CAPP

CANADIAN ASSOCIATION OF PETROLEUM PRODUCERS

Canada's Oil and Natural Gas Producers

REPORT

Update of Fugitive Equipment Leak Emission Factors

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The Canadian Association of Petroleum Producers (CAPP) represents companies, large and small, that explore for, develop and produce natural gas and crude oil throughout Canada. CAPP's member companies produce about 90 per cent of Canada's natural gas and crude oil. CAPP's associate members provide a wide range of services that support the upstream crude oil and natural gas industry. Together CAPP's members and associate members are an important part of a national industry with revenues of about $110 billion a year. CAPP's mission is to enhance the economic sustainability of the Canadian upstream petroleum industry in a safe and environmentally and socially responsible manner, through constructive engagement and communication with governments, the public and stakeholders in the communities in which we operate.

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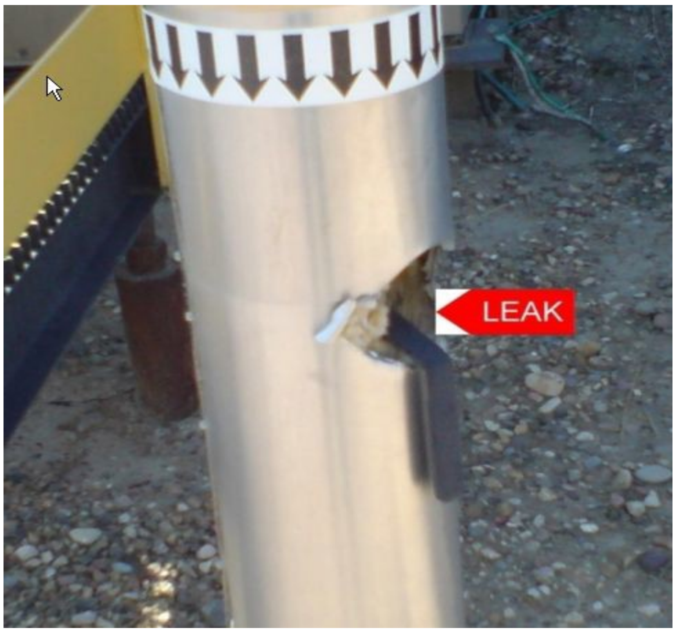
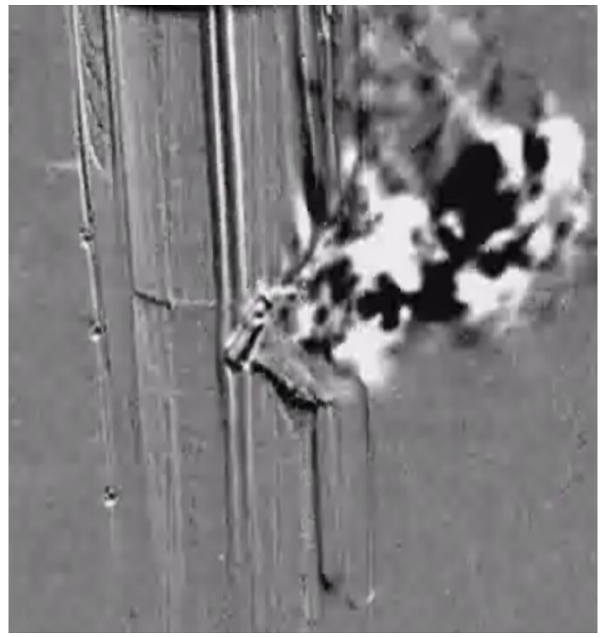
TECHNICAL REPORT





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EXECUTIVE SUMMARY

Currently, industry can assess atmospheric emissions due to fugitive equipment leaks by measurements and by estimation methods. The estimation methods often involve the use of average emission factors. An emission factors is a statistical parameter that relates the total amount of emissions from a population of sources to a relevant activity parameter for those sources. For fugitive equipment leaks, the activity parameter is the number of equipment components in hydrocarbon service. Different factors are applied for different types of components and different types of hydrocarbon service (e.g., gas/vapour, light liquid or heavy liquid). An emission factor is intended for estimating total emissions from large populations of sources, but is not appropriate for application to individual sources or small numbers of sources.

This report presents updated average emission factors for estimating emissions from fugitive equipment leaks at upstream oil and natural gas (UOG) facilities. The previous factors (CAPP, 2005) were developed based on measurement results collected from the mid 1990's to early 2000's. In 2007 CAPP published a best management practice (BMP) for Management of Fugitive Emissions at Upstream Oil and Gas Facilities and provincial regulations came into effect to better manage these emissions. The CAPP Fugitive Emissions BMP provides guidance on implementing directed inspection and maintenance (DI&M) procedures to specifically target fugitive equipment leaks. The updated factors are reflective of current conditions at UOG facilities that have implemented DI&M programs in accordance with the BMP and applicable regulatory requirements.

Through industry participation, leak survey results for 120 facilities in Alberta and British Columbia, comprising an estimated 276,947 equipment components, were compiled and assessed. In comparison, the CAPP (2005) factors are based on leak survey results for 251,431 equipment components. A comparison of the two data sets indicates that, overall, the emissions due to fugitive equipment leaks have decreased by 75 percent since the implementation of DI&M programs. Only emission factors for connectors in gas/vapour service at natural gas facilities were unchanged. Emission factors for all other categories with more than 50 leakers showed substantial reductuins compared the CAPP (2005) values. These results are a strong indication that DI&M programs and CAPP's best management practice for Management of Fugitive Emissions at Upstream Oil and Gas Facilities are effective in controlling fugitive equipment leaks.

For the current work it was necessary to identify and quantify the processes and major equipment units used at each facility and then, based on this information and the application of typical equipment schedules, develop detailed component counts for each facility. The examined facilities include those in both sweet and sour service, oil production facilities and natural gas facilities ranging from single-well batteries and compressor stations through to gas processing facilities.Some consolidation of the data was performed where source categories involving the same fundamental type of component were determined to be statistically equivalent and this either provided better alignment with categories used in other jurisdictions thereby allowing direct comparisons or aligned well with practicable-to-assess component categories. The results are presented in Table 10 herein. The consolidations included eliminating the distinction between fuel gas (FG) and gas/vapour (GV) service, and the distinction between sweet and sour service. While there is some correlation of the data with these two parameters, it is not often practicable to get the data needed to make such distinctions when developing emissions inventories (especially at the regional or national level). These consolidations reduced the list of component categories to two primary categories: oil systems and natural gas systems.

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LIST OF ACRYNOMS

C	Component
CAPP	Canadian Association of Petroleum Producers
CEL	Clearstone Engineering Ltd.
DI&M	Direct Inspection and Maintenance
EF	Emission Factor
FG	Fuel Gas
GV	Gas/Vapour (process and sales gas)
h	Hour
HL	Heavy Liquid
kg	Kilogram
LF	Leak Frequency
LL	Light Liquid
N	Number of components
Sr	Sour
Sw	Sweet
UOG	Upstream Oil and Gas

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1 INTRODUCTION

Emissions from fugitive equipment leaks at industrial facilities are most often estimated for use in emissions inventories by applying component-type average emission factors. Facility-level fugitive emission estimates based on these factors are used by companies for regulatory reporting and by governments to meet national and international reporting agreements.

For the upstream oil and natural gas (UOG) industry, the most up-to-date set of average emission factors was published as part of the CAPP/Environment Canada/NRCan Upstream Oil and Gas emission inventory (CAPP 2005). These factors were based on emissions data collected over the mid-1990s to the early 2000s time period.

Since 2007, regulations have been in effect in Alberta (Directive 060), and subsequently in BC and SK, that require UOG companies to conduct formal leak management programs. Industry has adopted a directed inspection and maintenance (DI&M) approach which is documented as a best management practice (BMP) by CAPP (2007), and is now a requirement of the regulations. The potential positive effect of these regulations and the implementation of the CAPP BMP for management of fugitive emissions on emissions from fugitive equipment leaks was expected to result in an over estimation of emissions when using the CAPP (2005) average emission factors.

The objective of this study was, therefore, to draw on recent leak survey results compiled by industry as part of regulated leak management programs to develop improved average emission factors for estimating atmospheric emissions from fugitive equipment leaks at UOG facilities. The review and assessment of fugitive equipment leaks, leak frequencies, and component-type average emission factors is provided herein.

The overall intent was to gather sufficient data from existing sources to provide an unbiased and statistically defensible update of the UOG average emission factors for fugitive equipment leaks. The scope was limited to upstream UOG infrastructure excluding oil sands operations.

Throughout this document, the term “fugitive emissions” refers specifically to atmospheric emissions due to leakage from equipment components in hydrocarbon service. Only leaks that result in the release of a process fluid to the atmosphere are considered. Leakage into the process or to a waste gas collection and treatment or recovery system is specifically excluded.

A component is considered to be in hydrocarbon service when the process fluid being handled contains greater than 10 percent hydrocarbons on a mass basis. Fugitive emissions from equipment leaks are unintentional losses and may arise due to normal wear and tear, improper or incomplete assembly of components, inadequate material specification, manufacturing defects, damage during installation or use, corrosion, fouling and environmental effects (e.g., vibrations and thermal cycling). The potential for such emissions depends on a variety of factors including the type, style and quality of components, type of service (gas/vapour, light liquid or heavy liquid), age of component, frequency of use, maintenance history, process demands, whether the process fluid is highly toxic or malodorous and operating practices.

Most of the atmospheric emissions from fugitive equipment leaks tend to be from components in natural gas or hydrocarbon vapour service rather than from those in hydrocarbon liquid service[1]. Components in odourized or H_2S service tend to have much lower average fugitive emissions than those in non-odourized or non-toxic service. Components tend to have greater average emissions when subjected to frequent thermal cycling, vibrations or cryogenic service. Different types of components have different leak potentials and repair lives.

1 This reflects the greater difficulty in containing a gas than a liquid (i.e., due to the greater mobility or fluidity of gases), and the general reduced visual indications of gas leaks.

2 HISTORIC AND CURRENT EMISSION FACTOR METHODOLOGIES

UOG-specific emission factors were developed in early 1990 in association with industry-wide emission inventories. Factor updates have been associated with UOG emissions inventory updates and have reflected changes in industry practice and regulatory initiatives.

Average, no-Leak and leak fugitive emission factors for various sources were developed in 1992 and used to compile a detailed inventory of CH_4 and VOC emissions from UOG operations in Alberta (CAPP 1992). The average factors are used to estimate the amount of emissions from fugitive equipment based on the total number of equipment component in hydrocarbon service in each applicable component category. The leak and no-leak factors are applied using a tiered approach in which the total number of components in each applicable category is disaggregated in those which produce a hydrocarbon screening value using US EPA Method 21 of 10,000 ppm or greater (i.e., leakers), and those that produce screening values of less than 10,000 ppm (non-leakers). The total emissions from this tiered approach are the sum of the leak and non-leak contributions.

The average, leak and no-leak factors were reported for source components types operating in gas/vapour (G/V), sweet gas/vapour (Sw G/V), sour gas (Sr G/V) and light liquid (LL) service. Source emission component types included:

- Valves in gas production
- Valves in oil production
- Connectors in gas production
- Connectors in oil production
- Compressor seals
- Pump seals
- Pressure relief valves and
- Open-ended lines.

In 2005, a Canada-wide inventory of emissions from oil and gas operations was completed (CAPP 2005). This report contained sets of average emission factors for emission source component types in gas and oil operations. Emission factors in G/V, Sw G/V, Sr G/V and LL service were reported. Also, factors for equipment components in Heavy Liquid (HL) service were reported. Additionally, default equipment component counts for various process and major equipment unit types employed in UOG industry were reported.

2.1 PUBLISHED EMISSION FACTORS

The CAPP (1992) emission factor results are presented in Table 1.

Table 1: Emission factors for THC emissions in the upstream oil and gas industry in Alberta (CAPP 1992).					
Component Type	Type of Service	Service	Average Emission Rate[1] kg/h/source	No-Leak Emission Rate[2] kg/h/source	Leak Emission Factor[2] kg/h/source
Valves	Gas Production	Sw G/V	0.43510	0.00023	0.26260
		Sr G/V	0.00518	0.00010	0.26260
		LL	0.00270	0.00081	0.85200
	Oil Production	G/V	0.01417	0.00008	0.04510
		LL	0.00121	0.00058	0.08520
Connectors	Gas Production	Sw G/V	0.00253	0.00061	0.03750
		Sr G/V	0.00031	0.00019	0.03750
		LL	0.00019	0.00013	0.03750
	Oil Production	G/V	0.00079	0.00023	0.03750
		LL	0.00019	0.00013	0.03750
Compressor Seals	All Sites	G/V	0.80488	0.00175	1.60800
Pump Seals	All Sites	LL	0.02139	0.00230	0.43700
Pressure Relief Devices	All Sites	G/V	0.12096	0.00019	1.69100
Open-Ended Lines	All Sites	All	0.00373	0.00183	0.01195
[1] From Table 5, page 49 of CAPP 1992					
[2] From Table 7, page 54 of CAPP 1992					

Subsequent to this publication, updated emission factors were developed using additional data and published as part of A National Inventory of Greenhouse Gas (GHG), Criteria Air Contaminant (CAC) and Hydrogen Sulphide (H_2S) Emissions (CAPP 2005). These updated factors are presented in Table 2. Sector (natural gas or oil systems), Facility Designation (All, Sweet or Sour), Component Service (fuel gas, gas/vapour, light liquid or heavy liquid) replaced the previous designations in Table 1 and, as a consequence, the list of average emission factors significantly expanded. Additionally, lower and upper uncertainty limits were developed for each emission factor.

Table 2: Summary of average emission factors for uncontrolled fugitive THC emissions (kg/h/source) at upstream oil and gas facilities (CAPP, 2005).						
Sector	Sweet/ Sour	Service	Component Type	Emission Factor (kg/h)	Lower Uncertainty (%)	Upper Uncertainty (%)
GAS	ALL	Fuel Gas	Connectors	8.18E-04	32	32
GAS	ALL	Fuel Gas	Compressor Seals	7.13E-01	36	36
GAS	ALL	Fuel Gas	Control Valves	1.62E-02	27	27
GAS	ALL	Fuel Gas	Open-Ended Lines	4.67E-01	58	172
GAS	ALL	Fuel Gas	Pressure Relief Valves	1.70E-02	98	98

Table 2: Summary of average emission factors for uncontrolled fugitive THC emissions (kg/h/source) at upstream oil and gas facilities (CAPP, 2005).						
Sector	**Sweet/ Sour**	**Service**	**Component Type**	**Emission Factor (kg/h)**	**Lower Uncertainty (%)**	**Upper Uncertainty (%)**
GAS	ALL	Fuel Gas	Pressure Regulators	8.11E-03	72	238
GAS	ALL	Fuel Gas	Valves	2.81E-03	17	17
GAS	ALL	Gas/Vapour	Connectors	7.06E-04	31	31
GAS	ALL	Gas/Vapour	Compressor Seals	7.13E-01	36	36
GAS	ALL	Gas/Vapour	Control Valves	1.46E-02	23	23
GAS	ALL	Gas/Vapour	Open-Ended Lines	4.27E-01	62	161
GAS	ALL	Gas/Vapour	Pressure Relief Valves	1.70E-02	98	98
GAS	ALL	Gas/Vapour	Pressure Regulators	8.11E-03	72	238
GAS	ALL	Gas/Vapour	Valves	2.46E-03	15	15
GAS	ALL	Light Liquid	Connectors	5.51E-04	90	111
GAS	ALL	Light Liquid	Control Valves	1.77E-02	45	45
GAS	ALL	Light Liquid	Open-Ended Lines	1.83E-02	79	127
GAS	ALL	Light Liquid	Pressure Relief Valves	5.39E-03	80	80
GAS	ALL	Light Liquid	Pump Seals	2.32E-02	74	136
GAS	ALL	Light Liquid	Valves	3.52E-03	19	19
GAS	SOUR	Gas/Vapour	Connectors	1.36E-04	72	72
GAS	SOUR	Gas/Vapour	Control Valves	9.64E-03	4	4
GAS	SOUR	Gas/Vapour	Open-Ended Lines	1.89E-01	79	127
GAS	SOUR	Gas/Vapour	Pressure Regulators	4.72E-05	74	126
GAS	SOUR	Gas/Vapour	Valves	1.16E-03	31	31
GAS	SWEET	Gas/Vapour	Connectors	8.18E-04	32	32
GAS	SWEET	Gas/Vapour	Control Valves	1.62E-02	27	27
GAS	SWEET	Gas/Vapour	Open-Ended Lines	4.67E-01	58	172
GAS	SWEET	Gas/Vapour	Pressure Regulators	8.39E-03	72	239
GAS	SWEET	Gas/Vapour	Valves	2.81E-03	17	17
OIL	ALL	Fuel Gas	Connectors	2.46E-03	15	15
OIL	ALL	Fuel Gas	Compressor Seals	8.05E-01	36	36
OIL	ALL	Fuel Gas	Control Valves	1.46E-02	21	21
OIL	ALL	Fuel Gas	Open-Ended Lines	3.08E-01	78	129
OIL	ALL	Fuel Gas	Pressure Relief Valves	1.63E-02	80	80
OIL	ALL	Fuel Gas	Pressure Regulators	6.68E-03	72	238
OIL	ALL	Fuel Gas	Valves	1.51E-03	79	79
OIL	ALL	Gas/Vapour	Connectors	2.46E-03	15	15
OIL	ALL	Gas/Vapour	Compressor Seals	8.05E-01	36	36
OIL	ALL	Gas/Vapour	Control Valves	1.46E-02	21	21
OIL	ALL	Gas/Vapour	Open-Ended Lines	3.08E-01	78	129
OIL	ALL	Gas/Vapour	Pressure Relief Valves	1.63E-02	80	80

Table 2: Summary of average emission factors for uncontrolled fugitive THC emissions (kg/h/source) at upstream oil and gas facilities (CAPP, 2005).						
Sector	**Sweet/ Sour**	**Service**	**Component Type**	**Emission Factor (kg/h)**	**Lower Uncertainty (%)**	**Upper Uncertainty (%)**
OIL	ALL	Gas/Vapour	Pressure Regulators	6.68E-03	72	238
OIL	ALL	Gas/Vapour	Valves	1.51E-03	79	79
OIL	ALL	Heavy Liquid	Connectors	7.50E-06	90	111
OIL	ALL	Heavy Liquid	Pressure Relief Valves	3.20E-05	80	80
OIL	ALL	Heavy Liquid	Pump Seals	3.20E-05	74	136
OIL	ALL	Heavy Liquid	Valves	8.40E-06	19	19
OIL	ALL	Light Liquid	Connectors	1.90E-04	90	111
OIL	ALL	Light Liquid	Control Valves	1.75E-02	44	44
OIL	ALL	Light Liquid	Open-Ended Lines	3.73E-03	79	127
OIL	ALL	Light Liquid	Pressure Relief Valves	7.50E-02	80	80
OIL	ALL	Light Liquid	Pump Seals	2.32E-02	74	136
OIL	ALL	Light Liquid	Valves	1.21E-03	19	19
Source: CAPP Vol 3, Table 19, 2004, 2005-0015 (CAPP 2005).						

2.2 EMISSION FACTOR UPDATE METODOLOGY

Subsequent to 2007, industry applied directed inspection and maintenance (DI&M) programs to reduce fugitive emissions. To assess the potential effectiveness of these programs, recent fugitive emission survey data were provided by various companies, compiled and analyzed, and used to develop emission factors reflecting current practice. The 95% confidence limits for these factors were assessed using the methodology delineated in Appendix C.

Through CAPP and participating UOG companies, fugitive emission reports were made available for assessment. In total, eight companies submitted field studies. One of the respondents withheld data on emissions from compressor seals in its submission on the basis that it deemed these to be a source of process venting rather than a source of leakage. All but one operator included leak and emission rate data by component type; that operator included only a list of leaking components with no leak-rate measurement results. One operator was not able to provide supporting facility drawings, so due to the resulting uncertainty regarding equipment at its facilities the fugitive emission data they provided were not used.

Only one operator provided facility component counts by component type. For the other reported facilities, detailed component counts were developed based on the application of default equipment schedules applied to the number and types of processes and major equipment units as determined from process flow drawings (PFDs) or piping and instrumentation drawings (P&IDs), meter schematics and equipment inventory files. Although the intent was to include facilities from BC, AB, SK and MB, only data from BC and AB was received. The total number of facilities by jurisdiction for which data were received and used is summarized in **Table 3**.

Table 3: Summary of facilities for which fugitive emission data was submitted and used in the emission factor update study.

Company	Facilities Included In Study		
	Total	BC	AB
A	14	0	14
B	27	5	22
C	21	21	0
D	5	0	5
E	4	4	0
F	10	6	4
G	39	2	37
Total	120	38	82

A count of the number of process and major equipment units by type of process and major equipment unit and province is presented in Table 13 in Appendix A. Based on those process and major equipment unit totals and the corresponding default component counts listed in Table 12, the study total equipment component counts are summarized in Table 4 by type of component.

Table 4: Summary of emission factor update study estimated total component counts by types and jurisdiction based on the equipment totals and default component counts.			
Component Type	**BC**	**AB**	**Total**
Compressor Seal (FG)	0	0	0
Compressor Seal (GV)	110	362	472
Connector (FG)	19,438	26,803	46,241
Connector (GV)	56,634	97,107	153,741
Connector (LL)	10,153	22,355	32,508
Control Valve (FG)	0	0	0
Control Valve (GV)	4	46	50
Control Valve (LL)	0	0	0
Open-Ended Line (FG)	0	0	0
Open-Ended Line (GV)	402	771	1,173
Open-Ended Line (LL)	2	2	4
Pressure Relief Valve (FG)	45	34	79
Pressure Relief Valve (GV)	313	741	1,054
Pressure Relief Valve (LL)	0	16	16
Pump Seal (FG)	0	0	0
Pump Seal (LL)	163	273	436
Regulator (FG)	27	0	27
Regulator (GV)	11	92	103
Regulator (LL)	0	0	0
Valve (FG)	1,724	1,586	3,310
Valve (GV)	8,732	18,482	27,214
Valve (LL)	3,303	7,216	10,519
Total of all component types	101,061	175,886	276,947

2.3 FUGITIVE EMISSION DATA ANALYSIS

The compiled information was managed in a relational MS Access database. The approaches used to process these data included:

- Method 1 - application of post-2007 leak frequency data and CAPP (1992) Leak and No-Leak emission factors. This method was only applied where leak-rate measurement results were unavailable.
- Method 2 - application of post-2007 leak detection and measurement results for leaking components and estimation of emissions contributions from non-leaking components using the CAPP (1992) no-leak emission factors. An equipment component is generally deemed to be leaking if it produces a screening value of 10,000 ppm or greater when

screened in accordance with U.S. EPA Method 21, or the emissions are detectable by a leak imaging infrared camera.

2.4 COMPONENT COUNTS

Each of the applied methods of analysis required knowledge of the actual or estimated inventory of equipment components in hydrocarbon service at each facility. For the emission survey results submitted, only one respondent included component counts and these were estimates rather than actual field-based counts. For the rest of the facilities, process flow drawings (PFDs) and piping and instrumentation drawings (P&IDs) were requested and used to identify the processes and major equipment units in operation at each facility as well as provide details of the yard piping. Typical (default) component counts (see Appendix A and CAPP[2005]) were applied to each type of process or major equipment unit, and the counting guidelines presented in Appendix B were applied to the yard piping and, where necessary, to refine the applied equipment schedules.

2.5 METHOD 1 EMISSION FACTORS

Method 1 (see Section 2.3) was applied to those facilities for which leak counts but no leak-rate measurement data were provided.

2.5.1 LEAK FREQUENCY (LF)

The Leak Frequency for any emission source component type is determined by the following equation:

$$LF = \frac{N_{Leakers}}{N_{Total}} \cdot 100$$ Equation 1

Where:

LF or LF_{Ci}	=	*leak frequency for Component Type "C_i" expressed as a %.*
$N_{Leakers}$	=	the actual number of leaks reported for Component Type "C_i" in the dataset.
N_{Total}	=	the total number of Component Type "C_i" determined for all facilities included in the dataset.

2.5.2 EMISSION FACTOR (EF)

The average emission factor ($EF_{Average}$) of any component type, using the CAPP (1992) Leak and No-Leak emission factors contained in Table 1, is determined by the following equation:

$$EF_{Average} = \frac{LF \cdot EF_{Leak} + (100 - LF) \cdot EF_{No-Leak}}{100} \qquad \text{Equation 2}$$

Where:

$EF_{Average}$ = the calculated average emission factor for component type "Ci", (kg/h/source).

EF_{Leak} = the Leak emission factor for Component type "C_i" as reported (CAPP 1992).

$EF_{No\text{-}Leak}$ = the No-Leak emission factor for Component type "C_i" as reported (CAPP 1992).

2.6 METHOD 2 EMISSION FACTORS

Method 2 (see Section 2.3) was applied to the survey data where the measured emissions rate of the identified leaks was provided. In addition, this method applied previously reported No-Leak emission factors to assess emission contributions by the non-leaking components (CAPP 1992). In theory, mechanical seals and connections are not perfect and will emit a certain amount of process fluid when they are in pressurized service, even when they are new and properly installed. The term "leakage" is used in the regulatory context to indicate that the component is emitting at an excessive rate and is in need of repair or replacement.

2.6.1 LEAK FREQUENCY (LF)

Leak frequency is determined as indicated in Section 2.5.1 above.

2.6.2 EMISSION FACTOR (EF)

The average emission factor ($EF_{Average}$) of any component type is determined by the following equation:

$$EF_{Average} = \frac{\sum (\text{Emissions from detected leaks}) + N_{No-Leak} \cdot EF_{No-Leak}}{N_{Total}} \qquad \text{Equation 3}$$

Where:

$EF_{Average}$ = the calculated average emission factor for Component Type "C_i" (kg/h/source).

∑Emissions...Leaks = the sum of all leaks reported for Component Type "C_i" in the dataset.

N_{Total} = the total number of components of type i.

$N_{No\text{-}Leak}$ = N_{Total} of component type "i" minus the number of leaking component type "C_i".

$EF_{No\text{-}Leak}$ = the No-Leak emission factor for Component Type "C_i" as reported (CAPP 1992).

2.7 COMBINING THE RESULTS OF METHOD 1 AND 2

A hybrid approach was used to combine the results of Method 1 and Method 2. This was done using Equation 4 for each component and service category (i.e., the summation is with respect to the different data sets where each data set has its own $EF_{Average}$ and N_{Total} values):

$$EF_{Average} = \frac{\sum N_{Total_{Method1}} \cdot EF_{Average_{Method1}} + \sum N_{Total_{Method\,2}} \cdot EF_{Average_{Method\,2}}}{N_{Total_{Method\,1}} + N_{Total_{Method\,2}}} \qquad \text{Equation 4}$$

3 COMPONENT EMISSION FACTORS

3.1 LEAK SURVEY RESULTS

Table 5 presents the total estimated number of each equipment component type and the number that were reported to be leaking at the facilities for which fugitive emission surveys were completed and submitted for consideration. The relative distribution of these results is depicted in Figure 1. A leak frequency of 17.37% was reported for Compressor Seals (GV). This is a component type that is expected to vent. The average emission rate of those reported was 0.24171 kg/h/source with a standard deviation of 233%. Similarly, for Control Valve (GV), a leak frequency of 38% was reported with a variability that was considerably less at 117%.

Some situations arose where certain component types occurred at a facility based on the leak survey results but were not identified for that facility by the applied methodology for developing facility-level equipment component counts. Additionally, some cases occurred where the estimated number of components in a given category for a facility was less than the number of leaking components identified by the leak survey for the facility. The occurrences of these two types of discrepancies are summarized in Table 6 and are attributed to weaknesses in the CAPP (2005) default equipment schedules used to develop the estimated component counts. While there is some potential to improve these default equipment schedules to help avoid the identified discrepancies and improve the overall accuracy for all applicable component categories, the uncertainties in the current schedules are not believed to have a significant adverse impact on the developed emission factors given that they were initially derived from a large reliable data set. Moreover, as a conservative approach, the estimated facility-level component counts were set equal to the population of reported leaks (i.e., an implied leak frequency of 100%) for categories where the initial estimated count was less than the reported number of leaks. The following are some examples of observed count discrepancies:

- 7 of 82 Compressor Seal (GV) components were reported leaking at facilities where no compressor seals were calculated to be present. Further the average leak rate of these compressor seals was 2.53 times the average leak rate reported for compressor seal leaks.
- All reported Control Valve (FG), Pressure Relief Valve (FG), Regulator (FG) and Regulator (LL) leaks were at facilities where the total component counts for those component types were zero.
- Except for Valve (GV), average leak rates of component types, at facilities where the total component count was zero, were greater than the average of the leaking components presented in **Table 5**.

Table 5: Summary of leak survey results showing leak frequency, average leak rate and leak rate standard deviation.							
Component Type	**Estimated Total Components[1]**	**Applied Total Components**	**Reported Leaking Components[2]**	**Leak Frequency: Average[3] (%)**	**Leak Rate: Average[4] (kg/h/source)**	**Leak Rate: STDEV[5] (kg/h/source)**	**STDEV/ Average (%)**
Compressor Seal (GV)	472	472	82	17.37	0.24171	0.56222	233
Connector (FG)	46,241	46,241	390	0.84	0.11701	0.17225	147
Connector (GV)	153,741	153,741	229	0.15	0.05795	0.16435	284
Connector (LL)	32,508	32,508	10	0.03	0.08497	0.18350	216
Control Valve (FG)	0	14	14	100.00	0.10670	0.09843	92
Control Valve (GV)	50	50	19	38.00	0.06349	0.07409	117
Open-Ended Line (FG)	0	23	23	100.00	0.36372	0.87591	241
Open-Ended Line (GV)	1,173	1,173	25	2.13	2.64852	5.01464	189
Open-Ended Line (LL)	4	4	0	0.00	0.00000	0.00000	0
Pressure Relief Valve (FG)	79	80	1	1.27	0.00000	0.00000	0
Pressure Relief Valve (GV)	1,054	1,054	2	0.19	0.00018	0.00006	35
Pressure Relief Valve (LL)	16	16	0	0.00	0.00000	0.00000	0
Pump Seal (FG)	0	3	3	100.00	0.06469	0.07612	118
Pump Seal (LL)	436	436	0	0.00	0.00000	0.00000	0
Regulator (FG)	27	66	44	162.96	0.19491	0.35115	180
Regulator (GV)	103	105	15	14.56	0.34456	1.08567	315
Regulator (LL)	0	1	1	100.00	0.00000	0.00000	0
Valve (FG)	3,310	3,310	64	1.93	0.08367	0.10892	130
Valve (GV)	27,214	27,214	122	0.45	0.08184	0.48082	588
Valve (LL)	10,519	10,519	11	0.10	0.03865	0.07048	182

[1] Total Components = Sum of components by type for all facilities included in survey.

Table 5: Summary of leak survey results showing leak frequency, average leak rate and leak rate standard deviation.							
Component Type	**Estimated Total Components[1]**	**Applied Total Components**	**Reported Leaking Components[2]**	**Leak Frequency: Average[3] (%)**	**Leak Rate: Average[4] (kg/h/source)**	**Leak Rate: STDEV[5] (kg/h/source)**	**STDEV/ Average (%)**
[2] Leaking components = Total number of leaking components by type included in survey.							
[3] Leak Frequency = Number leaking divided by total number by component type.							
[4] Leak Rate: Average of Leak Rate: Average = Sum of emissions from all components of that type divided by the total number of that component type.							
[5] Leak Rate: STDEV = SDTEV of all leak rates by component type.							

Table 6: Summary of leak survey results showing the number of leaking components, the average leak rate and the leak rate standard deviation for reported emissions where the estimated facility component count for the leaking component was zero.

Component Type	Leaking Components[1] (Number)	Leak Rate: Average[2] (kg/h/source)	Leak Rate: STDEV[3] (kg/h/source)	STDEV/ Average (%)	Leaking Components Table 5 (Number)	Leak Rate Table 6/Table 5 (Ratio)
Compressor Seal (GV)	7	0.61142	0.42697	70	82	2.530
Connector (FG)	14	0.21844	0.25549	117	390	1.867
Control Valve (FG)	14	0.10670	0.09843	92	14	1.000
Control Valve (GV)	7	0.08497	0.06722	79	19	1.338
Open-Ended Line (FG)	23	0.36372	0.87591	241	27	1.000
Open-Ended Line (GV)	1	0.00000			25	0.000
Pressure Relief Valve (FG)	1	0.00000			1	0.000
Pump Seal (FG)	3	0.06469	0.07612	118	3	1.000
Regulator (FG)	44	0.19491	0.35115	180	44	1.000
Regulator (GV)	10	0.49748	1.32425	266	15	1.444
Regulator (LL)	1	0.00000			1	0.000
Valve (FG)	2	0.11893	0.02403	20	64	0.287

[1] Leaking components = Total number of leaking components by type included in survey.

[2] Leak Rate: Average = Average of all leak rates by component type.

[3] Leak Rate: STDEV = SDTEV of all leak rates by component type.

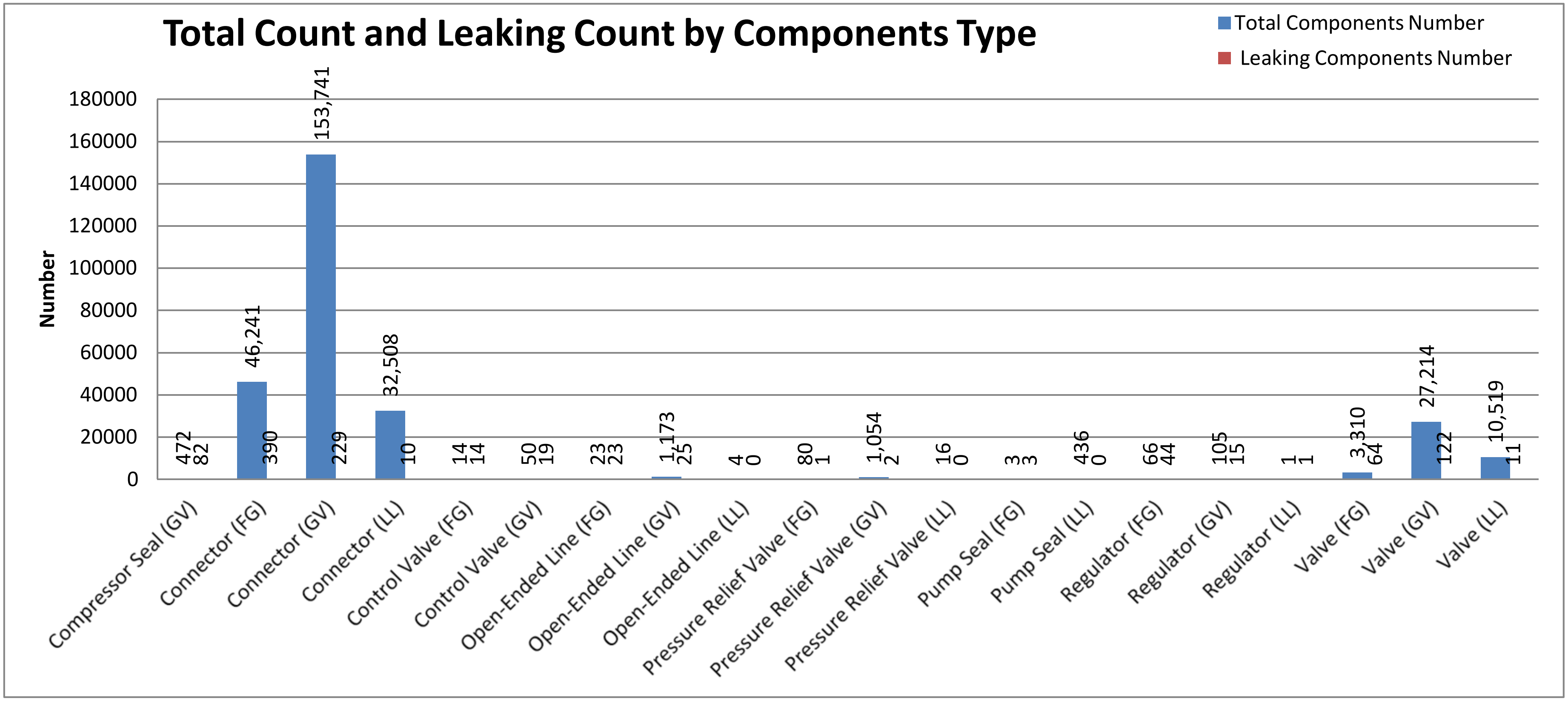

Figure 1: Distribution of the applied total count and leaking component count by component type in database and presented in Table 5.

3.2 METHOD 1 LEAK FREQUENCY AND EMISSION RESULTS

Company D provided leak data without emission measurements for a total of five facilities. The data provided was processed based on Method 1 described in Section 2.5 and the emission factor results are presented in Table 7**.**

All facilities in this category were from the crude oil sector, and all were designated as sour. Except for Valve (FG), the calculated emission factors for the component types listed were somewhat (ratio of 0.28 to 0.68) to considerably (ratio of 0.002 to 0.006) less than the CAPP (2005) emission factors. The emission factor for Valve (FG) compared favorably (ratio of 1.09) with the corresponding CAPP (2005) emission factor.

Component type counts, total and leakers, for all results in the Method 1 calculation category were small ranging from 1 for Open-ended Line (LL) to a maximum of 4831 for Connector (GV).

Table 7: Emissions and leak frequency results from application of Method 1 to sites having leaker counts but no leak measurement data.														
Sector	Sweet/ Sour	Component Type	Service	Leaker Count	Component Count		Leak Frequency (%)	EF (kg/source/d)		Method 1 EF[3,5] (kg/h/source)	95 % Lower Confidence Limit	95 % Upper Confidence Limit	CAPP 2005 EF[4] (kg/h/source)	Method 1 EF/ CAPP 2005 (Ratio)
					Estimated	Applied		Leak	No-Leak					
Oil	Sour	Compressor Seal	GV	0	16	16	0	1.60800	0.00175	0.00175	41%	501%	0.80500	0.0022
Oil	Sour	Connector	FG	32	2552	2552	1.25	0.03750	0.00023	0.00070	30%	165%	0.00246	0.2835
Oil	Sour	Connector	GV	7	4831	4831	0.14	0.03750	0.00023	0.00028	36%	406%	0.00246	0.1154
Oil	Sour	Connector	LL	0	1866	1866	0.00	0.03750	0.00013	0.00013	41%	501%	0.00019	0.6842
Oil	Sour	Control Valve	GV	0	0	0	0.00	0.04510	0.00008	0.00000	25%	25%	0.01460	0.0000
Oil	Sour	Open-Ended Line	GV	0	39	39	0.00	0.01195	0.00183	0.00183	41%	501%	0.30800	0.0059
Oil	Sour	Pressure Relief Valve	FG	0	0	0	0.00	1.69100	0.00019	0.00000	25%	25%	0.01630	0.0000
Oil	Sour	Pressure Relief Valve	GV	0	27	27	0.00	1.69100	0.00019	0.00019	41%	501%	0.01630	0.0117
Oil	Sour	Pump Seal	LL	0	36	36	0.00	0.43700	0.00230	0.00230	41%	501%	0.02320	0.0991
Oil	Sour	Regulator	FG	2	0	2	100.00	0.04510	0.00008	0.04510	77%	240%	0.00668	6.7515
Oil	Sour	Regulator	GV	0	0	0	0.00	0.04510	0.00008	0.00000	25%	25%	0.00668	0.0000
Oil	Sour	Valve	FG	5	144	144	3.47	0.04510	0.00008	0.00164	80%	83%	0.00151	1.0882
Oil	Sour	Valve	GV	1	915	915	0.11	0.04510	0.00008	0.00013	44%	312%	0.00151	0.0856
Oil	Sour	Valve	LL	0	580	580	0.00	0.08520	0.00058	0.00058	41%	501%	0.00121	0.4793

[1] Results are based on Company D data

[2] Results based on application of Equation 1

[3] Results based on application of Equation 2

[4] Default CAPP fugitive emission rate for component type from Table 2.

[5] No-Leak and Leak emission factors are from Table 1.

3.3 METHOD 2 LEAK FREQUENCY AND EMISSION RESULTS

Four companies provided leak survey data that included measured leak rates for 115 UOG facilities in both the oil and natural gas sectors, and included both sweet and sour facilities. The data were processed using Method 2 as described in Section 2.6. The results are presented in Table 8 and the developed emission factors are compared to the CAPP (2005) results. Except for a few categories comprising small numbers of components and, consequently, subject to high uncertainties, the rest of the categories showed significant decreases in the determined average emissions factors.

The presented confidence limits in Table 8 account for the combined effects of uncertainties in the following parameters:

- Average leaker emission rate per component (the values for each component category were calculated based on the standard deviation in the measured leak rates).
- Default no-leak rate per component (a lower uncertainty limit of -20% and an upper uncertainty limit of +500% were assumed).
- Number of leakers (an uncertainty of ±10% was assumed).
- Estimated number of non-leakers (an uncertainty of ±25% was assumed).

The procedures used to combine the above uncertainties are delineated in Section 8 (Appendix C). The developed factors tend to have greater uncertainties than the CAPP (2005) factors because they include additional uncertainties (i.e., the number of non-leakers).

The leak frequencies range from 0% to 100%. Considering only those component types where the total component count exceeds 500, leak frequencies are less than 1% with two exceptions: Gas-Sweet-Open-Ended Line (GV) and Gas-Sweet-Valve (FG). No apparent trend relating frequency to total count was noted as depicted by the data presented in Figure 2.

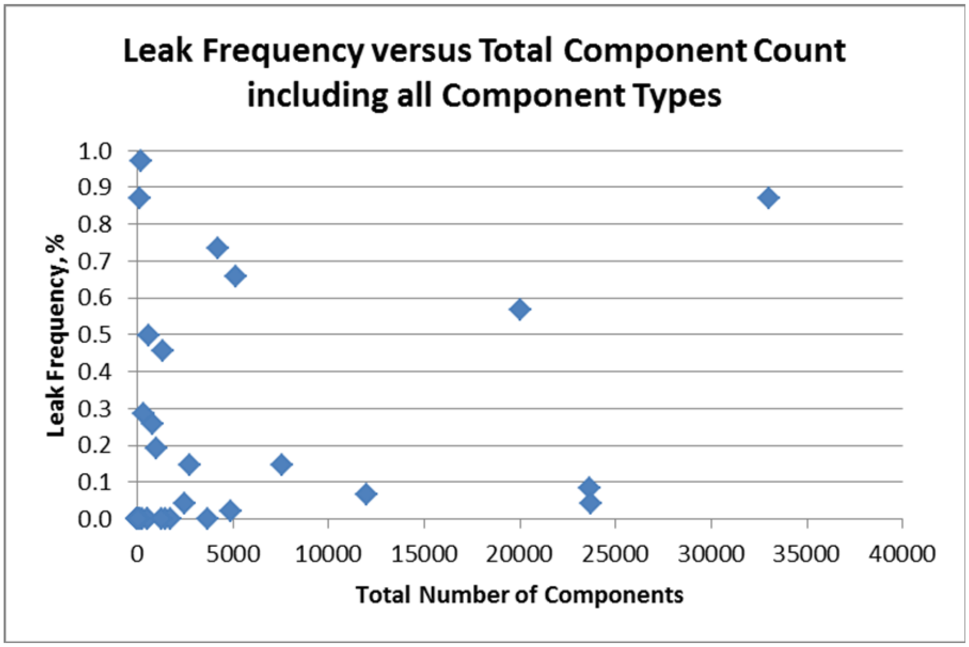

Figure 2: Leak frequency versus Total Component Count including all component types (frequencies greater than 1% and counts less than 500 and greater than 40,000 excluded).

The ratio of Method 2 emission factors to CAPP (2005) emission factors indicates that, with only a few exceptions, the Method 2 emission factors are less than CAPP (2005). If categories with fewer than 50 components are excluded, the exceptions are:

- Gas-Sour-Connector (FG) with a total count of 5,165 and a ratio of 1.911
- Gas-Sour-Connector (G/V) with a total count of 23,661 and a ratio of 1.764
- Gas-Sweet-Connector (FG) with a total count of 32,994 and a ratio of 1.911
- Oil-Sweet-Open-Ended Line (GV) with a count of 85 and a ratio of 1.048
- Oil-Sweet-Valve (GV) with a count of 2,734 and a ratio of 1.353

If the total assessed emissions (i.e., the sum of the estimated no-leak and measured leak contributions) for the sample population of components used to develop the Method 2 factors is compared to what would be estimated for the same sample set of components based on the pre-2007 emission factors (CAPP, 2005), then the overall result is a net emissions reduction of 73.7%.

3.4 COMBINED AND CONSOLIDATED EMISSION FACTOR RESULTS

The final emission factors determined by combining the results of the Method 1 and Method 2 data sets are presented in Table 9. Consolidating subcategories of each component type where the differences between like categories are not statistically significant results in the final set of developed emission factors, and these are presented in Table 10.

If the total assessed emissions (i.e., the sum of the estimated and measured leak contributions) for the sample population of components used to develop the combined factors is compared to what would be estimated for the same sample set of components based on the pre-2007 emission factors (CAPP, 2005), then the overall result is a net emissions reduction of 75.3%.

Table 8: Emissions and leak frequency results using Method 2 for sites with measured leak rates.														
Sector	Sweet/ Sour	Component Type	Service	Leaker Count	Component Count		Leak Frequency[2] (%)	Sum of Leaks (kg/h)	No-Leak EF (kg/h/source)	Method 2 EF[3,5] (kg/h/source)	95 % Lower Confidence Limit	95 % Upper Confidence Limit	CAPP 2005 EF[4] (kg/h/source)	Method 2 EF/ CAPP 2005 EF (Ratio)
					Estimate	Applied								
Gas	Sour	Compressor Seal	GV	7	22	22	31.82	4.2799	0.00175	0.19573	28%	28%	0.71300	0.2745
Gas	Sour	Connector	FG	34	5,165	5,165	0.66	4.9647	0.00061	0.00157	30%	195%	0.00082	1.9112
Gas	Sour	Connector	GV	20	23,661	23,661	0.09	1.3518	0.00019	0.00025	36%	386%	0.00014	1.7641
Gas	Sour	Connector	LL	0	1,509	1,509	0.00	0	0.00013	0.00013	41%	501%	0.00055	0.2364
Gas	Sour	Control Valve	GV	1	1	1	100.00	0.068	0.00010	0.06800	189%	189%	0.00964	7.0539
Gas	Sour	Open-Ended Line	GV	4	100	100	4.00	0.9755	0.00183	0.01151	36%	84%	0.18900	0.0609
Gas	Sour	Pressure Relief Valve	FG	0	17	17	0.00	0	0.00019	0.00019	41%	501%	0.01700	0.0112
Gas	Sour	Pressure Relief Valve	LL	1	0	1	100.00	0.00019	0.00019	0.00019	25%	25%	0.02139	0.0000
Gas	Sour	Pressure Relief Valve	GV	0	77	77	0.00	0	0.00019	0.00019	41%	501%	0.01700	0.0112
Gas	Sour	Pump Seal	LL	0	23	23	0.00	0	0.00230	0.00230	41%	501%	0.02320	0.0991
Gas	Sour	Regulator	FG	3	25	25	12.00	0.6796	0.00023	0.02739	50%	50%	0.00811	3.3769
Gas	Sour	Regulator	GV	2	5	5	40.00	0.0023	0.00010	0.00052	2115%	2116%	0.00005	10.4000
Gas	Sour	Regulator	LL	1	0	1	100.00	0.0001	0.00010	0.00010	25%	25%	0.00811	0.0000
Gas	Sour	Valve	FG	3	603	603	0.50	0.3609	0.00023	0.00083	56%	149%	0.00281	0.2944
Gas	Sour	Valve	GV	1	2,473	2,473	0.04	0.0001	0.00010	0.00010	41%	501%	0.00116	0.0862
Gas	Sour	Valve	LL	0	554	554	0.00	0	0.00081	0.00081	41%	501%	0.00352	0.2301
Gas	Sweet	Compressor Seal	GV	72	402	402	17.91	14.9113	0.00175	0.03853	26%	32%	0.71300	0.0540
Gas	Sweet	Connector	FG	287	32,994	32,994	0.87	31.7444	0.00061	0.00157	28%	195%	0.00082	1.9108
Gas	Sweet	Connector	GV	193	108,328	108,328	0.18	7.9791	0.00061	0.00068	38%	447%	0.00082	0.8324
Gas	Sweet	Connector	LL	10	23,694	23,694	0.04	0.8497	0.00013	0.00017	36%	393%	0.00055	0.3015
Gas	Sweet	Control Valve	FG	13	0	13	100.00	1.3239	0.00023	0.10184	44%	44%	0.01620	6.2863
Gas	Sweet	Control Valve	GV	17	47	47	36.17	1.0364	0.00023	0.02220	48%	48%	0.01620	1.3702
Gas	Sweet	Open-Ended	FG	20	0	20	100.00	7.3291	0.00183	0.36646	27%	27%	0.46700	0.7847

Table 8: Emissions and leak frequency results using Method 2 for sites with measured leak rates.														
Sector	Sweet/ Sour	Component Type	Service	Leaker Count	Component Count		Leak Frequency[2] (%)	Sum of Leaks (kg/h)	No-Leak EF (kg/h/source)	Method 2 EF[3,5] (kg/h/source)	95 % Lower Confidence Limit	95 % Upper Confidence Limit	CAPP 2005 EF[4] (kg/h/source)	Method 2 EF/ CAPP 2005 EF (Ratio)
					Estimate	Applied								
		Line												
Gas	Sweet	Open-Ended Line	GV	16	890	890	1.80	37.102	0.00183	0.04348	25%	33%	0.46700	0.0931
Gas	Sweet	Open-Ended Line	LL	0	2	2	0.00	0	0.00183	0.00183	41%	501%	0.01830	0.1000
Gas	Sweet	Pressure Relief Valve	FG	0	48	48	0.00	0	0.00019	0.00019	41%	501%	0.01700	0.0112
Gas	Sweet	Pressure Relief Valve	GV	2	779	779	0.26	0.0004	0.00019	0.00019	49%	501%	0.01700	0.0112
Gas	Sweet	Pressure Relief Valve	LL	0	16	16	0.00	0	0.00019	0.00019	41%	501%	0.00539	0.0353
Gas	Sweet	Pump Seal	FG	3	0	3	100.00	0.1941	0.00019	0.06470	108%	108%	0.02320	0.0000
Gas	Sweet	Pump Seal	LL	0	283	283	0.00	0	0.00230	0.00230	41%	501%	0.02320	0.0991
Gas	Sweet	Regulator	FG	33	2	33	100.00	5.128	0.00023	0.15539	29%	29%	0.00811	19.1608
Gas	Sweet	Regulator	GV	9	94	94	9.57	0.2389	0.00023	0.00275	98%	105%	0.00839	0.3277
Gas	Sweet	Valve	FG	54	2,099	2,099	2.57	4.2866	0.00023	0.00227	31%	58%	0.00281	0.8065
Gas	Sweet	Valve	GV	114	20,052	20,052	0.57	4.4144	0.00023	0.00045	31%	256%	0.00281	0.1597
Gas	Sweet	Valve	LL	11	7,584	7584	0.15	0.4252	0.00081	0.00086	39%	469%	0.00352	0.2457
Oil	Sour	Compressor Seal	GV	0	8	8	0	0	0.00175	0.00175	41%	501%	0.80500	0.0022
Oil	Sour	Connector	FG	6	1,314	1,314	0.46	0.6796	0.00023	0.00075	45%	160%	0.00246	0.3033
Oil	Sour	Connector	GV	1	4,905	4,905	0.02	0.1359	0.00023	0.00026	40%	448%	0.00246	0.1047
Oil	Sour	Connector	LL	0	1,750	1,750	0.00	0	0.00013	0.00013	41%	501%	0.00019	0.6842
Oil	Sour	Control Valve	GV	0	1	1	0.00	0	0.00008	0.00008	41%	501%	0.01460	0.0055
Oil	Sour	Open-Ended Line	GV	1	59	59	1.70	0.8495	0.00183	0.01620	36%	66%	0.30800	0.0526
Oil	Sour	Pressure Relief Valve	FG	0	4	4	0.00	0	0.00019	0.00019	41%	501%	0.01630	0.0117
Oil	Sour	Pressure Relief Valve	GV	0	49	49	0.00	0	0.00019	0.00019	41%	501%	0.01630	0.0117

Table 8: Emissions and leak frequency results using Method 2 for sites with measured leak rates.

Sector	Sweet/ Sour	Component Type	Service	Leaker Count	Component Count		Leak Frequency[2] (%)	Sum of Leaks (kg/h)	No-Leak EF (kg/h/source)	Method 2 EF[3,5] (kg/h/source)	95 % Lower Confidence Limit	95 % Upper Confidence Limit	CAPP 2005 EF[4] (kg/h/source)	Method 2 EF/ CAPP 2005 EF (Ratio)
					Estimate	Applied								
Oil	Sour	Pump Seal	LL	0	21	21	0.00	0	0.00230	0.00230	41%	501%	0.02320	0.0991
Oil	Sour	Regulator	FG	0	0	0	0.00	0	0.00008	0.00000	0%	0%	0.00668	0.0000
Oil	Sour	Regulator	GV	0	2	2	0.00	0	0.00008	0.00008	41%	501%	0.00668	0.0120
Oil	Sour	Valve	FG	1	115	115	0.87	0.068	0.00008	0.00067	167%	178%	0.00151	0.4441
Oil	Sour	Valve	GV	2	1,040	1,040	0.19	0.1189	0.00008	0.00019	91%	225%	0.00151	0.1286
Oil	Sour	Valve	LL	0	557	557	0.00	0	0.00058	0.00058	41%	501%	0.00121	0.4793
Oil	Sweet	Compressor Seal	GV	3	24	24	12.50	0.6286	0.00175	0.02772	47%	54%	0.80500	0.0344
Oil	Sweet	Connector	FG	31	4,216	4,216	0.74	4.5024	0.00023	0.00130	30%	93%	0.00246	0.5269
Oil	Sweet	Connector	GV	8	12,016	12,016	0.07	3.398	0.00023	0.00051	30%	226%	0.00246	0.2084
Oil	Sweet	Connector	LL	0	3,689	3,689	0.00	0	0.00013	0.00013	41%	501%	0.00019	0.6842
Oil	Sweet	Control Valve	FG	1	0	1	100.00	0.1699	0.00008	0.16990	98%	98%	0.01460	11.6370
Oil	Sweet	Control Valve	GV	1	1	1	100.00	0.1019	0.00008	0.10190	141%	141%	0.01460	6.9795
Oil	Sweet	Open-Ended Line	FG	3	0	3	100.00	1.0364	0.00183	0.34547	40%	40%	0.30800	1.1216
Oil	Sweet	Open-Ended Line	GV	4	85	85	4.71	27.2861	0.00183	0.32276	25%	25%	0.30800	1.0479
Oil	Sweet	Open-Ended Line	LL	0	2	2	0.00	0	0.00183	0.00183	41%	501%	0.00373	0.4906
Oil	Sweet	Pressure Relief Valve	FG	0	10	10	0.00	0	0.00019	0.00019	41%	501%	0.01630	0.0117
Oil	Sweet	Pressure Relief Valve	GV	0	122	122	0.00	0	0.00019	0.00019	41%	501%	0.01630	0.0117
Oil	Sweet	Pump Seal	LL	0	73	73	0.00	0	0.00230	0.00230	41%	501%	0.02320	0.0991
Oil	Sweet	Regulator	FG	6	0	6	100.00	2.3786	0.00008	0.39643	31%	31%	0.00668	59.3463
Oil	Sweet	Regulator	GV	4	2	4	100.00	4.9271	0.00008	1.23178	27%	27%	0.00668	184.3975
Oil	Sweet	Valve	FG	1	349	349	0.29	0.2209	0.00008	0.00071	73%	92%	0.00151	0.4720
Oil	Sweet	Valve	GV	4	2,734	2,734	0.15	5.3689	0.00008	0.00204	26%	33%	0.00151	1.3534
Oil	Sweet	Valve	LL	0	1,244	1,244	0.00	0	0.00058	0.00058	41%	501%	0.00121	0.4793

Table 8: Emissions and leak frequency results using Method 2 for sites with measured leak rates.														
Sector	Sweet/ Sour	Component Type	Service	Leaker Count	Component Count		Leak Frequency[2] (%)	Sum of Leaks (kg/h)	No-Leak EF (kg/h/source)	Method 2 EF[3,5] (kg/h/source)	95 % Lower Confidence Limit	95 % Upper Confidence Limit	CAPP 2005 EF[4] (kg/h/source)	Method 2 EF/ CAPP 2005 EF (Ratio)
					Estimate	Applied								

[1] Results are based on data from all companies except Company D.

[2] Results based on application of Equation 1

[3] Results based on application of Equation 3

[4] Default CAPP fugitive emission rate for component type from Table 2.

[5] Where Total Number = zero and Number Leakers is > zero, Method 2 emission factor = Sum Of All Leaks/Number Leakers and result is shaded in grey.

Table 9: Combined emission factor results from the Method 1 and Method 2 data sets.														
Sector	Sweet/ Sour	Component Type	Service	Method 1 Data		Method 2 Data		Combined Results			CAPP (2005) Results (kg/h/source)			Combined EF/ CAPP 2005 EF (Ratio)
				Applied Component Count	Average EF (kg/h/source)	Applied Component Count	Average EF (kg/h/source)	Average EF (kg/h/source)	95 % Lower Confidence Limit (%)	95 % Upper Confidence Limit (%)	Average EF (kg/h/source)	95 % Lower Confidence Limit (%)	95 % Upper Confidence Limit (%)	
Gas	Sour	Compressor	GV	0	0.00000	22	0.19573	0.19573	45.20	45.30%	0.71300	36	36	0.2745
Gas	Sour	Seal Connector	FG	0	0.00000	5,165	0.00157	0.00157	46.25	198.64%	0.00082	72	72	1.9112
Gas	Sour	Connector	GV	0	0.00000	23,661	0.00025	0.00025	50.51	387.33%	0.00014	72	72	1.7641
Gas	Sour	Connector	LL	0	0.00000	1,509	0.00013	0.00013	53.85	502.49%	0.00055	72	72	0.2364
Gas	Sour	Control	GV	0	0.00000	1	0.06800	0.06800	192.64	192.64%	0.00964	4	4	7.0539
Gas	Sour	Valve Open-	GV	0	0.00000	100	0.01151	0.01151	50.35	91.37%	0.18900	79	127	0.0609
Gas	Sour	Ended Line Pressure	FG	0	0.00000	17	0.00019	0.00019	53.85	502.49%	0.01700	98	98	0.0112
Gas	Sour	Relief Valve Pressure	LL	0	0.00000	1	0.00019	0.00019	43.30	43.30%	0.02139	80	80	0.0089
Gas	Sour	Relief Valve Pressure	GV	0	0.00000	77	0.00019	0.00019	53.85	502.49%	0.01700	98	98	0.0112
Gas	Sour	Relief Valve Pump Seal	LL	0	0.00000	23	0.00230	0.00230	53.85	502.49%	0.02320	74	136	0.0991
Gas	Sour	Regulator	FG	0	0.00000	25	0.02739	0.02739	61.29	61.40%	0.00811	74	126	3.3769
Gas	Sour	Regulator	GV	0	0.00000	5	0.00052	0.00052	2115.24	2116.03%	0.00005	74	126	10.4000
Gas	Sour	Regulator	LL	0	0.00000	1	0.00010	0.00010	43.30	43.30%	0.00811	74	126	0.0123
Gas	Sour	Valve	FG	0	0.00000	603	0.00083	0.00083	66.06	153.17%	0.00281	17	17	0.2944
Gas	Sour	Valve	GV	0	0.00000	2,473	0.00010	0.00010	53.84	502.29%	0.00116	31	31	0.0862
Gas	Sour	Valve	LL	0	0.00000	554	0.00081	0.00081	53.85	502.49%	0.00352	19	19	0.2301
Gas	Sweet	Compressor	GV	0	0.00000	402	0.03853	0.03853	43.72	47.52%	0.71300	36	36	0.0540
Gas	Sweet	Seal Connector	FG	0	0.00000	32,994	0.00157	0.00157	45.20	198.04%	0.00082	32	32	1.9108
Gas	Sweet	Connector	GV	0	0.00000	108,328	0.00068	0.00068	51.88	448.70%	0.00082	32	32	0.8324
Gas	Sweet	Connector	LL	0	0.00000	23,694	0.00017	0.00017	50.58	394.80%	0.00055	90	111	0.3015

Table 9: Combined emission factor results from the Method 1 and Method 2 data sets.

Sector	Sweet/ Sour	Component Type	Service	Method 1 Data		Method 2 Data		Combined Results			CAPP (2005) Results (kg/h/source)			Combined EF/ CAPP 2005 EF (Ratio)
				Applied Component Count	Average EF (kg/h/source)	Applied Component Count	Average EF (kg/h/source)	Average EF (kg/h/source)	95 % Lower Confidence Limit (%)	95 % Upper Confidence Limit (%)	Average EF (kg/h/source)	95 % Lower Confidence Limit (%)	95 % Upper Confidence Limit (%)	
Gas	Sweet	Control Valve	FG	0	0.00000	13	0.10184	0.10184	56.18	56.18	0.01620	27	27	6.2863
Gas	Sweet	Control Valve	GV	0	0.00000	47	0.02220	0.02220	59.40	59.50	0.01620	27	27	1.3702
Gas	Sweet	Open-Ended Line	FG	0	0.00000	20	0.36646	0.36646	44.40	44.40	0.46700	58	172	0.7847
Gas	Sweet	Open-Ended Line	GV	0	0.00000	890	0.04348	0.04348	43.39	48.05	0.46700	58	172	0.0931
Gas	Sweet	Open-Ended Line	LL	0	0.00000	2	0.00183	0.00183	53.85	502.49	0.01830	58	172	0.1000
Gas	Sweet	Pressure Relief Valve	FG	0	0.00000	48	0.00019	0.00019	53.85	502.49	0.01700	98	98	0.0112
Gas	Sweet	Pressure Relief Valve	GV	0	0.00000	779	0.00019	0.00019	60.39	501.90	0.01700	80	80	0.0112
Gas	Sweet	Pressure Relief Valve	LL	0	0.00000	16	0.00019	0.00019	53.85	502.49	0.00539	98	98	0.0353
Gas	Sweet	Pump Seal	FG	0	0.00000	3	0.06470	0.06470	114.02	114.02	0.02320	74	136	2.7888
Gas	Sweet	Pump Seal	LL	0	0.00000	283	0.00230	0.00230	53.85	502.49	0.02320	74	136	0.0991
Gas	Sweet	Regulator	FG	0	0.00000	33	0.15539	0.15539	45.67	45.67	0.00811	72	238	19.1608
Gas	Sweet	Regulator	GV	0	0.00000	94	0.00275	0.00275	104.48	111.10	0.00839	72	238	0.3277
Gas	Sweet	Valve	FG	0	0.00000	2,099	0.00227	0.00227	47.24	68.35	0.00281	17	17	0.8065
Gas	Sweet	Valve	GV	0	0.00000	20,052	0.00045	0.00045	47.30	258.91	0.00281	17	17	0.1597
Gas	Sweet	Valve	LL	0	0.00000	7,584	0.00086	0.00086	52.79	470.19	0.00352	17	17	0.2457
Oil	Sour	Compressor Seal	GV	16	0.00175	8	0.00175	0.00175	40.14	171.30	0.80500	36	36	0.0022
Oil	Sour	Connector	FG	2,552	0.00070	1,314	0.00075	0.00071	36.09	68.83	0.00246	15	15	0.2902
Oil	Sour	Connector	GV	4,831	0.00028	4,905	0.00026	0.00027	36.66	217.08	0.00246	15	15	0.1101
Oil	Sour	Connector	LL	1,866	0.00013	1,750	0.00013	0.00013	38.10	244.77	0.00019	90	111	0.6842

Table 9: Combined emission factor results from the Method 1 and Method 2 data sets.														
Sector	Sweet/ Sour	Component Type	Service	Method 1 Data		Method 2 Data		Combined Results			CAPP (2005) Results (kg/h/source)			Combined EF/ CAPP 2005 EF (Ratio)
				Applied Component Count	Average EF (kg/h/source)	Applied Component Count	Average EF (kg/h/source)	Average EF (kg/h/source)	95 % Lower Confidence Limit (%)	95 % Upper Confidence Limit (%)	Average EF (kg/h/source)	95 % Lower Confidence Limit (%)	95 % Upper Confidence Limit (%)	
Oil	Sour	Control Valve	GV	0	0.00000	1	0.00008	0.00008	53.85	502.49	0.01460	21	21	0.0055
Oil	Sour	Open-Ended Line	GV	39	0.00183	59	0.01620	0.01048	44.45	68.12	0.30800	78	129	0.0340
Oil	Sour	Pressure Relief Valve	FG	0	0.00000	4	0.00019	0.00019	53.85	502.49	0.01630	80	80	0.0117
Oil	Sour	Pressure Relief Valve	GV	27	0.00019	49	0.00019	0.00019	39.64	324.54	0.01630	80	80	0.0117
Oil	Sour	Pump Seal	LL	36	0.00230	21	0.00230	0.00230	39.38	188.23	0.02320	74	136	0.0991
Oil	Sour	Regulator	FG	2	0.04510	0	0.00000	0.04510	84.61	35.36	0.00668	72	238	6.7515
Oil	Sour	Regulator	GV	0	0.00000	2	0.00008	0.00008	53.85	502.49	0.00668	72	238	0.0120
Oil	Sour	Valve	FG	144	0.00164	115	0.00067	0.00121	77.69	136.24	0.00151	79	79	0.8022
Oil	Sour	Valve	GV	915	0.00013	1,040	0.00019	0.00016	64.77	147.81	0.00151	79	79	0.1085
Oil	Sour	Valve	LL	580	0.00058	557	0.00058	0.00058	38.09	247.69	0.00121	19	19	0.4793
Oil	Sweet	Compressor Seal	GV	0	0.00000	24	0.02772	0.02772	58.54	64.71	0.80500	36	36	0.0344
Oil	Sweet	Connector	FG	0	0.00000	4,216	0.00130	0.00130	46.27	99.42	0.00246	15	15	0.5269
Oil	Sweet	Connector	GV	0	0.00000	12,016	0.00051	0.00051	46.39	228.75	0.00246	15	15	0.2084
Oil	Sweet	Connector	LL	0	0.00000	3,689	0.00013	0.00013	53.85	502.49	0.00019	90	111	0.6842
Oil	Sweet	Control Valve	FG	0	0.00000	1	0.16990	0.16990	103.92	103.92	0.01460	21	21	11.6370
Oil	Sweet	Control Valve	GV	0	0.00000	1	0.10190	0.10190	145.23	145.23	0.01460	21	21	6.9795
Oil	Sweet	Open-Ended Line	FG	0	0.00000	3	0.34547	0.34547	53.21	53.21	0.30800	78	129	1.1216
Oil	Sweet	Open-Ended Line	GV	0	0.00000	85	0.32276	0.32276	43.39	43.47	0.30800	78	129	1.0479
Oil	Sweet	Open-	LL	0	0.00000	2	0.00183	0.00183	53.85	502.49	0.00373	78	129	0.4906

Table 9: Combined emission factor results from the Method 1 and Method 2 data sets.														
Sector	Sweet/ Sour	Component Type	Service	Method 1 Data		Method 2 Data		Combined Results			CAPP (2005) Results (kg/h/source)			Combined EF/ CAPP 2005 EF (Ratio)
				Applied Component Count	Average EF (kg/h/source)	Applied Component Count	Average EF (kg/h/source)	Average EF (kg/h/source)	95 % Lower Confidence Limit (%)	95 % Upper Confidence Limit (%)	Average EF (kg/h/source)	95 % Lower Confidence Limit (%)	95 % Upper Confidence Limit (%)	
		Ended Line												
Oil	Sweet	Pressure Relief Valve	FG	0	0.00000	10	0.00019	0.00019	53.85	502.49	0.01630	80	80	0.0117
Oil	Sweet	Pressure Relief Valve	GV	0	0.00000	122	0.00019	0.00019	53.85	502.49	0.01630	80	80	0.0117
Oil	Sweet	Pump Seal	LL	0	0.00000	73	0.00230	0.00230	53.85	502.49	0.02320	74	136	0.0991
Oil	Sweet	Regulator	FG	0	0.00000	6	0.39643	0.39643	47.31	47.31	0.00668	72	238	59.3463
Oil	Sweet	Regulator	GV	0	0.00000	4	1.23178	1.23178	44.31	44.31	0.00668	72	238	184.3975
Oil	Sweet	Valve	FG	0	0.00000	349	0.00071	0.00071	81.46	98.80	0.00151	79	79	0.4720
Oil	Sweet	Valve	GV	0	0.00000	2,734	0.00204	0.00204	44.04	48.18	0.00151	79	79	1.3534
Oil	Sweet	Valve	LL	0	0.00000	1,244	0.00058	0.00058	53.85	502.49	0.00121	19	19	0.4793

Table 10: Final consolidated emission factors for application in estimating fugitive emissions from upstream oil and gas facilities after the implementation of a formal DI&M program.													
Sector	Sweet/ Sour	Component Type	Service	Leaker Count	Component Count	Leak Frequency	Post-2007 Consolidated Results			CAPP (2005)			Combined EF/ CAPP 2005 EF (Ratio)
							EF (kg/h/source)	95 % Lower Confidence Limit	95 % Upper Confidence Limit	EF (kg/h/source)	95 % Lower Confidence Limit	95 % Upper Confidence Limit	
Gas	All	Compressor Seals	GV	79	424	18.63%	0.04669	40.98%	43.50%	0.71300	36%	36%	0.065
Gas	All	Connector	GV	534	170,148	0.31%	0.00082	36.22%	250.08%	0.00082	32%	32%	1.000
Gas	All	Connector	LL	10	25,203	0.04%	0.00016	53.81%	377.53%	0.00055	90%	111%	0.298
Gas	All	Control Valve	GV	31	61	50.82%	0.03992	43.70%	43.72%	0.01620	23%	23%	2.464
Gas	All	Open-Ended Line	All	40	1,012	3.95%	0.04663	41.85%	45.18%	0.46700	62%	161%	0.100
Gas	All	Pressure Relief Valve	All	3	938	0.32%	0.00019	54.60%	420.36%	0.01700	98%	98%	0.011
Gas	All	Pump Seal	All	3	309	0.97%	0.00291	50.01%	366.79%	0.02320	74%	136%	0.125
Gas	All	Regulator	All	48	158	30.38%	0.03844	44.83%	44.86%	0.00811	72%	238%	4.740
Gas	All	Valve	GV	172	25,227	0.68%	0.00057	37.63%	163.49%	0.00281	15%	15%	0.205
Gas	All	Valve	LL	11	8,138	0.14%	0.00086	54.80%	441.88%	0.00352	19%	19%	0.245
Oil	All	Compressor Seals	GV	3	48	6.25%	0.01474	59.93%	66.05%	0.80500	36%	36%	0.018
Oil	All	Connector	GV	85	29,834	0.28%	0.00057	27.05%	96.39%	0.00246	15%	15%	0.232
Oil	All	Connector	LL	0	7,305	0.00%	0.00013	36.49%	281.62%	0.00019	90%	111%	0.684
Oil	All	Control Valve	GV	2	3	66.67%	0.09063	86.67%	86.67%	0.01460	21%	21%	6.207
Oil	All	Open-Ended Line	All	8	188	4.26%	0.15692	46.64%	46.74%	0.30800	78%	129%	0.509
Oil	All	Pressure Relief Valve	All	0	212	0.00%	0.00019	37.71%	313.14%	0.01630	80%	80%	0.012
Oil	All	Pump Seal	All	0	130	0.00%	0.00230	38.39%	294.44%	0.02320	74%	136%	0.099
Oil	All	Regulator	All	12	14	85.71%	0.52829	38.03%	38.01%	0.00668	72%	238%	79.085
Oil	All	Valve	GV	14	5,297	0.26%	0.00122	44.15%	48.07%	0.00151	79%	79%	0.809
Oil	All	Valve	LL	0	2,381	0.00%	0.00058	36.94%	288.37%	0.00121	19%	19%	0.479

4 DISCUSSION OF RESULTS AND RECOMMENDATIONS

4.1 EQUIPMENT SCHEDULES

Establishing equipment schedules for each of the facilities, without detailed field inspections or operator feedback, presented significant challenges that reflect on the accuracy and uncertainty of the final results. Equipment and process count issues encountered are summarized in Table 11.

Table 11: Issued encountered in establishing equipment and process type counts for each facility.

Issue	Description
1	Meter schematics are not complete for purposes of making equipment counts. Equipment in process service is mostly included but non-process equipment supplied with fuel gas is typically not shown or listed.
2	PFDs, PI&Ds and meter schematics are inconsistent with respect to the types of equipment shown or listed. For example, pig receivers and launchers, meters, and ESD valves often are not shown.
3	Facility boundaries are not well defined. Drawings attempt to show boundaries but these are not necessarily clearly defined. Associated files listing equipment are not boundary compatible.
4	Equipment listed in equipment files for a facility may include off-site equipment associated with gathering systems and well sites.
5	The naming conventions and process unit boundaries used for equipment are not always compatible with those used in the CAPP default lists. For example glycol dehydrators are sometimes listed as process boiler with a note in the comments column indicating it is the dehydrator reboiler. Sometimes a contactor vessel is not listed. Same applies for gas-fired treaters. Line heaters were not always listed properly.
6	Office furnaces, catalytic heaters and gas-fired unit heaters seem to fall into the gas-fired unit heater category but not consistently.
7	Compressor vents are not completely defined resulting in miscoding of some emissions.
8	The equipment schedules would benefit from regrouping, editing and equipment defining.
9	Fugitive equipment leak component coding indicates that equipment component schedules do not always capture all component types reported in the corresponding leak surveys. Where this occurred it was for component types present in small numbers and therefore did not significantly compromise the overall quality of the developed component count estimates. Moreover, corrections were made to at least ensure that the component counts in these cases were at least equal to the number of detected leaks, which is conservative. Nonetheless, some opportunity for improvement exists.

4.1.1 EQUIPMENT SCHEDULE RECOMENDATIONS

The process and major equipment unit default equipment component schedules should be updated and republished with equipment and process definitions and application instructions. This should be done based on detailed component counts performed at actual facilities.

4.2 COMPONENT COUNTS

Default component counts listed in Table 12 are not complete and in some cases do not include all appropriate component types listed by service (FG, GV, LL or HL). Fugitive emission surveys identified some leaking component types at facilities where the estimated component type count was zero; although, in these cases, the missed components were only present in small quantities and corrections were made to account for these missed components.

4.2.1 COMPONENT COUNT RECOMMENDATIONS

These results should be reviewed and, where appropriate, used for updating the default component counts.

4.3 EMISSION FACTOR RESULTS

A direct comparison of the final developed emission factors with the previous CAPP (2005) factors is provided in Table 10. Overall, a net component-weighted reduction of 75 percent was observed across all of the component categories. The emission factors for control valves and regulators showed noteworthy increases for both natural gas and crude oil systems compared to the CAPP (2005) factors; this is may reflect the impact of better leak measurement data for these sources, but is suspected to be largely due to the poor quality of the component counts for these categories potentially resulting an overstatement of the leak frequencies. The emission factor for connectors in G/V service at natural gas facilities is unchanged. All other factors show substantial reductions compared to the CAPP (2005) values, and they are based on relatively large component populations which improves their reliability.

4.3.1 RECOMMENDATIONS

It is recommended that the average emission factors presented in Table 10 be used for estimating emissions due to fugitive equipment leaks at facilities that are actively applying the CAPP BMP for managing fugitive equipment leaks. The CAPP (2005) emission factors should still be used for periods prior to implementation of the CAPP BMP and for facilities that are not applying the CAPP BMP.

5 REFERENCES

CAPP. 1992. A Detailed Inventory of CH4 and VOC Emissions from Upstream Oil & Gas Operations in Alberta, Vol III, Results of the Field Validation Program, Table 7, Picard et al, March 1992.

CAPP. 2005 A National Inventory of Greenhouse Gas (GHG), Criteria Air Contaminant (CAC) and Hydrogen Sulphide (H2S) Emissions by the Upstream Oil and Gas Industry Volume 5, Compendium of Terminology, Information Sources, Emission Factors, Equipment Sched's and Uncertainty Data September 2004, Tables 3.1 and 4.1, Publication No. 2005-0015.

IPCC. 2000. Good Practice Guidance and Uncertainty Management in National Greenhouse Gas Inventories. http://www.ipcc-nggip.iges.or.jp/public/gp/english/.

6 APPENDIX A – DEFAULT COMPONENT COUNTS BY TYPE OF PROCESS OR MAJOR EQUIPMENT UNIT

The CAPP published schedule of default equipment component counts for specified process and major equipment unit types is tabulated in Table 12. The list of equipment or process types has been reordered and grouped to improve user application and additional equipment or process types have been added to clarify type designations. For new types no estimation of component counts is provided.

Table 12: Schedule of default component counts per equipment or process type (CAPP 2005).																						
Equipment / Process Type and Default Component Counts	**Connector (GV)**	**Connector (FG)**	**Connector (HL)**	**Connector (LL)**	**Control Valve (GV)**	**Compressor Seal(GV)**	**Compressor Seal (FG)**	**Open-Ended Line (FG)**	**Open-Ended Line (GV)**	**Open-Ended Line (LL)**	**Pressure Relief Valve (FG)**	**Pressure Relief Valve (GV)**	**Pressure Relief Valve (HL)**	**Pressure Relief Valve (LL)**	**Pump Seal (HL)**	**Pump Seal (LL)**	**Regulator (FG)**	**Regulator (GV)**	**Valve (FG)**	**Valve (GV)**	**Valve (HL)**	**Valve (LL)**
Absorption	200			46								4				1				82		21
Absorption: Cold Bed	134			12								1								31		7
Adsorption	200			46								4				1				82		21
Battery: Heavy Oil Satellite	42		42	84										1	1	1				10	13	24
Battery: Heavy Oil Single- Well	22		60	54										2	1	1				10	26	22
Battery: Satellite	66			231					1	1		2								11		57
Battery: Single Well Oil	68			15					1	1		1				1				12		21
Battery: SWB with Treater	246			71						1		2				1				33		38
Boiler: Process Boiler		25																	2			
Boiler: Utility Boiler		25																	2			
Bullet	39			60								1		1						15		27
Cleaning Plant: Crude Bitumen	659		562	1145								11	6	17	3	7				202	139	440
Cleaning Plant: Heavy Oil	137		120	237										6	2	2				40	52	111
Compressor Station: Coolers	2937																			19		
Compressor Station: Yard Piping	849								36			3								267		
Compressor: Centrifugal - Electric	495	38		11		2			2			1							14	32		5
Compressor: Centrifugal - Electric - Seals to Flare	495	38		11					2			1							14	32		5
Compressor: Centrifugal - Gas Engine																						
Compressor: Centrifugal -Gas Engine - Seals to Flare																						
Compressor: Reciprocating - Electric	275			2		2			4											20		1
Compressor: Reciprocating - Electric - Seals to Flare	275			2					4											20		1
Compressor: Reciprocating - Gas Engine	275	145		2		2			4										6	20		1
Compressor: Reciprocating - Gas Engine - Seals to	275	145		2					4										6	20		1

Table 12: Schedule of default component counts per equipment or process type (CAPP 2005).																						
Equipment / Process Type and Default Component Counts	**Connector (GV)**	**Connector (FG)**	**Connector (HL)**	**Connector (LL)**	**Control Valve (GV)**	**Compressor Seal(GV)**	**Compressor Seal (FG)**	**Open-Ended Line (FG)**	**Open-Ended Line (GV)**	**Open-Ended Line (LL)**	**Pressure Relief Valve (FG)**	**Pressure Relief Valve (GV)**	**Pressure Relief Valve (HL)**	**Pressure Relief Valve (LL)**	**Pump Seal (HL)**	**Pump Seal (LL)**	**Regulator (FG)**	**Regulator (GV)**	**Valve (FG)**	**Valve (GV)**	**Valve (HL)**	**Valve (LL)**
Flare																						
Compressor: Screw - Electric	228				1	1						2						2		35		
Compressor: Screw - Electric - Seals to Flare	228				1							2						2		35		
Compressor: Screw - Gas Engine																						
Compressor: Screw - Gas Engine -Seals to Flare																						
Compressor: Vapour Recovery - Electric																						
Compressor: Vapour Recovery - Gas Engine	25			2		1														5		3
Cycling	241			386		2						10				2				131		121
Deepcut	241			386		2						10				2				131		121
Dehydrator: Desiccant	100			14								1								24		7
Dehydrator: Glycol	100			14								1								24		7
ESD Station	10																			2		
Flare Knockout Drum	26			20																3		1
Fractionation	241			386								10				2				131		131
Fractionation: De-butanizer	177			208								6				2				79		80
Fractionation: De-ethanizer	177			208								6				2				79		80
Fractionation: De-propanizer	177			208								6				2				79		80
Gas Boot		37																		2		2
Gas Sweetening: Amine	702			3					3			2				1				60		1
Gas Sweetening: Diglycolamine	702			3					3			2				1				60		1
Gas Sweetening: Iron Sponge	134			12								1								31		7
Gas Sweetening: Proprietary	200			46								4				1				82		21
Gas Sweetening: Sulfinol	702			3					3			2				1				60		1

Table 12: Schedule of default component counts per equipment or process type (CAPP 2005).

Equipment / Process Type and Default Component Counts	Connector (GV)	Connector (FG)	Connector (HL)	Connector (LL)	Control Valve (GV)	Compressor Seal(GV)	Compressor Seal (FG)	Open-Ended Line (FG)	Open-Ended Line (GV)	Open-Ended Line (LL)	Pressure Relief Valve (FG)	Pressure Relief Valve (GV)	Pressure Relief Valve (HL)	Pressure Relief Valve (LL)	Pump Seal (HL)	Pump Seal (LL)	Regulator (FG)	Regulator (GV)	Valve (FG)	Valve (GV)	Valve (HL)	Valve (LL)
Gas Sweetening: Sulfreen	134			12								1								31		7
Header Tie-in: Cond/NGL				10					1													3
Header Tie-in: Flow Line				10					1													3
Header Tie-in: Gas Line				10					1													3
Heat Exchanger	13																			7		
Heater: Gas-fired Unit Heater		10																	1			
Heater: Line Heater	40	145										1								10		10
Heater: Salt Bath Heater		25																	2			
Heater: Tank Heater		10		2															2			
Heater: Unit Heater		10		2															2			
Incinerator	10																			1		
Main Line Block Valve	30								1											7		
Main Line Meter Station	1704								76			15								570		
Meter Station	70											2								34		
Meter/Regulator Station	94											2								34		
Metering	70											2								24		
Molecular Sieve	100			14								1								24		7
Pig Trap	11																			3		
Pipeline: Butane	10								1											3		
Pipeline: Ethane	10								1											3		
Pipeline: Pentanes Plus	10								1											3		
Pipeline: Propane	10								1											3		
Power Generator		74																	5			

Equipment / Process Type and Default Component Counts	Connector (GV)	Connector (FG)	Connector (HL)	Connector (LL)	Control Valve (GV)	Compressor Seal(GV)	Compressor Seal (FG)	Open-Ended Line (FG)	Open-Ended Line (GV)	Open-Ended Line (LL)	Pressure Relief Valve (FG)	Pressure Relief Valve (GV)	Pressure Relief Valve (HL)	Pressure Relief Valve (LL)	Pump Seal (HL)	Pump Seal (LL)	Regulator (FG)	Regulator (GV)	Valve (FG)	Valve (GV)	Valve (HL)	Valve (LL)
Table 12: Schedule of default component counts per equipment or process type (CAPP 2005).																						
Pump: Oil Pump (Recycle/Shipping)				10												1						3
Pump: Other Pumps				10												1						3
Pump: Pump Station	22			647								2		17		2				7		227
Pump: Water Pump (Recycle/Shipping)				5												1						2
Refrigeration:	170			31		2						2				2				65		13
Refrigeration: Joule-Thomson	79			41																19		11
Regulator Station	24																			10		
Separation	40			58												1				12		17
Separator: Inlet Separator	66			41																11		11
Separator: Test Separator	49			25								1								15		15
Stabilization	80			247								3				1				20		77
Sulphur Recovery	100																			10		
Tail Gas Cleanup	25																			5		
Tank: Farm				190												6						94
Tank: Pipeline Terminal Tanks				12																		3
Tank: Pop Tank				24												1						10
Tank: Production Tank	2			24												1				1		10
Tank: Pump Station Tanks				12																		3
Tank: Storage Tank				12																		3
Tank: Tank Farm Tanks				12																		3
Treater	178			56					1	1										21		17
Turbo Expander	123			9		1						6								48		2
Well: Gas - Deep > 1000 m	19			1																6		

Table 12: Schedule of default component counts per equipment or process type (CAPP 2005).

Equipment / Process Type and Default Component Counts	Connector (GV)	Connector (FG)	Connector (HL)	Connector (LL)	Control Valve (GV)	Compressor Seal(GV)	Compressor Seal (FG)	Open-Ended Line (FG)	Open-Ended Line (GV)	Open-Ended Line (LL)	Pressure Relief Valve (FG)	Pressure Relief Valve (GV)	Pressure Relief Valve (HL)	Pressure Relief Valve (LL)	Pump Seal (HL)	Pump Seal (LL)	Regulator (FG)	Regulator (GV)	Valve (FG)	Valve (GV)	Valve (HL)	Valve (LL)
Well: Gas - Injection	19																			6		
Well: Gas - Shallow < 1000 m	10																			3		
Well: Oil - Flowing				57																		14
Well: Oil - Heavy Primary				22																		9
Well: Oil - Heavy Thermal				22																		9
Well: Oil - Pumping				57												1						14

Table 13: Summary of equipment or process types by jurisdiction and in total that are included in the emission factor update database.			
Equipment / Process Type and Default Component Counts	**BC Facilities**	**AB Facilities**	**All Facilities**
Absorption			
Absorption: Cold Bed			
Adsorption			
Battery: Heavy Oil Satellite			
Battery: Heavy Oil Single- Well			
Battery: Satellite			
Battery: Single Well Oil			
Battery: SWB with Treater			
Boiler: Process Boiler	11		11
Boiler: Utility Boiler	5	14	19
Bullet		16	16
Cleaning Plant: Crude Bitumen			
Cleaning Plant: Heavy Oil			
Compressor Station: Coolers	2		2
Compressor Station: Yard Piping	1		1
Compressor: Centrifugal - Electric			
Compressor: Centrifugal - Electric - Seals to Flare			
Compressor: Centrifugal - Gas Engine			
Compressor: Centrifugal -Gas Engine - Seals to Flare			
Compressor: Reciprocating - Electric	3	13	16
Compressor: Reciprocating - Electric - Seals to Flare			
Compressor: Reciprocating - Gas Engine	48	132	180
Compressor: Reciprocating - Gas Engine - Seals to Flare	8		8
Compressor: Screw - Electric	2	28	30
Compressor: Screw - Electric - Seals to Flare			
Compressor: Screw - Gas Engine	2	16	18
Compressor: Screw - Gas Engine -Seals to Flare			
Compressor: Vapour Recovery - Electric	5	2	7
Compressor: Vapour Recovery - Gas Engine			
Cycling			
Deepcut			
Dehydrator: Desiccant	2		2
Dehydrator: Glycol	28	50	78
Engine: Gas	4		4
ESD Station	43	94	137
Fractionation: De-butanizer		1	1
Flare Knockout Drum	28	30	58

Table 13: Summary of equipment or process types by jurisdiction and in total that are included in the emission factor update database.			
Equipment / Process Type and Default Component Counts	**BC Facilities**	**AB Facilities**	**All Facilities**
Fractionation			
Fractionation: De-ethanizer		8	8
Fractionation: De-propanizer			
Gas Boot	2	3	5
Gas Sweetening: Amine	3	1	4
Gas Sweetening: Diglycolamine			
Gas Sweetening: Iron Sponge		2	2
Gas Sweetening: Proprietary			
Gas Sweetening: Sulfinol			
Gas Sweetening: Sulfreen			
Header Tie-in: Cond/NGL			
Header Tie-in: Flow Line	45	12	57
Header Tie-in: Gas Line	99	185	284
Heat Exchanger	3	34	37
Heat Exchanger: Liquid		5	5
Heater: Gas-fired Unit Heater	33	4	37
Heater: Line Heater	31	23	54
Heater: Salt Bath Heater		2	2
Heater: Tank Heater	2	2	4
Heater: Unit Heater	10		10
Incinerator	2		2
Main Line Block Valve	18		18
Main Line Meter Station			
Meter Station	5	106	111
Meter/Regulator Station	2		2
Metering	117	121	238
Methanol Sphere		4	4
Molecular Sieve			
Pig Trap	229	94	323
Pipeline: Butane			
Pipeline: Ethane			
Pipeline: Pentanes Plus			
Pipeline: Propane			
Power Generator	38	4	42
Pump: Oil Pump (Recycle/Shipping)	18	15	33
Pump: Other Pumps	8	26	34
Pump: Pump Station			

Table 13: Summary of equipment or process types by jurisdiction and in total that are included in the emission factor update database.			
Equipment / Process Type and Default Component Counts	**BC Facilities**	**AB Facilities**	**All Facilities**
Pump: Water Pump (Recycle/Shipping)	4		4
Refrigeration:		7	7
Refrigeration: Joule-Thomson		3	3
Regulator Station			
Scrubber	7	14	21
Separation	29	69	98
Separator: Inlet Separator	78	178	256
Separator: Test Separator	14	2	16
Stabilization		5	5
Sulphur Recovery			
Tail Gas Cleanup			
Tank: Farm	1		1
Tank: Pipeline Terminal Tanks			
Tank: Pop Tank			
Tank: Pop Tank	3	10	13
Tank: Production Tank	98	114	212
Tank: Pump Station Tanks			
Tank: Storage Tank	8	4	12
Tank: Tank Farm Tanks			
Treater	7	9	16
Turbo Expander			
Well: Gas - Deep > 1000 m	7	16	23
Well: Gas - Injection			
Well: Gas - Shallow < 1000 m	23		23
Well: Oil - Flowing			
Well: Oil - Heavy Primary			
Well: Oil - Heavy Thermal			
Well: Oil - Pumping		1	1

7 APPENDIX B - GUIDELINES FOR COUNTING EQUIPMENT COMPONENTS

The following guidelines were applied to count equipment components in hydrocarbon service from drawings showing yard piping details and may be applied in performing actual counts at facilities:

- **Compressor Seals**: A reciprocating compressor is deemed to have one seal associated with each compressor cylinder regardless of whether it is really a single or tandem seal. A centrifugal compressor has two seals, one on each side of the housing where the shaft penetration occurs. Other components on the compressor and on any associated cooler (e.g., valves, connectors, pressure relief valves, open-ended valves and lines, and gas-operated instruments) need to be accounted for separately. Seals that are connected to a flare, incinerator or other end control device rather than being vented are not counted.

- **Connectors**: Each threaded, flanged or mechanical connection is counted as a single connector. Welded or backwelded connections are not counted.

  Some types of components may have more than one set of connections associated with them. For example a union may have 3 sets of connecting surfaces (2 end connections and a centre connection), a nipple or reducer may have 2 (one at each end), and a tee may have 3 (one at each end). If all 3 connection points on a union are threaded then a union would be classified as a 3 connectors. A union that has welded end connections would be counted as only one connector.

- **Valves**: This category accounts for leakage from around the valve stem and from the valve body. The end connections and any leakage past the valve seat are counted separately (see connectors and open-ended valves or lines, respectively). A control valve is any valve that is equipped with an actuator. A manual block valve is any valve that must be manually operated. Venting by any pneumatic operators is not deemed to be leakage, so if the valve itself is not in hydrocarbon service, then it is not counted.

- **Pressure-Relief Valve**: Generally, a pressure-relief valve that discharges directly to the atmosphere or through a vent system is counted. However, if the valve discharges to a control device (e.g., flare or thermal oxidizer), or has a rupture disk installed upstream along with a monitoring system to indicate when the rupture disk has failed, then the valve is not counted.

  The connection on the upstream side of the valve is counted as a separate component. The connection on the downstream side also is counted if the relief valve is connected to a control device.

- **Open-ended Valves or Lines**: Each valve in hydrocarbon service that has process fluid on one side and is open to the atmosphere on the other (either directly or through a line) is counted as an open-ended valve or line. If the open side of the valve is fitted with a properly installed cap, plug, blind flange or second closed block valve, or is connected to a control device then it is no longer considered to be open-ended (i.e., there is zero leak potential).

  A drain valve that discharges into the top of an underground storage tank is considered an open-end line.
  The valve stem and body, and the connector on the process side of the valve are counted as separate components.

- **Sampling System** - This category accounts for hydrocarbons that are released to the atmosphere as part of actual sampling activities, and the results are adjusted to reflect the frequency of occurrence. The individual parts of the system should be counted as separate components. Thus, an open-ended line that is used for routine sampling would be counted as both a sampling system and an open-ended line.

  For manual gas sampling systems, the sampling emissions would include any initial purge volumes released to the atmosphere, plus the gas released when the sample container is disconnected.

While components may be counted from process diagrams, this frequently understates actual component numbers. This is especially true for fittings (e.g., connectors and valves less than 2 NPS) and any third-party packages (e.g., compressor units, heaters, and scrubbers) for which detailed drawings and a bill of materials is unavailable.

When counting each component it is important to also record the percentage of the time that it is out of service (i.e., there is zero gauge pressure on both sides of the component). This information can be used to adjust the estimated emissions accordingly.

8 APPENDIX C - METHODOLOGY FOR ASSESSING UNCERTAINTIES

The uncertainties in the presented emissions factors were assessed using an IPCC (2000) Tier-1 approach. This approach provides for the estimation of uncertainties by source using error propagation equations based on the assumption of uncorrelated normally distributed uncertainties under addition and multiplication. Convenient analytic expressions are given by IPCC for determining the combined uncertainty in individual multiplication and addition steps of the inventory development process. The multiplication steps in the emission factor assessment occur where default no-leak emission factors were applied to the portion of the component population that were determined not to be leaking, and where the total assessed emissions for a component category were multiplied by the inverse of the corresponding component count. The addition steps result from the aggregation of individual measurement results and no-leak estimates to determine the total emissions. For a given source category, the level of uncertainty will tend to decrease by a factor of $1/N^{0.5}$ where N is the number of sources.

8.1.1 COMBING UNCERTAINTIES IN MULTIPLICATION STEPS

The IPCC Tier-1 relation for combining uncertainties in multiplication steps is (this is approximate for all random variables):

$$U_{Total} = \sqrt{U_1^2 + U_2^2 + \ldots + U_n^2} \qquad \text{Equation 5}$$

where,

U_{Total} - is the percentage uncertainty in the sum of the quantities.

U_1, U_2, U_n - are the uncertainties in the individual quantities being multiplied.

8.1.2 COMBINING UNCERTAINTIES IN ADDITION STEPS

The overall uncertainty in the sum of the individual quantities is determined using the following relation (this expression is exact for uncorrelated or independent variables):

$$U_{total} = \frac{\sqrt{(U_1 \cdot x_1)^2 + (U_2 \cdot x_2)^2 + \ldots + (U_n \cdot x_n)^2}}{x_1 + x_2 + \ldots + x_n} \qquad \text{Equation 6}$$

where:

x_1, x_2, x_n - are the uncertain quantities being added.

8.1.3 UNCERTAINTIES IN INDIVIDUAL INPUT QUANTITIES

The uncertainty in an individual input quantity to a multiplication or addition step may be determined using the following approaches, presented in the order of decreasing preference:

- an error analysis of the available measurement data,
- applicable uncertainty estimates presented in the open literature,
- default uncertainty values published by IPCC (2000), and
- expert judgement.

In each case, the uncertainty is the probable error in the measurement or accounting techniques used to determine the input quantity, and in any related extrapolations or interpolations of these values. Where an input quantity has been built up through multiplication and/or summation of sub-parameters the IPCC Tier-1 rules for combining uncertainties in multiplication and addition should be applied to each of these steps.

The actual assumptions made herein are summarized below:

- The no-leak emission factors were assumed to have a lower confidence limit of 20% and an upper confidence limit of 500 percent.
- Reported leak counts were assumed to have a confidence limit of ±10%. This allows for the fact some components may have been incorrectly identified as leakers and some leakers may have been missed.
- The estimated component populations were assumed to have an uncertainty of ±25%.
- The leak measurement results were assumed to have an uncertainty of ±25%. This allows for some inaccuracies in the measurements as well as some variability in the source.

8.1.4 UPPER AND LOWER CONFIDENCE LIMITS

To determine the upper and lower limit of the emission factor confidence interval it is appropriate to consider the shape of the uncertainty probability function for each quantity being combined. Good practice in this regard (IPCC, 2000) is to assume either a normal or lognormal distribution depending on which provides the most realistic results (i.e., results in positive non-zero confidence limits). Other distributions should only be used where there are compelling reasons, either from empirical observations or from expert judgement backed by theoretical argument.

The applied approach was as follows. Whenever the percent uncertainty for a quantity was less than 100%, a normal probability function was assumed resulting in a symmetric distribution about the mean (i.e., a balanced uncertainty of $\pm U_i$). Wherever the percent uncertainty for a quantity was greater than 100%, the uncertainty value was taken to be $(100/U_i)\cdot 100$ when determining the lower limit and $+U_i$ when determining the upper limit resulting in an unbalanced uncertainty. This is equivalent to assuming a lognormal distribution and was done, where applicable, to avoid a negative or zero lower confidence limit for the target quantity. These rules concerning balanced and unbalanced uncertainties are applied appropriately to each quantity before combining uncertainties using Equations 5 and 6. Thus, two sets of calculations are performed: one to determine the combined uncertainty applicable for evaluation of the upper confidence limit, and one to determine the value applicable for evaluation of the lower confidence limit.

While use of the log normal assumption results in a tighter confidence interval than might otherwise be expected, it is conservative with respect to the potential amount of emissions since it results in greater estimated emissions at the lower confidence limit. Use of a normal distribution in these cases would result in a negative emission factor, which is meaningless, or, if the negative values are arbitrarily set to zero, an understatement of the lower probable emission rate.

In comparing the total uncertainty estimate for different source categories it is important to consider the number of sources in each category as well as the uncertainties in the individual emissions value for the sources in the category. The percentage uncertainty in the aggregate emission estimate for a category will tend to decrease by a factor of $1/N^{0.5}$ where N is the number of sources in that category.