GREENPATH 2016 ALBERTA FUGITIVE AND VENTED EMISSIONS INVENTORY STUDY

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EXECUTIVE SUMMARY

The GreenPath Alberta Fugitive and Vented Emissions Inventory Study (GreenPath Study) which took place over two phases in August and November-December 2016 was commissioned by the Alberta Energy Regulator (AER) to gain a more refined data set of fugitive and vented emissions at small facilities located throughout Alberta, where a significant gap exists in data related to fugitive emissions and venting.[1] The GreenPath Study also includes an inventory of equipment associated with methane leaks and vents. A total of 395 distinct facilities with 676 oil and gas wells at those surface locations were inspected by qualified emission technologists and AER staff inspectors during August and November-December 2016. To date, the GreenPath Study is the most extensive evaluation of methane emission leaks and equipment inventory at small facilities ever conducted in Alberta.

The survey focused on six geographical areas as defined by the AER's administrative regions: Grande Prairie (GP), Drayton Valley (DV), Red Deer (RD), Medicine Hat (MH), Midnapore (MR) and Bonnyville (BV). In aggregate, these six regions account for 91% of Alberta's gas production, 86% of the operating wells, and over 77% of all oil (non-bitumen) and gas production batteries within the province. Thus, when examining methane emissions from smaller assets, these regions provide a representative cross-section of relevant assets in the province. Focusing on these regions also enabled efficient deployment of resources to complete the survey in a timely manner. It is noted that despite only accounting for 7% of provincial natural gas production, the Medicine Hat area accounts for approximately half the operating gas wells in the province.

The facilities surveyed during this study included a diverse set of facilities operated by 16 different oil and gas production companies in Alberta, ranging from established majors to mid-sized companies. These companies account for roughly half of the natural gas production in Alberta and operate about half of the permitted natural gas wells and facilities in the province. The participant companies also represent roughly one third of all light oil production. The wells and facilities surveyed were selected using a specific methodology, as described in the following section, to ensure an equitable mix of facility types and production types for the sample size.

The first phase of the study was conducted in August 2016 and encompassed the collection of equipment inventories and the qualitative detection of methane leaks and vents via optical gas imaging (OGI) at approximately 240 unique facilities with more than 300 oil and gas wells across the GP, DV, RD and MH regions. The second phase of the study, which was largely undertaken by AER inspectors, was split into two components. The first element expanded the data collection from Phase I by increasing the number of sites inspected in Red Deer and by completing additional surveys in the Midnapore and Bonnyville administrative regions. For RD and MR, both equipment inventories and qualitative leak and vent data were collected in the same format as the data collected from the first phase of the project. For Bonnyville, the data did not include equipment inventories and was solely focused on qualitative detection of methane leaks and vents via OGI surveys at more than 100 Cold Heavy Oil Production with Sand (CHOPS) locations.

[1] For the purposes of this study, "small facilities" are single wells, up to and including small compressor stations (<1000hp). Generally, compressor stations (>1000hp) and larger facilities undergo regular leak detection and repair via optical gas imaging camera and generally use instrument air to operate pneumatic devices instead of fuel gas and thus emissions from larger facilities are better understood. In Alberta, however, there are more than 150,000 small facilities.

This summary provides an overview of the data gathered from the surveyed sites. Site-specific data, including more detail on the equipment that was observed to have fugitive or vented emissions, as well as a list of all the pneumatic devices with their make, model and use can be found in Appendix C.

Table 1: 2016 Gas production by AER administrative area[2]

Admin Boundary	% of Gas Production
Bonnyville (BV)	3%
Drayton Valley (DV)	27%
Edmonton (ED)	5%
Fort McMurray (FM)	0%
Grande Prairie (GP)	29%
Medicine Hat (MH)	7%
Midnapore (MR)	8%
Red Deer (RD)	17%
Slave Lake (SL)	1%
Wainwright (WW)	2%
TOTAL	**100%**

SITES SURVEYED

During the survey, 395 individual locations were surveyed; within these 395 locations, a total of 676 producing oil and gas wells were documented. Locations refer to a Legal Sub-Division (LSD) co-ordinate. Under the Dominion Land Survey (DLS) of Canada, oil and gas sites in Alberta can be located via the following co-ordinate system 00-00-000-00W0. Each unique identity under the DLS systems represents a unique “location.” The randomization process focused on an LSD “location” to investigate and all key methane emissions sources at each location were inventoried. In situations where more than one well was found at an LSD location, the key methane emission sources were reported at the well level. This was particularly important in the context of multi-well facilities commonly found in the Drayton Valley and Grande Prairie administrative areas. For example, there might be one multi-well battery at a particular LSD location, there could be anywhere from 1 to 10 producing wells at that battery location. To account for this variability in facility design, the fugitive and vented emissions data in this report are presented both in terms of the number of locations surveyed and the number of facilities in operation at those facilities.

Table 2: Locations surveyed

Locations surveyed (LSD)	BV	DV	GP	MH	MR	RD	TOTAL
Gas		79	38	52	32	34	**235**
Oil-Bit	102	11	1	8	6	16	**144**
Unknown		2	1	1	0	3	**16**
TOTAL	**102**	**92**	**40**	**61**	**38**	**53**	**386**

[2] Numbers may not add up due to some rounding.

Table 3: Facilities surveyed

Wells surveyed	BV	DV	GP	MH	MR	RD	**TOTAL**
Gas		118	76	54	32	49	**330**
Oil-Bit		16	1	8	6	29	**60**
CHOPS	279						**279**
Unknown		2	1	1		3	**7**
TOTAL	**279**	**136**	**78**	**63**	**38**	**81**	**676**

FUGITIVE AND VENTING EMISSIONS

In terms of the results, 395 distinct facility locations, representing 676 producing wells were inspected, with 77 leaks identified via (OGI) camera. A further 236 vents were also identified, mostly from tanks and wellhead casing vents. Generally, tank emissions are considered a 'vent' as opposed to a 'leak', although the excessive venting from tanks observed at certain facilities may have been indicative of scrubber dump valves not operating as designed or due to undersized separation equipment.

In addition to tank vents, one venting hydrogen sulphide (H_2S) analyzer was identified. This particular H_2S analyzer would not be classified as a pneumatic device, but does vent gas to atmosphere as a part of its normal operations. A few sites in the survey did not have a match within the AER data set, therefore their facility type and primary commodity on those sites cannot be confirmed.

Including data from the Bonnyville area, there are 8 leaks or vents visible via OGI for every 10 facilities inspected. At natural gas sites, there are approximately 3 leaks or non-pneumatic vents for every 10 locations. At conventional oil facilities, there are approximately 7 leaks or vents for every 10 locations. In the Bonnyville area there are 22 leaks/tank vents identified via OGI for every 10 production locations; these are mostly tank vents and well casing vents.

Table 4: Average emissions visible via OGI (leaks and vents) per location

Average number of leaks per location by commodity type	BV	DV	GP	MH	MR	RD	All Areas
Gas		0.23	0.53	0.1	0.03	0.47	**0.26**
Oil		0.18	3.00	0.25	-	1.31	**0.67**
CHOPS	2.21						**2.21**
TOTAL	**2.21**	**0.22**	**0.58**	**0.11**	**0.02**	**0.70**	**0.79**

In the data set, oil locations appear to be more likely to have leaks. The oil locations with leaks, as well as locations with tank venting, were focused in the Red Deer area. Despite the facilities surveyed in Grande Prairie being among the newest in Alberta, the frequency of leaks detected in the area was second highest to Red Deer among the natural gas and light oil production regions (excluding CHOPS).

The data collected by the AER inspectors in the Bonnyville area was focused on visible vents and leaks at CHOPS sites (as opposed to collecting a complete asset inventory) as most CHOPS-related methane emissions come from wellhead (casing) venting or tank venting.

Of the 102 locations surveyed in Bonnyville, 279 producing wells were inspected, and 116 further wells were shut-in and not operating or not accessible. Of the 102 locations surveyed, 225 leaks/vents were observed. Of those 225 leaks/vents observed, 38% were vents from the wellhead. These wellhead vents are a significant source of emissions in Alberta based on the current Federal National Inventory Report on Greenhouse Gas emissions. The survey also observed one of the basic challenges of methane mitigation from CHOPS in that vents from the wellhead were sometimes intermittent.

Table 5: Vents and leaks detected at CHOPS wells in Bonnyville area by land location/asset surveyed

Locations surveyed	Wells surveyed	Shut-in assets	Leaks/vents detected
102	279	116	225

Table 6: Leak/vent types Identified in Bonnyville administrative area from CHOPS wells

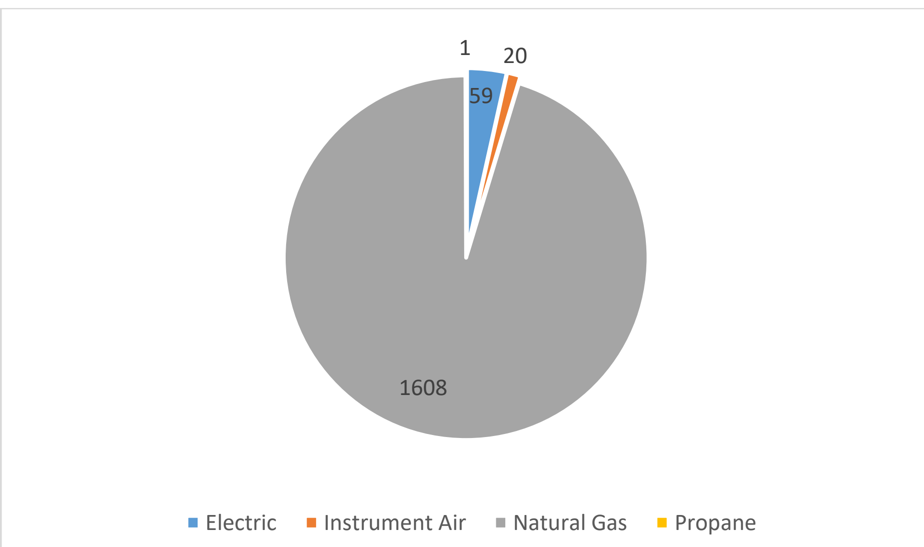
Wellhead vents	Tank vents	Leaks	Surface casing vents
86	136	1	2

PNEUMATICS

Over the course of the survey, the number of pneumatic devices powered by methane fuel gas, instrument air, propane and electricity were inventoried. A total of 1,688 pneumatic devices (1219 instrument, 469 pumps) were documented across the 396 oil and gas wells (excludes CHOPS wells) surveyed in GP, DV, RD, MH and MR regions[3]. At the surveyed facilities, process control and chemical injection processes were found to use pneumatic equipment driven by pressurized natural gas.

A very small number of sites were found to use electrically-driven process control equipment and chemical injection pumps, mainly in the Red Deer area where some sites surveyed had access to grid electricity.

Figure 1: Pneumatics by driver type



[3] Pneumatic device data was not collected during the surveys in the Bonnyville region

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In the Medicine Hat and Midnapore areas, many facilities did not have any pneumatic pumps or pneumatic controls in place. This was due to the facility design and the type of production from those facilities.

Of the surveyed sites, only one used propane as a pneumatic supply; however, this configuration is thought to represent a small percentage of sites (but likely more than the 0.05% presented in the data) in Alberta, where fuel gas is unreliable or of unsuitable quality.

Table 7: Pneumatic devices per land location

Device Type	DV	GP	MH	MR	RD	TOTAL
Pump	1.8	3.7	0.4	0.7	2.0	**1.7**
Controller	4.5	8.3	1.0	1.6	6.6	**4.2**
TOTAL	**6.3**	**12.0**	**1.4**	**2.3**	**8.6**	**5.9**

Table 8: Pneumatic devices per well

Device Type	DV	GP	MH	MR	RD	TOTAL
Pump	1.22	1.90	0.38	0.66	1.31	**1.18**
Controller	3.06	4.26	0.94	1.63	4.32	**3.07**
TOTAL	**4.28**	**6.15**	**1.32**	**2.29**	**5.63**	**4.25**

Examining pneumatic devices, there is significant variation in emissions per pneumatic device. As shown in *Table 9: Pneumatic controls by function*, 26.9% of the controllers found on site were high-pressure shutdown (HPSD) or high-level shutdown (HLSD) devices which have very low emission rates per the 2013 Prasino Study and should not be emitting large volume unless there is a device malfunction or a process upset.

Table 9: Pneumatic controls by function

Heat Trace	High Level Shutdown	High Pressure Shutdown	Level Control	Plunger Lift Control	Positioner	Pressure Control	Temperature Control	Transducer
0.2%	14.4%	12.5%	41.5%	2.0%	1.8%	17.4%	0.9%	9.4%

Level controllers were found to be the most common pneumatic control, with a typical configuration of two level controllers per separator. Despite level controllers being considered a "snap-acting" device, roughly one-thid of the level controllers encountered in the survey were found to be continuously venting.

Using make and model data, each pneumatic controller or chemical injection pump was mapped to the appropriate emission factor from the 2013 Prasino Study. Using the Prasino Study emission factors, average potential emissions from pneumatic devices in the study can be determined.[4] Methanol is generally injected seasonally; to be conservative, chemical injection pumps are assumed to only operate 50% of the year. All other pneumatic devices are assumed to operate 365 days per year. Using these factors and assuming methane content of 90% in fuel gas, the pneumatic emissions from the average well in the survey are equivalent to the CO_2e emissions of over 20 cars.

The data shows that areas such as Medicine Hat and Midnapore wells are generally pipe-in/pipe out configuration with no surface facilities such as separators and thus have limited emissions from pneumatic

[4] Devices on instrument air or electricity default to a zero value in the calculation

devices. The sites inspected in Drayton Valley and Grande Prairie included a large number of multi-well facilities, thus the differential between average emission per land location and per well.

Table 10: Average emissions per land location from pneumatic devices (tCH_4/year)

Methane emissions per location (tCH_4/year)	DV	GP	MH	MR	RD
Controllers	4.65	8.04	0.74	1.71	5.55
Pumps	4.58	8.48	0.67	1.70	4.45
TOTAL	**9.23**	**16.52**	**1.41**	**3.41**	**10.00**

Table 11: Average emissions per well from pneumatic devices (tCH_4/year)

Methane per well and battery per year (tCH_4/year)	DV	GP	MH	MR	RD
Controllers	3.19	4.08	0.53	1.55	3.74
Pumps	3.15	4.40	0.67	1.77	3.01
TOTAL	**6.34**	**8.49**	**1.20**	**3.32**	**6.75**

Using the average CH_4 emissions per well and cross-multiplying with facilities listed (assuming that wells and single well batteries are equivalent to wells in this study) and assuming the sample is representative, the five areas would have emissions of 502,777 tCH_4/year from pneumatics.

For comparison, the 2014 Clearstone Engineering inventory[5] shows emissions of 306,213 tCH_4 from unreported venting in 2010 for all of Alberta. The unreported venting category includes vented sources other than pneumatics suggesting that emissions from pneumatic devices are currently understated in the national emissions inventory or that the sample for this study was highly skewed towards facilities with pneumatic devices. Therefore, further research is required to better understand the contribution of emissions from pneumatic devices to the total emissions from the upstream oil and gas sector.

Table 12: Potential emissions from pneumatics in study areas

Potential Annual Emission per Area	DV	GP	MH	MR	RD	TOTAL
Average emissions per well (tCH_4)	6.34	8.49	1.20	3.32	6.75	3.96[6]
Wells and single well battery	14,491	13,177	57,735	18,584	22,477	126,464
TOTAL ($tCH_{4/year}$)	**94,565**	**115,102**	**70,011**	**63,492**	**159,606**	**502,777**

EMISSION FROM TANKS

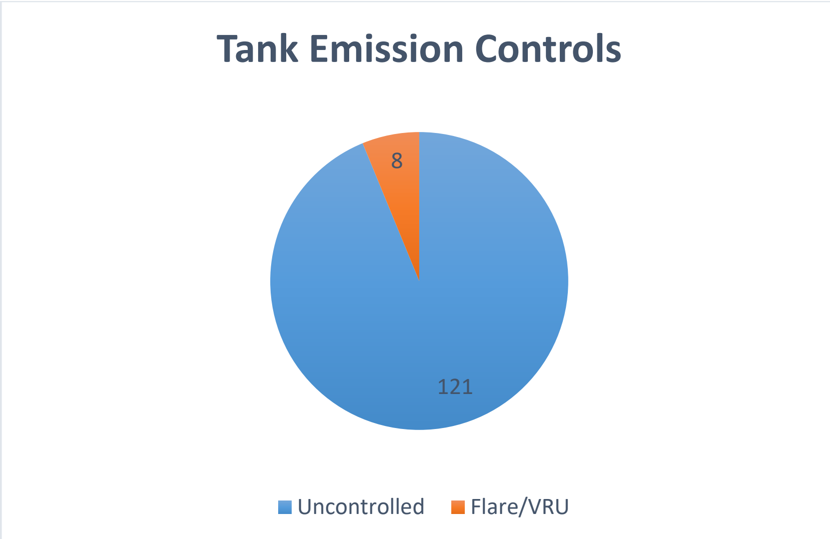
During the survey, tanks were inventoried along with their contents and size recorded, as well as the fate of any vented hydrocarbons from the tanks. Emissions from tanks were not quantified, but were observed qualitatively via OGI, with emissions from tanks often appearing significant. Only at one newer site with liquids-rich gas were emissions from tanks controlled by a vapour recovery unit.

[5] Clearstone Engineering Ltd. (2014). *Overview of GHG Emissions Inventory, Volume 1.* Table 20

[6] Weighted Average

Note: Tanks and controls in place were not inventoried in Bonnyville.

Figure 2: Emission controls on 129 tanks observed during study



ADDENDUM

The ratios of pneumatic device per facility have been adjusted as three facilities were misclassified when this report was published in March 2017. The misclassification was a result of inconsistencies in facility lists. The field notes from the survey showed "compressor station" but the facility list showed coal-bed methane and a gas well, respectively. The error was spotted by a participant company. Further examination was undertaken using a more comprehensive facility list to ensure no other facilities had been misclassified. This re-issue of the report addresses this error.

CONTENTS

TABLES AND FIGURES

ACRONYMS AND KEY TERMS

AER	Alberta Energy Regulator
ATS	Alberta Township System
CBM Well	Coal bed methane well
CFM	Cubic foot per minute
CO_2e	Carbon dioxide equivalent
DV	Drayton Valley AER administrative region
EDF	Environmental Defense Fund
FEMP	Fugitive Emission Management Plan
FLIR	Forward looking infrared
GHG	Greenhouse gas
GP	Grande Prairie AER administrative region
HLSD	High-level shutdown switch
HPSD	High-pressure shutdown switch
IPCC	Intergovernmental Panel on Climate Change
LDAR	Leak detection and repair
LSD	Legal subdivision
MH	Medicine Hat AER administrative region
OGI	Optical gas imaging
PTAC	Petroleum Technology Alliance of Canada
QA	Quality assurance
QC	Quality control
RD	Red Deer AER administrative region
UOG	Upstream oil and gas
UWID	Unique well identifier
VRU	Vapour recovery unit

ACKNOWLEDGEMENTS

The involvement of the AER in developing data sets and accompanying maps was a key success factor in accomplishing the study. Without the participation of the AER, sufficient data and mapping could not have been accomplished in the timeframe and within the budget. Business Intelligence Analyst Jill Hume was invaluable in generating data and maps that made this project possible during the condensed timeframe.

The operators who escorted GreenPath Emission Technologists and AER inspectors to site also deserve special thanks. In a time when every operator is expected to do more with less, we genuinely appreciate their time.

INTRODUCTION

GreenPath Energy Ltd. (GPE) of Calgary, Alberta was contracted by the Alberta Energy Regulator (AER) for services related to methane emissions measurements at multiple facility locations throughout the province. GreenPath completed a survey of facilities from August 15 to August 26, 2016 as part of the first phase of this project. The study was commissioned as a data gathering exercise to help resolve gaps within the AER and public understanding of methane emissions (sources and volumes) from upstream oil and gas operations in Alberta. A second phase was carried out in November 2016 to increase coverage in the Red Deer and Midnapore administrative areas and to assess emissions from CHOPS operations in the Bonnyville region.

The objective of this study was to measure emissions from smaller facilities in Alberta, including wellsites, batteries, multi-well pads, and booster stations. Fugitive Emission Management Plans (FEMP) currently under operation by oil and gas producers most commonly focus on large compression assets, gas plants, and large oil batteries hence smaller facilities are typically not covered by these programs; as a result, a data gap exists with regards to methane emissions from gas driven pneumatics and fugitive emissions.

This study presents the results of the field survey but does not extrapolate the results to the broader Alberta upstream oil and gas inventory, and is not a substitute for a pneumatic inventory of assets in Alberta, instead this report provides goal posts on which further analysis can be developed.

The GreenPath Alberta Fugitive and Vented Emissions Inventory Study (GreenPath Study) focused on five geographical areas in Alberta based on the administrative boundaries of the AER: Grande Prairie (GP), Drayton Valley (DV), Red Deer (RD), Medicine Hat (MH), and Midnapore (MR). These areas represent 92% of all gas wells, 82% of all gas group batteries, 94% of all oil proration batteries, and 63% of all non-heavy oil wells in the province. The areas represent a mix of conventional and unconventional assets which vary in age. The following tables provide a breakdown of gas production by region and facilities by region.

Table 13: Gas production by administrative region[7]

Admin Boundary	% of Gas Production
Bonnyville (BV)	3%
Drayton Valley (DV)	27%
Edmonton (ED)	5%
Fort McMurray (FM)	0%
Grande Prairie (GP)	29%
Medicine Hat (MH)	7%
Midnapore (MR)	8%
Red Deer (RD)	17%
Slave Lake (SL)	1%
Wainwright (WW)	2%
TOTAL	**100%**

[7] Numbers may not add up to 100% due to rounding.

Table 14: Oil and gas facilities by AER administrative region

Reporting Entity	Site Type	BV	DV	FM	GP	MH	MR	RD	SL	ED	WW	**TOTAL**	Survey Area Total	% of total
Gas Well	Well	2,465	7,869	71	8,082	52,347	16,401	16,018	623	2,981	4,722	**111,579**	**100,717**	**90%**
Oil Well	Well	32	5,140	0	4,098	4,772	1,440	4,048	1,403	2,912	7,161	**31,006**	**18,058**	**58%**
Crude Oil Group	Batt	1	30	0	33	27	19	50	27	27	155	**369**	**140**	**38%**
Crude Oil Single	Batt	26	597	0	490	407	486	791	198	296	1,082	**4,373**	**2,285**	**52%**
Gas Group	Batt	133	399	4	314	246	217	780	20	233	202	**2,548**	**1,739**	**68%**
Gas Group Nlr	Batt	0	2	0	3	2	4	37	0	5	1	**54**	**44**	**81%**
Gas Proration Not SE AB	Batt	10	1	2	36	99	185	303	2	10	49	**697**	**439**	**63%**
Gas Proration SE AB	Batt	2	1	0	0	313	109	10	0	0	5	**440**	**324**	**74%**
Gas Single	Batt	22	885	0	507	209	257	1,620	5	366	165	**4,036**	**3,221**	**80%**

ABOUT GREENPATH ENERGY

Founded in 2007, GreenPath Energy Ltd. offers a range of oil and gas methane emission detection, measurement and inventory development services for regulatory compliance and waste elimination programs. Our technical expertise and diverse experience in emissions management ensures we provide clients with solutions that will allow for efficient use of capital while still achieving significant emission reductions and regulatory compliance.

Our expertise in building best practice fugitive and vented emission management solutions has been developed over the past nine years through our extensive instrumentation backgrounds and by using the best available technology. We engage regularly with government, regulatory bodies, industry associations, and technology providers to ensure we are at the leading edge of emission management program requirements and solutions.

KEY DEFINITIONS

The most critical (and often misunderstood) definitions for methane emissions in oil and gas production are "leaks" and "vents". GreenPath has defined these two terms as follows:

Table 15: Leak and vent definitions

Leaks (unintentional releases of methane)	Vents (intentional releases of methane)
Pneumatic switch venting excessively	Pneumatic controls (even if venting in building)
Leak on chemical injection pump diaphragm	Pneumatic pumps
Loose flange	Tank vent – goose neck
Tank vent – thief hatch (if VRU in place)	Tank vent – thief hatch (if no VRU)
Surface casing vent flow (SCVF)	Compressor rod packing
Loose threaded connection	Compressor starter vent
Valve not seating	H_2S Analyzer emissions

For this study, non-pneumatic vents have been grouped with leaks. The most common non-pneumatic vent encountered was tank venting, associated with flashing losses or gas carryover from upstream sources such as scrubber dump valves. Storage tanks that exhibit excessive and continuous emissions are a symptom of upstream sources leaking gas to the storage tank such as scrubber dump valves not functioning as designed.

Pneumatic devices are process control devices which use pressurized gas (natural gas, most commonly) to control an element of process at an oil and gas facility. In this study, the concept of high- or low-bleed devices has not been used, as data has shown that with the most common pneumatic devices (level controllers), the bleed rate is not a useful indicator of actual emissions to atmosphere. Instead, pneumatic devices have been grouped into three primary categories: pneumatic switches (on/off) which only emit in a process upset, pneumatic controllers (with variable emissions based on the process condition), and chemical injection pumps. Emission factors were assigned based on the 2013 Prasino Study, in which devices with an emission rate above $0.17m^3/hr$ were classed as high rate (HR) devices, and those below $0.17m^3/hr$ were classed as low rate (LR) devices. When an equivalent device was not found in the Prasino Study, specifications were used to class a device as HR or LR. If manufacturers' specifications could not be found, the device defaulted to LR.

Table 16: Examples of pneumatic device classifications

Pneumatic Switch	Pneumatic Controller		Chemical Injection Pump
HPSD-Fisher 4660	Fisher 4150	Norriseal 1001a	Texsteam 5100
HLSD-SOR 1530	Fisher C1	Fisher I2p-100	CVS 5100
	Fisher L2	Fisher 546	Williams P250

Emissions rates for pneumatic devices presented in the study are derived from the 2013 Prasino Study (Prasino Study)[8]. GreenPath completed the field measurements for the survey, and the lead author of this report (Michael D'Antoni) performed QA/QC on behalf of the BC Ministry of Environment for the Prasino Study.

Throughout the report, results from each administrative area have been grouped as "locations" and "wells." Each unique identity under the DLS systems (00-00-000-00W0) represents a unique "location." The

[8]Prasino Study, http://www2.gov.bc.ca/assets/gov/environment/climate-change/stakeholder-support/reporting-regulation/pneumatic-devices/prasino_pneumatic_ghg_ef_final_report.pdf

randomization process focused on a legal subdivision (LSD) to investigate and all assets at the location were inventoried.

Wells refer to distinct infrastructure at the location. For example, a compressor station could have a permitted wellsite or a multi-well battery at the LSD in addition to the compressor. This is particularly important in the context of multi-well facilities commonly found in the Drayton Valley and Grande Prairie administrative areas. For example, from a location perspective there would be one multi-well battery at a location; however, there could be 8 or 12 wells at the land location. Thus, in terms of extrapolating out from this survey, one would look at the 8 or 12 wells found at the site versus the one “multi-well” facility at the location. This concept of assets provides greater accuracy and granularity.

METHODOLOGY

GreenPath Energy worked with the AER and the Environmental Defense Fund (EDF) to develop a robust methodology designed to minimize bias in selection. The following section details the pre-planning and field execution required for the GreenPath Study.

FACILITY DEFINITIONS

For the purposes of this study, the term "facility" includes all upstream oil and gas facilities ranging from single wells to gas gathering systems. Facilities for the survey were identified using AER classifications found in AER Manual 11.[9] Commodity produced at the facility is also defined within the AER database. If a site was operating in a function not matching permitted use (for example, a battery being used as a metering station), the facility definition in the AER database was used.

At multi-well facilities (multi-well batteries and pads), the count of the facilities inspected is open to interpretation. For example, a two-well battery could be classed as either a multi-well battery (1) or two wells (2). In large multi-well Montney facilities in Grande Prairie could be treated as (1) multi-well facility, or 12 wells. For the purposes of this report, a multi-well facility such as the aforementioned Montney well pad has been counted as 12 facilities. The report also includes raw data on sites inspected in Appendix C.

The list of eligible facilities for the survey was generated using a formula based on the Alberta Township System (ATS) classification system. The ATS is a land survey system used in Western Canada to assign unique well identifiers (UWI) to each drilled hole. This nomenclature is used for wells in Manitoba, Saskatchewan, Alberta, and the Peace Country in north-western British Columbia.

GreenPath Energy worked with the Business Intelligence Unit of AER to compile a list of potential sites for inspection within Alberta. The AER generated a list of all permitted facilities within the four administrative regions as listed in the Introduction section above. Within those regions, townships with more than 20 facilities (more than 50 sites in Medicine Hat) were assigned a random number via Microsoft Excel formula and then ranked. The top 15 townships in sequential order generated by the randomization process per administrative area where then placed on a map. Townships greater than two hours' drive from a center (such as Grande Prairie, Brooks, Medicine Hat, etc.) were removed, as extensive drive time from local accommodation would generate challenges for project execution over the two-week period.

The sampling plan was reviewed and approved by staff scientists from the Environmental Defense Fund. The process was designed to be sufficiently random to minimize selection bias.

DESKTOP PLANNING

Within each township selected, all sites were randomized and ranked using Microsoft Excel. The first 15 sites were ranked using randomization, then placed on a detailed area map; the randomized sample was compared against the overall township characteristics. In general, if a township's site count was less than 95% wells, an additional non-well facility was added to the survey (the first non-well facility on the random-ranked list).

The objective of the field survey was to inventory and inspect 10 facilities per township. Each township was ranked based on a random number generator and each facility was randomly ranked from 1 to 15, with

[9] AER Manual 11, http://www.aer.ca/documents/manuals/Manual011.pdf

additional facilities listed as backup locations. If sites were shut in or inaccessible, the survey team would move further down the list to ensure the appropriate allocation within each township.

Data collection templates were pre-populated with the list of potential sites, to reduce the probability of data entry errors. The pre-populated list of sites (in a consistent format) allowed for querying the AER corporate database to provide details such as owner, commodity, facility type, and facility start date. When multiple permits existed for the same facility, the newest permitted facility type was used.

The lists were then arranged by participant company, and the list of potential sites provided to the participant company roughly 48 hours before the survey team arrived on site. The lists provided to participant companies included all potential sites were *not* ranked in order of likelihood to be visited.

The AER inspectors were provided with a “Pneumatic Field Guide” to assist in identifying pneumatic instruments on site.

FIELD SURVEY PROCESS

At the start of each day, maps provided by AER were used to plot the most efficient route through selected sites. For participant companies, arrangements were made to meet with the local operator and receive an escort to sites usually 24 hours prior to site arrival. An operator from the company would follow an emission technologist/AER inspector. Operator assistance proved particularly valuable in the Medicine Hat area as route finding without operator assistance would have proved problematic. In the Drayton Valley area, heavy rains resulted in a revision to the selected townships.

On the first day of the survey in each area, the AER inspector worked closely with the lead emission technologist on site to identify pneumatic equipment and other emission sources and to gain critical insight into the inspection process. After this, inspectors were sent to inventory sites on their own.

Any company-specific safety indoctrination was completed prior to arrival. As noted in *Appendix B: Safety*, all GreenPath Emission Technologists have H_2S Alive, First Aid, CPR, WHMIS, TDG, and Enform EGSO training.

ON-SITE PROCEDURE

The emission technologist/AER inspector either used a specialized oil and gas GPS unit or was driven to the site by an operator. When arriving on site, the technologist reviewed the site for hazards and undertook any site-specific safety indoctrination. Upon arriving at site, the emission technologist records the site location (usually on the building or on the access road leading to the site). In the case of multi-well facilities, the downhole location associated with the legal subdivision (LSD) is also recorded.

The inspection of each facility was a full LDAR inspection and inventory of major emitting equipment. The entire site including inside buildings was inspected via FLIR (Forward Looking Infrared Optical Gas Imaging Camera), with a focus on equipment known to leak such as flanges, threaded connections, or regulators. Potential leaking items were inspected from 3 to 5 feet away.

Tank tops were inspected from as close a distance as possible while still visualizing the top of the tank, typically 20 to 30 feet away. The inspection was done using the high-sensitivity mode of the FLIR Camera, which helps to identify smaller leak sources. When a visible leak is detected by FLIR that leak is recorded on the camera (10 seconds in normal view, 20 seconds in thermal mode).

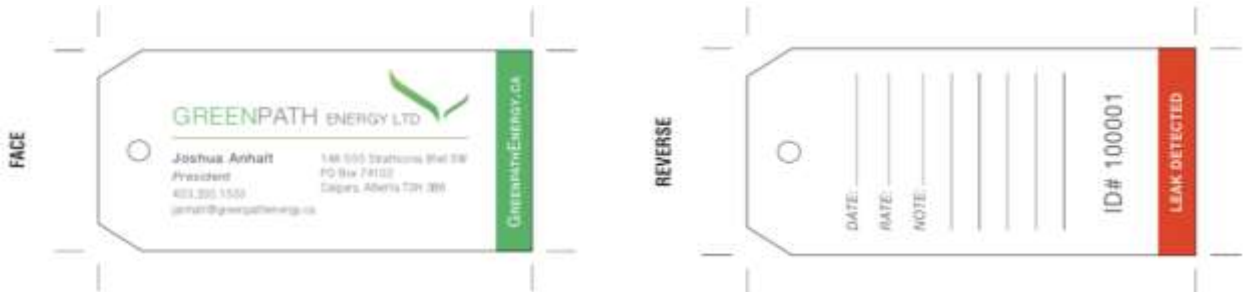
Figure 3: FLIR GF320 optical gas imaging camera

The file number for the recorded video file is recorded by the technician and matched with the file number in the secure online server. GreenPath uses a cloud-based database to capture fugitive and emission inventory equipment.

When leaks were found on site, a leak tag was also affixed to the leaking component, as shown in the image below. If a significant leak or safety issue was detected, the operator was notified.

During the survey, a total of two operators were notified for those reasons: one safety issue (H_2S personal alarm triggered), and one tank was found to be excessively venting. In cases where the operator was escorting the inspection team, some identified leaks were resolved before the leak could be fully quantified.

Figure 4: Sample GreenPath Energy leak tag



A small subset of leaks was quantified using a Bacharach Hi-Flow Sampler™. The Hi-Flow had a defective sensor on days 1 and 2 of the survey (Red Deer, Phase 1), thus there were no quantified rates for the area for those days. Replacement parts were purchased after day one and installed the evening of survey day two.

Figure 5: Bacharach Hi-Flow Sampler

Equipment counts were inventoried based on the table below. Further clarification was noted if required; for example, if a snap-acting controller such as a level controller was found to be continuously venting (CV) this was recorded. The pneumatic system (Fuel Gas, Propane, Instrument Air, Electric) was also recorded.

Table 17: Emitting equipment inventoried on site

Compression	Engine make/model Horsepower Compressor Starter – Starter type/ fate of starter gas (VRU, Flare, Atmosphere) Compressor Seals – Tied to flare/VRU/to atmosphere Number of throws for reciprocating compressors
Pneumatic devices	All controllers (make/model/function) Supply pressure for instrumentation (e.g. 20 psig or 35 psig) Pneumatic pumps (make/model/chemical injected) Injection pressure for pumps Injection rate (L/day) if available and fluid type for pumps
Dehydrators	Use of stripping gas Pump type Controls in place If there is a flash tank, if any stripping gas is being used, and if there is a condensing tank for the still column vapours
Heaters	Type Rating
Tanks	Fate of vent gas (VRU/Flare/Atmosphere) Size Contents (if readily available)
Other vent sources	Cactus dryers Gas driven heat trace pumps

A detailed description of GreenPath Energy's leak detection survey is attached in *Appendix A: Detailed Leak Detection Methodology*.

TECHNICIANS

For this survey, GreenPath President and CEO Joshua Anhalt completed the majority of site inspections and inventories. Joshua is a graduate of the Southern Alberta Institute of Technology (SAIT) and a Red Seal instrument technician. Joshua has more than nine years of experience performing FLIR-based leak detection surveys. Joshua has completed over 1,000 inspections of oil and gas facilities in Western Canada and the United States, as well as inspection in the Ukraine, Tunisia and Kazakhstan.

In the Grande Prairie area, senior GreenPath emission technologist Abin Edelhose conducted two days of surveys. Abin has an engineering degree and has worked in the oil and gas sector for 7 years, including 2.5 years as an OGI emission technologist. The facilities he surveyed in the Grande Prairie area were similar to other facilities he has inspected for another client in the area, where he has completed over 300 similar surveys.

During the project, GreenPath Energy was supported by two inspectors from the Alberta Energy Regulator, each with more than 15 years' experience as inspectors for the AER and significant time logged with the Gas Find FLIR OGI Camera. One inspector carried out facility inspections and inventories in the Midnapore area; the other completed the FLIR inspections of vents and leaks at CHOPS sites in the Bonnyville area.

DATA QA/QC

Data records were scanned and emailed to GreenPath's Victoria, BC office for review and compiled into pre-validated spreadsheets which were designed to minimize issues related to LSD locations being incorrectly recorded, as well as variability in the description of pneumatic devices. For example, without these document controls, i2-100 and I2P100 would show up as different pneumatic devices. The pre-validated lists, however, had to be revised periodically as new types of pneumatic controllers were encountered in the field.

The data was reviewed and clarifications were requested from the field technicians to ensure that the data was adequately captured. If data did not seem to meet the pattern of similar facilities, subsequent questions were asked of the inspectors. After the data was compiled, it was reviewed by Joshua Anhalt. Anonymous versions of the data were also reviewed by staff with the AER and EDF.

The results from the survey where an "N/A" is present in the data represent sites which were not on the pre-selected list of sites, or there was an error in recording the selected site location and location. GreenPath worked with the AER to attempt to resolve as many as possible, but there are sites where the recorded location did not match the AER data set. Transposition combinations as well as "flip" of surface and downhole locations were used to attempt to resolve this issue. These "N/A" sites are most common in the Drayton Valley area as heavy rains forced a significant revision in the survey plan in terms of sites inspected.

CONFIDENTIALITY OF RESULTS

To maintain the confidentiality of participating companies, the data went through a rigorous process to remove any identifying information. In the global data set, company names were replaced with a single letter code. Only GreenPath Energy has the key to identify each company. Participant companies have been provided with their individual survey results upon request.

The next step in the sequence was to make the individual locations anonymous. All surveyed LSDs were assigned a number. This number code was then used during the study to reference a specific location. In the case of multi-well facilities, individual wells were given a unique “sub-code.” Only GreenPath Energy has the full list of sites by LSD that indicate the encoded locations.

RESULTS

With the assistance of AER inspectors, GreenPath Energy completed fugitive surveys in 40 townships within Alberta. Within the 40 townships, 296 distinct LSDs were inspected accounting for 396 facilities. In the course of the inspections, over 1688 pneumatic devices were inventoried, 74 leaks were identified via FLIR camera, 14 intentional vents, 9 from tanks, two compressors packing vents, two controllers venting inside the building, and one H_2S Analyzer.

SUMMARY OF ALL SURVEYED AREAS

Figure 6 below provides a vis al representation of the areas in which the GreenPath Study was undertaken. Specific townships have been obscured so individual operators could not be identified, though one operator is often dominant within a given township. The survey is heavily weighted towards gas production assets, as these comprise a more significant proportion of potential methane emitting assets than conventional oil production or oil sands operations. Oil sands operations were out of scope for this project.

Figure 6: Map of townships surveyed

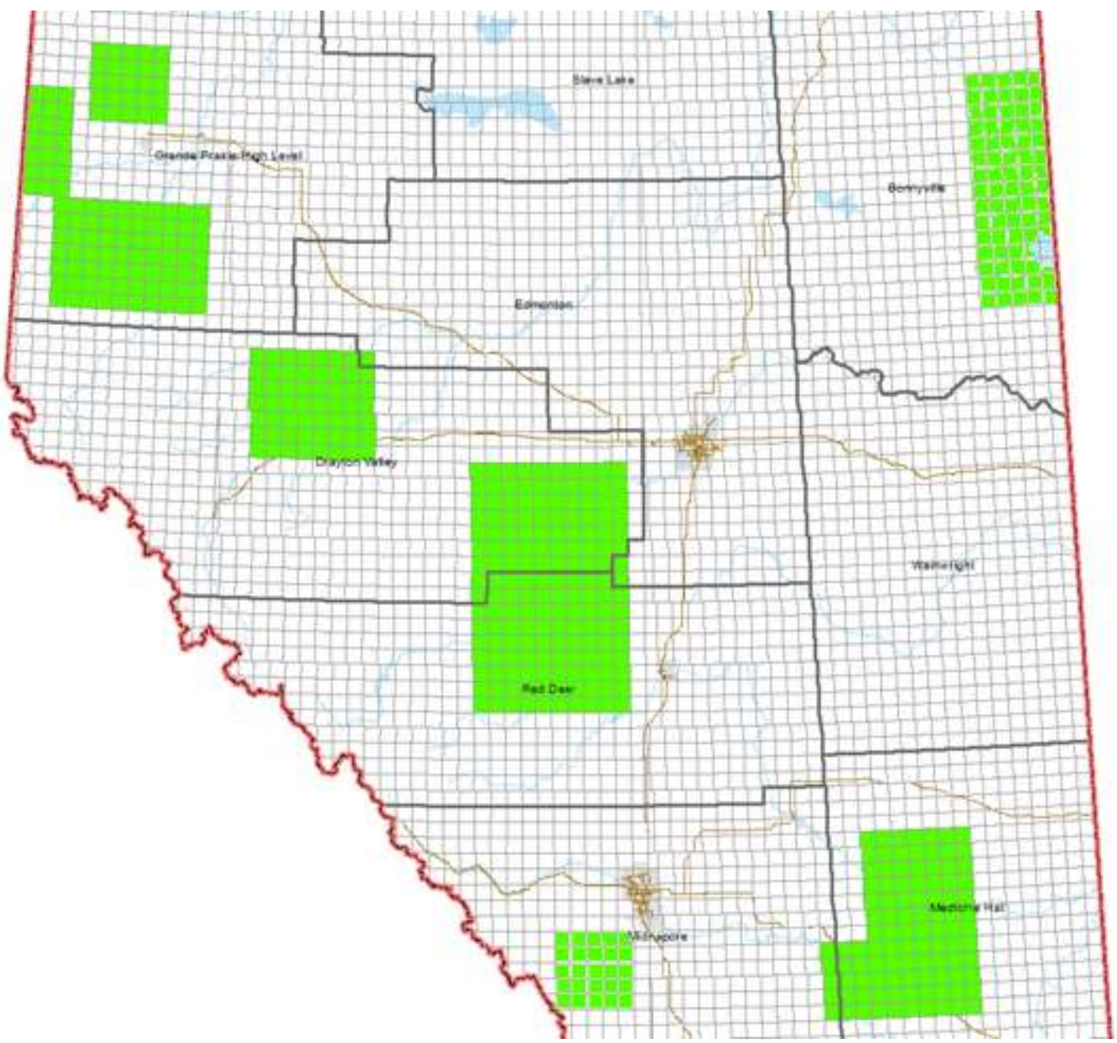


Table 18: Gas facilities surveyed

Service Area	Coalbed Methane Well	Compressor Station	Gas Battery	Gas Gathering System	Gas Multi-Well Group Battery	Gas Multi-Well Proration Outside SE Alberta Battery	Gas Single	Gas Single-well Battery	Gas Well	Meter Station	TOTAL
DV	0	0	0	0	4	1	0	15	98	0	**118**
GP	0	0	0	1	2	31	0	0	42	0	**76**
MH	14	2	0	0	0	3	0	0	35	0	**54**
MR	0	1	0	0	0	0	0	0	32	0	**33**
RD	0	1	1	0	8	1	3	8	26	1	**49**
TOTAL	**14**	**4**	**1**	**1**	**14**	**36**	**3**	**23**	**233**	**1**	**330**

Table 19: Oil facilities surveyed

Service Area	Crude Oil Multi-Well Proration Battery	Crude Oil Single	Crude Oil Single-well Battery	Crude Oil Well	Enhanced Recovery Scheme	Oil Battery	Oil Well	TOTAL
DV	1	0	1	14	0	0	0	**16**
GP	0	0	0	0	1	0	0	**1**
MH	0	0	1	7	0	0	0	**8**
MR	0	5	0	0	0	0	1	**6**
RD	5	0	19	5	0	1	0	**30**
TOTAL	**6**	**5**	**20**	**26**	**1**	**1**	**1**	**61**

Table 20: Injection and unknown commodity wells

Service Area	Injection	n/a	Water injection well	TOTAL
DV	0	2	0	**2**
GP	0	1	0	**1**
MH	0	0	1	**1**
RD	1	1	0	**2**
TOTAL	**1**	**4**	**1**	**6**

Table 21: Detected leaks and vents by area and commodity

Service Area	Gas	Oil-Bit	TOTAL
DV	18	2	**20**
GP	20	3	**23**
MH	5	2	**7**
RD	16	21	**37**
MR	1	0	**1**
TOTAL	**60**	**28**	**88**

Table 22: Leaks and vents by commodity type

Emission Type	Gas	Oil	TOTAL
Leak	56	18	**74**
Vent	4	10	**14**
TOTAL	**60**	**28**	**88**

Table 23: Leaks and vents by process block

Emission Type	Compression	Filter/ Separation	Flare/ ESD	Heater	Meter Station	Piping	Tankage	Well-head	TOTAL
Leak	2	26	2	1	1	4	5	33	**74**
Vent	2	3	0	0	0	0	9	0	**14**
TOTAL	**4**	**29**	**2**	**1**	**1**	**4**	**14**	**33**	**88**

Table 24: Leaks and vents by component main type

Emission Type	Compressor Seal	Connecto r	Control Valve	Open-Ended Line	Pump Seal	Regulator	Surface Casing Vent	Valve	TOTAL
Leak	0	25	2	7	7	6	11	16	**74**
Vent	2	1	0	11	0	0	0	0	**14**
TOTAL	**2**	**26**	**2**	**18**	**7**	**6**	**11**	**16**	**88**

Based on the survey, the proportion of leaking component types appear to be reasonably similar relative to PTAC study *Historical Canadian Fugitive Emissions Management Program Assessment* (FEMP Assessment)[10].

Connectors and valves are the most common leaking components. The data within the FEMP Assessment is focused on gas plants and compressor stations, whereas this study is focused on smaller facilities, wells and batteries, but the type of leaking component is reasonably similar. One of the other key differences is that within the FEMP Assessment, leak-free sites are reasonably rare; whereas within this data set, leak free sites are far more common thank sites where leaks are present.

Table 25: Pneumatic devices by area and commodity

Service Area	Gas	Unknown	Oil	TOTAL
DV	573	0	9	**582**
GP	469	3	8	**480**
MH	69	0	14	**83**
MR	72	0	15	**87**
RD	262	7	187	**456**
TOTAL	**1445**	**10**	**233**	**1,688**

[10] Petroleum Technology Alliance of Canada, Historical Canadian Fugitive Emissions Management Program Assessment. http://auprf.ptac.org/wp-content/uploads/2017/02/Report-FUGITIVE-EMISSIONS-16-ARPC-02.pdf

Table 26: Pneumatic devices by production type

Pneumatic Device Type	Gas	n/a	Oil	TOTAL
Heat Trace	2	0	0	**2**
High Level Shutdown	144	1	31	**176**
High Pressure Shutdown	117	1	34	**152**
Level Controller	435	3	66	**504**
Plunger Lift Controller	14	1	9	**24**
Positioner	22	0	0	**22**
Pressure Controller	169	1	42	**212**
Pump	419	2	48	**469**
Temperature Controller	9	0	2	**11**
Transducer	113	1	1	**115**
TOTAL	**1445**	**10**	**233**	**1,688**

Level controllers are the most common pneumatic device encountered during the survey. For each gas asset encountered, on average more than one chemical injection pump was inventoried.

Table 27: Pneumatic controllers by function and make/ model

Pneumatic Device Make & Model	Qty	High Rate (HR) or Low Rate (LR) [11]	Device Category
HEAT TRACE TOTAL	***2***		
Kold Katcher HT-12	1	LR	Pump
LiquidFire	1	HR	Pump
HIGH LEVEL SHUTDOWN	***176***		
Array AIL 020P	1	LR	Pneumatic Switch
CVS 7970	46	LR	Pneumatic Switch
Fisher 2680a	1	LR	Pneumatic Switch
Fisher L2	1	LR	Pneumatic Switch
HLR	6	LR	Pneumatic Switch
HLR HLPSD	2	LR	Pneumatic Switch
Kimray 220 Electra HLSD	1	LR	Pneumatic Switch
Kimray 2200	1	LR	Pneumatic Switch
Linc 282	9	LR	Pneumatic Switch
Murphy L1200	29	LR	Pneumatic Switch
Murphy L1200 NDVO	2	LR	Pneumatic Switch
SOR 1530	1	LR	Pneumatic Switch
SOR 1503	1	LR	Pneumatic Switch
SOR 1530	61	LR	Pneumatic Switch
Unknown	8	LR	Pneumatic Switch
Wellmark	2	LR	Pneumatic Switch
Wellmark 87988	1	LR	Pneumatic Switch

[11] Based on Prasino Study Values (high rate = emission factor from study >0.17m^3/hr)

Pneumatic Device Make & Model	Qty	High Rate (HR) or Low Rate (LR) [11]	Device Category
Wellmark HLSD	1	LR	Pneumatic Switch
Wellmark s12p-97	1	LR	Pneumatic Switch
Wellmark st2p-73	2	LR	Pneumatic Switch
HIGH PRESSURE SHUTDOWN TOTAL	***152***		
AMOT 4023e6410	1	LR	Pneumatic Switch
AMOT 42023e6410	3	LR	Pneumatic Switch
CCS 6600ge20	7	LR	Pneumatic Switch
CVS 1530	33	LR	Pneumatic Switch
Fisher 4600	1	LR	Pneumatic Switch
Fisher 4660	87	LR	Pneumatic Switch
HLR	7	LR	Pneumatic Switch
Murphy L1200	2	LR	Pneumatic Switch
n/a n/a	10	LR	Pneumatic Switch
Wellmark st2p-73	1	LR	Pneumatic Switch
LEVEL CONTROLLER TOTAL	***504***		
Cemco 2ab	1	HR	Pneumatic Control
CVS 1001XL	1	HR	Pneumatic Control
Fisher 2500	1	HR	Pneumatic Control
Fisher 2660a	2	HR	Pneumatic Control
Fisher 2680	18	HR	Pneumatic Control
Fisher 2680a	4	HR	Pneumatic Control
Fisher 2900	7	LR	Pneumatic Control
Fisher L2	372	HR	Pneumatic Control
Fisher L2e	1	LR	Pneumatic Control
Invalco CTU-4155	2	LR	Pneumatic Control
Kimray Gen II	4	HR	Pneumatic Control
Mallard 3100	1	LR	Pneumatic Control
Norriseal 1001a	79	HR	Pneumatic Control
Norriseal 1001a electric	4	LR	Pneumatic Control
Unknown	5	LR	Pneumatic Control
Wellmark 2001nb	2	LR	Pneumatic Control
PLUNGER LIFT CONTROLLER TOTAL	***24***		
EVO II Plunger	1	LR	Pneumatic Switch
EVO n/a	1	LR	Pneumatic Switch
MegaLift n/a	1	LR	Pneumatic Switch
PCS 2000	2	LR	Pneumatic Switch
PCS 3000	1	LR	Pneumatic Switch
PIT n/a	8	LR	Pneumatic Switch
Process Technology n/a	1	LR	Pneumatic Switch
Unknown n/a	6	LR	Pneumatic Switch
Weatherford n/a	1	LR	Pneumatic Switch
Wellmark PT980-29-1	1	LR	Pneumatic Switch

Pneumatic Device Make & Model	Qty	High Rate (HR) or Low Rate (LR) [11]	Device Category
POSITIONER TOTAL	***22***		
Fisher DVC6200	22	LR	Pneumatic Control
PRESSURE CONTROLLER TOTAL	***212***		
CVS 4150	14	HR	Pneumatic Control
CVS 4150le	1	HR	Pneumatic Control
Dyna-Flo 4000	10	HR	Pneumatic Control
Dyna-Flo 4000r	3	HR	Pneumatic Control
Dyna-Flo 5000	2	HR	Pneumatic Control
Fisher 4150	74	HR	Pneumatic Control
Fisher 4150K	1	HR	Pneumatic Control
Fisher 4150kr	3	HR	Pneumatic Control
Fisher 4160KR	1	HR	Pneumatic Control
Fisher 4660	1	HR	Pneumatic Control
Fisher C1	100	LR	Pneumatic Control
Fisher Wizard	2	HR	Pneumatic Control
TEMPERATURE CONTROLLER	***11***		
Kimray HT-12	11	LR	Pneumatic Control
TRANSDUCER	***115***		
Fisher 546	5	HR	Pneumatic Control
Fisher I2P-100	108	HR	Pneumatic Control
Fisher i2p-100(l)	1	LR	Pneumatic Control
Unknown	1	LR	Pneumatic Control
DEVICE TOTAL	**1219**		

Using emission factors from the Prasino Study, the most common high rate devices were level controllers, pressure controllers and transducers.

Table 28: Chemical injection pumps inventoried in survey

Pump	Count
Arrow 5100	3
Bruin	1
Bruin 5100	68
Bruin MSM-500	1
Calscan Bear	2
CVS 50	2
CVS 5100	110
CVS C-252	1
CVS CIP	1
CVS D0434	11
CVS series 50	2
Innovel Technologies Collection Bottle	2
Invalco Rep301e-38itf	2
n/a n/a	12
n/a Sirius	1
Other (describe in notes)	2
Pressure Matic	1
SIRIUS	5
Texsteam 5100	160
Texsteam MSM-500	4
Timberline 2513	1
Twister 5030CCEBT	4
Unknown	8
Williams	2
Williams 125	4
Williams 250	9
Williams P125	1
Williams P500	49
Total	**469**

Overwhelmingly, the pneumatic pumps inventoried were diaphragm pumps instead of piston pumps. In the 2013 Prasino Study, 53% of all pumps quantified were piston pumps (as opposed to diaphragm chemical injection pumps).

DRAYTON VALLEY

The Drayton Valley area resulted in the most assets inventoried due to the availability of two AER inspectors to conduct inventories and inspections. Surveyed sites included newer assets with high-productivity wells.

Table 29: Drayton Valley service area characteristics

% Gas Assets	75%
% Oil-Bit Assets	25%
% Assets Startup up to and including 2009	62%
% Assets Startup Post-2009	38%
% Gas Production	27%

Table 30: Facilities surveyed in Drayton Valley

Crude Oil Multi-Well Proration Battery	Crude Oil Single-Well Battery	Crude Oil Well	Gas Multi-Well Group Battery	Gas Multi-Well Proration Outside SE Alberta Battery	Gas Single-well Battery	Gas Well	N/A	**TOTAL**
1	1	14	4	1	15	98	2	**136**

Table 31: Drayton Valley pneumatic devices by facility type

Component	Crude Oil Well	Gas Multi-Well Group Battery	Gas Single-well Battery	Gas Well	**TOTAL**
HLSD	0	0	5	40	**46**
HPSD	2	0	5	63	**70**
Level Controller	6	8	23	147	**183**
Plunger Lift Controller	0	0		2	**2**
Pressure Controller	1	4	16	73	**94**
Pump	0	4	19	143	**166**
Temperature Switch	0	0		2	**2**
Transducer	0	4	2	13	**19**
TOTAL	**9**	**20**	**70**	**483**	**582**

Table 32: Drayton Valley leaks and vents by process block

Emission Type	Filter/Separation	Piping	Tankage	Wellhead	**TOTAL**
Leak	8	1		9	**18**
Vent	1		1		**2**
TOTAL	**9**	**1**	**1**	**9**	**20**

Table 33: Drayton Valley leaks and vents by facility commodity type and process block

Facility Commodity	Filter/Separation	Piping	Tankage	Wellhead	**TOTAL**
Gas	9	1	0	8	**18**
Oil	0	0	1	1	**2**
TOTAL	**9**	**1**	**1**	**9**	**20**

GRANDE PRAIRIE

The Grande Prairie administrative area includes Montney and Duvernay production formations, and has grown in assets and production in the last five years. Multi-well pads are common. Generally, one inspector can inventory and inspect 10 well-sites per day; in this survey, one inspector day was used to inventory and inspect a 12-well pad.

Table 34: Grande Prairie area characteristics

% Gas Assets	67%
%Oil-Bit Assets	33%
% Assets Startup up to and including 2009	70%
% Assets Startup Post-2009	30%
% Gas Production	29%

Table 35: Facilities surveyed in Grande Prairie

Compressor Station	Enhanced Recovery Scheme (Oil)	Gas Gathering System	Gas Multi-Well Group Battery	Gas Multi-Well Proration Outside SE Alberta Battery	Gas Well	N/A	**TOTAL**
2	1	1	2	31	40	1	**78**

Table 36: Grande Prairie pneumatic devices by facility type

	Compressor Station	Enhanced Recovery Scheme	Gas Gathering System	Gas Multi-Well Proration Outside SE Alberta Battery	Gas Well	N/A	**TOTAL**
High Level Shutdown	1	1	0	50	1	0	**53**
High Pressure Shutdown	0	0	0	0	3	0	**3**
Level Controller	1	1	3	83	37	1	**126**
Plunger Lift Controller	0	0	0	0	4	0	**4**
Positioner	0	0	0	11	0	0	**11**
Pressure Controller	0	0	1	20	15	0	**36**
Pump	0	3	2	93	49	1	**148**
Temperature Controller	0	2	0	0	4	0	**6**
Transducer	5	1	0	63	23	1	**93**
TOTAL	**7**	**8**	**6**	**320**	**136**	**3**	**480**

Table 37: Grande Prairie leaks and vents by process block

Emission Type	Compression	Filter/Separation	Flare/ESD	Piping	Tankage	Wellhead	**TOTAL**
Leak	2	3	2	2	2	11	**22**
Vent	1	0	0	0	0	0	**1**
TOTAL	**3**	**3**	**2**	**2**	**2**	**11**	**23**

MEDICINE HAT

The Medicine Hat area is dominated by shallow gas production. The area accounts for almost half of the active wells in Alberta, but only 7% of total production. Within the survey, the most common type of configuration was a simple pipe in/pipe out configuration with no pneumatic controls or other infrastructure in place. In an earlier version of this report, two facilities were classified as coal bed methane wells (MH-73 and MH-222) when they were in fact compressor stations. Discussion with the operators of these sites and a refined facility list from the AER showed that these two facilities were compressor stations per the field notes.

Table 38: Medicine Hat service area characteristics

% Gas Assets	92%
%Oil-Bit Assets	8%
% Assets Startup up to and including 2009	88%
% Assets Startup Post 2009	12%
% Gas Production	7%

Table 39: Medicine Hat facilities surveyed

Compressor Station	Coalbed Methane Well	Multi-well Proration Battery	Gas Well	Oil Well	Oil Battery	Water Injection Well	**TOTAL**
2	14	3	35	7	1	1	63

Table 40: Medicine Hat pneumatic devices by facility type

Pneumatic Device Type	Compressor Station	Coalbed Methane Well	Crude Oil Well/Battery	Gas Multiwell Proration SE Alberta Battery	Gas Well	**TOTAL**
Heat Trace		0	0	0	1	**1**
High Level Shutdown	2	0	2	0	6	**10**
High Pressure Shutdown		0	2	0	7	**9**
Level Controller	6	0	3	1	13	**23**
Positioner	10		0	0	0	**10**
Pressure Controller	2	0	3	0	1	**6**
Pump		1	4	3	16	**24**
TOTAL	20	**1**	**14**	**4**	**44**	**83**

Table 41: Medicine Hat leaks and vents by process black

Emission Type	Filter/Separation	Tankage	Wellhead	**TOTAL**
Leak	1	0	4	**5**
Vent	1	1	0	**2**
TOTAL	**2**	**1**	**4**	**7**

MIDNAPORE

The Midnapore service area is south of Calgary, often with older assets than other service areas in the study, and predominantly gas-prone. In addition, this is an older area where facilities have older pneumatic equipment or are a pipe-in-pipe out configuration.

Table 42: Midnapore service area characteristics

% Gas Assets	91%
% Oil-Bit Assets	9%
% Assets Startup up to and including 2009	82%
% Assets Startup Post 2009	18%
% Gas Production	8%

Table 43: Facilities surveyed in Midnapore area

Compressor Station	Crude Oil Single Well Battery	Gas Well	Oil Well	**TOTAL**
1	5	32	1	**39**

Table 44: Pneumatic devices in Midnapore inventoried

Pneumatic Device Type	Gas Well	Crude Oil Single Well Battery	Compressor Station	**TOTAL**
High Level Shutdown	9	1	0	**10**
High Pressure Shutdown	8	1	0	**9**
Level Controller	18	4	4	**26**
Pressure Controller	12	4	1	**17**
Pump	20	5	0	**25**
TOTAL	**67**	**15**	**5**	**87**

Table 45: Detected leaks and vents in Midnapore area

Commodity Type	Leak	Vent	**TOTAL**
Gas	1	0	**1**
Oil	0	0	**0**
TOTAL	**1**	**0**	**1**

RED DEER

The Red Deer Service area was the most diverse area that GreenPath and AER inspectors inspected and inventoried in terms of facility types, see Table 47 below. Red Deer was also selected for a second inspection during Phase 2 of the project.

Table 46: Red Deer service area characteristics

% Gas Assets	75%
% Oil-Bit Assets	25%
% Assets Startup up to and including 2009	67%
% Assets Startup Post 2009	33%
% Gas Production	17%

Table 47: Facilities surveyed in Red Deer area

Gas Multiwell Proration Outside SE Alberta Battery	1
Crude Oil Multiwell Proration Battery	6
Crude Oil Single-well Battery	19
Gas Multiwell Group Battery	9
Gas Well	26
Injection	1
n/a	1
Compressor Station	1
Crude Oil Well	5
Gas Single-well Battery	11
Meter Station	1
TOTAL	**81**

Table 48: Red Deer pneumatic devices by facility type

Pneumatic Device Type	Crude Oil Battery	Gas Battery	Crude Oil Well	Gas Well	Compressor Station	Meter Station
Heat Trace	0	1	0	0	0	0
High Level Shutdown	23	15	3	15	0	0
High Pressure Shutdown	26	14	3	17	0	0
Level Controller	44	41	9	48	2	1
Plunger Lift Controller	8	3	1	4	0	1
Positioner	0	1	0	0	0	0
Pressure Controller	29	16	5	8		
Pump	32	28	4	34	5	2
Temperature Controller	0	0	0	3	0	0
Transducer	0	2	0	1	0	0
TOTAL	**162**	**121**	**25**	**130**	**7**	**4**

Table 49: Red Deer leaks and vents by process block

Emission Type	Compression	Filter/Separation	Heater	Meter Station	Piping	Tankage	Wellhead	TOTAL
Leak	0	13	1	1	1	3	9	**28**
Vent	1	1	0	0	0	7	0	**9**
TOTAL	**1**	**14**	**1**	**1**	**1**	**10**	**9**	**37**

Table 50: Red Deer leaks and vents by facility commodity classification

Commodity Type	Compression	Filter/ Separation	Heater	Meter Station	Piping	Tankage	Wellhead	TOTAL
Gas	1	5	1	1	0	1	7	**16**
Oil-Bit	0	9	0	0	1	9	2	**21**
TOTAL	**1**	**14**	**1**	**1**	**1**	**10**	**9**	**37**

BONNYVILLE (COLD HEAVY OIL PRODUCTION WITH SAND)

The Bonnyville administrative area was surveyed by AER inspectors. A different survey methodology was followed relative to the other areas surveyed. The Bonnyville Area survey was still randomly designed, but the stratum within which the survey occurred were wells and facilities that could be classed as CHOPS wells from production data.

The main function of the Bonnyville survey was not to inventory major emitting equipment, but to determine the number of observable emissions via FLIR Camera.

Multi-well configurations were reasonably common within the Bonnyville area, especially at newer developments.

AER inspectors surveyed 102 land locations, with 279 producing wells found. A further 116 shut in wells were found during the survey. During the survey, 225 leaks and vents were observed via OGI.

Table 51: Bonnyville Sites Surveyed

Locations Surveyed	Wells Surveyed	Shut-in Wells
102	279	116

Wellhead Vents	Tank Vents	Leaks	Surface Casing Vents
86	136	1	2

Similar data on pneumatics and major equipment is not available for the CHOPS area. Instead the main output was observations on detectable emissions at CHOPS sites.

The majority of observable vents are from tanks, either from the Goose Neck or hatch. In some cases, steam was observed to have mixed with hydrocarbons emitting from tanks.

LESSONS LEARNED

Location information is the key data element which allows multiple data sets to work together to produce a meaningful result. The pre-validated lists of sites were invaluable, ensuring that data captured in the field could be cross referenced with AER corporate data. However, there were instances where even though a broader data set was included, a match with the AER data set could not be found.

Various methods were used to attempt to resolve this data gap, including an analysis of different potential iterations of the location, as well as cross-referencing with bottom hole location. In further surveys, the location should be recorded via photograph of building and lease entry to ensure that a transposition error was not the cause of a match not being found in the AER corporate database.

In terms of stratification, the survey did not randomly select a large number of facilities with compression assets onsite. In further surveys, a percentage of the sample should be reserved for dedicated compression assets.

Generally, LDAR surveys are "exception-driven" in that only emitting sources are recorded; non-emitting facilities are generally not recorded in a data set unless a previously reported leak has been resolved. During the survey, GreenPath revised procedures to properly record leak and emission free facilities. The GreenPath online data platform has also been revised to more rapidly record and report on non-emitting facilities.

When data exceeds 100 facilities, spreadsheets become less effective in managing data. The use of a database platform is recommended for any significant LDAR program.

APPENDIX A: DETAILED LEAK DETECTION METHODOLOGY

INFRARED OPTICAL GAS IMAGING CAMERA TECHNOLOGY

FLIR GF320 & GasFindIR camera has a detector response of 3-5 µm which is further spectrally adapted to approximately 3.3µm by use of a cooled filter. This makes these cameras the most responsive to the gases commonly found in the oil and gas industry. The camera has been laboratory tested against 19 gases:

Benzene	Hexane	Octane
Butane	Isoprene	Pentane
Ethane	MEK	1-Pentane
Ethylbenzene	Methane	Propane
Ethylene	Methanol	Propylene
Heptane	MIBK	Toluene

TARGET COMPONENTS

The first step is determining which types of components will be targeted. The objective is to minimize the potential for leaks in the most practicable manner possible. This is done by focusing efforts on the components and service applications most likely to offer significant cost-effective control opportunities. Target components for inspection include:

Compressor - Reciprocating and Centrifugal	Valve covers	Cylinder head
	Variable volume pocket	Cylinder bleed
	Governor	Cylinder body
Compressor Seals	Packing case drain	Common vent
	Distance piece vent	Crank case vent
Engine	Governor	Injector
	Crank case vent	
Valves (All types)	Stem packing	Seal
	Diaphragm	Body
	Actuator seal	
Connections	Threaded	Mechanical
	Flanged	Instrument fitting
Open-Ended Line	All	
Storage Tanks	All	
Pump Seals	All	
PSV/PRV	All	
Regulators	All	
Pneumatic Instrumentation Controls	All	

FACILITY INSPECTION PROCESS

At every facility we inspect, we always go beyond the “lens” of the FLIR camera to source the origin of an emission. Many emission sources are located simply following the trial of clues with trained senses. These clues include odors, staining, ground depressions, audible traces, noticeable damage, building doors and windows propped open, bypassed or disconnected LEL detectors.

Our scanning methodology follows a general sequence of scanning each component from one end to the other. To ensure we detect all sources of fugitive emissions at each facility we inspect, we scan each targeted component from at least two separate angles with the FLIR camera firmly stabilized. This ensures the effectiveness of the FLIR camera and that the best possible video recording quality is obtained.

Video of detected fugitive emissions, are recorded for a minimum of 10 seconds directly to our specialized Our fugitive emission inspections follow a general methodology:

From an advantageous perspective, we scan all outdoor stacks, vents, tanks and flares and building vents. Emissions from these sources can be safety concerns and/or a symptom of other underlying issues such as passing PSV/PRVs, faulty separator dump valves and incorrect operation of equipment. This general broad scan gives us a sense of what we can anticipate further in the inspection and allows us to note any safety concerns. Emissions detected at this stage are further investigated with the intent to report the cause and not the symptom of the emission source.

Scanning the facility usually follows the flow of gas as it is moved from one production stage to another.

Inlet → Separation → Compression → Dehydration → Sales

At each production stage an exterior scan of the building process envelope is performed. Each exterior component is scanned from at least two different angles; any emissions detected are recorded and reported.

After inspecting the outer envelope process components, we focus inspection efforts on target components contained within the boundaries of the building envelope. Again, each component is scanned from at least two different angles and all emissions detected are recorded and reported.

Once all outer and inner process envelopes are scanned, all piping and components that connect each process together are inspected.

By the end of inspection tour, the entire facility located within the operating boundaries has been inspected.

During inspections, we vigilantly take the individual facility characteristics and circumstances into consideration and when required to do so, we adjust our detection methodology accordingly. Cause for change can include:

- Co-ordination with other workers on site
- Extreme environmental conditions
- Needs and availability of field operations
- Unplanned equipment failures and shut-downs

EMISSION QUANTIFICATION

Primarily, quantification of sweet methane emissions involves the use of the Hi-Flow Sampler. The Hi-Flow Sampler is accurate (+/- 10%), intrinsically safe, efficient and cost effective.

Quantifying fugitive emissions allows personnel to understand the economic consequences of leaking and venting emissions thus enabling them to make educated repair and reduction decisions. Other methods of quantification that we employ are:

- Vane anemometer (Extech-AN100)
- Positive displacement meter

QUANTIFICATION DEVICE CALIBRATION

As per CAPP BMP record keeping and measurement requirements, GreenPath quantification devices will be calibrated according to legislative, manufacturers', or other written specification or requirements confirm the accuracy and that the devices are operating correctly.

FLOW METERS

GreenPath shall use measurement methods, maintenance practices and calibration methods prior to the first reporting year and in each subsequent reporting year using appropriate standards.

HIGH VOLUME SAMPLER

1. A technician following manufacturer instructions shall conduct measurements, including equipment manufacturer operating procedures and measurement methodologies relevant to using a high-volume sampler, positioning the instrument for complete capture of the fugitive equipment leaks without creating back pressure on the source.
2. If the high-volume sampler with all attachments available from the manufacturer is *not* able to capture emissions from the source, then use anti-static wraps or other aids to capture all emissions without violating operating requirements as provided in the instrument manufacturer's manual.
3. Estimate CH_4, CO_2 volumetric and mass emissions from volumetric natural gas emissions calculations.
4. Calibrate the instrument at 2.5% methane with 97.% air and 100 percent CH_4 by using calibrated gas samples and by following manufacturer's instructions for calibration.

COMPONENT TAGGING

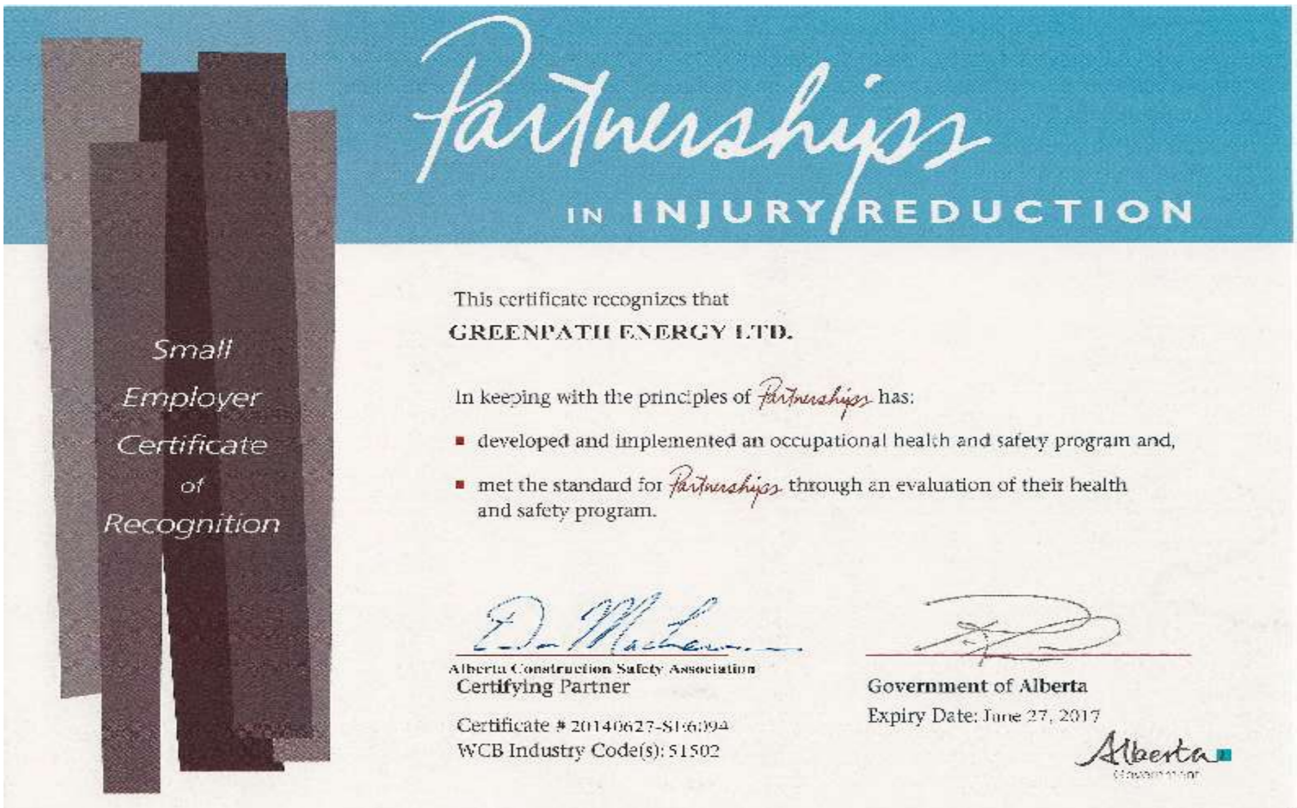
Detected fugitive emission sources at each facility are tagged with chemical resistant tags to aid with repair, reduction and identification actions. Each tag provides:

- Unique serial # for tracking emission source
- Detailed description of emission source
- Quantified flow rate
- Tracking for emission repairs and reduction attempts

Emission tags are attached as close as possible to the emission source. If it is not feasible to attach directly to the source, the tag is placed as close as possible in a location that is visible to facility personnel. These tags should remain in place even after repairs have been made for future tracking and facility inspections.

APPENDIX B: SAFETY

Safety is an important aspect of GreenPath Energy Ltd.'s field services work. We consider the health and safety of all employees, subcontractors and associated trades and individuals to be the prime consideration in carrying out our work. Our goal is to eliminate all accidents and injuries, both on and off the project site.



Partnerships IN INJURY REDUCTION

Small Employer Certificate of Recognition

This certificate recognizes that
GREENPATH ENERGY LTD.

In keeping with the principles of Partnerships has:

- developed and implemented an occupational health and safety program and,
- met the standard for Partnerships through an evaluation of their health and safety program.

Alberta Construction Safety Association
Certifying Partner

Certificate # 20140627-SI:6:394
WCB Industry Code(s): 51502

Government of Alberta
Expiry Date: June 27, 2017

Alberta

We believe that superior performance in health and safety can be achieved through the support and active participation of all employees. A variety of programs are in place to ensure the safety and welfare of workers and visitors on site.

GreenPath Energy Ltd. facilitates regular safety courses for employees. All fugitive emission inspections performed by GreenPath Energy Ltd. honor:

- Client\facility safety specific clearance requirements
- Municipal, provincial and federal health, safety and environmental regulations
- GreenPath Energy Ltd. safe operation procedures and practices.

APPENDIX C: ANONYMOUS DATA SET

Document attached in Excel (.xls) format.

APPENDIX D: REFERENCES

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