

Final Report

**Measurement and Assessment of Equipment Leak Fugitives
in Industrial Ethylene and Other Chemical Sources**

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TABLE OF CONTENTS

	Page
1. INTRODUCTION.....	1-1
2. MEASUREMENT AND DETECTION OF FUGITIVE EMISSIONS	
USINGA PORTABLE OPTICAL GAS IMAGING (CO₂ LASER) DEVICE.....	2-1
Study Findings.....	2-1
Summary of Results from Site A.....	2-4
Summary of Results from Site B.....	2-7
3. IMPACT OF PEGGED AND FALSE NEGATIVE MONITORING.....	3-1
Background.....	3-1
False Negatives.....	3-2
Nontraditional Component Emissions.....	3-3
Pegged Components.....	3-5
Summary of Emission Impacts.....	3-6
4. CORRELATION EQUATIONS FOR ETHYLENE	
AND PROPYLENE SOURCES.....	4-1
Background.....	4-1
Data Availability for Developing Ethylene/Propylene-Specific	
Correlation Equations.....	4-1
Data Adequacy.....	4-2
Additional Data Needed to Develop Correlation Equations.....	4-4
Plan to Develop Additional Data.....	4-5
5. ASSESSMENT OF FUGITIVE EMISSION COMPONENT COUNTS.....	5-1
Fugitive Emission Monitoring Programs.....	5-1
Study Approach.....	5-4
Study Findings.....	5-5
Conclusions.....	5-13

TABLES

Table 2-1.	Components monitored at Site A.....	2-4
Table 2-2.	Calculated mass rates from traditional sources at Site A.....	2-5

Table 2-3.	Comparison of bagging results with calculated mass rates at Site A	2-6
Table 2-4.	Calculated mass rates from traditional sources at Site B	2-8
Table 2-5.	Comparison of bagging results with calculated mass rates at Site B	2-10
Table 3-1.	Summary of false negative occurrences at Site A and B... ..	3-2
Table 3-2.	Estimated emission impacts of false negatives at Sites C through G	3-3
Table 3-3.	Summary of nontraditional component leaks.....	3-4
Table 3-4.	Comparison of emissions from traditional and nontraditional component.....	3-4
Table 3-5.	Comparison of pegged emission factors to bagged data.....	3-5
Table 3-6.	Comparison of emission correlation equations to bagged data.....	3-6
Table 4-1.	Bagging data obtained from Sites A and B available in required ranges	4-3
Table 4-2.	Additional data required to meet EPA protocol	4-4
Table 4-3.	Additional data required for combined service correlation equation	4-5
Table 5-1.	Summary of Site C fugitive emission component count	5-5
Table 5-2.	Summary of Site D fugitive emission component count	5-6
Table 5-3.	Summary of Site E fugitive emission component count.....	5-7
Table 5-4.	Summary of Site F fugitive emission component count.....	5-8
Table 5-5.	Summary of Site G fugitive emission component count	5-9
Table 5-5.	Summary of Site H fugitive emission component count	5-10
Table 5-6.	SOCMI leak rate/screening value correlation equations	5-12
Table 5-7.	SOCMI average emission factors	5-12
Table 5-8.	Calculated versus reported fugitive emissions	5-13

FIGURES

Figure 2-1.	Emission rate of bagged components from Sites A and B	2-3
Figure 2-2.	Ethylene mass rate by component at Site A.....	2-5
Figure 2-3.	Propylene mass rate by component at Site A.....	2-6
Figure 2-4.	Ethylene mass rate by component at Site B.....	2-8
Figure 2-5.	Propylene mass rate by component at Site B.....	2-9

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1. INTRODUCTION

In August and September 2000, an intensive field study, called the Texas Air Quality Study (TxAQS), was conducted in the Houston-Galveston area (HGA) to study ozone and other air pollution issues in that region. As part of TxAQS, aerial surveys of chemical species in the atmosphere above the HGA showed higher ozone and ozone-precursor concentrations than would be expected from the emission inventory of volatile organic compounds (VOCs). In a Technical Support Document dated June 5, 2002, the Texas Natural Resource Conservation Commission (TNRCC)¹, notes this discrepancy:

“Much of the early analysis focused on why the HGA is different from other areas of the nation. A survey of the area indicates the most striking difference in HGA and other areas of the nation is the extensive refining and petrochemical industry located around the Houston Ship Channel. The HGA produces over half of the chemical and refining needs of the nation. Not surprisingly, the early results have pointed to high levels of VOC emissions from industrial sources in the area; which are much higher than those reported in the annual and special emissions inventories.”²

One possible source of unreported emissions from industrial facilities are fugitive emissions. Fugitive emissions are relatively small and hard-to-detect emissions from valve packings, pump seals, compressor seals, and piping connections that occur as part of normal industrial plant operations. They are characterized by a diffuse release of volatile organic compounds (VOCs) or hydrocarbons into the atmosphere. Fugitive emissions from refineries and chemical plants have historically represented a large percentage of the volatile organic compound (VOC) and hazardous air pollutant (HAP) emissions from these facilities.

In May, 2002, ENVIRON International Corporation was retained by the Houston Advanced Research Center (HARC) to manage a project entitled “Measurement and Assessment of Equipment Leak Fugitives and Vent Emissions in Industrial Ethylene and Other Chemical Sources (Project H5.2002)”. This project was recommended for funding by the TNRCC and approved by the Science Advisory Committee (SAC) of the Texas Environmental Research Consortium (TERC). The primary objectives of this project were as follows:

- evaluate the effectiveness of a portable optical gas imaging device (CO₂ laser) for measuring/detecting ethylene fugitive emissions;

¹ On September 1, 2002, the TNRCC formally changed its name to the Texas Commission on Environmental Quality, or the TCEQ.

² TNRCC Technical Analysis Division, Air Modeling and Data Analysis Section. *Technical Support Document*. June 5, 2002

- evaluate the effectiveness of a portable optical gas imaging device for measuring/detecting ethylene emissions from process vents and other potentially undetected fugitive sources;
- collect sufficient data and information from ethylene/propylene sites to assess the quality of fugitive emission inventory component counts;
- determine the impact of pegged fugitive emission components and leaking equipment falsely identified as non-leaking; and
- develop correlation equations specific for ethylene and propylene sources for estimating emissions from equipment leak fugitives.
- assess the accuracy of fugitive emission inventories based on component count information collected at various facilities.

To complete this project, ENVIRON managed a team which included technical staff from URS Corporation, ICF Consulting, Gas Imaging Systems, and EFSI. Project work involved two comprehensive field studies to evaluate a portable optical gas imaging device for measuring/detecting fugitive emissions. In addition, the project team counted traditional fugitive emission components in seven separate industrial facilities.

This report discusses the work conducted by the project team and the technical results obtained from this study. The report is organized as follows:

- **Section 2: Measurement and Detection of Ethylene Fugitive Emissions Using a Portable Optical Gas Imaging (CO₂) Device** – In this section, results of field studies conducted to measure and detect fugitive emissions using a portable optical gas imaging device are summarized. Complete technical information supporting the summary shown in Section 2 including background information on analyzers used in traditional leak detection and repair programs and the CO₂ laser used in this study, the protocols used in the evaluation of the CO₂ laser, and the technical results obtained in the field studies are presented in Appendix A.
- **Section 3: Impact of Pegged and False Negative Monitoring** – In this section, efforts made to determine the impact on VOC emission inventories of components that might be under-estimated because they are identified as “pegged” or false negatives are presented.
- **Section 4: Correlation Equations for Ethylene and Propylene Source** - In this section, the results of efforts to determine the sufficiency of existing data to develop emission correlation equations specific to ethylene/propylene sources is presented.

- **Section 5: Assessment of Fugitive Emission Component Counts** – In this section, an assessment of the accuracy of reported fugitive emission inventories is discussed.

In addition to the information contained in the sections described above, other relevant information to support study results are shown in Appendices.

2. MEASUREMENT AND DETECTION OF FUGITIVE EMISSIONS USING A PORTABLE OPTICAL GAS IMAGING (CO₂ LASER) DEVICE

In this section of the report, the results of field studies conducted to measure and detect fugitive emissions using a portable optical gas imaging device are summarized. These field studies were conducted at two olefin facilities located in Texas between May and August 2002¹. The results and discussions presented here represent the outcome of the project statement of work, which included the following activities:

- conduct a demonstration of a portable optical gas imaging device in two industrial sites (ethylene and polyethylene producers) to evaluate the capability of the device in detecting fugitive emissions under normal chemical plant operating conditions;
- identify, if possible, leaking equipment detected with the portable optical gas imaging device but listed as non-leaking when monitored under Method 21 procedures;
- gather data that could be used to establish the mass emission detection capability of the portable optical gas imaging device; and
- gather data that could begin to establish the sensitivity of the portable optical gas imaging device to various factors that might be encountered during routine use at a chemical plant including, but not limited to, distance from scanned components, sight lines and angle-of-view, infrared backscatter and absorption properties of background components, weather conditions, and chemical composition of emissions.

STUDY FINDINGS

From analysis of the field study data conducted as part of this project, the primary findings from this effort are as follows²:

1. The field studies demonstrated that the portable optical gas imaging device (CO₂ laser) was able to identify leakers while monitoring both traditional and nontraditional components under normal petrochemical plant operating conditions and good weather conditions (light wind, clear sky, summer temperatures).
 - At Site A, the CO₂ laser identified 95 leaking components (70 traditional and 25 nontraditional) in three process blocks; at Site B, the CO₂ laser identified 52 leaking

¹ Throughout this report, these two facilities are identified as Sites A and B.

² Detailed information from which this section of the report was prepared is presented in Appendix A.

components (49³ traditional and 3 nontraditional) in 28 equipment areas within three operating units.

- At Site A, the mass rate of leaks, as determined by bagging, ranged from 5.63×10^{-7} kg/hr to 2.32×10^{-2} kg/hr. At Site B, the mass rate of leaks, as determined by bagging, ranged from 1.3×10^{-5} kg/hr to 2.34×10^{-2} kg/hr.
 - At Site A, six of the ten bagged leaks (60%), detected by the CO₂ laser, had a mass emission rate in excess of 0.1 g/hr. Four of these six components (67%) were above 1 g/hr. At Site B, 18 of the 19 bagged leaks (95%), detected by the CO₂ laser, were above 0.1 g/hr. 15 of the 19 components (79%) were above 1 g/hr. This is illustrated in Figure 2-1. As seen in the figure, the camera successfully saw leaks from all components with a mass leak rate greater than 1.0 g/hr.
 - Ethylene was the only species detected during testing at both Sites.
2. The majority of components detected as leaking had screening values above 1,000 ppmv. This result is in keeping with trends seen in other industrial studies.
- At Site A, 96.7% of the 95 detected leaking components (traditional and nontraditional) had screening values over 1,000 ppmv; 63.3% had screening values over 10,000 ppmv.
 - At Site B, 83% of the 52 detected leaking components (traditional and nontraditional) had screening values over 1,000 ppmv; 56% of the 52 leakers were above 10,000 ppmv.
3. Additional testing of the CO₂ laser is warranted to more fully establish the sensitivity of the instrument to factors such as distance, reflective background, wind speed, sight lines, angle-of-view and hydrocarbon species, and conditions that might be encountered during routine use at a petrochemical facility.
- In the field studies, leaks from as close as 4 feet to as far as 20 feet were detected. The component with the lowest mass rate was detected from a distance of greater than 10 feet. The highest leaking component was detected from a distance of 8 feet 1 inch. No attempt was made to determine the viewing threshold of any of the detected leaks.
 - The CO₂ laser successfully detected leaks against a variety of typical reflective backgrounds found at petrochemical facilities – smooth and rough surfaces; shiny, flat, painted and corrugated metal surfaces; concrete; and convex and concave surfaces.

³ Three of the traditional components were valves that are excluded from routine LDAR monitoring.

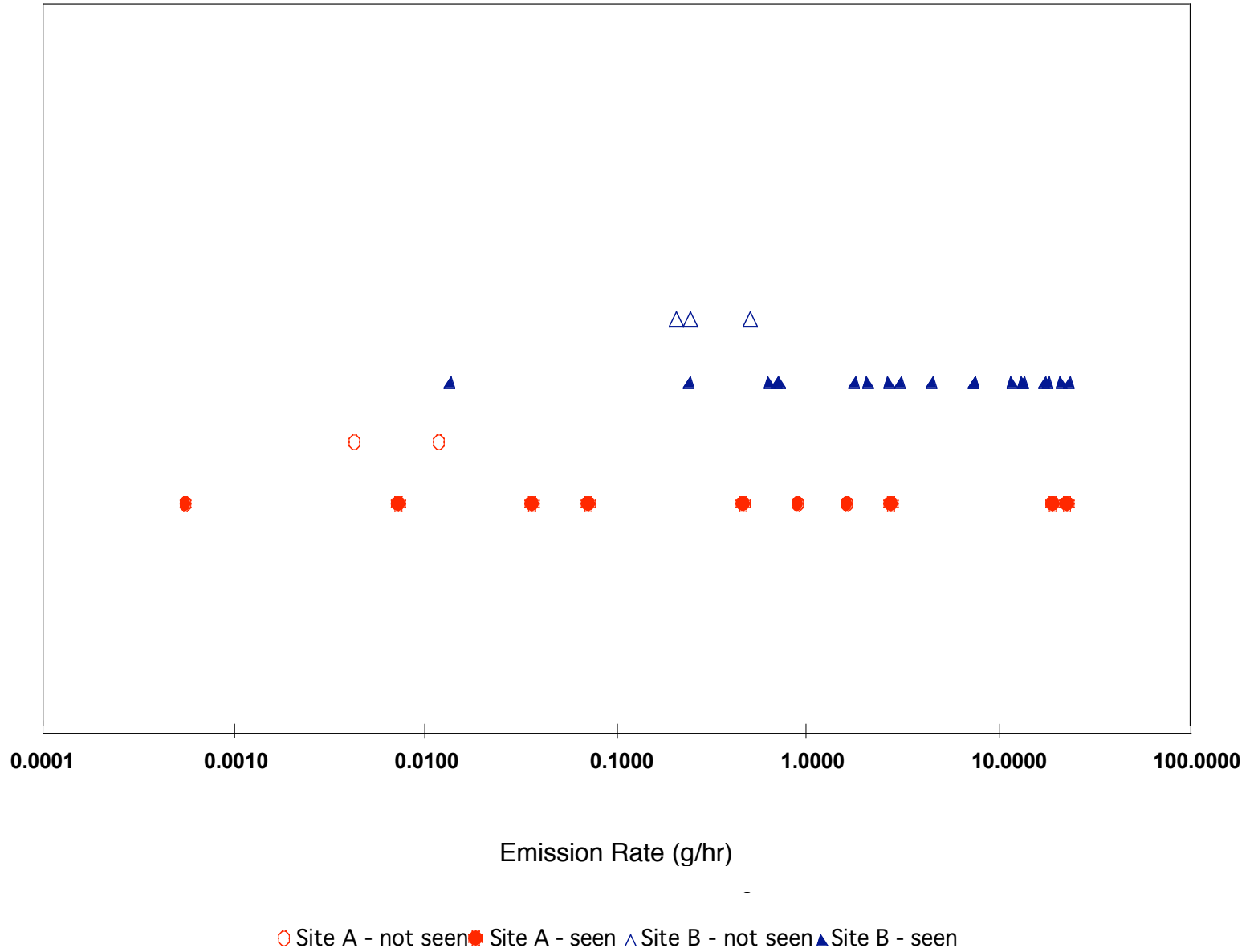


Figure 2-1. Emission rate of bagged components at Sites A and B.

- Leaking components were detected at eye-level, beneath equipment, and at elevations above normal Method 21 reach.
- The CO₂ laser successfully detected leaks with wind speeds ranging from 0 meters/second to 3.9 meters/second.

SUMMARY OF RESULTS FROM SITE A

The first field study was conducted at Site A between May 13 and 16, 2002. At site A, the components monitored included nontraditional and about 18 percent of Site A's traditional LDAR components in three process blocks as shown in Table 2-1:

Table 2-1. Components monitored at Site A.

Block Description	Total Number of Components in Process Block LDAR Program	Components Monitored during Field Study
Cold Section	16,985	3,342
Drying Area	8,455	3,701
Compressor Area	<u>12,423</u>	<u>144</u>
TOTALS	39,253	7,187

Screening was conducted on both traditional and nontraditional fugitive emission components including piping manifolds, valves, flanges, threaded fittings and other connectors, heat exchangers and other process vessels, open-ended lines, pumps and compressors. Much of the equipment in the Cold Section was coated in heavy insulation and sheet metal cladding that covered virtually the entire vessel and piping flanges.

Mass Rate Calculations

At Site A, emissions of propylene and ethylene were known to be present in the areas screened with the CO₂ gas imaging device. 70 of the 95 components found leaking were traditional LDAR components. These 70 components represent the following:

- 73.7% of the total leak sources detected during the field study;
- about one percent (0.97%) of all components monitored during the field study; and
- about 0.2% of all components in Site A's LDAR program.

Applying the EPA's correlation equations, the mass rate was calculated for each detected leak from a traditional component. Table 2-2 shows the mass rates of ethylene and propylene from

each component category. Figures 2-2 and 2-3 illustrate the percentages of each component in the calculated ethylene and propylene mass rates.

Table 2-2. Calculated mass rates from traditional sources.

Component Type	Number of Components		Total Mass Rate (Kg/hr)		Percentage of Total Mass		Average Mass Rate (Kg/hr)	
	E	P	E	P	E	P	E	P
Open-ended line (oel)	3	0	0.03	0.00	0.94%	0.00%	0.01	Not Applicable
Compressor seal	1	0	0.09	0.00	3.32%	0.00%	0.09	Not Applicable
Connector	27	3	1.96	0.11	72.73%	20.47%	0.07	0.04
Valve	24	12	0.62	0.41	23.01%	79.53%	0.03	0.03
TOTALS	55	15	2.70	0.52			0.20	0.07

Notes:

E= ethylene

P = propylene

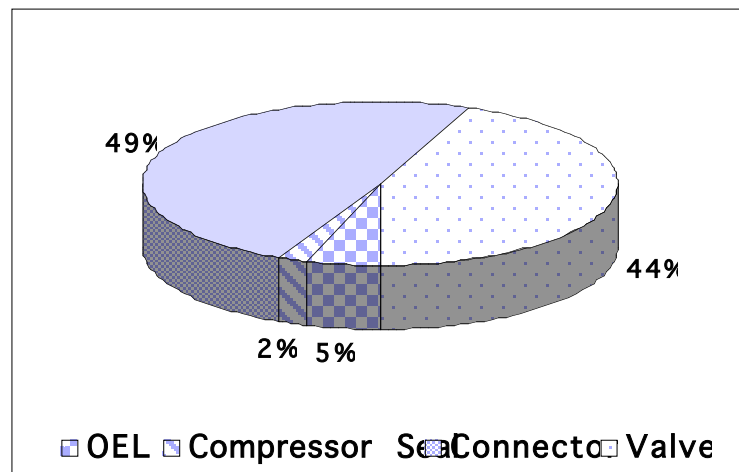


Figure 2-2. Ethylene mass rate by component at Site A.

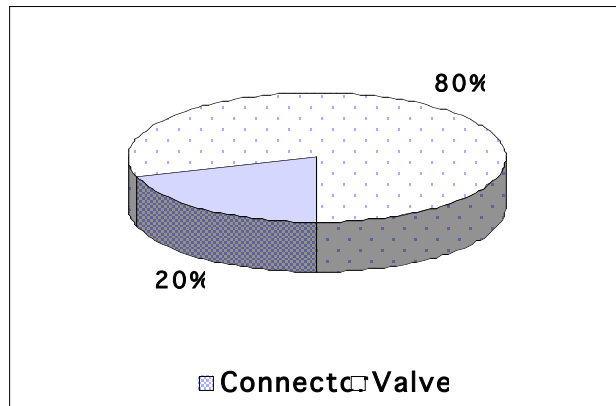


Figure 2-3. Propylene mass rate by component at Site A.

Comparison of Mass Rates from Bagging and Correlation Equations

12 of the 70 traditional components recorded as leaking were bagged during the field study. Leaks at two of the 12 components were not detected by the CO₂ laser (tags 644 and 769) and were known to be leaking propylene. Table 2-3 compares the mass rates determined by bagging and those calculated using EPA’s correlation equations. Because the calculation of mass rate assumed all fluids except cracked gas are pure compounds of a single constituent, the calculated results are for either ethylene or propylene. This method certainly overestimates the quantity of the dominant constituent in a mixed stream; however it is the most reasonable approach based on data readily available.

In all cases, the calculated mass rate were several orders of magnitude larger than the bagging results. Bagging results show the smallest detected leak had a mass emissions rate of 5.63E-07 kg/hr, compared to a correlated mass rate five orders of magnitude higher at 0.012 kg/hr. The largest detected leak was emanating from a connector (tag 3815) with mass emissions of 2.32 E-02 kg/hr. The correlated mass rate for tag 3815 was 0.127 kg/hr.

Table 2-3. Comparison of bagging results with calculated mass rates.

Component Data		Plant Area	Seen by Laser?	Bagging Result (Kg/hr)		Correlation Result (Kg/hr)	
Tag #	Type			E	P	E	P
510	Connector	Cold Area	Yes	7.24E-05	ND ^a	0.006	NA
1535	Valve	Cold Area	Yes	4.70E-04	ND	0.006	NA
0090	Connector	Cold Area	Yes	3.66E-05	5.76E-07	0.01 ^d	NA
644	Valve	Cold Area	No	4.33E-06	2.60E-04	NA	0.05
769	Valve	Cold Area	No	1.20E-05	2.10E-04	NA	0.01 ^e

Component Data		Plant Area	Seen by Laser?	Bagging Result (Kg/hr)		Correlation Result (Kg/hr)	
Tag #	Type			E	P	E	P
3496	Connector	Cold Area	Yes	7.41E-06	6.65E-07	0.03	NA
3815	Connector	Compressor	Yes	2.32E-02	ND	0.127 ^f	NA
3451	Connector	Compressor	Yes	9.05E-04	ND	0.05 ^g	NA
4278	Valve	Compressor	Yes	2.80E-03	2.64E-06	0.009 ^h	NA
4279	Connector	Compressor	Yes	1.95E-02	7.30E-06	0.017	NA
Bull Plug ^b	Connector	Compressor	Yes	1.62E-03	6.39E-07	0.01	NA
Seal Oil Breather Vent ^c	Other	Compressor	Yes	5.63E-07	ND	0.09	NA

Notes:

E= Ethylene

P= Propylene

^a ND = not detectable

^b This bull plug was not tagged, nor was the valve near it.

^c This seal oil breather vent was not tagged.

^d Average of the three screening values taken on 5/14 and 5/16.

^e Average of three screening values taken on 5/13 and 5/14.

^f Average of two screening values taken on 5/15 and 5/16.

^g Average of two screening values taken on 5/15 and 5/16.

^h Average of three screening values taken on 5/15.

SUMMARY OF RESULTS FROM SITE B

The field study at Site B occurred between August 5 and 8, 2002. Site B is a large producer of ethylene with operations conducted in two on-site locations, a base plant and an expansion plant. The field study focused on those areas of the plant where high concentrations of ethylene were present in the process pipes and vessels. The first two days of testing were spent in the base plant; as the week progressed, field study activities moved to the expansion plant. Monitoring was conducted in three primary process areas:

- Cold Ends
- Ethylene Product Pumps and Heater
- Compressor Shed

The types of equipment and components screened in these areas included piping manifolds, valves, flanges, threaded fittings and other connectors, heat exchangers and other process vessels, compressors, open ended lines, and pumps. In all, approximately 1,178 components in the three areas were screened and field data recorded from 52 leaking sources.

Mass Rate Calculations

At Site B, 49 (or 94%) of the 52 components detected as leaking during the field study were traditional components. All but one of the 49 sources were leaking of ethylene. Applying EPA’s correlation equations, the mass rate was calculated for each detected leak from a traditional component. Table 2-4 shows the calculated mass rates of ethylene and propylene from each component category. As seen in the table, although 69% of the leaking components were valves, connectors accounted for 66% of the calculated mass rate.

Table 2-4. Calculated mass rates from traditional sources at Site B.

Component Type	Number of Components		Total Mass Rate (Kg/hr)		Percentage of Total Mass		Average Mass Rate (Kg/hr)	
	E	P	E	P	E	P	E	P
connector	15	0	1.413	0.000	69.0%	0.0%	0.094	0.000
valve	33	1	0.635	0.004	31.0%	100.0%	0.019	0.004
TOTALS	48	1	2.048	0.004				

Notes:
 E= ethylene
 P = propylene

The pie charts in Figures 2-4 and 2-5 illustrate the percentages of each component in the calculated ethylene and propylene mass rates.

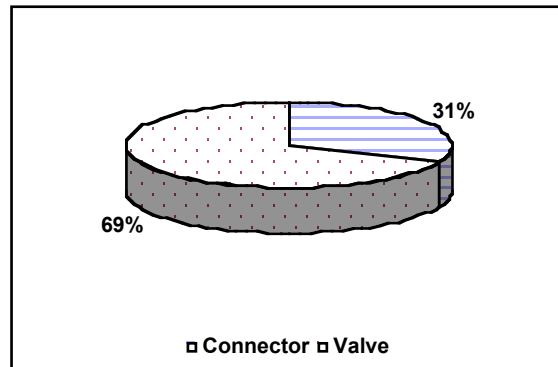


Figure 2-4. Ethylene mass rate by component at Site B.

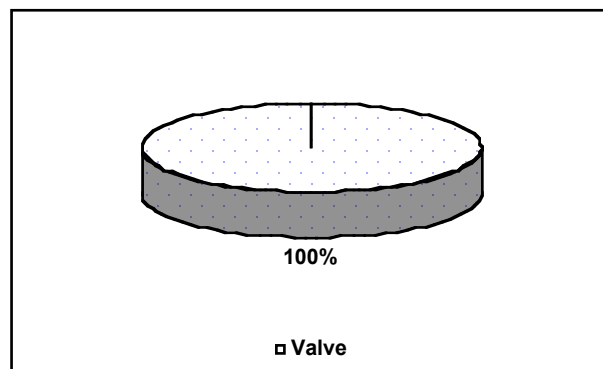


Figure 2-5. Propylene mass rate by component at Site B.

Comparison of Mass Rates from Bagging and Correlation Equations

Twenty of the 52 leaking components were bagged during the test⁴. Table 2-5 compares the mass rates determined by bagging and those calculated using EPA correlation equations. Because the calculation of mass rate assumed all fluids to be pure compounds of a single constituent, the calculated results are for one species – ethylene. This method may overestimate the quantity of the dominant constituent in a mixed stream; however, it is the most reasonable approach based on data readily available from Site B.

A comparison of the bagged and calculated mass rates of ethylene emissions shows mixed results as summarized below:

⁴ The bagging report in Appendix I shows 21 leaking sources. A connector (tag 1405) was excluded from the analysis (per discussion in the opening of this section) as it was determined later in the test week that the source was not tag 1405 but rather a component located below 1405.

- In nine cases (e.g. tags 15792 and 15859), the bagged and calculated mass rates are of the same order of magnitude.
- In two of the nine cases where the bagged and calculated mass rates are of the same magnitude (nontraditional valve and tag 15910), bagging mass rates were larger than the calculated mass rates.
- In twelve cases, the results differ by one or more orders of magnitude. The calculated mass emissions for these twelve cases are larger than the mass rate determined by bagging.
- It is unclear why the CO₂ laser was unable to detect two leaks of about 2×10^{-4} kg/hr at components 15792 and 15846 while it detected leaks of similar and smaller size at other locations.

Table 2-5. Comparison of bagging results with calculated mass rates at Site B.

Component Data		Plant Area	Seen by Laser	Bagging Result (Kg/hr)			Correlation Result (Kg/hr)		
Tag #	Type			E	P	M	E	P	M
valve near 1454 ^a	Valve	Base Plant C ₂ = Prod. Pump	Yes	7.37E-03	ND ^b	4.87E-05	2.99E-03	NA	NA
1358	Connector	Base Plant C ₂ = Prod. Pump	Yes	3.02E-03	ND	1.31E-05	2.59E-02	NA	NA
15792	Valve	Base Plant	No	2.44E-04	1.36E-07	7.57E-07	8E-04	NA	NA
15884	Valve	Base Plant – Off-spec Line	Yes	6.20E-04	4.50E-06	1.41E-07	4.63E-03	NA	NA
15859	Valve	Base Plant – Off-spec Line	Yes	2.03E-03	1.97E-07	ND	4.1E-03	NA	NA
15846	Valve	Base Plant – Off-spec Line	No	2.00E-04	ND	4.94E-08	1.28E-03	NA	NA
15910	Valve	Base Plant – Off-spec Line	Yes	4.44E-03	ND	ND	1.25E-03	NA	NA
15918	Valve	Base Plant – Off-spec Line	Yes	1.813-02	ND	2.48E-07	3.66E-02	NA	NA
16639	Connector	Base Plant – Cold Ends	Yes	7.46E-03	3.12E-07	1.91E-07	2.85E-01	NA	NA

Component Data		Plant Area	Seen by Laser	Bagging Result (Kg/hr)			Correlation Result (Kg/hr)		
Tag #	Type			E	P	M	E	P	M
16854	Flange	Base Plant – Compressor	Yes	1.34E-02	7.20E-07	1.25E-08	2.45E-02	NA	NA
16358	Flange	Base Plant – Cold Ends	Yes	7.08E-04	1.20E-07	ND	3.78E-01	NA	NA
11737	Valve	Base Plant – Cold Ends	Yes	1.31E-02	7.53E-07	7.03E-07	1.423E-02	NA	NA
9930	Valve	Expansion Plant – Prod. Manifold	Yes	2.41E-04	2.47E-07	ND	4.26E-03	NA	NA
9933	Valve	Expansion Plant – Prod. Manifold	Yes	1.71E-02	1.29E-06	1.67E-06	6.19E-02	NA	NA
9951	Valve	Expansion Plant – Prod. Manifold	Yes	6.82E-04	1.23E-07	ND	1.03E-02	NA	NA
9934	Valve	Expansion Plant – Prod. Manifold	Yes	2.08E-02	ND	4.47E-07	1.02E-02	NA	NA
9988	Valve	Expansion Plant – Prod. Manifold	Yes ^c	1.16E-02	1.27E-02	1.50E-06	2.77E-02	NA	NA

Component Data		Plant Area	Seen by Laser	Bagging Result (Kg/hr)			Correlation Result (Kg/hr)		
Tag #	Type			E	P	M	E	P	M
10575	Valve	Expansion Plant	Yes	1.33E-05	ND	1.34E-07	6.19E-02	NA	NA
10577.2 ^d	Connector		No	4.95E-04	ND	1.37E-07	NA ^e	NA	NA
10597.2	Connector	Expansion Plant	Yes	1.75E-03	ND	ND	4.47E-02	NA	NA
12404	Valve	Expansion Plant C ₂ = Prod. Pump	Yes	2.64E-03	ND	ND	2.18E-02	NA	NA
15496	Valve	Expansion Plant 2 nd Level Platform	Yes	2.34E-02	1.74E-05	5.34E-03	2.68E-02	NA	NA

Notes:

E= Ethylene

P= Propylene

M= Methane

^a Nontraditional component^b ND = not detectable^c Leak was through a pinhole on the bonnet and was only clearly visible when a corkboard was used as a background.^d This component was bagged although no leak was detected from component when area was screened with the CO₂ laser and no data was recorded in the field notes for this source. The data is retained because it is instructive of the mass rates that the CO₂ laser can detect.^e Not applicable as neither methane nor propylene was the species of interest or a dominant species. As such, no emission rate was calculated.

3. IMPACT OF PEGGED AND FALSE NEGATIVE MONITORING

As part of this project, efforts were made to determine the impact of components that might be underestimated because they are identified as “pegged” or false negatives on VOC emission inventories. A “pegged” reading is a Method 21 monitoring value that goes to (or above) the maximum concentration that the monitoring instrument can detect. A false negative is a Method 21 reading below the regulatory leak definition for a component that should have read higher than the leak definition. Components that leak but are not part of normal Method 21 monitoring are similar to the false negatives, except that the leak is missed because Method 21 is not routinely applied to the component. In this section of the report, these efforts are discussed.

BACKGROUND

The fugitive equipment leaks portion of facility VOC inventories are typically developed from Method 21 monitoring data using a combination of correlation equations, default zero emission factors, and pegged emission factors. The default zero emission factors are assigned to components whose Method 21 value are no different than background (i.e., zero contribution from the component), and these emission factors are very low, in the range of 10^{-6} to 10^{-8} kg/hr. Any errors related to components assigned default zero emission factors are likely to be insignificant in their impact to the overall VOC emission inventory; as a result, they have not been analyzed in this task.

Components that fall within the normal range of the monitoring instruments typically use EPA correlation equations to estimate emissions. The correlation equations have very wide error bars around them when applied to any single component, but since the errors are randomly distributed, the correlation equations can provide a reasonably good estimate of the emissions from large populations of components. The correlation equations, however, are no better than the data (i.e., the Method 21 readings) that goes into them; errors in reading an accurate Method 21 value will cause errors in the emissions estimate. Part of this task is to examine the impact of missing leaks using Method 21. For this, the results from monitoring with the CO₂ laser (as summarized in Section 2 of this report) were used to identify leaks that Method 21 missed.

In addition, there are some process fittings which have the potential to leak, but which have traditionally not been covered in leak detection and repair (LDAR) regulations. These “nontraditional” components include manways, heat exchanger heads, insulation seams (exit point for leaks from components under the insulation), and sight glasses. The CO₂ laser detected leaks from some of these types of components during the field studies, and this analysis uses that data to estimate the impact on VOC emission inventories from not including these types of components.

The final category of components which were evaluated as part of this task are those whose Method 21 value exceeds the maximum concentration that the monitoring instrument can accurately read. Earlier monitoring instruments typically could read only up to 10,000 ppm using an analog readout that would literally “peg” the needle off the high end of the scale. Dilution probes were sometimes used to extend the range of these monitoring instruments to 100,000 ppm by diluting the sample flow by a ratio of 1:10 with fresh air. Consequently, the EPA *Protocol for Equipment Leak Emission Estimate*¹ contains pegged emission factors for 10,000 ppm and 100,000 ppm levels. Modern instruments using digital readouts can read up to 50,000 ppm, and can log even higher values when attached directly to a data logger. Some facilities use dilution probes along with these instruments as well. For this analysis, any value of 50,000 ppm or higher is treated as pegged, since that is the upper end of the instrument’s range according to the manufacturer. The emissions from these pegged components can represent 90%+ of the total fugitive equipment leaks VOC emissions. This part of the task examines whether the pegged emission factors are underestimating the emissions of these components when compared to bagging data and extrapolation of the correlation equations.

FALSE NEGATIVES

This subsection examines the data from Sites A and B for both Method 21 and the CO₂ laser to determine the frequency of false negatives. For this exercise, a leak is defined as either a Method 21 reading of 500 ppm (or greater) or as any emission seen by the CO₂ laser. By these definitions, a false negative is any component where the Method 21 reading is <500 ppm and the CO₂ laser was able to detect a leak. Table 3-1 presents a summary of the false negatives found in the field studies at Sites A and B. This table only shows the traditional component types that are routinely monitored and for which at least one false negative was found in the data from Sites A and B.

Table 3-1. Summary of false negative occurrences at Sites A and B

Component Type	Number Tested by Laser and M21	Number of False Negatives	Percent of False Negatives	95% Confidence Intervals on % of False Negatives
Valves	2235	1	0.04%	0% to 0.28%
Connectors	5981	2	0.03%	0.01% to 0.12%

The data in Table 3-1 show that false negatives were a relatively rare occurrence at Sites A and B. Limitations of the method, the analyzer, or the technique of the inspector can cause false negatives. The data in Table 3-1 indicate that any limitations in the method and the analyzer are

¹ U. S. Environmental Protection Agency. Protocol for Equipment Leak Emission Estimates. Research Triangle Park, NC. Publication No. EPA-453/R-95-017. November 1995.

relatively low. It is possible that the inspectors performing Method 21 during the demonstration tests at Sites A and B were more careful than usual because of the number of observers present. As a result, it is possible that the figures in Table 3-1 under-represent the actual frequency of false negatives.

Table 3-2 presents estimates of the impact of these false negatives on the total emissions from a facility's valves and connectors. Actual component populations and monitoring data from five SOCFI process units were collected as part of this project and are used here to test the impact on emissions. The emission rates for the estimated false negatives were set at the lowest bagging emission measurement for a leak seen by the CO₂ laser, which was 0.00047 kg/hr for valves and 0.0000106 kg/hr for connectors.

Table 3-2. Estimated emission impacts of false negatives at Sites C through G.

Site	Valves		Connectors		Emissions, kg/hr		
	Population	Est. False Negatives	Population	Est. False Negatives	Based on M21	Missed	% Error Due to False Negatives
C	1,622	0.73	2,288	0.77	0.082	0.00035	0.42%
D	5,276	2.36	1,269	0.42	0.13	0.0011	0.82%
E	3,256	1.46	10,531	3.52	0.12	0.00072	0.62%
F	5,344	2.39	13,328	4.46	2.87	0.0012	0.04%
G	222	0.10	995	0.33	0.004	0.000050	1.16%
Totals	15,720	7.04	28,411	9.50	3.20	0.0034	Avg. = 0.11%

The data in Table 3-2 illustrate that the rates of false negatives observed at Sites A and B have minimal impacts on the total emissions for valves and connectors. The impacts when applied to data from the five other sites ranged from an underestimation of 0.04% to 1.16% with a weighted average of 0.11%. Repeating the calculations in Table 3-2 using the upper confidence interval of the false negative frequencies from Table 3-1 and an emission rate equal to that which correlates to the 500 ppm leak definition results in a weighted average of 2.0% underestimation with a range from 0.9% to 25.6%. The weighted average is driven down by the large numbers of leaks at high levels at Site F. A simple arithmetic average of the five site's potential underestimation would be around 11.3 percent, which should be considered as the upper boundary of potential under-estimation due to false negatives.

The above analysis of false negative impacts to emissions estimates is based on an assumption that the false negatives are a function of the total numbers of components monitored. This does not take into account the fact that some process units will tend to have more leaks than others. Another approach would be to express the false negative frequency in terms of percent of leaks found, which would cause the estimated number of leaks missed to be higher at units that had high leak rates and lower at units with low leak rates (instead of just proportional to component population). This approach implicitly assumes that Method 21 monitoring is being done with

equal care and skill at all facilities, and could penalize a facility that reported a high leak rate because they were doing Method 21 with greater care than average.

It also should be noted that Method 21 can have false positives as well as false negatives. A false positive would be when Method 21 gets a reading over the leak definition and classes the component as a leak when the actual emission rate is well below the correlated value for the leak definition. No attempt was made to quantify this effect in this study.

NONTRADITIONAL COMPONENT EMISSIONS

There are a number of types of process equipment that have the potential to leak, but not part of routine leak detection and repair (LDAR) programs. Method 21 monitoring will not find leaks in these components because Method 21 inspections are not routinely conducted on them. These components could be subject to measurements and/or repair if leaks were detected by sensory means (sight, smell, or hearing). Some types of equipment in this category include manways, heat exchanger heads, insulated components, buried components, sight glasses, and some instrumentation components (such as transmitters). The definitions of components covered in Method 21 and the federal and state fugitive emission regulations can be somewhat vague and open to interpretation. Because of this, some facilities may be routinely monitoring one or more of the nontraditional component types mentioned above while others are not monitoring them at all.

As reported in Section 2, the CO₂ laser found leaks in some of these nontraditional component types. The data on nontraditional component leaks is summarized in Table 3-3. It is very difficult to estimate the emissions impact for these nontraditional components because none were bagged at Sites A and B and there are no directly applicable emission factors or correlation equations available. Only a percent leaking is presented in the table, and this is based on a very rough estimate of the number scanned with the CO₂ laser.

Table 3-3. Summary of nontraditional component leaks.

Component Type	Estimated Number Scanned	Number Leaking	Percent Leaking
Manways	100	2	2.0%
Insulation Seams	2,000	18	0.9%
Open Plug Holes	20	4	20.0%
Gauges	500	2	0.4%
Transmitters	200	2	1.0%

Tables A-17 and A-29 (located in Appendix A) present rough emission estimates based on using connector correlation equations for these nontraditional component types. Table 3-4 presents a comparison of estimated emissions from traditional and nontraditional components at Sites A and B.

Table 3-4. Comparison of emissions from traditional and nontraditional components.

Component Class	Estimated Emissions, kg/hr		Percent of Emissions	
	Site A	Site B	Site A	Site B
Traditional	3.22	1.58	82%	95%
Nontraditional	0.72	0.09	18%	5%
Totals	3.94	1.67	100%	100%

The data in Table 3-4 show significant disparity in terms of the relative contribution of nontraditional component types between the two sites. Most of that disparity can be explained by the manner in which insulated connectors are handled. Site A had many insulated connectors with no weep holes or other tell-tales to indicate whether a leak might have occurred under the insulation. Site B also had many insulated connectors, but virtually all of them had been provided with a weep hole through the insulation that was being monitored by Method 21 at the regular frequency for connectors. Notwithstanding the disparity between sites, Table 3-4 shows that there is the potential to underestimate a facility's fugitive emissions by 5% to 18% as the result of the omission of nontraditional components from a facility's emission inventory.

PEGGED COMPONENTS

Bagging was done on 14 components that could be considered "pegged" (i.e., at or above the upper limit of detection specified by the instrument manufacturer). These data included five connectors and nine valves. Table 3-5 compares the mass emission rate measured by bagging to the emission rate estimated by using the SOCFI pegged emission factor at 10,000 ppm. In all cases, the SOCFI pegged emission factor at 10,000 ppm was higher than the bagged emission rate, by an average of 68% for connectors and 73% for valves. The SOCFI pegged emission factor at 100,000 ppm overestimated these component emissions by a much greater factor. These data support the conclusion that the use of pegged emission factors is not a significant contributor to overall under-estimation of fugitive equipment leaks emissions.

Table 3-5. Comparison of pegged emission factors to bagging data.

Component Type	ID #	Service, (G or LL)	Method 21 (ppm)	Bagging, kg/hr	Pegged 10K, kg/hr	Under-Estimation	% Under-Estimation
Connector	16639	NA	800,000	0.00746	0.044	-0.0370	-83%
Connector	1358	NA	54,000	0.00304	0.044	-0.0410	-93%

Component Type	ID #	Service, (G or LL)	Method 21 (ppm)	Bagging, kg/hr	Pegged 10K, kg/hr	Under-Estimation	% Under-Estimation
Connector	4279	NA	97,000	0.03560	0.044	-0.0084	-19%
Connector	3815	NA	170,600	0.02300	0.044	-0.0210	-47%
Connector	16358	NA	1,000,000	0.00071	0.044	-0.0430	-98%
Connector Mean				0.01400	0.044	-0.0300	-68%
Valve	11737	G	54,000	0.01310	0.024	-0.0110	-45%
Valve	12404	LL	54,000	0.00265	0.036	-0.0330	-93%
Valve	769	LL	62,000	0.00022	0.036	-0.0360	-99%
Valve	4278	G	63,000	0.00510	0.024	-0.0190	-79%
Valve	9951	LL	210,000	0.00068	0.036	-0.0350	-98%
Valve	15496	LL	900,000	0.02870	0.036	-0.0073	-20%
Valve	9988	LL	1,000,000	0.01160	0.036	-0.0240	-68%
Valve	10575	LL	1,000,000	0.00001	0.036	-0.0360	-100%
Valve	15918	LL	>100,000	0.01800	0.036	-0.0180	-50%
Valve Mean				0.008900	0.033	-0.0240	-73%

The application and interpretation of these pegged factor data is not straightforward. Table 3-5 assumes that facilities are using the SOCFI pegged emission factors for any component with a Method 21 reading of 50,000 ppm or greater. There is insufficient detail on how facilities are estimating emissions from this class of components to make firm conclusions. It is possible that some facilities are using the correlation equations to estimate emissions from any component whose Method 21 value can be displayed or logged as a discrete number.

Table 3-6 provides a comparison of the emissions estimated by the correlation equation approach versus the bagged emission measurements. The correlation equations result in an even greater degree of overestimation of the emissions for this group of high Method 21 value components than do the pegged emission factors. This indicates that there is little potential that facilities are underestimating their “pegged” component emissions regardless of which emission estimation approach they are using.

Table 3-6. Comparison of emission correlation equations to bagging data.

Component Type	ID #	Service, (G or LL)	Method 21 (ppm)	Bagging, kg/hr	Emission Correlation, kg/hr	Under-Estimation	% Under-Estimation
Connector	16639	NA	800,000	0.00746	0.510	-0.500	-98.5%
Connector	1358	NA	54,000	0.00304	0.047	-0.044	-93.5%

Component Type	ID #	Service, (G or LL)	Method 21 (ppm)	Bagging, kg/hr	Emission Correlation, kg/hr	Under-Estimation	% Under-Estimation
Connector	4279	NA	97,000	0.03560	0.079	-0.043	-54.9%
Connector	3815	NA	170,600	0.02300	0.130	-0.110	-82.2%
Connector	16358	NA	1,000,000	0.00071	0.620	-0.620	-99.9%
Connector Mean				0.01400	0.280	-0.260	-95.0%
Valve	11737	G	54,000	0.01310	0.025	-0.012	-48.3%
Valve	12404	LL	54,000	0.00265	0.038	-0.035	-93.0%
Valve	769	LL	62,000	0.00022	0.042	-0.042	-99.5%
Valve	4278	G	63,000	0.00510	0.029	-0.023	-82.3%
Valve	9951	LL	210,000	0.00068	0.110	-0.110	-99.4%
Valve	15496	LL	900,000	0.02870	0.360	-0.330	-92.0%
Valve	9988	LL	1,000,000	0.01160	0.390	-0.380	-97.0%
Valve	10575	LL	1,000,000	0.00001	0.390	-0.390	-100.0%
Valve	15918	LL	>100,000	0.01800	NA	NA	NA
Valve Mean				0.00890	0.17239	-0.160	-94.8%

The data and conclusions regarding pegged component emissions need to be interpreted with reference to the data gathered at sites A and B. It should be noted that the emissions from these pegged components can represent 90%+ of the total fugitive equipment leak VOC emissions, and that most of those emissions can come from just a few super-high leaking components. It is possible that super-high leaking components were present in other areas of these facilities. Omitting even a single super-high leaking component could shift the overall over/underestimation of the pegged emission factors significantly. Even recognizing this caveat, the pegged emission data from Sites A and B show no indication that this component class is likely to result in significant underestimation of emissions.

SUMMARY OF EMISSION IMPACTS

This section examined three possible causes for underestimating fugitive emissions based on test data gathered during the field studies conducted at two olefins production facilities. The three possible causes are:

- False negatives (i.e., leaking components that are missed by Method 21) on traditional component types;
- Omission of emission estimates for nontraditional component types; and
- Under-estimation of pegged component emissions.

The data from Sites A and B show some interesting features related to these three possible modes of underestimating emissions, but they are generally not robust enough to allow statistically significant quantitative analyses. It seems clear from the data that the omission of emissions from nontraditional component types is likely to be the largest contributor to the underestimation of fugitive emissions, but only to the extent of 5% to 18%. The impact of false negatives appears to be less significant, with at most around 10 percent underestimation likely. The application of pegged emission factors appears to be more of a source for overestimation than underestimation of emissions and may compensate for the underestimation in other areas. The pegged emission factor analysis can be highly dependent on identifying one or two extremely high leak rate components, and one such component could have changed the conclusions for that component category. The other categories share that vulnerability to a lesser extent. The highest estimate of potential underestimation of fugitive emissions would appear to be around 30 percent based on the Site A and B data, but the error bars around that would likely be from a 90% overestimate to a 150% underestimate. While these wide error bars make any conclusions difficult, it does seem clear that these data do not indicate a potential for fugitive equipment leaks to be underestimated by a factor of six as the aerial sampling data gathered as part of TxAQS might suggest.

4. CORRELATION EQUATIONS FOR ETHYLENE AND PROPYLENE SOURCES

As part of this project, efforts were made to determine the sufficiency of existing data for use in developing emission correlation equations specific to the ethylene/propylene industry. In this section of the report, these efforts are discussed.

BACKGROUND

Fugitive emission estimates are developed to meet requirements for permitting and emission inventories, and to meet various regulatory requirements [e.g., Superfund Amendments and Reauthorization Act of 1986 (SARA)]. In determining compliance with standards of performance or evaluating the effectiveness of individual programs of emissions reduction, estimating emissions from a given source is a key element. While testing for process emission sources is a relatively straightforward procedure, estimating emissions from widely dispersed fugitive emission sources can be somewhat more difficult.

Currently, five methodologies can be appropriately used to develop emission estimates for equipment leaks of volatile organic compounds and volatile hazardous air pollutants. These methods include the average emission factor method; the leak/no-leak emission factor method; the stratified emission factor method; the application of EPA correlation equations; and the development of new, site and/or industry-specific correlation equations.

All five methods require some data collection, data analysis, and/or statistical evaluation. The average factor method is the least complex and demanding, while developing site and/or industry-specific correlation equations is the most complex and data demanding. The end product of each methodology is an emissions inventory for equipment leaks organized by type of equipment and by service (e.g., light liquid, gas, or heavy liquid).

DATA AVAILABILITY FOR DEVELOPING ETHYLENE/PROPYLENE INDUSTRY-SPECIFIC CORRELATION EQUATIONS

At present, there are two known possible sources of data that could be used for the development of correlation equations specific to ethylene/propylene sources:

- bagging test data obtained at Sites A and B of the CO₂ laser demonstration conducted as part of this project and discussed in Section 2 of this report; and,

- bagging test data obtained during the SOCOMI Six-Unit Maintenance Study conducted in 1980^{1,2}.

The bagging test data from the field studies conducted at Sites A and B have been compiled and are available for use in developing correlation equations. The SOCOMI Six-Unit Maintenance Study data specific to olefin plants could not be found during the course of this project. Technical staff from Radian Corporation, now part of URS Corporation, performed the SOCOMI Maintenance Study as well as the component bagging activities in the field studies at Sites A and B. For this project, the project team conducted a thorough search of the URS library and warehouse in Austin, Texas, but were unable to locate the SOCOMI Maintenance Study data. In addition, staff at the EPA's Office of Air Quality Planning and Standards were contacted during this project; they also reported that they did not have the original data from the SOCOMI study³.

DATA ADEQUACY

Chapter 2 of the EPA's 1995 *Protocol for Equipment Leak Emission Estimates* (Appendix J) provides guidelines for developing unit-specific correlation equations between Method 21 screening values and corresponding mass emissions data (i.e. component bagging data)⁴. Among other things, these guidelines define the minimum amount of data required to develop new correlation equations. Specifically, the guidelines state:

"In developing new correlations, a minimum number of leak rate measurements and screening value pairs must be obtained according to the following methodology. First, equipment at the process unit is screened so that the distribution of screening values at the unit is known. Then, mass emissions data must be collected from individual sources that have screening values distributed over the entire range. The criteria for choosing these sources is as follows. For each equipment type (i.e., valves, pumps, etc.) and service (i.e., gas, light liquid, etc.), a random sample of a minimum of six components should be chosen for bagging from each of the following screening value ranges:

¹ Radian Corporation, Analysis of SOCOMI VOC Fugitive Emissions Data, EPA-600/2-81-111, Final Report, June, 1981.

² As part of the Six-Unit Maintenance Study, bagging tests were performed to determine the emission reduction for repairs of light liquid pumps, gas valves, and light liquid valves.

³ In 1990, EPA developed revised SOCOMI emission factors and correlation equations. For that, EPA had to read the 1980 SOCOMI data from hard copy plots in the original reports. Since the hard copy plots do not identify which type of chemical process each data point was taken from, there is no way to identify olefin plant data as required to develop ethylene/propylene industry-specific correlation equations.

⁴ U. S. Environmental Protection Agency. *Protocol for Equipment Leak Emission Estimates*. Research Triangle Park, NC. Publication No. EPA-453/R-95-017. November 1995. Page 2-40.

Screening Value Range (ppmv)

- 1 - 100
- 101 - 1,000
- 1,001 - 10,000
- 10,001 - 100,000
- > 100,000

The *Protocol for Equipment Leak Emission Estimates* goes on to state that there are two primary reasons for the six component minimum requirement when developing unit-specific correlation equations: 1) to ensure a high degree of confidence in the representativeness of the data, and 2) to accurately reflect the range of possible mass emission rates associated with a given screening value. As stated in the EPA’s document:

“The importance of the first reason is self-evident: The more data collected the better the representativeness. The importance of the second reason is that a given screening value does not necessarily have a “true” emissions rate. For a single screening value, the mass emissions may range over several orders of magnitude depending upon several factors, including the equipment type (i.e., gate valve versus ball valve versus plug valve, etc.) and operating parameters (i.e., chemical handled, temperature, pressure, etc.). This range of possible mass emission rates is accounted for when the correlation is developed, and it is important to obtain enough data to accurately reflect the range.”⁵

The data collected at Sites A and B during this project is available in enough detail to be used to develop the desired correlation equations, but there is not enough of it to meet the cited EPA guidelines⁶. Table 4-1 summarizes the bagging data available from Sites A and B.

Table 4-1. Bagging data obtained from Sites A and B available in required ranges.

Method 21 Monitoring Range (ppm)	Site A				Site B				Total			
	Connector		Valve		Connector		Valve		Connector		Valve	
	G	L	G	L	G	L	G	L	G	L	G	L
1 – 100												
101 – 1000												
1,001 – 10,000							1	4			1	4
10,001 – 100,000	6		1	2	1	1	2	4	7	1	3	6
> 100,000	1		1			1		2	1	1	1	2

⁵ U. S. Environmental Protection Agency. *Protocol for Equipment Leak Emission Estimates*. Research Triangle Park, NC. Publication No. EPA-453/R-95-017. November 1995. Pages 2-40,41.

⁶ The data collected at Sites A and B is concentrated towards the upper end of the monitoring range.

ADDITIONAL DATA NEEDED TO DEVELOP CORRELATION EQUATIONS**Gas/Vapor and Light Liquid Service**

The additional data needed to develop correlation equations specific to ethylene/propylene sources in strict adherence to EPA's protocol is shown in Table 4-2.

Table 4-2. Additional data required to meet EPA protocol.

Method 21 Monitoring Range (ppm)	Valves						Connectors					
	G/V	G/V	G/V	LL	LL	LL	G/V	G/V	G/V	LL	LL	LL
	P	A	N	P	A	N	P	A	N	P	A	N
1 – 100	6	0	6	6	0	6	6	0	6	6	0	6
101 – 1000	6	0	6	6	0	6	6	0	6	6	0	6
1,001 – 10,000	6	1	5	6	4	2	6	0	6	6	0	6
10,001 – 100,000	6	3	3	6	6	0	6	7	0	6	1	5
> 100,000	6	1	5	6	2	4	6	1	5	6	1	5
Total Needed			25			18			23			28

Notes:

G/V means gas/vapor service category

LL means light liquid service category

P means the protocol criteria for tests needed in each screening range category

A means available test data

N means the number of tests needed to meet the protocol criteria

As seen in Table 4-2, a total of 94 additional component bagging tests will be needed to achieve the criterion of 6 or more observations for each component type/service combination. If correlation equations for additional component types beyond valves and connectors are desired, a minimum of 30 additional observations will be required for each type.

Combined Gas/Vapor and Light Liquid Service

Some recent correlation equations have been developed that combine the gas/vapor and light liquid service categories for valves and connectors. Under this approach, the number of additional component bagging tests would be significantly reduced as shown in Table 4-3.

As seen in Table 4-3, a total of 38 additional bagging tests could be used to develop combined service correlation equations for valves and connectors. If this approach is adopted, the additional tests for both component types should be weighted towards lower Method 21 monitoring range components, predominantly in the 1 to 100 ppm and 101 to 1,000 ppm.

Table 4-3. Additional data required for combined service correlation equations

Method 21 Monitoring Range (ppm)	Valves			Connectors		
	G/V and LL			G/V and LL		
	P	A	N	P	A	N
1 – 100	6	0	6	6	0	6
101 – 1000	6	0	6	6	0	6
1,001 – 10,000	6	5	1	6	0	6
10,001 – 100,000	6	9	0	6	8	0
> 100,000	6	3	3	6	2	4
Total Needed			16			22

Notes:

G/V means gas/vapor service category

LL means light liquid service category

P means the protocol criteria for tests needed in each screening range category

A means available test data

N means the number of tests needed to meet the protocol criteria

PLAN TO DEVELOP ADDITIONAL TEST DATA

The additional test data required to meet the EPA's criterion for ethylene/propylene industry-specific correlation equations could be obtained in one or more field tests at an olefins production facility or facility which uses olefins. Components in the lower monitoring value ranges will be easier to find than higher monitoring range components, and it is recommended that candidate components be identified based on the site LDAR monitoring values.

5. ASSESSMENT OF FUGITIVE EMISSION COMPONENT COUNTS

Despite prescriptive regulations that date back to the late 1970's, comparison monitoring conducted by the EPA's National Enforcement Investigations Center (NEIC) suggests that the number of leaking valves and components in refineries may be up to 10 times greater than that reported by certain facilities. EPA believes that this disparity between what facilities are reporting and what the NEIC is finding may be attributable to facilities not monitoring in strict accordance to the EPA's Method 21 protocols. Areas where potential discrepancies between actual monitoring practices and Method 21 requirements may exist include, but are not necessarily limited to, the identification and routine monitoring of all regulated components, the improper training of field personnel in Method 21 monitoring procedures, the failure to monitor for the appropriate amount of time, and the failure to properly identify the highest leaking point on a component prior to source screening.

In May 2002, ENVIRON International Corporation (ENVIRON) was retained by the Houston Advanced Research Center (HARC) to manage a project entitled "Measurement and Assessment of Equipment Leak Fugitives and Vent Emissions in Industrial Ethylene and Other Chemical Sources (Project H5.2002)". As part of that project, an effort was made to assess the accuracy of fugitive emission component counts in several chemical facilities in the Houston/Galveston area (HGA) and from these counts evaluate the accuracy of each facility's fugitive emissions inventory by comparing the emissions inventory calculated from components counted in this project with those reported to the Texas Commission on Environmental Quality (TCEQ). This report provides information obtained in this effort.

FUGITIVE EMISSION MONITORING PROGRAMS

At present, federal and state fugitive emission monitoring programs are based on EPA Method 21¹, which involves the use of a portable hydrocarbon analyzer to monitor for a leak at the leak interface of equipment such as valves, pumps, compressors, and connectors. Monitoring is performed so that leaks can be identified – this is done by comparing the hydrocarbon analyzer reading, or screening value, with the leak definition in the applicable regulation. Data gathered from monitoring is then used to determine what actions are needed to decrease and/or eliminate the leak concentration. Generally if a component is found to be leaking, an attempt to repair the component must be completed within a specified time frame. If the component cannot be repaired within this time frame, it must be repaired at the next available plant shutdown.

Federal and state regulations require facilities to submit reports on their fugitive emissions monitoring program. These reports are used primarily for the purpose of compliance

¹ U.S. Environmental Protection Agency, Method 21, Code of Federal Regulations, Title 40, Part 60, Appendix A – Test Methods.

determination. In the initial report, facilities are required to identify the type and number of components that are included in their fugitive emission monitoring program.² Thereafter, any revisions to items reported in the initial report must be described and discussed in semiannual reports.

Identifying Fugitive Emission Components

The basis of any fugitive emissions monitoring program is the complete and precise identification of all applicable fugitive emission components. Without this information, fugitive emissions monitoring and subsequent emission inventories resulting from this monitoring will not accurately represent the total emissions resulting from operations. In the state of Texas, a component is defined as a piece of equipment, including, but not limited to, pumps, valves, compressors, connectors, and pressure relief valves, which has the potential to emit volatile organic compounds (VOCs) into the atmosphere. A fugitive emission is defined as a VOC entering the atmosphere that could not reasonably pass through a stack, chimney, vent, or other functionally equivalent opening designed to direct or control its flow. Under Texas LDAR Permitting Requirement 28MID, leak detection and repair standards apply to all components except those that meet the following conditions:^{3,4}

- where the concentration of VOCs in the process stream is less than 10 percent by weight;
- the VOC has an aggregate partial pressure or vapor pressure of less than 0.44 psia at 68° F;
- to piping and valves two inches nominal size and smaller; or
- where the operating pressure is at least 5 kilopascals (0.725 psi) below ambient pressure.

In 30 TAC, Chapter 115, Subchapter D, Division 3, fugitive emission control requirements for petroleum refining, natural gas/gasoline processing, and petrochemical processes in ozone nonattainment areas within the State of Texas are defined. Under these standards, facilities are required to identify fugitive emission components (including the equipment type and the process unit where the component is located) and maintain records on those components.

² The type of components that must be identified in these initial reports varies by regulation. For example, under 40 CFR Part 60, Subpart VV, facilities are required to provide the number of valves in gas/vapor service or light liquid service, the number of pumps in light liquid service, and the number of compressors. Under 40 CFR Part 63, Subpart H, facilities subject to the HON standards must provide information on the number of valves, pumps, compressors, agitators, connectors, and screwed connectors (excluding those in vacuum service).

³ Four of the facilities evaluated in this task fall under Texas LDAR Permitting Requirement 28MID; the fifth facility evaluated falls under Texas LDAR Permitting Requirement 28M.

⁴ Components that are excluded from the leak detection and repair standards under 28MID and 28M must be identified in a list.

Field personnel (either employed by the owner/operator of a facility or a contractor) identify fugitive emission components through a series of steps designed to ensure that all regulated components are properly accounted for in the facility's fugitive emissions monitoring program. Typically these steps include the following:

1. Using process flow diagrams (PFDs) and piping and instrument drawings (P&IDs), an initial count of fugitive emission components is made to determine the number of identification tags that are required for each process unit.⁵ In addition, a tagging strategy to be followed as part of the identification process is determined in this initial assessment.⁶
2. Field personnel begin component identification and tagging activities by identifying regulated process streams. Once identified, field personnel tag regulated equipment by following process lines.
3. Information on tagged and referenced components is recorded on field data sheets. Information collected can include all or part of the following data:
 - process unit
 - process area
 - component identification number
 - component type (i.e., valve, pump, compressor, agitator, etc.)
 - component size
 - service (i.e., light liquid, heavy liquid, gas/vapor)
 - location description
4. Information gathered in the field is entered into the facility's fugitive emission database or other electronic program used to record component information.

Calculating Fugitive Emissions

Once components have been identified, screening values are obtained through component monitoring. Screening values are used to calculate fugitive emission inventories. Fugitive emission estimates are developed to meet requirements for permitting and emission inventories, and to meet various regulatory requirements [e.g., Superfund Amendments and Reauthorization

⁵ At least one supplier of fugitive emission monitoring services provides a "leakless" tagging system for identifying components. According to the supplier, field drawings of fugitive emission components are converted to "intelligent" isometric CAD drawings that provide detailed information on the individual location and types of LDAR components included in the program.

⁶ Various tagging strategies can be employed to identify components. At some facilities, all components are physically tagged with identification tags. At other facilities, major components (e.g., pumps, valves, compressors) are tagged while other components are identified by reference to a tagged component. For all components (tagged and referenced), a unique identification number is assigned to the component.

Act of 1986 (SARA)]. In determining compliance with standards of performance or evaluating the effectiveness of individual programs of emissions reduction, estimating emissions from a given source is a key element. While testing for process emission sources is a relatively straightforward procedure, estimating emissions from widely dispersed fugitive emission sources can be somewhat more difficult.

Currently, five methodologies can be appropriately used to develop emission estimates for equipment leaks of volatile organic compounds and volatile hazardous air pollutants. These methods include the average emission factor method; the leak/no-leak emission factor method; the stratified emission factor method; the application of EPA correlation equations; and the development of new, site and/or industry-specific correlation equations.

Each of the five methodologies for estimating emissions resulting from equipment leaks is derived from the identification and/or monitoring of applicable fugitive emission components. Under the most basic approach for calculating fugitive emission inventories (average emission factor method), EPA-developed average emission factors are applied to the equipment counts for each process unit in a facility. The product of the emission factor and the number of equipment components yields the emission rate per source type, and the sum of the emission rates for all source types provides the unit-specific emission estimates. At the other extreme, mathematical correlation equations have been developed which offer a continuous function over the entire range of screening values. EPA has published correlations relating screening values to mass emissions rates. EPA's correlations are based upon OVA measurements taken using Method 21 procedures with an instrument calibrated to methane.

STUDY APPROACH

For this study, detailed component counts were made at six facilities located in the Houston/Galveston area.⁷ In addition, screening values on each identified component were obtained.⁸ Using this information, fugitive emission inventories were calculated and compared with those previously submitted by the facility to the TCEQ.

To calculate the fugitive emission inventory at each site and assess the accuracy of the facility's fugitive emissions inventory, the following five steps were employed:

1. A detailed count of all regulated fugitive emission components was conducted to ensure that all components were properly identified. Counts were conducted by areas that correspond to reporting areas identified as "FIN" in the Texas Emission Inventory Questionnaire.

⁷ Throughout this report, these facilities are identified as Sites C through H.

⁸ The screening values used to calculate the fugitive emission inventory for each facility corresponded to the latest annual emission inventory filed with the TCEQ.

Regulated components included valves, pumps, pump seals, compressors, connectors (flanges), pressure relief valves, and open-ended lines. Component counts were divided between those components that were two inches in size or larger and those that were less than two inches in size.

2. For any component located in the field for which a fugitive emission identification tag was not present (or any other method for identifying that the component was included in the facility’s fugitive emission program), a notation was made. Following this, the facility’s fugitive emission database and/or other data records were researched to determine whether the component was included in the facility’s program.⁹
3. Monitoring records for the facility were obtained so that emission estimates could be calculated using EPA SOCOMI correlation equations. For components that had not been previously identified (and therefore had not previously been monitored), average emission factors were used to calculate fugitive emissions.
4. Calculated emission estimates were compared to emission inventories previously submitted to the TCEQ.
5. For calculated emission estimates that differed by more than 10% from that reported to the State, further evaluations were conducted to ascertain, if possible, the reasons for these discrepancies.

STUDY FINDINGS

Tables 5-1 to 5-6 show the fugitive emission components counted at each site by component type, service, and component size. Detailed component count lists are shown for each site in Appendix K.

Table 5-1: Summary of Site C fugitive emission component count.

Site	Components ≥ 2 inches	Components < 2 inches
SIC: 2810 and 2860 Location: Harris County		
Compressors		
• light liquid	0	0
• gas/vapor	0	0

⁹ It is not highly uncommon for fugitive emission identification tags to be missing from applicable components as a result of improper tagging and/or removal of tags for maintenance purposes. Many facilities keep boxes near unit control buildings so that tags that are found can be replaced on the component.

Site	Components ≥ 2 inches	Components < 2 inches
Connectors		
• light liquid	1,087	883
• gas/vapor	225	93
Open-Ended Lines		
• light liquid	0	0
• gas/vapor		0
Pumps (seals)	1	85
• light liquid		
Pressure Relief Valves	0	8
• light liquid	21	15
• gas/vapor		
Valves	399	1,042
• light liquid	35	97
• gas/vapor		
	1,768	2,223
ALL COMPONENTS	1,487	2,018
• light liquid	281	205
• gas/vapor		

Table 5-2: Summary of Site D fugitive emission component count.

Site	Components ≥ 2 inches	Components < 2 inches
SIC: 2840, 2860, and 2890 Location: Harris County		
Compressors		
• light liquid	0	0
• gas/vapor	0	0
Connectors		
• light liquid	684	327
• gas/vapor	202	56
Open-Ended Lines		
• light liquid	0	0

Site	Components ≥ 2 inches	Components < 2 inches
• gas/vapor	0	0
Pumps (seals)		
• light liquid	12	172
• heavy liquid	0	1
Pressure Relief Valves		
• light liquid	9	2
• gas/vapor	17	1
• heavy liquid	4	0
Valves		
• light liquid	1,712	3,445
• gas/vapor	74	27
• heavy liquid	0	14
ALL COMPONENTS	2,714	4,045
• light liquid	2,417	3,946
• gas/vapor	293	84
• heavy liquid	4	15

Table 5-3: Summary of Site E fugitive emission component count.

Site	Components ≥ 2 inches	Components < 2 inches
SIC: 2990		
Location: Harris County		
Compressors		
• light liquid	0	0
• gas/vapor	0	0
Connectors		
• light liquid	2,649	2,702
• gas/vapor	958	864
Open-Ended Lines		
• light liquid	0	0
• gas/vapor	0	0
Pumps (seals)		

Site	Components ≥ 2 inches	Components < 2 inches
• light liquid	7	96
Pressure Relief Valves		
• light liquid	27	18
• gas/vapor	45	12
Valves		
• light liquid	1,088	1,555
• gas/vapor	286	327
ALL COMPONENTS	5,060	5,574
• light liquid	3,771	4,371
• gas/vapor	1,289	1,203

Table 5-4: Summary of Site F fugitive emission component count.

Site	Components ≥ 2 inches	Components < 2 inches
SIC: 2820 and 2860 Location: Harris County		
Compressors		
• light liquid	0	0
• gas/vapor	0	0
Connectors		
• light liquid	4,393	8,499
• gas/vapor	176	260
Open-Ended Lines		
• light liquid	0	0
• gas/vapor	0	0
Pumps (seals)		
• light liquid	2	169
Pressure Relief Valves		
• light liquid	46	37
• gas/vapor	14	1
Valves		

Site	Components ≥ 2 inches	Components < 2 inches
• light liquid	1,345	3,762
• gas/vapor	47	90
ALL COMPONENTS	6,023	12,818
• light liquid	5,786	12,467
• gas/vapor	237	351

Table 5-5: Summary of Site G fugitive emission component count.

Site	Components ≥ 2 inches	Components < 2 inches
SIC: 2820 and 2860 Location: Harris County		
Compressors		
• light liquid	0	
• gas/vapor	9	
Connectors		
• light liquid	2,191	
• gas/vapor	2,403	
• heavy liquid	765	
Open-Ended Lines		
• light liquid	0	
• gas/vapor	0	
Pumps (seals)		
• light liquid	9	
• heavy liquid	7	
Agitators (seals)		
• gas/vapor	34	
Pressure Relief Valves		
• light liquid	4	
• gas/vapor	60	
Valves		
• light liquid	404	451

Site	Components ≥ 2 inches	Components < 2 inches
• gas/vapor	273	511
• heavy liquid	145	167
ALL COMPONENTS	6,304	1,129
• light liquid	2,608	451
• gas/vapor	2,779	511
• heavy liquid	917	167

Table 5-6: Summary of Site H fugitive emission component count.

Site	Components ≥ 2 inches	Components < 2 inches
SIC: 2810, 2860, and 2870 Location: Matagorda County		
Compressors		
• light liquid	0	0
• gas/vapor	0	0
Connectors		
• light liquid	456	53
• gas/vapor	433	53
Pumps (seals)		
• light liquid	0	13
Pressure Relief Valves		
• light liquid	0	0
• gas/vapor	2	0
Valves		
• light liquid	107	60
• gas/vapor	33	22
ALL COMPONENTS	1,031	201
• light liquid	563	126
• gas/vapor	468	75

Each site included in this study had completed the tagging of all fugitive emission components within the past several years. As such, most regulated components at these sites had been

identified and were included in the facility's fugitive emissions monitoring program. Notwithstanding this, each site had some components that were not tagged and/or identified (at Site G, approximately 21% of tagged gas/vapor components or 9.2% of total components equal to or greater than two inches were found to be in vacuum service and exempt from monitoring requirements. Similarly, approximately 12% of tagged gas/vapor components or 5.3% of total components less than two inches were found to be in vacuum service.)

The primary reasons for these "missed" components include the following:

- Some regulated components were missed during the initial component identification and tagging effort. As discussed above, tagging crews identify regulated components by determining regulated process streams and following process lines, which contain these streams. Occasionally, components were missed during these initial efforts generally at points where schedules and/or technicians intersect (i.e., work ended one day but began in a slightly different location on the next). These missed components were confirmed through a review of field data sheets.
- Some components were not previously tagged as a result of confusion over the applicability of regulatory requirements. This confusion generally resulted from the misidentification of process streams (e.g., streams that contain 10% or more volatile organic compounds, heavy liquid streams versus light liquid streams), at points where regulated process areas interface with non-regulated areas (e.g., utility and process systems), and the size of equipment (i.e., components equal to or greater than 2 inches versus components less than two inches). These missed components were confirmed through a review of process flow diagrams and piping and instrument drawings.
- Some components were not tagged as a result of minor modifications to a previously tagged process area. These missed components were confirmed through the facility walk-through and a review of the site's fugitive emissions database.

Emissions from Fugitive Components

To calculate emissions from fugitive emission components, screening values corresponding to the latest emission inventory submittal to the TCEQ for each site were obtained.¹⁰ EPA

¹⁰ For all but one site, the latest available emission inventory covered the period ending December 1, 2000. For Site F, the latest emission inventory available from the TCEQ covered the period ending December 31, 1998. For that site, calculated fugitive emissions were compared to information obtained in the site's 2000 Toxic Chemical Release Inventory submittal. The federal Toxic Chemical Release Inventory (TRI) reporting program is designed to

correlation equations as shown in Table 5-6 were used. Where screening values were unavailable for a given component, SOCFI average emission factors as shown in Table 5-7 were used.

Table 5-6. SOCFI leak rate/screening value correlation equations.¹¹

Equipment type	Correlation ^{a,b}
Gas Valves	Leak rate (kg/hr) = $1.87E - 06 \times (SV)^{0.873}$
Light liquid valves	Leak rate (kg/hr) = $6.41E - 06 \times (SV)^{0.797}$
Light liquid pumps ^c	Leak rate (kg/hr) = $1.90E - 05 \times (SV)^{0.824}$
Connectors	Leak rate (kg/hr) = $3.05E - 06 \times (SV)^{0.885}$

Notes:

^a SV = Screening value in ppmv.

^b These correlations predict total organic compound mass emission rates.

^c The correlation for light liquid pumps can be applied to compressor seals, pressure relief valves, agitator seals, and heavy liquid pumps.

Table 5-7. SOCFI average emission factors.¹²

Equipment type	Service	Emission factor (kg/hr/source) ^a
Valves	Gas	0.00597
	Light Liquid	0.00403
	Heavy Liquid	0.00023
Pump Seals ^b	Light Liquid	0.0199
	Heavy Liquid	0.00862
Compressor seals	Gas	0.228
Pressure relief valves	Gas	0.104
Connectors	All	0.00183
Open-ended lines (OEL)	All	0.0017
Sampling connections	All	0.0150

provide public disclosure of the use and disposition of toxic chemicals by individual facilities. This is accomplished by having each eligible site report annually its usage of certain specific toxic chemicals. The report requires a detailed "mass balance" analysis of emissions of these chemicals to air, water, land, products, or wastes. The report is filed on EPA "Form R" or "Form A," in accordance with the requirements of Section 313 of the Federal Emergency Planning and Community Right-To-Know Act (EPCRA), also known as the Superfund Amendments and Reauthorization Act of 1986 (SARA), Title III.

¹¹ U.S. EPA, Protocol for Equipment Leak Emission Estimates, EPA-453/R-95-017, pg. 2-26, November 1995, Research Triangle Park, NC.

¹² U.S. EPA, Protocol for Equipment Leak Emission Estimates, EPA-453/R-95-017, pg. 2-12, November 1995, Research Triangle Park, NC.

Notes:

^a These factors are for total organic compound emission rates.

^b The light liquid pump seal factor can be used to estimate the leak rate from agitator seals.

Applying EPA's correlation equations and average emission factors presented above, mass emissions were calculated for each site. Calculated emissions, and those reported to the TCEQ in the 2000 fugitive emission inventory, are shown in Table 5-8.

Table 5-8. Calculated versus reported fugitive emissions.

	Calculated emissions using SOCMI equations and average emission factors (pounds)	Reported 2000 fugitive emission inventory (pounds)	Difference in amount calculated from that reported (pounds)	Difference from amount reported (%)
Site C	3,610	3,580	30	0.84
Site D	12,200	5,480	6,720	122.63
Site E	2,510	7,480	- 4,970	- 66.44
Site G	2,021	1,916	105	5.48
Site H	<u>314</u>	<u>NA</u> ¹³	<u>314</u>	<u>NA</u>
TOTAL ALL SITES	20,655	18,456	2,199	11.91

In total, fugitive emissions calculated from year 2000 monitoring data were 2,199 pounds higher than that reported to the TCEQ (or 11.91%).¹⁴ As seen above, one site (Site E) reported higher fugitive emissions to the TCEQ than that calculated in this study. This resulted from the use of emission factors other than SOCMI correlation equations as used in this analysis. Two other sites (Sites C and G) reported fugitive emissions within 5.5% of calculated emissions.

Of primary concern is Site D, which had approximately 123% more emissions, as calculated from 2000 monitoring data, than that reported to the TCEQ. In a subsequent evaluation of the site, it was determined that the under-reporting of fugitive emissions resulted primarily from the exclusion of one process unit (with 1,109 components greater than 2 inches in size and 384 components less than 2 inches in size) from the reported fugitive emission. While the

¹³ Facilities are not required to report fugitive emission inventories of less than one ton.

¹⁴ Calculated fugitive emissions from Site F were 37,100 pounds. For 2000, the facility reported 48,180 pounds of fugitive emissions on their 2000 Toxic Chemical Release Inventory. Since the Toxic Chemical Release Inventory contains a broader range of chemicals than would be reported to the TCEQ as part of an annual emissions inventory, comparing calculated fugitive emissions, as determined in this study, to the Toxic Chemical Release Inventory provides only a general tool to assess the accuracy of the inventory (e.g., are calculated emissions and the Toxic Chemical Release Inventory within the same range of magnitude).

components in the excluded unit are identified and currently being monitored as required under Texas regulation, no reason was given for its exclusion in the 2000 inventory. Furthermore, the subsequent evaluation found that the site is monitoring all components greater than 1 inch in size although it was unclear from information obtained for this study whether screening values on 1 to 2 inch components were included in the reported emission inventory.

CONCLUSIONS

The conclusions reached in this study suggest that an independent assessment of the accuracy of a facility's fugitive emission inventory, based on component counts and available monitoring data, can result in a range of calculated emissions both over and under that reported by the facility. The variability in calculated results is determined primarily by the accuracy of the facility's inventory of components and the emission factors used to convert emission concentrations to mass. Results also suggest that many facilities base their fugitive emission inventories on information provided, in many cases, by contractors responsible for conducting leak detection and repair and/or rely on fugitive emission software programs to calculate emission inventories from screening values. As a result, the facility's ability to conduct quality assurance/quality control assessments on the calculated emissions may be somewhat limited. As seen here, the use of one type of emission factor methodology over another for calculating fugitive emissions can have a large impact on the total emissions reported.

Areas where improvements can be made at a facility in regards to the calculation of fugitive emissions include the following:

- Better assurance that all regulated components are identified and monitored on a routine basis - this assurance requires that the facility have a clear understanding of which components must be identified, the process stream that the component is in contact with, and the regulatory status of each process area within the facility. In conjunction with a clearer understanding of which components are regulated and fall within the scope of the facility's LDAR program, self-audits and effective management of change programs are required for quality assurance/quality control purposes to ensure that new components are identified and added to the LDAR program, and old components removed.
- Consistent use of emission factors for all components in a facility – for facilities with different contractors and/or methods for calculating mass emissions, the use of a single method will provide more consistent results for the entire facility and a greater degree of control over calculated results. Notwithstanding this, it is recognized that certain methods for calculating emissions may be more suitable for various areas of a facility (i.e., unit-specific correlation equations) and therefore multiple approaches may be necessary. Regardless, the method used for calculating fugitive emissions should be clearly defined in the facility's LDAR operating procedures.

- Quality assurance/quality control of fugitive emission inventories – many of the commercially available fugitive emission databases used by plant and contract personnel have the ability to calculate fugitive emission inventories under a variety of calculation methods. Moreover, these databases allow facilities to speciate component streams. Generally, if speciated data is not available, the database will calculate emissions based on the single compound identified for that stream. Facilities should periodically review stream information to ensure that it remains accurate and current. Furthermore, the method by which emission inventories are calculated in the database should be periodically reviewed to ensure that it provides the most accurate assessment of the facility's fugitive emissions.