GWP and 2 to the 100 year GWP.

The AR-5 100-year value GWP value for methane without feedback or oxidation adjustment is 28 (slightly higher than the AR-4 value of 25). With the adjustment for fossil methane it is 30. The value with feedback and adjustment for oxidation is 36. The 20 year values in the AR-5 are 84 without feedback or oxidation and 87 with feedback and oxidation. These results are summarized below. These new findings in the AR-5 have not been accepted by all parties and many entities, including some government and regulatory agencies, use the values without feedback, while few organizations are currently using the values with the feedback and oxidation factor.

Global Warming Potentials for Methane for Different Lifetimes (including feedbacks)

IPCC AR	Year Published	20 – Year GWP	100 - Year GWP
AR-4	2007	72	25
AR-5*	2014	84/86/87	28/34/36

*Without feedback/With feedback/With oxidation

Source: IPCC