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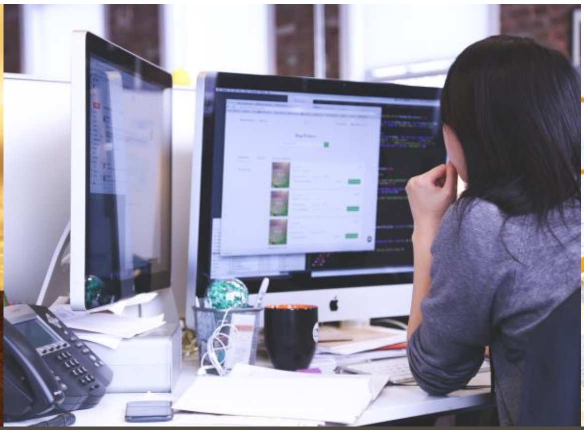
Pneumatic Inventory Study

March 2018


Cap-Op Energy Inc.
Suite 610, 600 6 Ave SW
Calgary, AB
T2P 0S5
403.457.1029
www.CapOpEnergy.com

Cap-Op Energy Pneumatic Inventory Study

Prepared for:	Submitted On:
Climate Policy Assurance Team	Thursday, March 29, 2018
Alberta Energy Regulator	

Executive Summary

Developing a better understanding of emissions from pneumatic devices in Western Canada is important to governments, regulators, NGO's, and industry alike. In 2013 and 2014, the Prasino Group and Cap-Op Energy Inc. (now, collectively, Cap-Op) conducted two studies on behalf of the British Columbia Climate Action Secretariat (BC CAS), the Canadian Association of Petroleum Producers (CAPP), and the Petroleum Technology Alliance of Canada (PTAC) concerning opportunities to reduce GHG emissions from Alberta upstream oil and gas assets. These influential studies were some of the first sources of information for understanding the methane emission profile of pneumatically operated control instruments and pumps (pneumatics, pneumatic devices) in Western Canada's upstream oil and gas industry.

Since then, Cap-Op has been actively campaigning for methane abatement in the oil and gas industry through the conversion of gas-powered pneumatic devices. In these efforts, Cap-Op drafted the Quantification Protocol for Greenhouse Gas Emission Reductions from Pneumatic Devices (published in 2017), and launched the Methane Abatement Project Platform (MAPP) in the same year as a cloud-based tool for leading oil and gas companies to inventory their pneumatic devices. Cap-Op has worked with these companies to quickly compile a dataset of more than 10,000 pneumatic device records and was engaged by the Alberta Energy Regulator (AER) to analyze these records. The aim of the study is to improve understanding around pneumatic emission profiles, including information gaps from prior pneumatic inventory studies, to support national and provincial methane reduction initiatives.

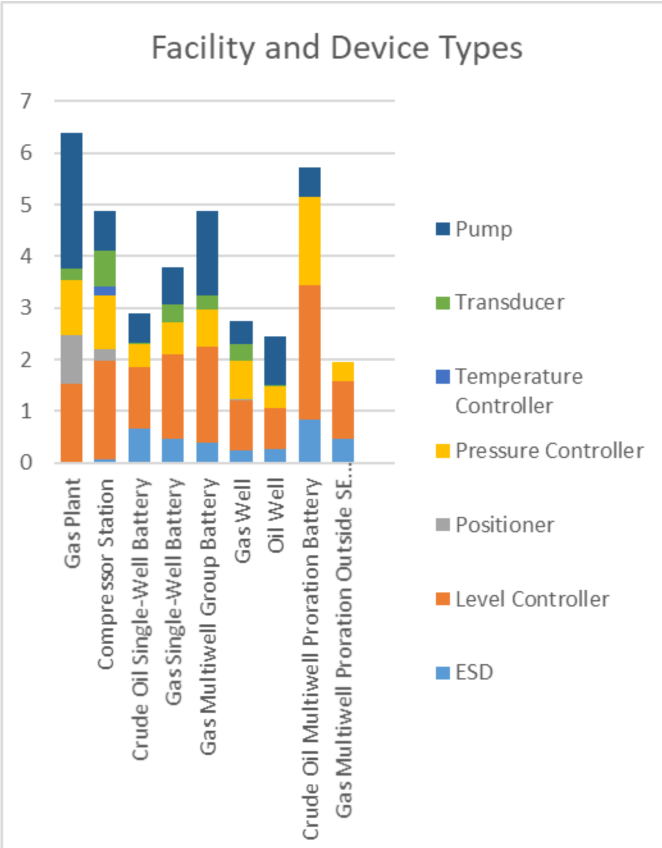
MAPP Dataset at a Glance

Total Device Records Included in Evaluation	10,037
Total Sites Represented	3,382
Control Instruments	8,176
Pumps	1,891
Total Liquid Produced by Facilities in Study (2016)	25,198,454 m^3 (3.3% of Province)

A literature review analysed the methodology and limitations of other pneumatic inventory studies conducted in North America, and included studies by the EPA in 1996, GreenPath studies in 2016 and 2017, The Prasino Group Study in 2013, and the University of Texas Studies in 2013 and 2014. In addition to the overall objective of providing additional depth of pneumatics information, three specific data gaps were identified:

1) **Large Facility Pneumatics**: Gas plant and compressor station pneumatic inventories.
2) **Level Control and Liquids Production**: Existence of level control instruments at wet and dry gas wells, in particular focused on understanding the population of level control instruments as a function of (and/or correlated to) liquids production.
3) **Make and Models**: Make and model functions and classification of device types in order to develop a more granular understanding within existing classification schemes.

The first data gap involved comparing the differences in control systems at large facilities such as gas plants and compressor stations with well sites and single-well batteries. The second data gap aimed to test the assumption that more level controllers would be present at sites that produced greater levels of liquids. The third data gap involved studying the major makes and models of pneumatic devices installed at sites to gain a better understanding of site configuration and functionality, especially emergency shutdown applications.



The MAPP Dataset was compiled and pre-processing methodologies were employed in order to address any inconsistent terminology and classification schemes. In addition, several data challenges were identified, including:

- the dataset contained inventory information from sites which had not been the subject of "exhaustive" data collection exercises, meaning site inventories were in some cases incomplete; and
- the dataset includes thousands of records that are intended to support carbon offset projects; meaning there is an inherent bias towards low-bleed or no-bleed pneumatic alternatives that may not represent the general population of pneumatics in Alberta.

After deploying mitigation approaches to resolve each challenge, the dataset was summarized and analysed both generally and against the specific gaps.

A wide variety of pneumatic device profiles was observed within each category of facility type, with Large Facilities typically having more total pneumatic devices, serving more applications, than wellsites and single-well batteries. Multiwell batteries appear to exhibit more similarity to gas plants and compressor stations than to single-well batteries in terms of their pneumatic device profile.

Although logical, correlation between liquids production and level controller populations was not observed. This may be a result of data challenges with regard to reporting and prorating liquids to individual wells, may have resulted from incomplete inventories, or may result from a combination of these and other factors.

In all, 175 models from 35 manufacturers were observed and classified according to similar functions and capabilities. When accounting for devices with the same or similar design from more than one manufacturer, the 19 most common models accounted for over 80% of the observed population while a single manufacturer (Fisher) accounted for nearly 75% of all control instruments observed. A relatively small set of just 4 models accounted for 97.5% of emergency shutdown (ESD) applications observed.

Nonetheless, further study and data will be required to build more robust emissions estimates. This includes collecting more and better inventory data from operators and analysing their information in a consistent manner. Ultimately, the only way to achieve an accurate pneumatic emissions inventory is to continue collecting inventory and measurement data and to combine these with robust estimation tools – such as predictive algorithms – which can serve both the accurate estimation and the cost-effective reduction of methane emissions from pneumatic devices.

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Glossary

- **Control Instrument:** Any device used for process control such as switches and controllers; predominantly includes the classifications emergency shutdown (ESD), pressure controller (includes pressure switch), level controller (includes level switch), positioner, temperature controller, and transducer.
- **Device Classification:** Pneumatic devices were classified according to types selected by the project team; emergency shutdown (ESD), pressure controllers, level controllers, positioners, temperature controllers, transducers, and pumps (further detail below).
- **Facility:** Any site/location may be considered a facility within this report, including wellsites.
- **Large Facility:** Refers to compressor stations and gas plants.
- **Non-Reporting Facility:** Refers to individual gas, crude oil or coal-bed methane (CBM) wells.
- **Pneumatics:** Refers to control instruments and pumps, including non-pneumatic (e.g. electric drive) equipment according to the classifications above.
- **Pump:** Any device used for chemical injection at wellsites, compressor stations, batteries or gas plants; no classification was employed in this report although the observed pump types include diaphragm positive displacement pumps and electric drive positive displacement pumps.
- **Reporting Facility:** Refers to a facility with a Reporting Facility ID from the AER.
- **Site Classification:** Sites, or facilities, were classified according to existing AER classification schemes including gas wells, oil wells, single well batteries, as further delineated in Appendix 1.1.

Background

Cap-Op Energy was engaged by the AER and authorized by its clients in the oil and gas industry to compile and analyze information about the inventory of pneumatic devices at sites across Alberta. As both a pneumatic project facilitator and offset project aggregator, Cap-Op is continually acquiring highly detailed pneumatic inventory information across Western Canada, with particular emphasis on Alberta. The dataset that Cap-Op has compiled is approximately one order of magnitude larger than any other known pneumatic inventory outside the US, and comprises a range of Operators, Licensees, and geographic regions in Western Canada. As a result of ongoing outreach, education, and proactive activities by oil and gas operators, Cap-Op's dataset continues to grow, becoming a valuable resource for understanding pneumatic emissions.

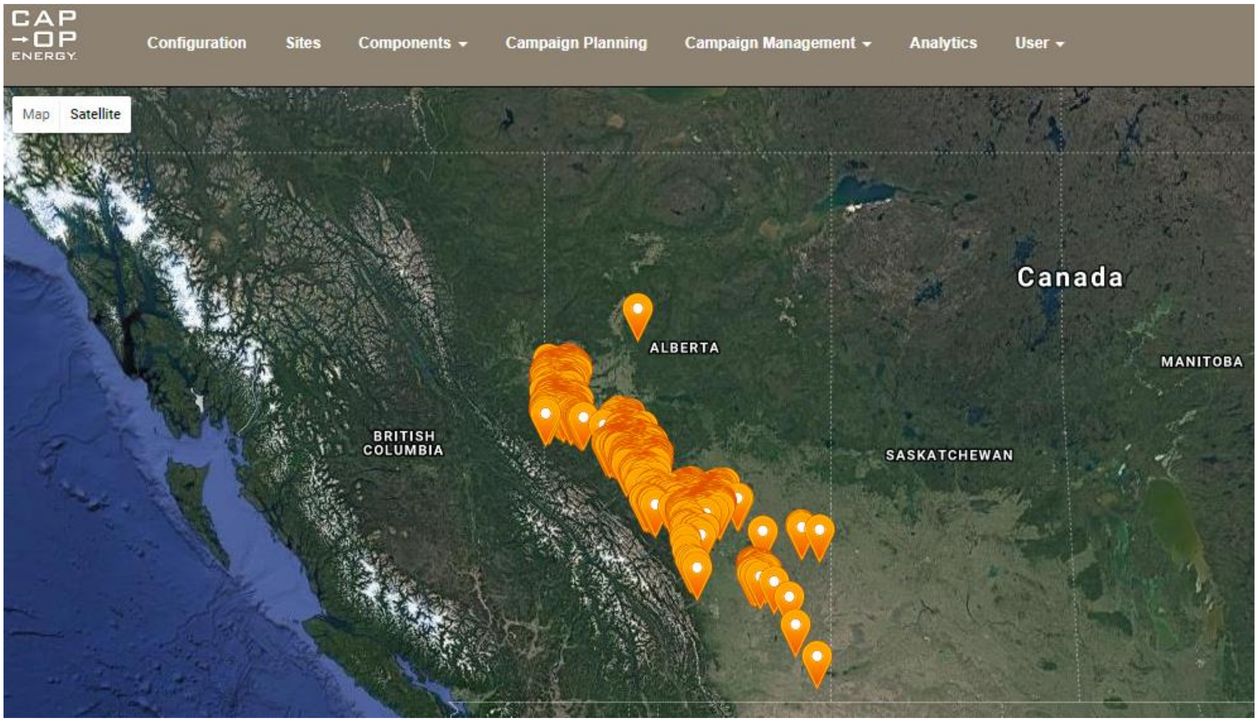

Figure 1: Screen capture of Cap-Op's Methane Abatement Project Platform (MAPP); geospatial view of dataset

The study applies Cap-Op and other industry personnel's expertise to the available dataset in order to inform the regulatory development process. Although a range of emissions estimates are available, regulators, industry and non-governmental organizations (NGOs) agree that pneumatics represent a material proportion of methane emission sources. Learnings from proactive industry-driven projects including Field GHG Emission Reductions[1] and draft regulations[2] released by Environment and Climate Change Canada (ECCC) suggest that addressing pneumatics could play a large part in achieving various policy targets – most notably, the 40-45% methane emission reduction from upstream oil and gas that is outlined in the North American Climate, Clean Energy and Environment Partnership[3] signed by the US, Mexico, and Canada and which is broadly aligned with Alberta's target under the Climate Leadership Plan.[4] Understanding pneumatic emission sources is an important technical question, and additional study is

[1] http://eralberta.ca/wp-content/uploads/2017/05/ConocoPhillips-Final-Report-July-29-2016.pdf
[2] http://www.gazette.gc.ca/rp-pr/p1/2017/2017-05-27/html/reg1-eng.php
[3] https://pm.gc.ca/eng/news/2016/06/29/leaders-statement-north-american-climate-clean-energy-and-environment-partnership
[4] https://www.alberta.ca/climate-methane-emissions.aspx

required. This study aims to communicate observations made from a sample that is still small relative to the total population of pneumatic devices.

Based on the size of the existing dataset, and according to prior work on pneumatic inventory data, three data gaps were identified and investigated:

1) Large Facility Pneumatics
2) Level Control and Liquids Production
3) Makes and Models

A brief literature review was conducted to understand the sources of existing data and analysis currently used by regulators and industry.

Pneumatic Device Inventory and Emissions – Literature Review

The first pneumatic inventory for estimating US GHG emissions was conducted in 1996 by the EPA,[5] where data from 28 companies was collected that included information on 7,000 pneumatic devices from over 11,000 gas wells and 3,000 oil wells. While the study focused on all methane sources across the oil and gas production industry and included wells without pneumatic devices, an average of 0.5 to 1.6 pneumatic controllers per well was calculated. The inventory collected also revealed that an estimated 65% of pneumatic controllers in the petroleum production segment were low-bleed and 35% are high-bleed. The 1996 study established EPA emission factors using average emissions from continuous bleed and intermittent natural gas-driven pneumatic controllers, which are still used for calculating total methane emissions today. The EPA applies a yearly discount factor to a calculated national methane inventory figure, determined by analysing voluntary emission reduction data submitted to the Natural Gas STAR Program.

More recently, work has focused on improving the understanding of both the number and type of pneumatic devices, the emissions from these devices, and the geographic variability of each. Beginning in 2013 with The Prasino Group (now Cap-Op Energy), field work and analysis of Western Canadian oil and gas operations has sought to provide relevant information for regulators and industry to better estimate and reduce emissions from pneumatics. Table 2 summarizes the more recent efforts to develop a robust national inventory of methane emissions from pneumatic devices at oil and gas sites and outlines some of the differences between these efforts and this study.

GreenPath Alberta Fugitive and Vented Emissions Inventory Study (2017)

The GreenPath Alberta Fugitive and Vented Emissions Inventory Study (GreenPath Study)[6] took place in 2016/2017, commissioned by the Alberta Energy Regulator (AER). A total of 395 distinct facilities with 676 oil and gas wells were inspected by qualified emission technologists and AER staff inspectors over six geographical areas including Grand Prairie, Drayton Valley, Red Deer, Medicine Hat, Midnapore, and Bonnyville.[7] The GreenPath Study involved the collection of equipment inventories and the qualitative detection of methane leaks and vents via optical gas imaging (OPI) at various locations. A total of 1,688 pneumatic devices were inventoried in a survey of 397 oil and gas wells[8] (1,218 controller and 469 pumps). Of the total devices, 1,608 were natural gas powered, 59 were electric, 20 were instrument air and one was propane powered. Pneumatic controllers by function were according to the table below.

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[5] https://www.epa.gov/sites/production/files/2015-12/documents/ng-petro-inv-improvement-pneumatic-controllers-4-10-2015.pdf

[6] http://www.greenpathenergy.com/wp-content/uploads/2017/03/GreenPath-AER-Field-Survey-Results_March8_Final_JG.pdf

[7] ttp://www.greenpathenergy.com/wp-content/uploads/2017/03/GreenPath-AER-Field-Survey-Results_March8_Final_JG.pdf - page 2

[8] Only 397 of 676 total wells visited were represented in the pneumatics dataset because the Bonnyville area was excluded from pneumatic device inventory work.

Table 1: Pneumatic Controls by Function from GreenPath Study

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%	41.4%	2.0%	1.8%	17.4%	0.9%	9.4%

To determine total emissions from pneumatic instrumentation, the make and model data from each pneumatic device was mapped to the appropriate emission factor from the 2013 Prasino Study (see below). All devices were assumed to operate 365 days a year, with 182 days for chemical injection pumps, which were assumed to operate seasonally. A methane content of 90% in fuel gas was assumed. A weighted average of 5.69 tCH_4 of emissions per well from pneumatic devices was calculated, putting the total emissions at 489,951 tCH_4 across all wells in Alberta in 2013.

GreenPath Modelling Inputs for Upstream Oil and Gas Methane Emission Sources (2016)

The GreenPath Modelling Inputs for Upstream Oil and Gas Methane Emission Sources[9] study was completed in 2016 and was commissioned by Environment and Climate Change Canada (ECCC). The study aimed to provide ECCC with inputs to model methane emissions from pneumatic devices in the Canadian upstream oil and gas industry, using data sets from British Columbia and Alberta. Data included field surveys to compare results of optical gas imaging detection versus readings in field settings, expert opinions to develop count estimates and observations on current fugitive emission management practices. For pneumatic controllers, the study built a matrix that analyzed the type of device: level controller, pressure controller, transducer, positioner, hi-level switch, pressure pilot, temperature controller – against the facility type: compressor station, gas plant (sweet), metering station, multi-well battery, multi-well prorated battery, satellite battery, and single-well battery. Chemical injection pump counts were analyzed along a similar matrix of facility types.[10]

The Prasino Group – Determining Bleed Rates for Pneumatic Devices in British Columbia (2013)

The Prasino Group (now Cap-Op Energy) conducted a study in 2013 for the BC Climate Action Secretariat (BC CAS)[11] to determine bleed rates for a suite of common pneumatic controllers and pumps. Bleed rates were sampled from pneumatic devices using a positive displacement bellows meter at upstream oil and gas facilities across a variety of producing fields in the Fort St. John, BC and surrounding areas. The results of the study led to the development of three generic bleed rates and twenty specific bleed rates for common pneumatic controllers and pumps. On average, the rate for high-bleed and intermittent controllers were lower than the EPA default. However, the average rate for low-bleed controllers and pumps were both higher than the EPA default. The differences in bleed rates, according to the report may have been attributed to field conditions compared to steady-state air consumption in a lab setting observed by the manufacturer, as well as potential limitations of measurement equipment. The figures from the Prasino study were integrated into the Western Climate Initiative Addendum to Canadian Harmonization.[12]

University of Texas - Measurements of Methane Emissions at Natural Gas Production Sites in the US (2013)

The University of Texas conducted a study in 2013 on methane emissions at natural gas production sites in the US.[13] The study focused on oil and gas wells and separation facilities with samples taken from the Gulf Coast, Appalachian, Rocky Mountain, and Midcontinent regions. Measurements were directly taken at the emission point and included pneumatic controllers and pumps. For wells in routine operation, emissions

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[9] Not publicly available; the report was provided to Cap-Op for review.

[10] Control instruments and pumps summarized on pages 14 and 18, respectively.

[11] http://www.bcogris.ca/sites/default/files/ei-2014-01-final-report20140131.pdf

[12] https://www2.gov.bc.ca/assets/gov/environment/climate-change/ind/quantification/wci-2013.pdf

[13] https://www.ncbi.nlm.nih.gov/pmc/articles/PMC3816463/

from pneumatic controllers were found to be higher than EPA national emission projections, about 29% higher for intermittent and 270% higher for low-bleed. Emissions per pump were within 10% of emissions estimated using EPA factors. In extrapolating the data collected, it was found that emissions from pneumatic devices were 70% higher than the current EPA net emission estimates at the time.

University of Texas – Methane Emissions from Process Equipment at Natural Gas Production Sites in the US: Pneumatic Controllers (2014)

The University of Texas in 2014 conducted another study on methane emissions from the process equipment at natural gas production sites in the US that was focused on pneumatic controllers.[14] The goal of the study was to directly measure emissions from pneumatic controllers across a wider population of wells, geographically distributed across the US. Emission measurement methods included the primary supply line measurement and the secondary/QC exhaust measurement. 400 measurements were taken from 377 unique devices across the US, with a split of 85% intermittent vent controllers and 15% continuous vent controllers. The study found that a small subset of devices, level controllers on separators and compressors, dominated the majority of total emissions, but that average emissions across all devices were comparable to EPA emission factors. 19% of devices with emissions higher than 6 scf/h accounted for 95% of all emissions.[15] The study also found that the average number of controllers at a well site was 2.7, which is higher than the EPA average at 1.0.

Table 2: Summary Table of Studies Conducted to Date on Emissions from Pneumatic Devices

Study and Year Completed	Methodology	Differences Relative to Current Study
GreenPath - Alberta Fugitive and Vented Emissions Inventory Study, 2015	In-field inspection of over 395 distinct facilities from five regions in Alberta, taking an inventory of equipment and using emission factors to calculate total emissions	The study calculated a total inventory of methane emissions including non-pneumatic sources, and employed assumptions regarding emission factors, operating hours and gas composition.
GreenPath – Modelling Inputs for Upstream Oil and Gas Methane Emission Sources, 2016	Expert interviews, some in-field data collection and inventory analysis to determine national inventory model inputs	Uncertainty as to the source of the data used (reference to expert interviews, field experience, and other qualitative sources).
Prasino Group – Determining Bleed Rates for Pneumatic Devices in British Columbia, 2013	In-field sampling of pneumatic devices to observe bleed-rates and determine the average bleed rate of pneumatic pumps and controllers operating under field conditions	The study measured the bleed rates of pneumatic devices, but did not address building an inventory of devices, or to predict the total emissions from pneumatic instrumentation.
University of Texas - Measurements of Methane Emissions at Natural Gas Production Sites in the US, 2013	Direct sampling of emissions from pneumatic controllers and pumps (305 sites) to compare actual emissions to EPA published figures	The study measured the bleed rates of pneumatic devices but did not differentiate between make and models or build an inventory of devices/emissions. Only US sourced data.

[14] http://pubs.acs.org/doi/pdf/10.1021/es5040156
[15] Page 636

University of Texas – Methane Emissions from Process Equipment at Natural Gas Production Sites in the US: Pneumatic Controllers, 2014	In-field measurement of pneumatic controllers at numerous well sites across geographies in the US. 400 measurements from 377 unique devices were taken	Only US well sites were included in the study. The study did not develop a national inventory, its purpose was to determine the validity of the emission factors calculated in the EPA 1996 study.

Objectives

The overall objective of the study was to provide a pneumatic inventory data summary to supplement current inventory numbers, presented as control instrument and pump counts by device type and by facility type. To support this objective, the study included characterization of the dataset to generate learnings and questions for further study. In addition to this objective, priority data gaps were identified and selected based on availability of sufficient data to support analysis of these gaps. The three priority data gaps are:

1) Large Facility Pneumatics: Gas plant and compressor station pneumatic inventories.
2) Level Control and Liquids Production: Existence of level control instruments at wet and dry gas wells, in particular focused on understanding the population of level control instruments as a function of (or correlated to) liquids production.
3) Make and Models: Make and model functions and classification of device types in order to develop a more granular understanding within existing classification schemes.

Further detail on each of these Data Gaps is provided below.

Gap #1: Large Facility Pneumatics

Control systems at very large oil and gas processing facilities are typically designed to be electrically operated or, if pneumatic, to be driven by compressed air. The importance of inventory information is considerably lower in these cases since these control systems do not directly vent methane. Instrument gas, or fuel gas, is more commonly employed at wellsites, single-well batteries, and multi-well batteries. Large Facilities may exhibit greater diversity in their control systems as a result of the different sizes, vintages, and functions of compressor stations and gas plants.

The dataset included the following quantities of Large Facilities and logged devices (Table 3). The sample size was assessed to be large enough to draw meaningful conclusions although additional samples would improve these conclusions especially for small gas processing facilities.

Table 3: Large Facilities included in the dataset

Facility Type	Number of Sites	Number of Devices
Gas Plants	13	83
Compressor Stations	144	717

Gap #2: Level Control and Liquids Production

Level control instruments are often used to control oil, condensate, water, or combinations thereof. It stands to reason that the more liquids (volume, or number of different liquids) that are produced, the more level control instruments would be observed. However, analyzing this correlation is not straightforward since level control instruments may be required at sites that do not report their liquid production directly, or may exist at sites that no longer produce liquids. In order to investigate the potential correlation between level control instruments and liquids production, it is required to estimate the liquid production (or at least presence of liquids) for as many sites as possible. The distinction between “wet” and “dry” gas wells is of particular interest in order to better understand variability in the presence of level control instruments at wellsites.

Liquids production figures are summarized in the AER's ST-60 report (2016 production for the studied facilities is summarized in Figure 2). Using additional information supplied by AER, Cap-Op was able to correlate downhole and/or surface locations with the Reporting Facility ID, for both wells and Reporting Facilities. Since liquids production was not available at the well level, this correlation provided a relatively direct insight into the liquids production of the batteries through which these wells report their fluid volumes en route to market. It is recognized that it is possible that an individual well does not produce liquids but reports its dry gas to a multi-well battery which accepts wet gas from another well, but this was deemed an acceptable data limitation for the purposes of this study.

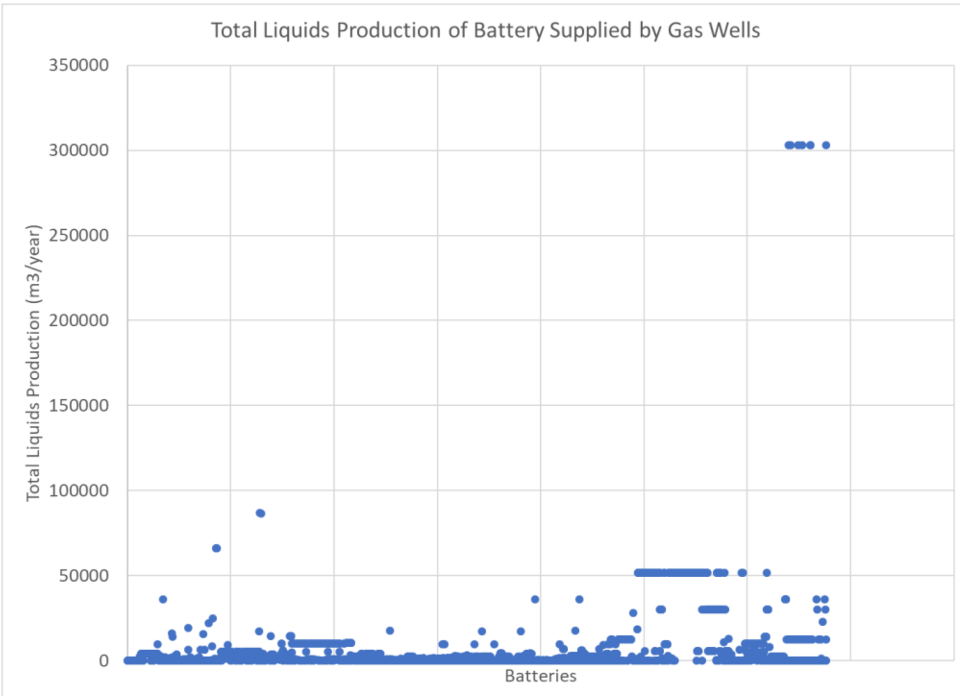


Figure 2: Annual liquid production (2016) of batteries supplied by studied gas wells

Gap #3: Makes and Models

As a technology-driven industry, the oil and gas sector employs a large percentage of engineers and other highly technical staff capable of devising a diversity of control system designs. Creativity in the design of control systems is common, and a single model of pneumatic control instrument model may be used in different contexts for different functions. Some instruments are capable of performing different functions depending on the configuration of other connected equipment. In order to better understand the pneumatic population demographics within a device classification scheme it is necessary to analyze the observed functionality across a range of installations.

Data

Data Collection

Cap-Op has been accumulating a pneumatic dataset since first developing our in-field data collection application, MAPP-Inventory, for the Prasino Group study referenced above. The January 2017 release of the *Quantification Protocol for Greenhouse Gas Emission Reductions from Pneumatic Devices*, and release of the draft *Regulations Respecting Reduction in the Release of Methane and Certain Volatile Organic Compounds (Upstream Oil and Gas Sector)* in Canada Gazette 1 (CG1) later in the same year highlighted the value of collecting pneumatic inventories. As a result, there has been a significant increase in pneumatic inventory data collection activities by industry – using both Cap-Op's tool and other methods – and Cap-Op has compiled many of these data into a single database. This database underpins the MAPP-Campaign software platform. A visual representation of the dataset is provided in Figure 1.

As a result of the carbon offset opportunity or for other reasons, some operators have targeted inventory activities towards certain device types. Others have acquired relatively complete inventories of all pneumatic devices, either in preparation for regulatory requirements outlined in CG1, to maximize the efficiency of travel time or for other operational reasons. The device types that would be targeted for offset projects include level control instruments, pressure control instruments, transducers and pumps. It is believed that this coincides with the most common device types based on analysis by others.

Data which were not gathered using the MAPP-Inventory application generally required additional processing by Cap-Op personnel in order to be useful to the analysis. Industry standard practices, as well as data-specific methodologies outlined in **Appendix 1.1 Data Pre-Processing and Equivalency Mapping,** were employed to pre-process the data.

Results

The number of facilities of each type that were included in the study are outlined in Table 4:

Table 4: Total facilities observed by facility type

Facility Types	# of Facility Type
Gas Plant	13
Compressor Station	146
Crude Oil Single-Well Battery	78
Gas Single-Well Battery	167
Gas Multiwell Group Battery	108
Gas Well	2628
Oil Well	189
Crude Oil Multiwell Proration Battery	25
Gas Multiwell Proration Outside SE Alberta Battery	28
Total	**3382**

Table 5 and Table 6 provide a summary of the dataset in terms of the observed total devices and observed average devices per facility across each device type and facility type observed.

Table 5: Total devices by type and facility type

Facility Types	ESD	Level Control	Positioner	Pressure Control	Temperature Control	Transducer	Pump
Gas Plant	0	20	12	14	0	3	34
Compressor Station	11	276	35	152	25	100	113
Crude Oil Single-Well Battery	51	93	0	36	0	2	43
Gas Single-Well Battery	76	274	1	102	0	58	121

Gas Multiwell Group Battery	42	202	0	77	0	29	177
Gas Well	616	2552	77	1930	0	842	1178
Oil Well	51	150	0	78	0	5	181
Crude Oil Multiwell Proration Battery	21	65	0	43	0	0	14
Gas Multiwell Proration Outside SE Alberta Battery	13	31	0	11	0	0	0
Total	**881**	**3663**	**125**	**2443**	**25**	**1039**	**1861**

Table 6: Devices per facility by type and facility type

Facility Types	ESD	Level Control	Positioner	Pressure Control	Temperature Control	Transducer	Pump
Gas Plant	0.00	1.54	0.92	1.08	0.00	0.23	2.62
Compressor Station	0.08	1.89	0.24	1.04	0.17	0.68	0.77
Crude Oil Single-Well Battery	0.65	1.19	0.00	0.46	0.00	0.03	0.55
Gas Single-Well Battery	0.46	1.64	0.01	0.61	0.00	0.35	0.72
Gas Multiwell Group Battery	0.39	1.87	0.00	0.71	0.00	0.27	1.64
Gas Well	0.23	0.97	0.03	0.73	0.00	0.32	0.45
Oil Well	0.27	0.79	0.00	0.41	0.00	0.03	0.96
Crude Oil Multiwell Proration Battery	0.84	2.60	0.00	1.72	0.00	0.00	0.56
Gas Multiwell Proration Outside SE Alberta Battery	0.46	1.11	0.00	0.39	0.00	0.00	0.00
Average	**0.376**	**1.512**	**0.133**	**0.796**	**0.019**	**0.212**	**0.919**

The dataset was observed to contain 175 distinct models across 35 separate manufacturers. Individual models were observed to be associated with more than one manufacturer; especially the more popular models that become standardized over time. In order to evaluate the models and model-equivalents, the manufacturer was ignored, and some similar models were grouped together as further outlined in **Gap #3 – Make and Model Classification** Analysis.

Table 7 presents the 10 most common makes and models and number of control instruments observed of each. Note that the models do not (necessarily) correspond to the manufacturers listed as each were analyzed separately. Pumps were also analyzed separately.

Table 7: The 10 most common manufacturer names and model names observed (control instruments only)

Manufacturer Name	Number of Devices	Model Name	Number of Devices
Fisher	6241	L2	2123
Norriseal	666	4150	1424
SOR	520	i2P-100	895
CVS	368	4660	807
Murphy	136	1001A	642
Dyna-Flo	131	546	584
Samson	98	1530	516
Fairchild	63	2680A	367
Wellmark	39	C1	242
Arico	35	L1200N	136

The most common functions associated with each model of control instrument observed is addressed in further detail in Gap #3 – Make and Model Classification Analysis. The following table outlines the primary function observed for the 10 most common devices:

Model Name	Primary Observed Function/Classification
L2	Level Controller
4150	Pressure Controller
i2P-100	Transducer
4660	ESD
1001A	Level Controller
546	Pressure Controller
1530	ESD
2680A	Level Controller
C1	Pressure Controller
L1200N	Level Controller

None of the most commonly models were classified as temperature controllers or positioners.

Pumps were observed to exhibit considerably less variability although data input issues were more prevalent. Over 70% of the pumps observed were manufactured by Morgan, Bruin, Texsteam, or Williams. Part numbers, serial numbers, and other non-model information provided in the "model" field prevented in-depth analysis of pump models. The majority of pumps for which model numbers were observed were deemed equivalent to the industry standard 5100 series, while the remaining models indicated Williams P125, P250 and P500 models in approximately equal proportions.

Analysis

Data Challenges and Mitigation Strategies

A variety of challenges were identified both prior to and during the study. The project team discussed each of these and determined suitable and feasible mitigation strategies to deal with the challenges.

Incomplete Inventory Activities

Due to the diversity of contexts under which Cap-Op obtained the data – for example, only control instruments from one operator, and only pumps from another – it is acknowledged that not every site in the dataset had been exhaustively inventoried.

Mitigation: While incomplete inventory activities may suggest that extrapolating will underestimate the total number of devices, some wells in certain regions are known to not require any control instruments. Therefore any inventory based on device counts that does not explicitly observe (and include) zero-device sites could result in overestimating the total number of devices.

One operator in particular was known to have developed exhaustive inventories; these were reviewed in isolation in order to confirm that overall results were representative. The proportions of different types of control instruments may reflect operating philosophies and design standards of different producers, but the overall number of devices per site should indicate at least directionally the extent to which the overall dataset is complete. This operator's inventory, comprising only the facility types listed in Table 8, was found to include an average of 32% more total devices.

Table 8: Comparison of exhaustive inventory to overall dataset for four available facility types

Facility Type	Total Average Pneumatic Devices Per Site Relative to Overall Dataset
Compressor Station	+20%
Gas Single-Well Battery	+41%
Gas Multiwell Group Battery	+32%
Gas Well	+33%

Three scenarios were also developed to remove outliers ("trim the tails") and compare subsets of the overall dataset to further assess representativeness. These scenarios can also help to better understand how device profiles may change at sites with more devices, or minimum numbers of certain device types. Additional detail on scenarios are detailed in **Appendix 1.2 Scenario Analysis**.

The exhaustive inventory was +/- 15% of the first two scenarios investigated.

Site and Device Classification Challenges

Cap-Op site classification and control instrument classification categories were not identical to the client's requested categorization. Cap-Op takes in data in varying formats, and even our standardized MAPP-Inventory data collection tool allows users to input text fields ("Other") where the appropriate option does not exist in a drop-down menu. The list is reviewed periodically and "Other" classifications are added to the drop-down options, where applicable. Cap-Op also distinguishes between different types of pumps which was not deemed necessary for this study.

Mitigation: data-mapping techniques were applied to re-classify existing data (control instruments), and publicly available data was supplied by the AER in order to apply lookup techniques (sites). Records of different types of chemical injection pumps were simply re-labeled generically as pumps. Cap-Op facility classifications were grouped to align with Petrinex sub-type facility classifications used by the AER. Additional details are presented in **Appendix 1.1 Data Pre-Processing and Equivalency Mapping**.

Bias Towards Executed Offset Projects

Cap-Op datasets are inherently biased towards high-to-low bleed and high-to-no bleed conversion projects which are eligible for emission offsets under the Alberta Offset System. In order to conduct quantification and verification of these projects, detailed information is required to be collected on both Baseline (pre-project) and Project (post-project) conditions.

Mitigation: Baseline information was used for the analysis exclusively, disregarding any conversions to no- or low-bleed equipment. Indicative information regarding known and estimated conversion projects was provided for illustrative purposes only (see **Known Abatement Activities**). Further, as above, the overall dataset was compared to a subset of inventory information which was known to have been complete.

Gap #1 – Large Facility Pneumatic Counts Analysis

As with prior studies, the majority of pneumatic inventory information was from wellsites. Most of the facilities in Alberta are non-reporting facilities, e.g. wellsites, which is consistent with the profile of studied sites. Further, most of the wells in the dataset produced gas. This is consistent with the overall set of non-abandoned wells in Alberta, although this may also be an artifact of the data sources and intended use cases.

Table 9: Number of Large Facilities observed in dataset

Facility Types	# of Facility Type
Gas Plant	13
Compressor Station	144

As was expected, Large Facilities were observed with higher numbers of total pneumatic devices as well as higher numbers of distinct types of pneumatic devices. There are more total pneumatic devices, serving more applications, at Large Facilities than at Wellsites and Single-Well Batteries. The distinction between Multiwell Batteries (both Gas and Oil) relative to Compressor Stations and Gas Plants is less clear. In fact, Crude Oil Multiwell Proration Batteries were observed to have the second highest number of pneumatic devices overall (especially level controllers). This may be a result of the difficulty in defining a facility which has compression, and/or gas processing equipment, and which may also accumulate gas and/or liquids from multiple wells, as a single facility type. While documents such as AER Manual 011[16] contain guidance on defining and classifying different facility types, ultimately facilities are designed based on the needs of the operation and so may have a variety of equipment types on site.

Table 10: Large Facilities relative to wells and single-well batteries, and multiwell batteries (devices per site)

Facility Types	ESD	Level Control	Positioner	Pressure Control	Temperature Control	Transducer	Pump
Gas Plant	0.00	1.54	0.92	1.08	0.00	0.23	2.62
Compressor Station	0.08	1.89	0.24	1.04	0.17	0.68	0.77
Wellsites and Single-Well Batteries	0.26	1.00	0.03	0.70	0.00	0.30	0.50
Multiwell Batteries	0.47	1.85	0.00	0.81	0.00	0.18	1.19

[16] http://www.aer.ca/documents/manuals/Manual011.pdf

Large Facilities were not found to have the highest proportion of ESD applications. Since the operation of these facilities may interact with a larger number of upstream and downstream facilities it may seem logical that they would require additional emergency controls to deal with upstream variability and to ensure that process upset conditions do not propagate through a larger downstream system. While there are likely ESD devices at almost every facility, these may not have been classified this way and/or may not have been included in the inventory (for example, they may not be pneumatic devices).

Gap #2 – Level Control and Liquid Production Analysis

The first step involved in Gap #2 was to determine an appropriate threshold for what constitutes a "Wet" or "Dry" Gas Well. Considering the battery was used as a proxy for well-level liquids production, it is not a given that any amount of liquid was generated specifically from the well. Various thresholds were investigated to determine the impact on the classification:

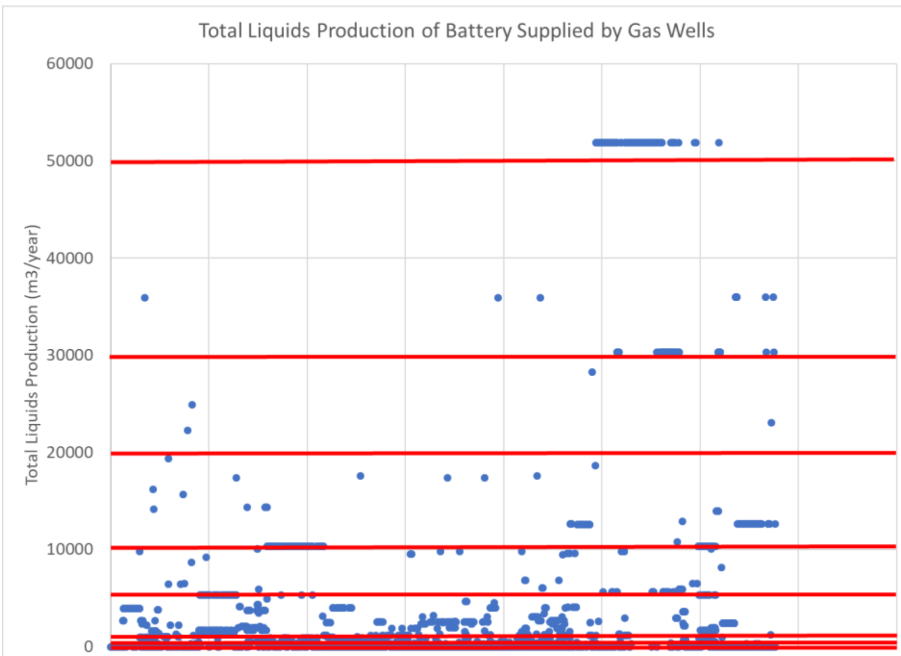


Figure 3: Annual liquid production (2016) of batteries supplied by studied gas wells (outliers removed); liquids production thresholds investigated for classification of "wet" or "dry" (red lines)

Naturally, as the threshold was decreased, more wells were classified as wet; using a liquids production threshold of 0m3/year (meaning any amount of liquids production from the battery) approximately 74% of gas wells studied would be classified as wet.

Since the threshold carried a significant impact, a goal-seeking algorithm was employed in order to find the approximate mid-point where half of the gas wells would be classified as wet and half as dry. This turned

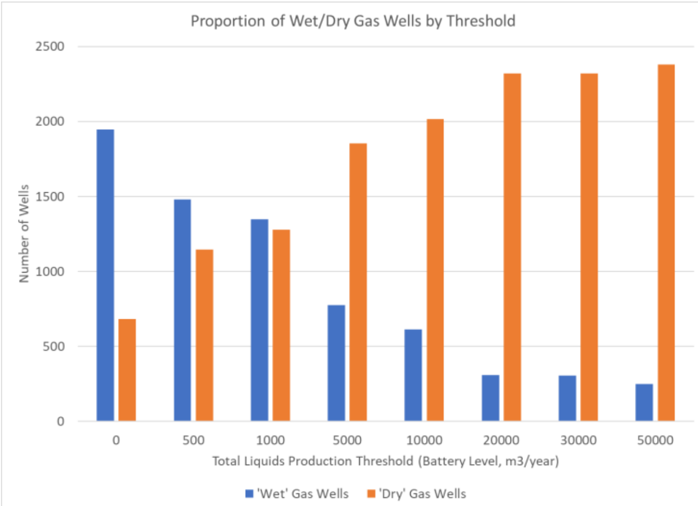


Figure 4: Wet/dry gas wells at different thresholds of minimum annual liquid production. Further detail in Appendix 1.3.

out to be approximately 1000 m^3/year. This would provide the maximum number of records to each classification (over 1,000 sites each).

However, the average number of level control instruments per site was not observed to be higher for the 'wet' gas wells than the 'dry' gas wells in any of the scenarios.

The number of liquids, as opposed to the volume, was also investigated as a method for characterizing gas well production. Both were found to have no observable correlation within the dataset, regardless of the threshold for site classification. In fact, most of the analyses showed a negative correlation between the volume of liquids produced and the number of level controllers, and all showed a negative correlation between the number of liquids reported and the number of level controllers. This is not a logical result, although a number of factors could complicate the analysis, such as:

1. Snapshot: liquids production was only investigated for a single year (2016) due to time, data, and scope constraints. Wells which historically produced liquids (and were therefore designed to handle them) but which had "dried up" may not have been indicated as liquids-rich wells as a result of this factor. A variety of other challenges may be introduced by this temporal limitation.
2. Battery-level Liquids Reporting: liquids production is only reported at the battery and so it is impossible to distinguish dry gas wells supply batteries that are also served by liquids-rich wells from actual liquids-rich wells. It is burdensome, and may be technically infeasible, to report liquids at the well-level and so the only way to manage this factor would be larger datasets or more complete information.
3. Incomplete Inventories: (see **Data Challenges and Mitigation Strategies**)
4. Facility Design: level control instruments may be installed in case of slugs of wet gas from otherwise dry gas, and/or standard equipment packages may be deployed across facilities within operating regions despite different reservoir characteristics.

Analyzing all sites in the dataset, there was no observed strong correlation for any device types with liquids production or number of liquids produced. The highest observed correlation with liquid volume was for Transducers (0.6) which is neither statistically significant nor even necessarily logical. Although this was greater than any observed correlation between device types (for example, at sites reporting greater than 1,000 m^3 of total liquids for 2016 where at least 1 level controller was observed, existence of Positioners and Pumps were correlated at 0.52). Correlation results and configurations for four scenarios are compiled in **Appendix 1.4 Correlation and Regression Results.**

Non-linear correlations were investigated visually and using Excel trendlines (logarithmic, up to polynomial order 6) and regression tools. As illustrated below there was no apparent correlation between with liquids production volume or number of liquids (maximum observed R^2 was 0.2). Many sites with observed liquids production were not observed to have level control instruments. This is assumed to be an artifact of incomplete inventories. The topic requires further study.

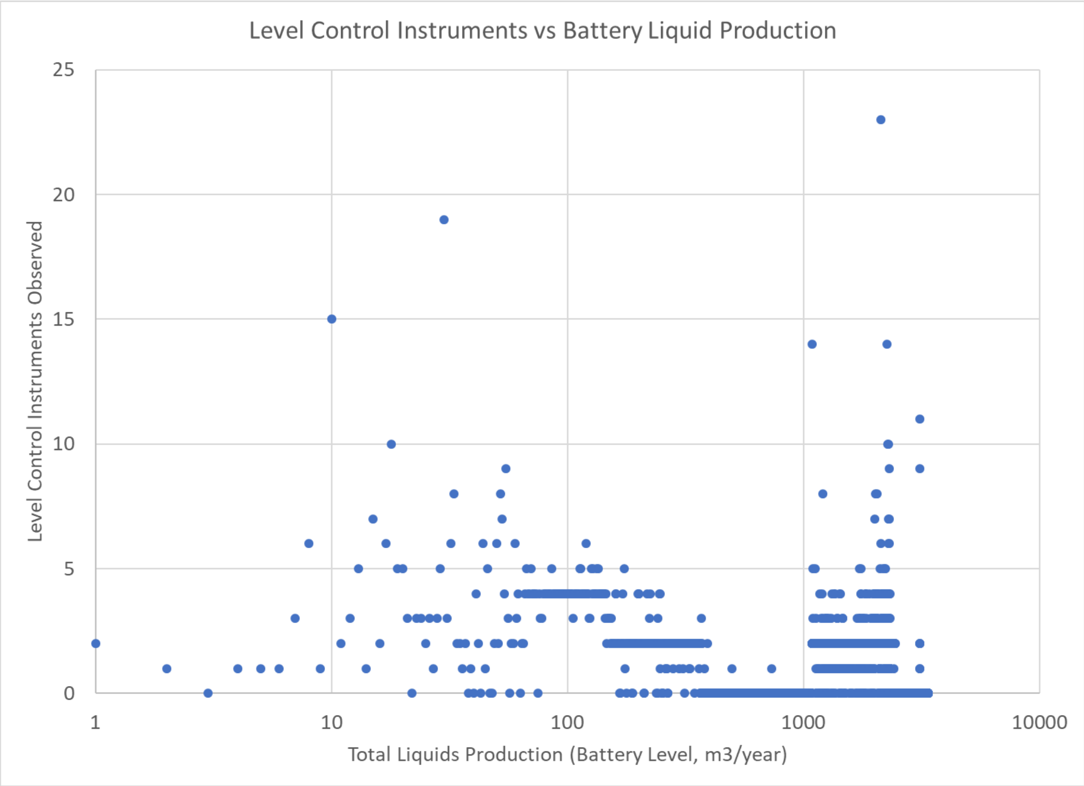


Figure 5: No correlation between volume of liquid produced in 2016 and number of observed level control instruments

Gap #3 – Make and Model Classification Analysis

All Cap-Op data includes make and model information, and encourages the use of drop-down menus for data validation as it is entered. However, the option for "other" entries always remains and, since many of the data investigated were not acquired using the MAPP-Inventory software, a vast range of different makes and models can be observed – 35 makes and 175 models.

Over the years, popular models of pneumatic devices have been replicated or re-branded by different vendors and manufacturers. Even original equipment manufacturers have modified these industry-standard models to add flexibility or functionality to them. Disregarding the make of a given device can reduce the number of combinations analyzed considerably; for example, Cap-Op evaluated the Fisher 4150 and CVS 4150 as equivalent since they are designed to be functionally equivalent. Device equivalency was further evaluated within similar models in order to produce a more focused evaluation. Cap-Op has consulted industry experts and publications such as the *Quantification Protocol for Greenhouse Gas Emission Reductions from Pneumatic Devices* to better understand device equivalency and end use cases although this is an area of potential further study.

As alluded to above, the manufacturers were ignored in order to minimize the vast number of permutations for make/model that needed to be analyzed. Further, similar models were combined where logical based on known device equivalency relationships. Once combined, the most common 19 models were observed to represent over 80% of the total device records in the dataset. The top 5 devices represent more than half the sample set.

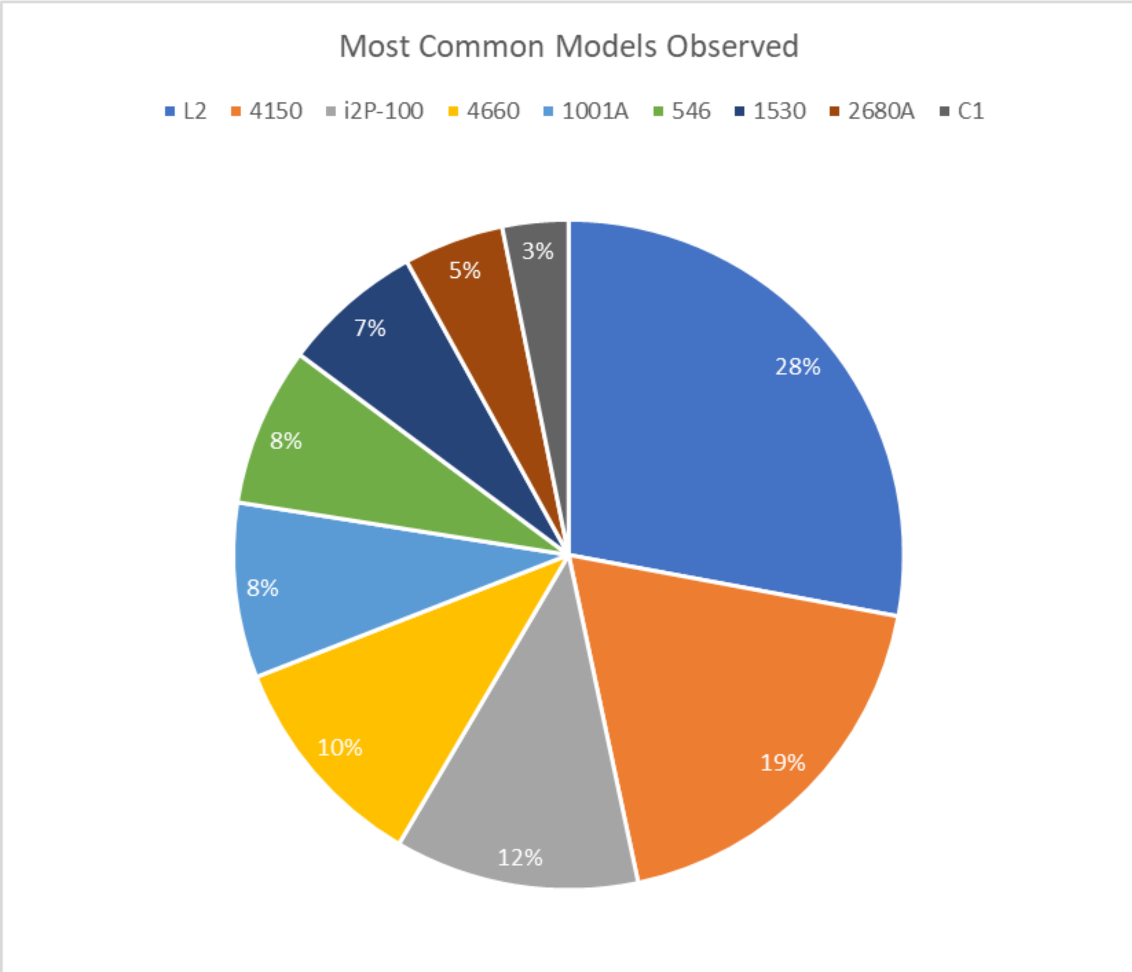


Figure 6: Proportions of the dataset represented by the most common models observed

These models perform a variety of functions, typically dedicated to the control of process parameters - pressure, level, or temperature – or pumping of chemicals. It is believed that some devices were incorrectly categorized by operators, although Cap-Op did not analyze every potential control design exhaustively and this may warrant further study. One objective of Gap #3 was to delineate which make/model combinations could be used in ESD situations. Both the full list and the shortened list were analyzed for multi-functions and ESD, which tended to be observed together once removing outliers (e.g. single data points that were classified as ESD). This can be explained by the fact that ESD is itself a subset of the other functions observed (e.g. high pressure shutdown or high level shutdown applications are also pressure and level applications, respectively).

This analysis was executed by evaluating the proportion of each model that was classified under each device type and calculating the maximum observed percentage. For a device that can only operate as a single function, the maximum percentage would always be 100%. Lower maximum percentages indicate “multi-function” or “multi-application” devices. Often, but not always, this indicated that the device had been classified as ESD and also a control instrument for one process parameter. In some cases more than one process control parameter was indicated. Further research is recommended in order to better document device equivalency and to understand whether additional operator education is required for accurate inventories.

Pumps were excluded from the analysis for Gap #3.

Table 11: Common models and their observed applications/functions

Model	Primary Observed Function/Classification	Secondary Observed Function/Classification	Manufacturer Description
L2	Level Controller	ESD	Liquid Level Controller
4150	Pressure Controller	Level Controller (N/A)	Pressure Controller
i2P-100	Transducer	Pressure Controller	Electro-pneumatic Transducer
4660	ESD	Pressure Controller	Pneumatic Hi-Lo Pressure Pilot
1001A	Level Controller	N/A	Liquid Level Controller
546	Pressure Controller	Transducer	Transducer
1530	ESD	Transducer/Level Controller	Level Switch
2680A	Level Controller	ESD	Liquid Level Controller
C1	Pressure Controller	Level Controller	Pneumatic Controller and Transmitter
L1200N	Level Controller	Transducer	Liquid Level Switch
2900	Level Controller	N/A	Level Controller
3761	Positioner	Transducer	Positioner
5000	Level Controller	N/A	Level Controller
DVC6000	Positioner	Transducer	Digital Valve Controller
TC-X17850-403	Transducer	N/A	Transducer
2500	Level Controller	Pressure Controller	Level Controller
ST2TP	Level Controller	N/A	Liquid Level Controller
HT-12	Temperature Controller	N/A	Temperature Controller

A further sub-objective of Gap #3 was to derive an understanding of which models had been employed in ESD applications. Only 13 models were observed to indicate ESD at least once, two of which (4150 and 4150KR) are very similar models.

Table 12: Models observed in ESD applications

Models	Number Observed	ESD (Number)	ESD (% of model)
1530	451	433	96%
4660	805	391	49%
L2	2119	13	1%
4150KR	445	12	3%

4150	581	10	2%
7970	14	8	57%
1001	218	5	2%
2680	213	2	1%
CTS 215	5	2	40%
L1200	14	2	14%
2500	29	1	3%
Hoadley	1	1	100%
25M60	1	1	100%

Known Abatement Activities

It is understood that most, if not all new facilities are now designed using low-bleed or no-bleed equipment. It is further anticipated that significant uptake of the pneumatic carbon offset program will be observed over the coming months and years based on interactions and planning sessions with producers. Projected emissions from pneumatics must take into account this changing behaviour and design standards.

Emissions estimates must also acknowledge early action on pneumatics. During periods of high gas pricing, for example, or as participation in programs which value the environmental attributes of such projects, oil and gas producers have been compelled to install low- and no-bleed equipment in both greenfield and retrofit scenarios. It is estimated that a material number of conversions and proactive greenfield installations may have been completed in Alberta to date. Table 13 outlines the approximate number of low-bleed control instrument, no-bleed pump, and instrument air projects that Cap-Op has observed and/or validated through March 2018:

Table 13: Known pneumatic methane abatement projects through 2018

Time Period	**Control Instrument Projects**	**Electric Pump Projects**	**Instrument Air Projects**
2005-2016	1,500+	1,000+	15+
2016-2017	2,000+	250+	10+
2018 to date	175+	5+	5+

In addition to the projects Cap-Op has observed and/or validated to date, other carbon offset service providers are understood to be bringing projects forward. Although the program sizes are confidential, Cap-Op assumes that the aggregate total of all other offset providers could be similar to Cap-Op (or could be larger). In addition, Cap-Op is aware of hundreds of projects that appear to have been executed but lack proper documentation for the pursuit of carbon offsets (and/or are currently owned by producers without an interest in pursuing offsets). Assuming Cap-Op is aware of 50% of the total projects that were not fully documented, a conservatively high estimate, the total executed projects through March 2018 could exceed 6,000 in Alberta alone. This figure includes high-to-low bleed control instrument conversions, electric chemical injection pumps, and instrument air conversion projects and could be conservative. Further study is recommended although projects are likely to be better documented going forward as a result of carbon offset and other incentive opportunities requiring detailed project information.

Conclusions and Recommendations

Understanding emissions from pneumatics in Western Canada and North America will continue to play an important role in provincial/state and national emissions inventories, policy and regulatory development, and ultimately in reducing the greenhouse gas emissions intensity of the oil and gas sector. A dataset comprising over 10,000 pneumatic devices across geographic regions and facility types presents an opportunity to improve this understanding for government agencies, NGOs, and industry alike. Analysis of the dataset has indicated the following:

- Pneumatic Inventory Data
    - Average numbers of devices per facility were observed as described in Table 6 by device type and facility type. No zero-device sites were included, which may result in over representation of pneumatic devices especially at wellsites.
    - Conversely, comparison to a single operator's exhaustive inventory indicated that the data may under represent pneumatic devices by ~30%. The exhaustive inventory also did not include zero-device sites).
    - Scenarios 1 and 2, described in the Appendix (1.2 and 1.5), were observed to more closely match the single operator's exhaustive inventory when assessed using the total average pneumatic devices per site; the exhaustive inventory contained 13% more average devices than Scenario 1 and 14% fewer average devices than Scenario 2.
- Large Facilities
    - Large Facilities were observed to exhibit higher pneumatic device counts and variety of pneumatic devices, especially compressor stations.
    - Multiwell batteries, especially crude oil multiwell proration batteries, were observed to have similar average device counts as compressor stations, but fewer types of devices.
    - Some gas plants were observed to have very high counts of pneumatic devices, especially level control instruments and pumps; these were also the most common pneumatic device types across all facility types.
    - The sample size of gas plants was relatively small and further study may be required for this facility type.
- Level Control and Liquids Production
    - Level control instruments were not observed to exist more often or in greater numbers at sites with higher estimated liquids production; although no correlations were observed, it is logical that there should be a relationship.
    - Further study may be required on both the pneumatic inventories and the liquids production reporting and proration methodologies.
- Make and Model Classification
    - Although a wide variety of makes and models was observed, especially in control instruments, approximately 10% of the distinct models represented over 80% of the observed control instruments, and a single manufacturer (Fisher) represented nearly 75% of the observed control instruments.
    - Over 70% of the pumps observed were manufactured by Morgan, Bruin, Texsteam, or Williams. Data issues challenged analysis of pump models although the majority of pumps for which model numbers were observed were deemed equivalent to the industry standard 5100 series, while the remaining models indicated Williams P125, P250 and P500 models in approximately equal proportions.
    - Level Switches, Hi/Lo Pressure Pilots, Liquid Level Controllers and Pressure Controllers were the instrument types most commonly observed in ESD applications, and just four models represented 97.5% of the observed ESD population (1530, 4660, L2, and 4150).

Cap-Op has also identified the following recommendations for operators and others who are collecting, compiling, analyzing and reporting pneumatic inventory information:

- Sites with no pneumatics should be recorded, along with exhaustive inventory efforts, in order to ensure that a complete inventory of all sites is obtained (including zero-device sites). This will refine pneumatics information and emissions estimates based on extrapolation. Additional study may be required in order to understand how common zero-device sites are.

- Operators should, wherever possible, use common language and AER-specific facility classification codes (or Unique Well Identifiers (UWI)) to ensure pneumatic inventory reporting consistency.
- Inventory information should be gathered with care by qualified personnel; a number of device classifications were deemed to be errors (e.g. liquid level controller as pressure control instrument); this is particularly pertinent to classification of emergency shutdown applications. Since ESD is a subset of other device classifications, it may be better to be an additional piece of information (e.g. classify as “pressure control instrument in ESD application,” as opposed to pressure control instrument or ESD).

Appendix: Supplemental Information and Data Tables

1.1 Data Pre-Processing and Equivalency Mapping

1.1.1 Control Instrument Classifications

The Cap-Op control instrument classifications that were observed did not match the AER control instrument classifications. Each was automatically assigned to an appropriate AER Control Instrument Classification as described in Table 14.

Table 14: Control instrument classification data-mapping

AER Control Instrument Classification	Deemed-Equivalent Cap-Op Control Instrument Classifications
ESD	HLSD, HPSD, High Level Shutdown, Pipeline LPSD, High Pressure Shutdown, Pipeline HLPSD, Sales Line HLPSD
Level Controller	Level Controller, Level Switch
Plunger Lift Controller	Plunger Lift Controller
Positioner	Positioner
Pressure Controller	Pressure Controller, Pressure Switch, Hi/lo Pressure Switch
Temperature Controller	Temperature Controller
Transducer	Transducer

1.1.2 Site Classifications

With regard to site classifications, the study required differentiation between gas and oil wells (among other facility types), which was not consistently observed in the dataset – many records were listed simply as wellsites. Where possible, the facility type was resolved using the physical location (surface or downhole) and publicly available datasets formatted and supplied by the AER (e.g. ST-37). AER data on non-abandoned wells was cross-referenced against the available DLS information (both surface and downhole) in order to retrieve the well license numbers, which were themselves cross-referenced against fluid type in order to establish whether wells were gas-producing or oil-producing. For locations that did not result in a match against well license numbers, the locations were cross-referenced against Reporting Facility ID's (surface locations). Nonetheless, approximately 5% of the sites did not return definitive results (either no result, conflicting results from multiple lookups[17], or out-of-province locations[18]). The user-entered data was reviewed in order to assess facility type where possible, and sites which could not be mapped were excluded (approximately 200 of 3600). Some facility types had very few observed records in the dataset and so these were combined with similar types of facilities.

Site Classifications were mapped as follows:

Table 15: Site classification data-mapping

AER Facility/Site Labels Observed	Category Label Applied for Study and Rationale
Crude Oil Well	Oil Well

[17] For example, looking up the LSD against surface locations returned **gas well** and looking up the LSD against downhole locations return **oil well**, and the record was not supplied with an indication of whether the LSD was surface or downhole.

[18] Less than 4% of sites were outside of Alberta; although these were not expected to skew the data they were excluded as information on fluid type (gas or oil) was unavailable.

Gas Well	Gas Well
Coalbed Methane-coals&oth Lith Well	Combined with Gas Well – only 9 observed in sample set
Gas Gathering System	Combined with Compressor Station – only 2 observed in sample set
Gas Multiwell Group Battery	Gas Multiwell Group Battery
Gas Single-well Battery	Gas Single-well Battery
Gas Multiwell Proration Outside Se Alberta Battery	Gas Multiwell Proration Outside Se Alberta Battery
Gas Multiwell Proration SE Alberta Battery	Combined with Gas Multiwell Group Battery – only 4 observed in sample set
Crude Oil Single-well Battery	Crude Oil Single-well Battery
Crude Oil Multiwell Proration Battery	Crude Oil Multiwell Proration Battery
Crude Oil Multiwell Group Battery	Crude Oil Multiwell Proration Battery – only 3 observed in sample set
Gas Plant	Gas Plant
Compressor Station	Compressor Station
Gas Multiwell Effluent Measurement Battery	Combined with Gas Multiwell Group Battery – only 9 observed in sample set
Gas Test Battery	Combined with Gas Single Well Battery (see below) – 29 observed in sample sets
Field Meter Station	Combined with Compressor Station – only 1 observed in sample sets

1.2 Scenario Analysis

A fair number of sites (27%) were observed to have only one device which may be related to the lower pneumatic devices per facility. As identified in **Data Challenges and Mitigation Strategies** this could be a result of including incomplete inventories (e.g. sites where perhaps only one device was inventoried, perhaps for the purpose of pursuing carbon offsets, but other devices actually exist onsite that were not included).

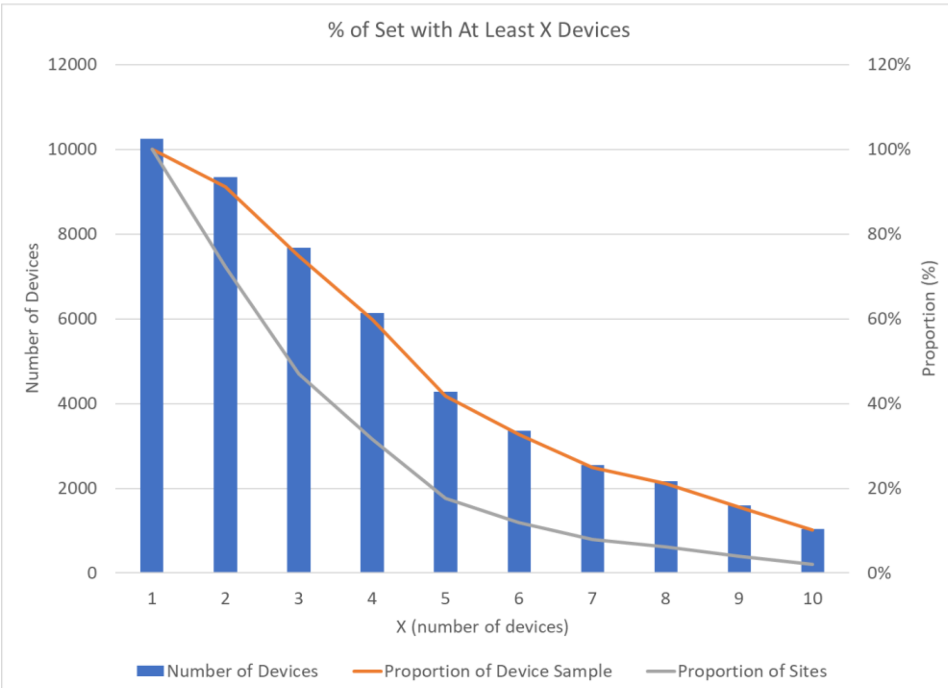


Figure 7: Number and proportions of sites/devices with at least X devices

In order to mitigate this challenge and better understand the dataset, two subsets were developed and evaluated according to the following rules:

1. Multi-Device Facilities Only: exclusion of sites with only a single device record (investigating only sites at which 2 or more device records were observed).
2. Null Exclusion: excluding sites at which there were zero control instruments from the denominator of the calculation of control instruments per site, and excluding sites at which there were zero pumps from the denominator of the calculation of pumps per site.

These approaches carry their own limitations but were evaluated in order to better understand the dataset in an attempt to identify a more representative subset. The two scenarios above, when compared to an operator's known exhaustive inventory, reduced the difference in overall devices per site to within 15% from 32% for the entire dataset. The exhaustive inventory contained 13% more average devices than Scenario 1 and 14% fewer than Scenario 2.

The approach above is unable to distinguish whether a site did not have a pump, or one at which the pump was simply not inventoried, for example. The approaches may also introduce the risk that device counts would be overestimated, for instance if there are wellsites at which only one control device or pump is actually required then these should contribute to the overall average. As described above, any inventory based on device counts without consideration for zero-device sites risks overestimation. This risk is explicitly increased in Scenario 2 because the total average devices per site includes two non-identical, overlapping subsets of sites but could be interpreted as the average devices for a single site. In other words, there could be sites with control instruments but no pumps, and sites with pumps but no control instruments. These are both acknowledged as limitations of the study and available dataset.

Relative to the exhaustive inventory and the overall dataset, the average devices per site in each of the subsets created by the rules above is as follows:

Table 16: Representativeness of scenarios assessed as comparison of total average device per facility (overall and non-weighted average of facility type totals

	Overall Average (Total Devices / Total Facilities)	Non-Weighted Average of Facility Type Totals
Exhaustive Inventory (1 Operator, 4 facility types)	4.58	4.46
Overall Dataset	2.97	3.97
Multi-Device Facilities Only	3.82	4.96
Null Exclusion	11.50	7.05

The non-weighted average takes into account the different facility classifications. Application of these figures should be disaggregated either by facility type or by both facility type and device type (see **Appendix 1.5 Data Tables - Scenarios** for data tables showing detailed breakdowns). The following figures summarize this disaggregated data by facility type in each scenario:

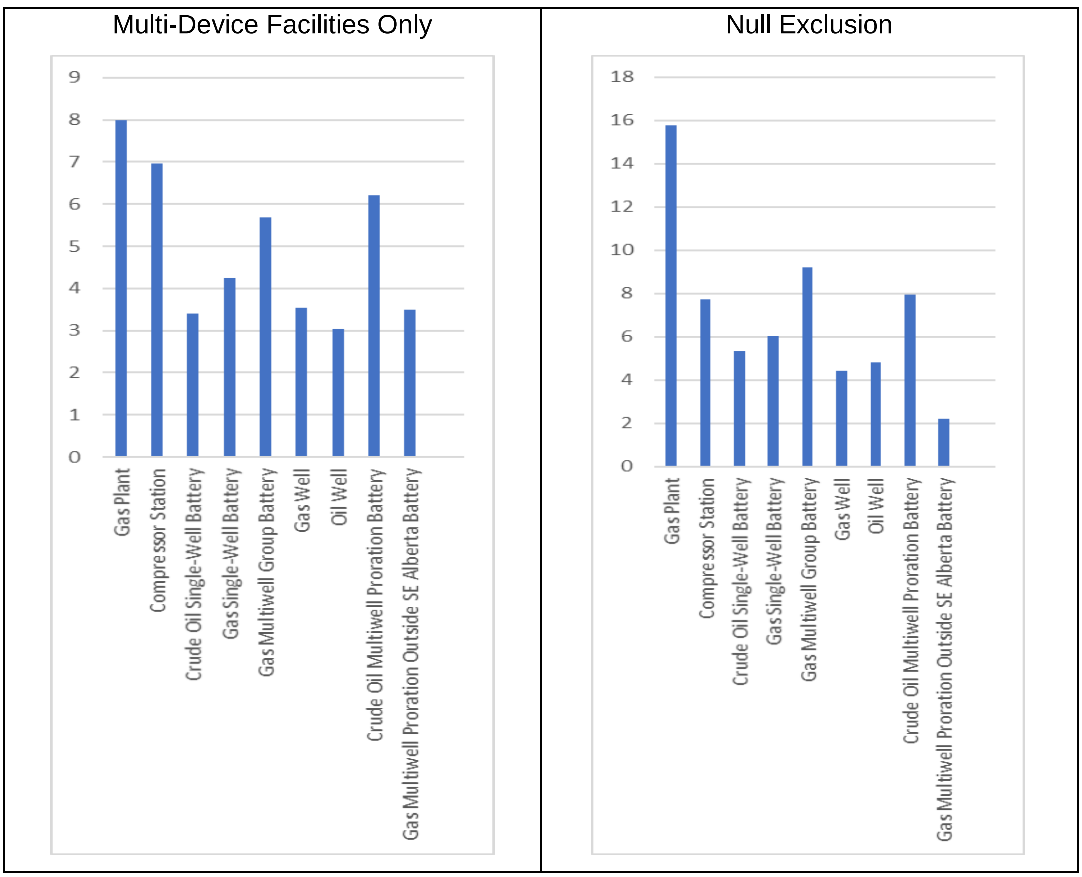


Figure 8: Average total pneumatic devices per facility by facility type in four observed scenarios

It is expected that as the number of facilities excluded goes up, the average number of devices per facility would increase (see Figure 7). What was observed was that the rate of increase across different facility types is not equal. In particular, gas wells and gas plants were observed to increase considerably when applying the Multi-Device Facility filter – this would suggest that when more advanced pneumatic systems are required, the number of pneumatic devices can increase quickly even at small facilities (gas wells in particular). As more sites are excluded, the average number of pneumatic devices increases on the order of 100% (double). Compressor stations, on the other hand, increased less than 50% and crude oil multiwell proration batteries increased less than 25%. At the same time, it may simply be that Large Facilities were less likely to overestimate counts as they were exhaustively inventoried.

The overall device breakdown was observed in each of the scenarios was observed as follows:

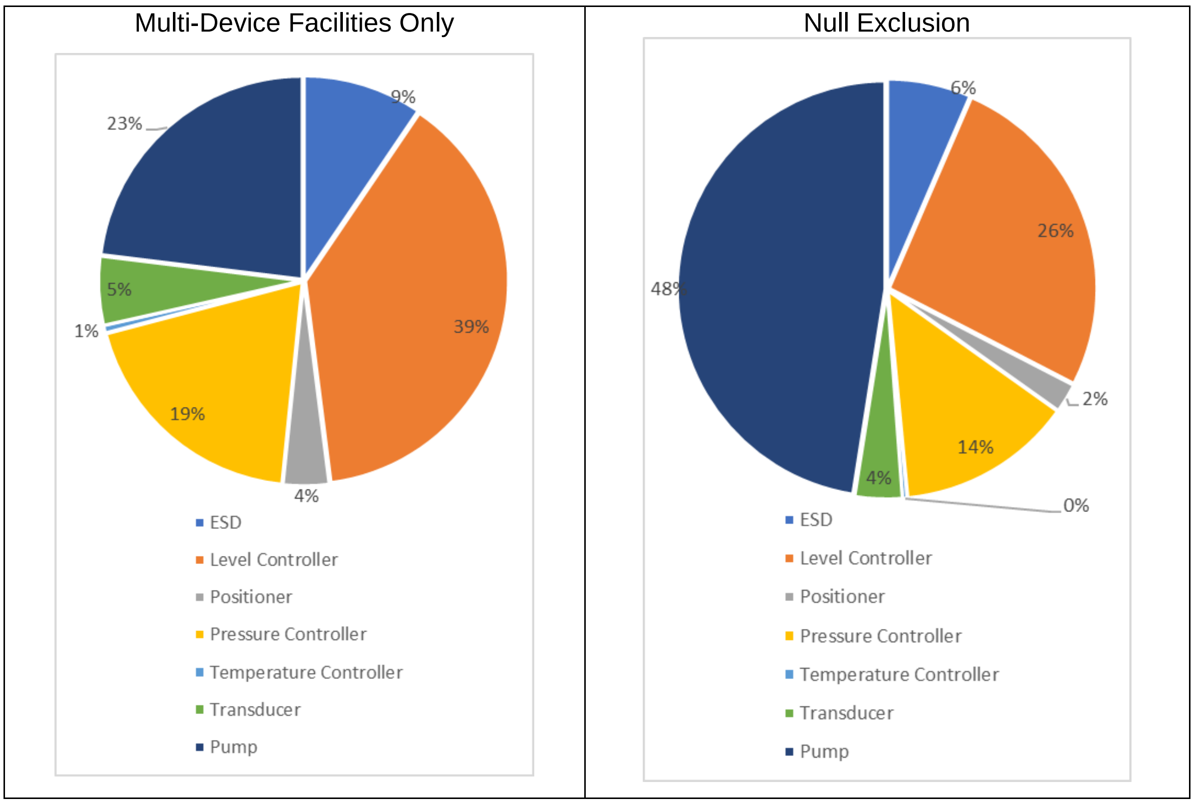
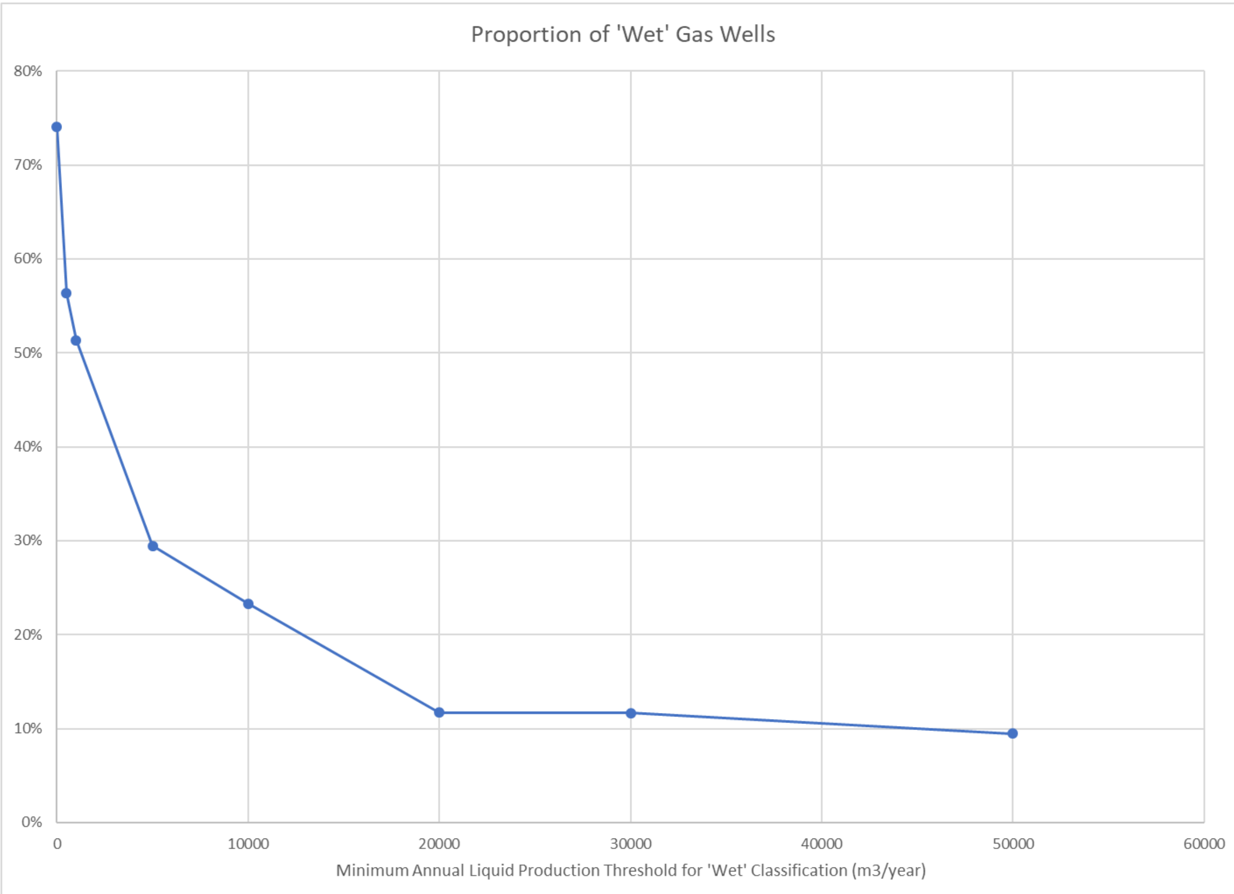


Figure 9: Device type breakdown in four observed scenarios

In terms of the breakdown, little variance was observed when applying the Multi-Device Facility filter whereas the other filters indicated a much larger proportion of pumps. The representativeness appears to be impacted by a large number of sites which had only pumps inventoried.

1.3 Proportion of Wet/Dry Gas Wells by Threshold Liquid Production of Batteries



1.4 Correlation and Regression Results

Total Dataset	*Liq Vol*	*Liq #*	*ESD*	*Level Controller*	*Positioner*	*Pressure Controller*	*Temperature Controller*	*Transducer*	*Pump*	*Other*	*Total*
Liq Vol	1										
Liq #	0.187318	1									
ESD	-0.13912	0.015956	1								
Level Controller	-0.22897	-0.09192	0.267054535	1							
Positioner	-0.03275	-0.03869	-0.05123588	0.246679476	1						
Pressure Controller	0.057	0.128302	-0.1475945	0.106606206	0.055070363	1					
Temperature Controller	-0.02157	-0.07737	-0.02371811	0.154075241	0.213498487	0.119162864	1				
Transducer	-0.03999	0.109618	-0.12314915	0.137292792	0.227327063	0.118449887	0.165651069	1			
Pump	-0.01872	-0.04533	-0.13084845	0.006804682	0.067753813	-0.021433445	0.026381431	0.018425036	1		
Other	0.017542	-0.02628	-0.05435416	-0.094363535	-0.014094665	-0.059703574	-0.007454091	-0.018608858	0.661455827	1	
Total	-0.14313	-0.01064	0.165711651	0.616681763	0.325293319	0.330471222	0.223415684	0.378858358	0.64888885	0.449571	1

Scenario A	*Liq Vol*	*Liq #*	*ESD*	*Level Controller*	*Positioner*	*Pressure Controller*	*Transducer*	*Pump*	*Other*	*Total*
Liq Vol	1									
Liq #	0.327711	1								
ESD	-0.17082	-0.01327	1							
Level Controller	0.03107	-0.09857	-0.07914034	1						
Positioner	0.123209	-0.10101	-0.18009524	0.396301798	1					
Pressure Controller	0.064402	-0.04609	-0.2137189	0.216748989	0.165441808	1				
Transducer	0.596268	0.230215	-0.18076455	0.145453628	0.240241834	0.100759616	1			
Pump	0.284683	0.047588	-0.45417677	0.189606358	0.417337963	0.468588946	0.435637119	1		
Other	0.007211	-0.01904	-0.02984839	0.026415223	0.07682863	0.039495092	0.011086732	0.017284774	1	
Total	0.287588	0.013469	-0.0154784	0.678763518	0.514202011	0.611227623	0.54788645	0.648884269	0.051496381	1

Scenario B	*Liq Vol*	*Liq #*	*ESD*	*Level Controller*	*Positioner*	*Pressure Controller*	*Transducer*	*Pump*	*Other*	*Total*
Liq Vol	1									
Liq #	0.141216	1								
ESD	-0.14973	0.109668	1							
Level Controller	-0.04955	-0.23684	-0.10986363	1						
Positioner	0.000663	-0.35209	-0.21177197	0.421850129	1					
Pressure Controller	0.036118	-0.14672	-0.1229709	0.252312532	0.190998952	1				
Transducer	0.572434	0.171532	-0.22206458	0.136202711	0.192763089	0.096069981	1			
Pump	0.266604	-0.10022	-0.44875107	0.222382848	0.473876814	0.40530498	0.488032882	1		
Other	-0.01513	-0.06014	-0.0340399	0.023496858	0.068911983	0.046122057	0.000266162	0.011213366	1	
Total	0.235454	-0.14642	-0.07641004	0.703207532	0.545192222	0.605969813	0.569013185	0.674798003	0.04878538	1

Scenario C	*Liq Vol*	*Liq #*	*ESD*	*Level Controller*	*Positioner*	*Pressure Controller*	*Transducer*	*Pump*	*Other*	*Total*
Liq Vol	1									
Liq #	0.066845	1								
ESD	-0.14868	0.213746	1							
Level Controller	-0.10372	-0.29475	-0.10506965	1						
Positioner	-0.06983	-0.45588	-0.22338642	0.42621686	1					
Pressure Controller	0.070784	-0.28368	-0.13590933	0.270242636	0.249285561	1				
Transducer	0.542131	0.142189	-0.23338787	0.116979459	0.149800888	0.137277709	1			
Pump	0.255832	-0.27411	-0.44447088	0.222552492	0.51235348	0.410202569	0.520502072	1		
Other	-0.02811	-0.07668	-0.0355661	0.02055507	0.065033872	0.056441789	-0.006983773	0.00813833	1	
Total	0.199449	-0.26543	-0.08762034	0.709188278	0.560663343	0.605372761	0.580936448	0.684013193	0.046556469	1

Scenario D	*Liq Vol*	*Liq #*	*ESD*	*Level Controller*	*Positioner*	*Pressure Controller*	*Transducer*	*Pump*	*Other*	*Total*
Liq Vol	1									
Liq #	0.296321	1								
ESD	-0.17402	0.00442	1							
Level Controller	0.035186	-0.11219	-0.09132491	1						
Positioner	0.113164	-0.18433	-0.18453899	0.412691854	1					
Pressure Controller	0.05787	-0.10552	-0.20396363	0.235798956	0.166071388	1				
Transducer	0.596329	0.236133	-0.18893979	0.156373862	0.237091531	0.098480101	1			
Pump	0.278261	-0.02077	-0.45947055	0.210644618	0.420599597	0.467787579	0.441120051	1		
Other	0.005328	-0.03335	-0.03050074	0.027587183	0.076113605	0.039869038	0.010262391	0.016362477	1	
Total	0.284562	-0.03791	-0.02631904	0.68636086	0.518906986	0.617054372	0.552920553	0.657111546	0.051466583	1

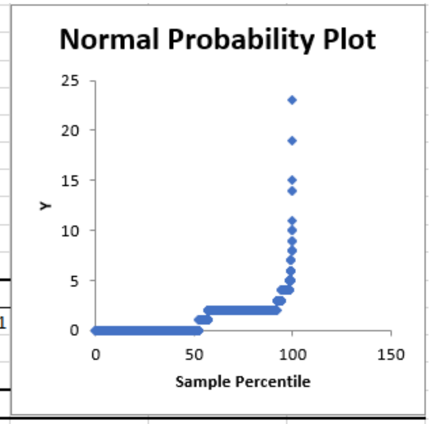
Scenario	**Minimum Total Devices**	**Minimum Level Control Instruments**	**Minimum Number Liquids Produced**	**Minimum Volume Liquid Produced (m^3)**
A	2	1	1	>0
B	2	1	1	>500
C	2	1	1	>1,000
D	2	1	2	>0

SUMMARY OUTPUT

Regression Statistics	
Multiple R	0.228965615
R Square	0.052425253
Adjusted R Squa	0.052144905
Standard Error	1.436991661
Observations	3382

ANOVA

	df	*SS*	*MS*	*F*	*Significance F*
Regression	1	386.1466335	386.1466335	187.0009259	1.78717E-41
Residual	3380	6979.514218	2.064945035		
Total	3381	7365.660852			



	Coefficients	*Standard Error*	*t Stat*	*P-value*	*Lower 95%*	*Upper 95%*	*Lower 95.0%*	*Upper 95.0%*
Intercept	1.220964814	0.026418627	46.21605811	0	1.169166708	1.272762921	1.169166708	1.272762921
X Variable 1	-1.71559E-05	1.25456E-06	-13.67482819	1.78717E-41	-1.96157E-05	-1.46962E-05	-1.96157E-05	-1.46962E-05

Figure 10: Number of level control instruments (Y) against total liquid production (X) of battery supplied by wells

1.5 Data Tables - Scenarios

1.5.1 Scenario 1: Multi-Device Facilities Only

Facility Types	ESD	Level Control	Positioner	Pressure Control	Temperature Control	Transducer	Pump
Gas Plant	0	18	12	13	0	3	34
Compressor Station	11	271	35	126	25	99	102
Crude Oil Single-Well Battery	49	89	0	34	0	1	41
Gas Single-Well Battery	75	268	1	95	0	56	117
Gas Multiwell Group Battery	42	197	0	73	0	25	175
Gas Well	609	2519	76	1414	0	698	1102
Oil Well	50	149	0	59	0	5	171
Crude Oil Multiwell Proration Battery	21	65	0	43	0	0	14
Gas Multiwell Proration Outside SE Alberta Battery	9	22	0	11	0	0	0
Total	**866**	**3598**	**124**	**1868**	**25**	**887**	**1756**

Facility Types	ESD	Level Control	Positioner	Pressure Control	Temperature Control	Transducer	Pump
Gas Plant	0.00	1.80	1.20	1.30	0.00	0.30	3.40
Compressor Station	0.11	2.82	0.36	1.31	0.26	1.03	1.06
Crude Oil Single-Well Battery	0.78	1.41	0.00	0.54	0.00	0.02	0.65
Gas Single-Well Battery	0.52	1.86	0.01	0.66	0.00	0.39	0.81
Gas Multiwell Group Battery	0.47	2.19	0.00	0.81	0.00	0.28	1.94
Gas Well	0.34	1.39	0.04	0.78	0.00	0.39	0.61
Oil Well	0.35	1.04	0.00	0.41	0.00	0.03	1.20

Crude Oil Multiwell Proration Battery	0.91	2.83	0.00	1.87	0.00	0.00	0.61
Gas Multiwell Proration Outside SE Alberta Battery	0.75	1.83	0.00	0.92	0.00	0.00	0.00
Average	**0.470**	**1.909**	**0.179**	**0.956**	**0.029**	**0.271**	**1.143**

1.5.2 Scenario 2: Null Exclusion

Facility Types	ESD	Level Control	Positioner	Pressure Control	Temperature Control	Transducer	Pump
Gas Plant	0	20	12	14	0	3	34
Compressor Station	11	276	35	152	25	100	113
Crude Oil Single-Well Battery	51	93	0	36	0	2	43
Gas Single-Well Battery	76	274	1	102	0	58	121
Gas Multiwell Group Battery	42	202	0	77	0	29	177
Gas Well	616	2552	77	1930	0	842	1178
Oil Well	51	150	0	78	0	5	181
Crude Oil Multiwell Proration Battery	21	65	0	43	0	0	14
Gas Multiwell Proration Outside SE Alberta Battery	13	31	0	11	0	0	0
Total	**881**	**3663**	**125**	**2443**	**25**	**1039**	**1861**

Facility Types	ESD	Level Control	Positioner	Pressure Control	Temperature Control	Transducer	Pump
Gas Plant	0.00	1.82	1.09	1.27	0.00	0.27	11.33
Compressor Station	0.10	2.42	0.31	1.33	0.22	0.88	2.46
Crude Oil Single-Well Battery	0.82	1.50	0.00	0.58	0.00	0.03	2.39

Gas Single-Well Battery	0.52	1.88	0.01	0.70	0.00	0.40	2.52
Gas Multiwell Group Battery	0.48	2.32	0.00	0.89	0.00	0.33	5.21
Gas Well	0.26	1.08	0.03	0.81	0.00	0.36	1.87
Oil Well	0.50	1.47	0.00	0.76	0.00	0.05	2.03
Crude Oil Multiwell Proration Battery	0.91	2.83	0.00	1.87	0.00	0.00	2.33
Gas Multiwell Proration Outside SE Alberta Battery	0.52	1.24	0.00	0.44	0.00	0.00	0.00
Average	**0.457**	**1.839**	**0.160**	**0.962**	**0.024**	**0.257**	**3.349**

Cap-Op Energy
610-600 6th Ave SW
Calgary, AB, Canada
T2P 0S5
403.457.1029