CLEAN RESOURCES FINAL PUBLIC REPORT

Systematic Third-party Validation of Environmental and Economic Performance of Methane Reduction Technologies (STV)

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A. EXECUTIVE SUMMARY

Objective

This project was implemented to demonstrate and evaluate various technologies targeting four specific methane emissions sources found at small and remote oil and gas field facilities. The technology areas targeted were:

1) replacing natural gas-actuated chemical pumps with solar-powered pumps.
2) installing instrument air compressors to allow conversion of sites from natural gas-powered instruments and devices to air-actuated operation.
3) testing the performance of enclosed combustors to convert higher volume methane process vents to CO_2 through enclosed controlled combustion.
4) using alternate methods of providing electrical power to sites that are remote from the existing power grid to reduce methane venting from various devices.

The goal of the work was to:

- Remove critical barriers to reducing methane emissions by filling a knowledge gap about cost-effective, high-quality methane emissions reduction equipment.
- Provide neutral third-party information about the costs and performance of the various technologies to allow end-users to gain confidence to purchase and widely deploy methane emissions reduction equipment.
- To open the door for revenue for Alberta innovators and manufacturers to champion and market proven methane emissions reduction technologies in Canada and internationally.

Scope of Testing

Figure 1 - Overall Metrics for STV Project

This project encompassed a total of 46 field pilot sites with 15 vendors supplying equipment for the four technology options. Test sites were provided by 4 direct industry participants and 10 indirect industry participants. Overall expenditures for testing totaled $1.9 million over ~2 years. The distribution of test sites and vendor selection were made by the industry site hosts based on project priorities and requirements, prior experience, and economic considerations.

Key Results

The project included feedback from field operations at a wide range of sites with a variety of issues with real-life technology applications covering costs, estimates of abatement costs, and installation or maintenance issues. The experience is assisting in the further roll-out of the technologies tested by the companies participating in the trials and helped vendors identify overall improvements to make further additions or adjustments to their technology offerings to better meet the needs of the end-users.

A key result was the development of a chart showing potential abatement costs by technology type based on field trial results. Low and high estimate ranges are shown since the same equipment could be used on emissions streams over a wide range of rates. A quick note here is that some of the sub-projects were single devices at a single site, while others are averages for a larger sample of sites and solutions.

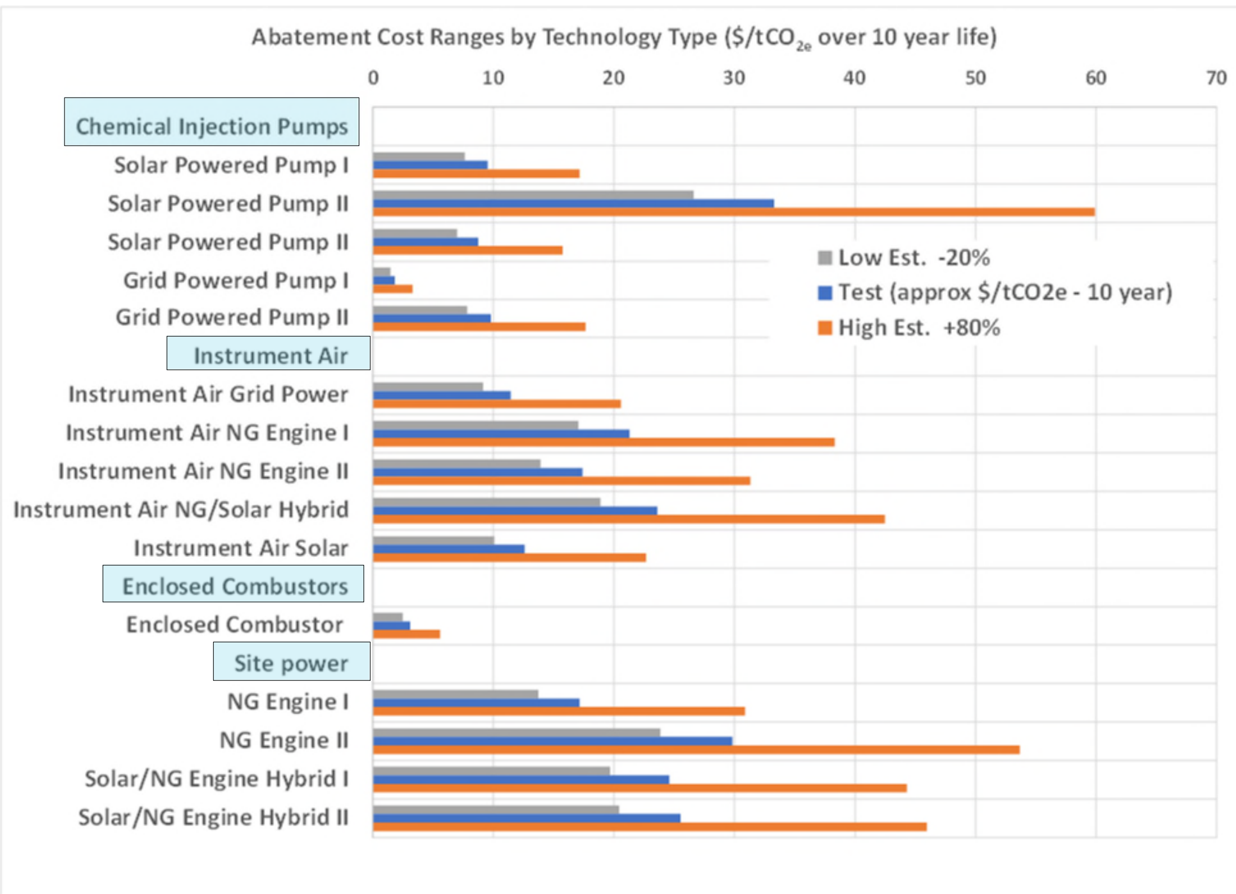

Figure 2 - Abatement Cost Ranges for STV Sub-Projects Based on An Assumed 10-Year Equipment Life

Learnings

There were valuable learnings in each of the technology areas in addition to those related to abatement costs. The following summarizes some high-level leanings in general and by technology type, with more detail provided later in this report. These learnings provide key information which can assist other end-users in planning and effectively installing these technologies in a large range of additional sites. Also, as technologies are further explored in other sections of this report, comments on operations and direct implementation of technologies within projects provide insight to technology developers on potential improvements and new product lines.

- **General** – The following are some general conclusions from the overall test program.
    - The **greatest benefits** for any given technology are achieved at sites with the highest methane emissions. While this seems obvious it is a result of most of the technologies coming in standard sizes so cost per site for a give type of installation may be constant, but the abatement cost is not the same for the same installation at all sites. Therefore, new installations should be prioritized.
    - **Retrofitting systems** in the field is more costly, and these costs increase when there are more methane sources on the sites as more piping is required and site layouts are not optimized for the alternative technology. "Plug and Play" packaged systems can partially overcome this barrier.
    - **Improvements over incumbent technologies –** Incumbent technologies for all types of methane venting sites were designed to meet site needs at the lowest cost, greatest reliability, and the lowest perceived environmental impacts at the time they were installed. Over the last 10 years, concerns about GHGs in general and methane in particular have increased, providing motivation and justification for emission mitigation. At the same time technologies such as solar power, instrument air, power and combustor systems for oil and gas applications have greatly improved so are more reliable and sustainable than they were 10-20 years ago.
- **Chemical Injection Pumps** – These technologies are well adapted to "plug and play," which facilitated field installations with minimal problems identified and many advantages which could provide additional economic or operational benefits to similar sites in other locations.
- **Air Compressors** – As with chemical injection pumps, the main factor in selecting the appropriate technology is the availability of grid or solar power on the site. The major factor in installation is the need to add piping to separate the fuel and instrument gas systems.
- **Enclosed Combustors** – For a site with high vent flows which cannot be captured or avoided, these devices offer extremely low-cost mitigation even though some emissions remain as a result of the conversion of methane to CO_2. It also shows the need for mobility as one unit was installed at a site that stopped venting due to an unexpected drop in production, so, at that site, no emissions were actually mitigated. This demonstrated the need to actively manage deployment of the technology between field sites to maximize the reductions gained from the devices.

- **Alternate Power Systems** – For sites with larger numbers and volumes of vents without grid power, the most effective mitigation can be through the installation of alternative power systems. Due to higher and more variable loads, natural gas engines or solar power with natural gas engine backup as a hybrid showed strong economics and reliability.

Outcomes

The project resulted in a direct reduction of about 15,000 tCO_{2e}/yr at the cost of $1.9 million (AI contribution $0.54 million or 28% of total) for an overall abatement cost of ~$12.70/$tCO_{2e}$ over an expected 10-year life of the equipment installed. This abatement cost makes the overall project economic compared to a carbon tax of $15-$50/tCO_{2e}.

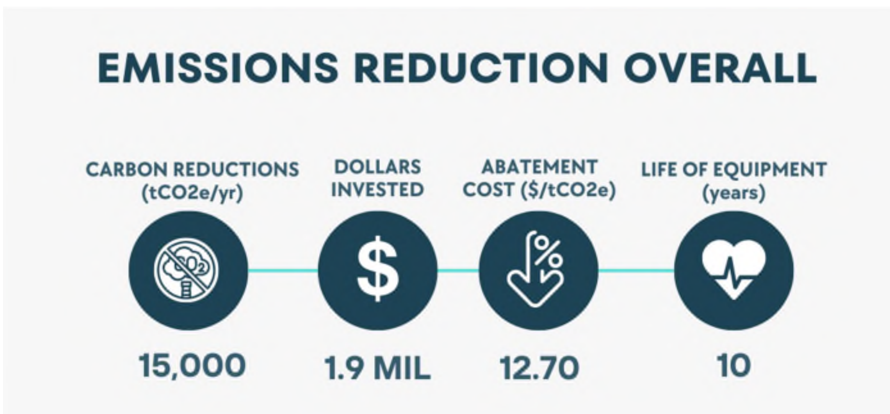

Figure 3: Overall Emissions Reductions Impact by STV

Industry participants in the field trials have all indicated that the results of the trials already have impacted plans for more installations of some of the technologies, with some of those plans already implemented over the past 1-2 years to reduce emissions on a widespread basis. Vendors and technology innovators have gained valuable insight into the needs and preferences of the end-users, allowing them to improve or refine their equipment offerings. Increased numbers of installations in Canada should support increased sales of technologies in the U.S. and other locations internationally. The volume of site methane emissions and number of emissions sources on a site determines which of the abatement technologies are the most appropriate. Key criteria for best results are as follows:

- **Enclosed combustors** – This technology is preferred for sites with large volumes of emission from a few sources such as heavy oil production casing vents where there is no opportunity to capture and sell the methane. Two units from a single vendor installed by a single producer, however, 1 of the two sites stopped producing gas early in the test.

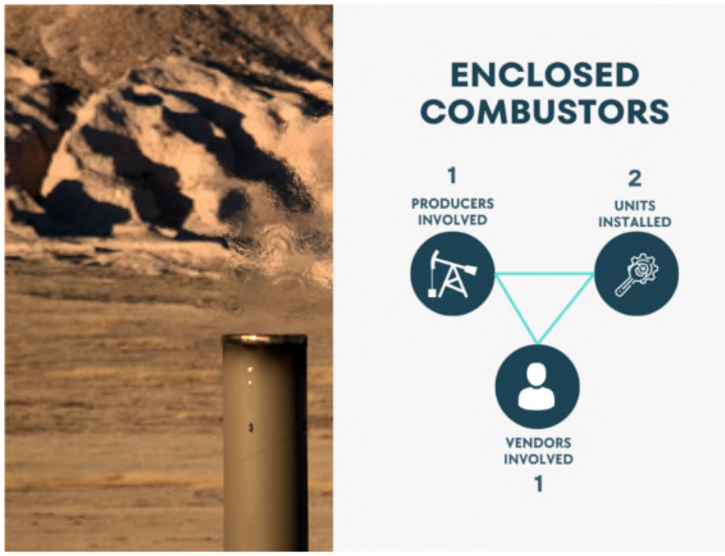

Figure 4: Enclosed Combustors STV Overview

(Image source: https://www.mrw-tech.com/Enclosed-Combustors)

- **Alternative Power Systems** – This technology is preferred for large emitting sites with no access to line power and a large number of devices of different types which can be converted to electric actuated devices or a mixture of electric and pneumatic devices with the addition of an instrument air compressor. Five units were installed by 3 producers, supplied by 3 vendors. Three were hybrids with solar supplemented with power generation while two were natural gas engines.

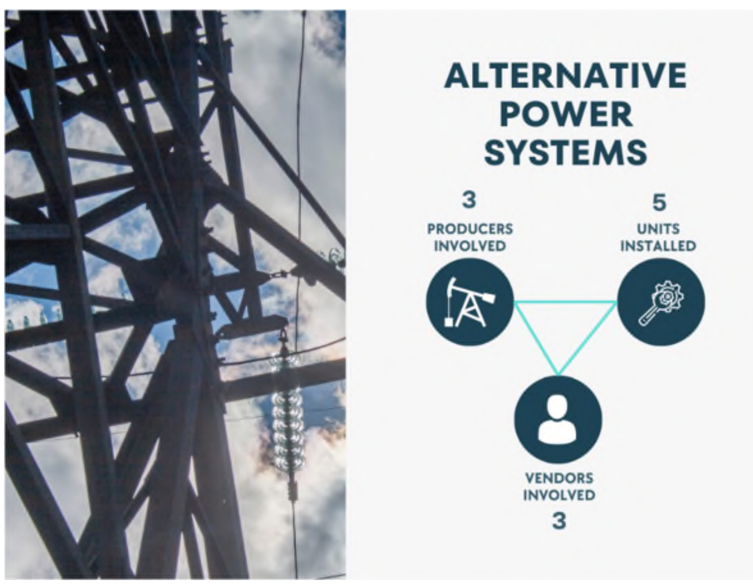

Figure 5: Alternative Power Systems STV Overview

- **Instrument Air Compressors** – This technology could be solar powered, or line powered if a grid connection is available. The air directly replaced the use of natural gas in existing pneumatic devices at sites with medium demand for gas for pumps, control valves or controllers. Tests by 3 producers on 5 sites using 5 vendors with 2 units powered from the grid, 1 natural gas engine powered, 1 solar/NG hybrid and 1 solar powered.

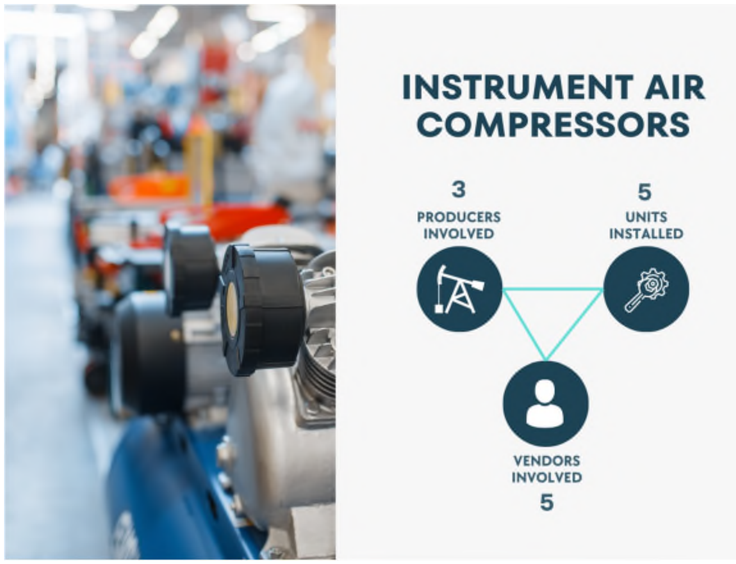

Figure 6: Instrument Air Compressors STV Overview

- **Solar/Grid Chemical Pumps –** This technology is preferred for smaller natural gas sites which may have one or more chemical pumps driven with pressurized natural gas. If the total load is low enough power can be supplied with solar panels and batteries, if the site is connected to the electrical grid they may be replaced with electric pumps. Three producers tested this type of technology which were installed at a total of 27 sites (15 simplex, 14 duplex, and 2 triplex pumps) with equipment from 5 vendors replacing 44 gas powered pumps, 18 units were solar powered while another 9 were powered from the grid.

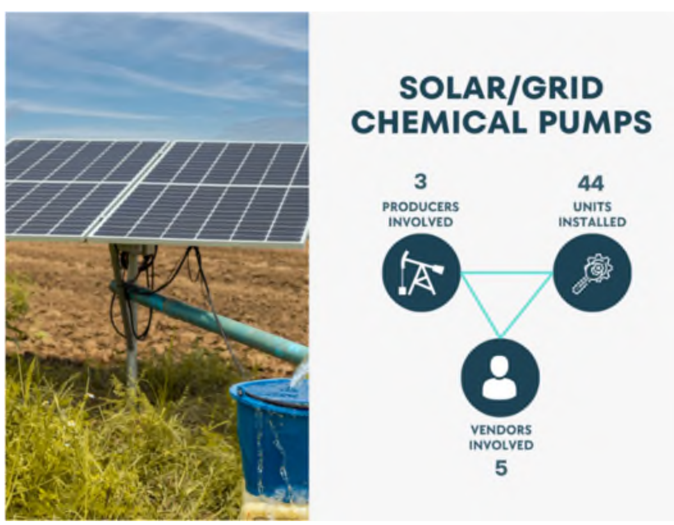

Figure 7: Solar/Grid Chemical Pumps STV Overview

Benefits

The project helped to provide confidence to solidify roll-out plans for the tested technologies by the three industry participants which will result in hundreds of additional installations over the next year and into the future. It also provided vendors and innovators with valuable information on what is needed to support end-users in converting sites to mitigate emissions. The main gaps resolved were to confirm ease of installation, sizing parameters, pros and cons of specific installation options and criteria for selecting a system for a particular site. Some gaps were identified in providing documentation to support installation for some systems which have now been resolved and also identifying extra costs which can be encountered with retrofits of technology. Some, more exotic systems, did not prove to be as economic as other options indicating potential for future design enhancements to reduce costs of those system. These insights are equally valuable to potential installers of these products as well as technology developers looking to enter the market or improve their existing product lines.

B. INTRODUCTION

Sector Introduction

This project targets remote upstream oil and gas facilities where past design practices to ensure sustainable operations with low environmental, economic and security impacts resulted in the use of pumps, instruments, and controls powered by pressure from produced natural gas streams. Natural gas is always available at these sites, especially at the large number of sweet natural gas production sites. Other options for powering these devices were historically very costly both economically and environmentally. Bringing in grid power to remote sites, would result in a great deal of tree clearing or disturbance of farmland or ecosystems and increased potential for starting or being affected by forest fires. Use of natural gas to power devices was not seen as a major environmental issue until climate change concerns resulted in a mandate for producers to reduce methane emissions from these vent sources. In recent years developments in lower-cost, small-scale, and more reliable solar power systems, reliable small-scale power generation, or methane mitigation equipment have opened up the opportunity to mitigate these methane sources. Since historically base load grid power mainly came from inefficient coal fired power plants even where grid power was available, the high emissions intensity of grid power did not provide as much of a GHG reduction as it does now with more renewables and natural gas cogeneration power supplying the grid.

Knowledge or Technology Gaps

The major knowledge and technology challenges are related to establishing best practices of upgrading or replacing the proven incumbent systems with new lower emissions options. Since the sites are small and remote, and each site is in many ways different from other sites, there has been resistance to the widespread application of less proven options. This project addresses those gaps by supported, documented, and assessed trials of various options developed by vendors and technology innovators over the last decade as the concern about the impact of methane emissions have grown.

C. PROJECT DESCRIPTION

Technology Description

This project demonstrated a wide number of options to replace the incumbent technologies which were resulting in methane venting at a range of diverse sites. The demonstrations were to show that the newer, low emissions technologies could be applied safely and result in significant and cost-effective methane emissions reductions. As indicated above the incumbent technologies were the most sustainable solutions available at the time the original sites were designed and provided economic results, with minimum ecological impact and reliable and safe site operations. New design option now available are solar power systems with lower cost and improved panels, batteries, and support systems; more reliable and low maintenance power systems; improved options for avoiding flare stacks; and increased motivation to reduce methane emissions. Most test periods ran over approximately 12 months and most of the test equipment is still in operation.

The technologies being demonstrated consisted of four types of technology demonstrated in field trials.

- **Chemical Injection Pumps** – In general, electrically powered pumps for injection of a range of chemicals in different applications driven by pressured natural gas and then vented to the atmosphere are common field practices. The STV project facilitated the testing of chemical injection pumps to reduce venting. Some pumps were powered by the grid, while others were solar powered. The project demonstrated the economics, conversion issues, and emissions reductions possible from various sites tested by industry participants. Forty-four gas-powered chemical injection pumps were replaced by 27 simplex, duplex, and triplex pump heads. Units of various types were tested by all three industry participants. Generally, an exact baseline is impossible to establish for these operations as the methane vent rate is proportional to the chemical pumped and rates vary widely over time as production rates and seasons change at the various sites. The only indication of vent rates are chemical usage records with vendor supplied charts relating chemical pump volumes to natural gas use at different pressures. However, the solutions take the emissions rate to essentially zero. As a result, emissions reductions in GHG equivalents are very high for installations tested in the STV project.

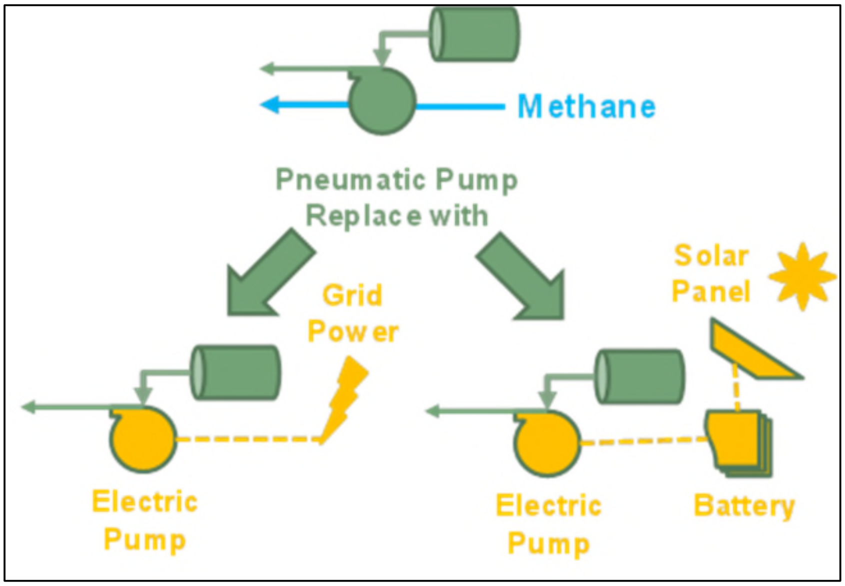

Figure 8: Overview of Chemical Pump Replacement Options

- **Instrument Air Compressors** – These STV technologies were replacing methane power gas with air from grid, solar, or hybrid-driven instrument air compressors to reduce methane emissions. Five instrument air compressors, either solar, grid, engine, or hybrid solar/engine systems, were installed at five larger sites. In addition, an airflow meter and electricity consumption meter were installed at two sites to allow validation of carbon credits and demonstrate the replacement of incumbent instrument methane with novel instrument air to reduce methane emissions. As with chemical pumps, it is impossible to baseline instrument air usage, as demand varies widely by hour, day, and year. Sites with very stable flows will consume very little instrument gas, while sites with variable flows can consume a great deal of gas at different times. Average air use will be small and peak usage will be less than the sum of the pneumatic end-devices, many of the sites had already had emissions reduced through installation of low bleed devices before air compressors was added. As with chemical pumps it is easier to monitor compressor run time after the change of technology has occurred. One industry participant tested air flow and power flow at two compressor sites, however, it would not be feasible to do this at all sites.

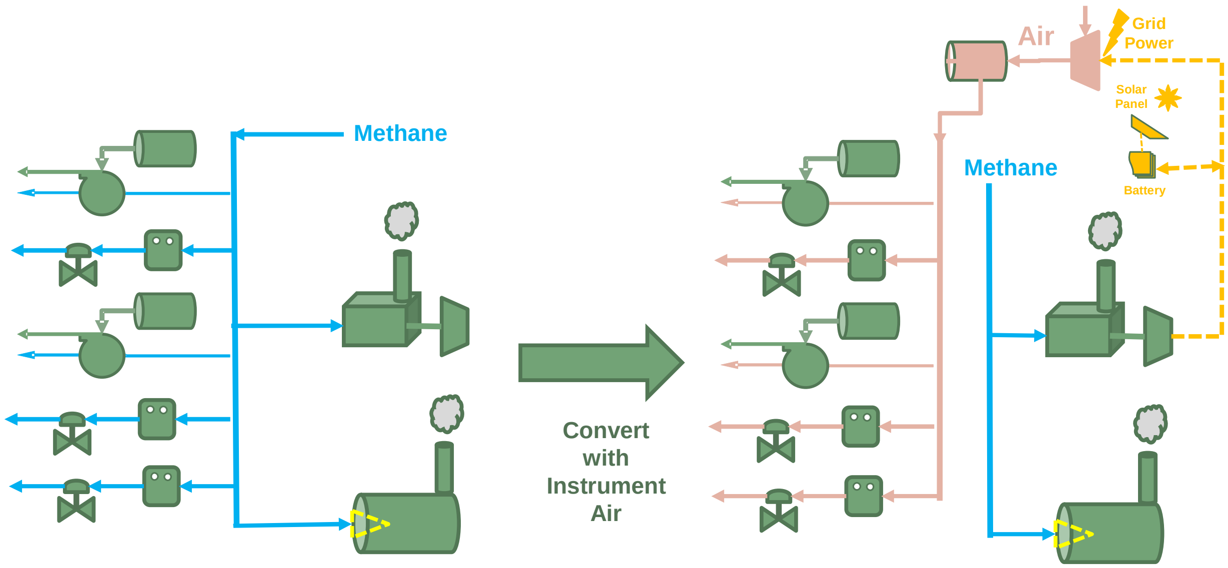

Figure 9 – Overview of Instrument Air Compression Options

- **Enclosed Combustion** – This STV technology is a viable solution to reduce vented streams on sites where other technologies are not applicable or their use is limited. This may be due to site location, type, and other production factors of the site. One producer installed two units were installed at separate dual well heavy oil sites to combust production casing vent gas. One operated successfully to convert a large volume methane stream to CO_2. The second unit was unable to operate as the well pad it was installed on stopped producing, so there was no gas to combust. The one unit which operated demonstrated the potential for low-cost conversion of methane to CO_2 to reduce methane emissions. Produced gas vent volumes are measured or estimated by producers and reported to the AER and the public database. After conversion to combustors the produced gas converted was measured.

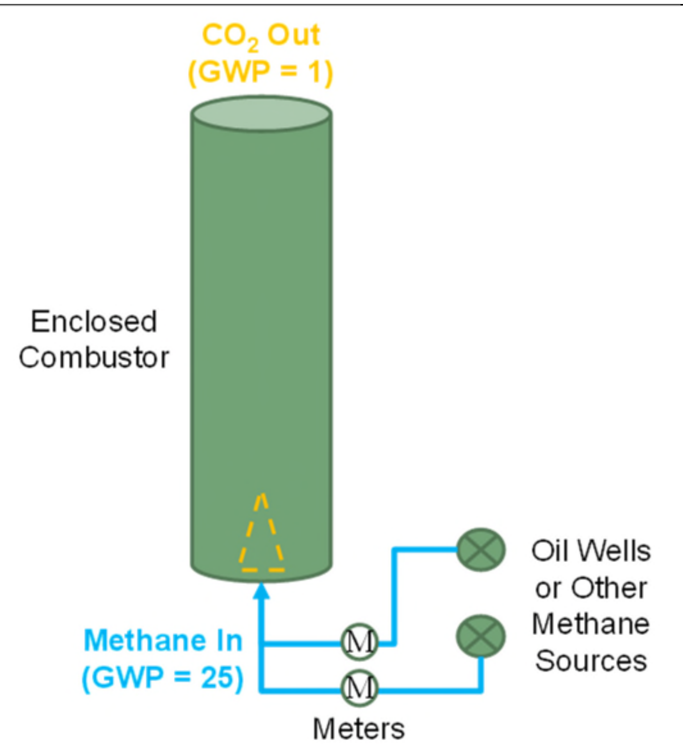

Figure 10: Overview of a Single Enclosed Combustor Unit

- **Novel Onsite Power Systems** – Remote sites with extensive power needs are generally higher emitters of GHGs. Five sites with high energy demands, and a diversity of remote locations, generally located in west central and northwest Alberta were converted through the addition of onsite power generation systems. One site was solar powered, two sites were equipped with a natural gas engine generator, and two sites were powered by a solar/natural gas engine hybrid system. For solar powered systems, hours of sunlight by season are important considerations. These sites showed that larger remote sites could effectively be converted to low-emissions power to replace many methane sources. Newly powered sites were also impossible to establish baseloads for as they have a mix of chemical pumps and instruments/controls, so rates of energy and air demand vary widely over time based on the stability of the operation and chemical usage.

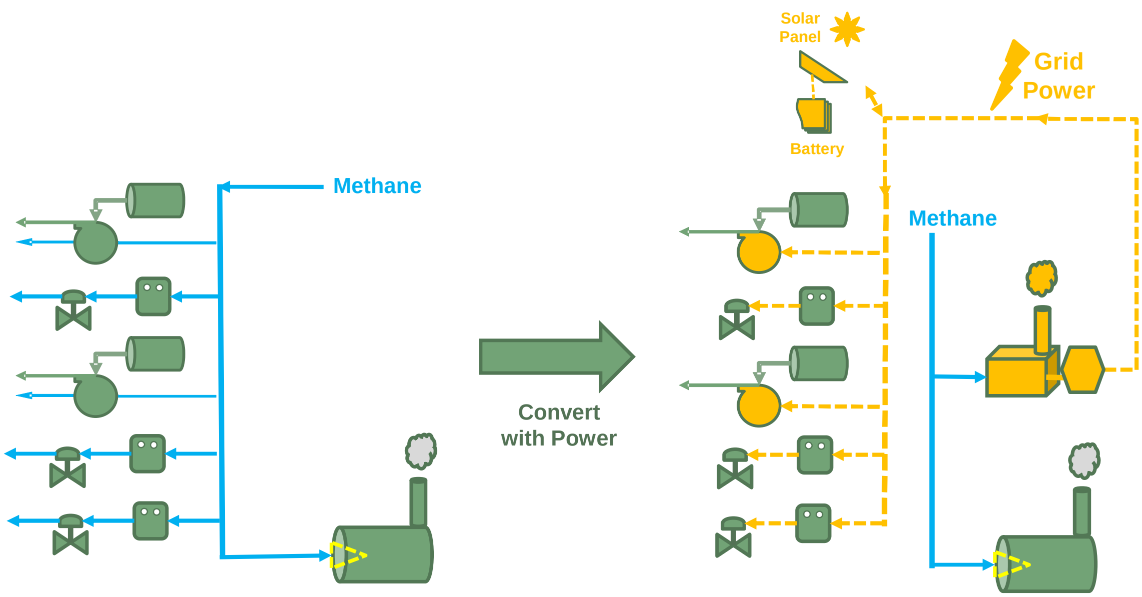

Figure 11 – Overview of Alternative Site Power Options

Updates to Project Objectives

There were no major changes to project objectives which remained as follows:

- **Field Trials** - Producers worked with their onsite teams to ensure the integration of the technologies (solar electric chemical injection pumps, instrument air, enclosed combustors, and novel onsite power systems) with their respective onsite requirements. Testing was performed for several months after the initial installation and commissioning of the technologies were complete.
- **Technical analysis, project management, reporting and dissemination -** Participating companies provided internal resources to share results and analysis and derive conclusions from the field validations. PTAC provided project management, financial management, and reporting to Alberta Innovates and stakeholders, as well as dissemination activities for project outcomes. STV progress reports, learnings, and outcomes were shared at periodic meetings of PTAC committees such as ARPC and TEREE, as well as at PTAC events and workshops, through the PTAC newsletter, for

incorporation in the PTAC handbook, and at engagement activities of the Methane Emissions Reduction Network.

Performance Metrics

- **Investment in Clean Technology –** The project invested a total of $1.9 million for field demonstrations. The Commercialization/Implementation target was $400 million, which should be achieved after ten years. The industry participants indicated near-term corporate plans to install hundreds of site conversions and that many others have already been completed.
- **Number of Field Pilots/Demonstrations** – Original plan was for 26 separate installations and the actual number was 46 different sites.
- **Number of Publications** – The publication target was 5. Publications were targeted in a variety of ways, and those include:
    - PTAC maintains a directory of methane emissions reduction technologies which included the technologies use in these tests.
    - PTAC features the STV project at regular methane mitigation and net zero conferences including a summary of results at PTAC's 2021 and 2022 Net Zero conferences.
    - The PTAC CRIN innovation showcase features many of these technologies. The showcase is constantly shared with both PTAC and CRIN audiences all year round
    - PTAC hosts Focused Conversations events, targeting emissions reduction technologies, where STV technologies and results have been shared.
    - PTAC's Canadian Emissions Reduction Innovation Consortium (CanERIC) committee and events feature STV results
- **Number of Clients Selling Goods or Services Internationally** – At least 5 of the vendors involved in STV trials have communicated with PTAC that the results of the STV project will now be used to support more aggressive moves to sell their products in international markets.
- **Number of Projected New Jobs Created from Future Deployment** – This will be determined from future deployment. It is anticipated to be well over 200, with personnel from equipment vendors, contractors doing site installations, and end-user personnel.
- **Projected GHG Emissions Reductions from Future Deployment** – Projected to be 55 $MtCO_{2e}$ on a cumulative basis by 2030 to 2040, depending on the pace of deployment.
- **Number of Sector HQSP Trained** – Estimate of 70 Industry HSP employed and trained during the project to support the manufacturing, installation, operation, and analysis of 46 field installations.
- **Cost Intensity Reduction on Commercial Development** – To be determined from future deployment. Estimated to be at least a 10% to 30% reduction due to lessons learned on retrofitting and design improvements on "Plug and Play" equipment items.

- **Number of End-users Participating** – Due to corporate mergers, the number of direct industry participants dropped from 4 to 3. However, the number of sites controlled by participants remained the same. Another 10+ producers were involved through their participation in PTAC's methane network.

D. METHODOLOGY

Information Collected on Equipment Field Trails

Participating end-users prepared brief summaries of learnings and spreadsheets to collect information on equipment trials conducted in their field areas. These confidential spreadsheets were completed and submitted to PTAC as of September 30, 2022, for further analysis to validate the results, summarize project findings and prepare this report for Alberta Innovates.

Figure 12: Information Collected from Industry Participants (Producers)

The spreadsheet requested contacts from host site participants to provide insights in five key areas as follows:

1. Technology Overview – General description of the technology being tested in the sub-project
    a. Technology/Vendor Name
    b. Category (Chem Pumps, Instrument air, Enclosed Flare or Remote Power)
    c. Description – Main attributes of the technology

2. Purchase and Installation Overview – Basic quantitative and qualitative aspects affecting the economics of applying the technology, including Capital, Installation, etc.
    a. Date of installation – month and year
    b. Purchase Cost – Cost to the participant or, in some cases, estimated cost of product was subsidized by the vendor or other funding sources.
    c. Installation Cost – Direct cost of installation. Note in some cases, other work was needed at the sites to reactivate the sites or perform other work. For example, the sites hosting the enclosed combustor units were reactivated sites, so the cost of reactivating the wells was not considered part of the project.
    d. Ease of Installation Commentary – This is a key qualitative assessment to indicate the time and ease of conversion for retrofit installations to existing sites. In most cases, these comments would not apply to greenfield installations.

3. Operations Overview – Impacts on operating costs, maintenance, reliability, and other factors. Not all factors apply to all technologies.
    a. Performance Parameters – Might include running hours for power systems, service intervals, etc.
    b. Operating Cost – Generally focused on operating costs for power. However, there is no base case cost, as gas for powering pneumatics or venting has no direct cost associated with it. Directionally it is considered a long-term loss in reserves.
    c. Percent uptime – Where appropriate, what interval of time was the equipment available.
    d. kWh produced – Specific to power generation options
    e. $/kwh – Specific to power options, although again, this will not include energy costs as solar and natural gas have no book value
    f. The efficiency of chemical injections relative to legacy technologies – Specific to chemical pumps related to ease of monitoring, controlling, and optimizing chemical injection rates compared to incumbent manual methods.
    g. % Of Electricity demand covered – Specific to power options
    h. Operations Commentary – Any issues with operations that need to be resolved to optimize benefits and ensure operator acceptance of the technology.

4. Reliability and Maintenance – Reliability is a key factor in the acceptance of new technologies for remote and relatively unattended operations.

a. Reliability and maintenance commentary – General issues which may be due to winterizing, frequency, ease of maintenance, etc.

5. Emissions Overview (Technology Specific) – What was the strategy to achieve GHG emissions reductions?
    a. Comments on the baseline, post-project, and comments on emissions (complete reduction, partial reduction, etc.

    b. Abatement Overview – Emissions mitigation economic factors. This was seen as a key metric for this project but can be difficult to assess as different sites, even with the same equipment, can have radically different emissions. Technologies come in a fixed range of sizes. In some cases, data for a single site may differ from the average for many sites. It is assumed that abatement projects will be prioritized to convert the largest emitting sites first.
    c. Comments on Economics and abatement costs – In some cases, participants attempted payout calculations like more routing oil and gas investments.
    d. Abatement costs (approx. $\$/tCO_{2e}$) – This is a useful indicator of the relative value of abatement activities. Again, to maximize the impacts of investments in mitigation, changes with the lowest abatement costs should be implemented first.

Review and Analysis

PTAC engaged a third-party consultant to review the information submitted, and technology information on vendor equipment and work with participants to validate the test descriptions, results achieved, and overall assessments of the relative viability and utility of the technologies tested through the STV project.

After reviewing the responses to confidential spreadsheet data submitted for each sub-project, participating companies were provided with a list of questions to clarify the test conditions, equipment and to glean additional learnings by comparing results from several locations, producers, and technology providers. The focus of additional information gathering was to obtain information on issues such as: a) Latitude/township of locations with solar equipment to assess range of summer/winter daylight encountered; b) Information on chemical pump configurations uses (simplex, duplex, triplex); c) impact of other concurrent testing of measurement devices; and d) qualitative assessments of costs for field retrofits vs. greenfield installations.

Key learnings were found in all the categories of information listed on the confidential spreadsheets (see the above description). Additional information was provided by participants indicating plans for further roll-out of the technologies, potential modifications, or comments on relative benefits. Some participants also tested measurement technologies which would be useful in assessing benefits and particularly emissions reductions achieved in the field in areas where the information has not been consistently available historically.

GHG Reductions

In almost all cases (except measurement trials) methane emissions reductions were achieved in the field trials. Total annual methane emission reductions from all sites included in the STV are estimated at ~15,000 tCO_{2e}/yr. Instrument air system installations and the single combustor each contributed about 25-30% of the reduction, while chemical pumps and power project technology contributed about 20% each. While the volumes of methane abated at each site varies widely, the mitigation costs for most of the installed systems fell in the range of \$10-\$30/tCO_{2e} over an assumed 10-year life. The exceptions were lower abatement costs for the enclosed combustor and a site where line power was more readily available at the site, so abatement costs were less than \$5/tCO_{2e} over a 10-year life. This indicates that, at least in the case of methane used for power gas, the mitigation costs are generally proportional to the volume of methane being reduced. For combustors the units are designed to handle an extremely large range of flows so for the test site where there was gas flow the combustor unit was closer to its higher design rate, while the site with no gas showed the other extreme of an infinite abatement cost if there is not methane to abate. In conclusion, test sites were mostly successful in reducing emissions and technologies tested in this STV project can be implemented to reduce sources of emissions on a diverse range of sites.

Reliability and Confidence in Some Technologies were Demonstrated

Expanded use of the technologies is an excellent indicator of the testing program's success in increasing confidence in the reliability and cost-effectiveness of the technologies. Participants indicated intention or actual expansion of some tested technologies in other operations. In many cases, statistically significant experience in factors such as reliability will require more installations than was possible in the STV project.

E. PROJECT RESULTS

General Analysis of Project Results by Technology Type

This section provides a high-level summary of the variation on the technology covered by testing and possible other variations or factors which might be considered.

1. **Chemical Injection Pumps** – It was stated by some participants that this service tends to be the highest volume source of methane emissions from controlled sources. The volume of power gas avoided is dependent on the volume of chemicals pumped based on an optimized dosage for a given set of conditions. Some pumps may operate continuously, others seasonally, but from necessity, the pumps will all be required to have variable rates that are adjusted by the operator either onsite or remotely based on their experience with each site. Chemical usage at each site with incumbent technology is not recorded as the operators simply refill the chemical pump tanks as needed to ensure there is always chemical available. The ability to optimize chemical dosing can provide an additional economic incentive for implementing this technology change and is provided as an option with some electrically powered chemical pump systems, so this benefit is difficult to quantify with incumbent technology, so the benefit will also be more difficult to quantify. One participant noted that chemical volumes pumped might be reduced by selecting

new chemicals now on the market, which may be more expensive but require lower dosing, so may be more economical, while at the same time reducing air or power gas required for pumping. Pumps with multiple heads can also have advantages to allowing pumping of more than one chemical if piping changes to implement the conversion are not too extensive or if the installation is a "greenfield" facility. The chart below shows the range of potential abatement costs for this technology options showing a range of costs and that if a grid connection is already supplied to a site, then grid power is the preferred option. For solar powered pumps some of the wider range is a function of additional options selected by the end users and the number of pump heads per pump.

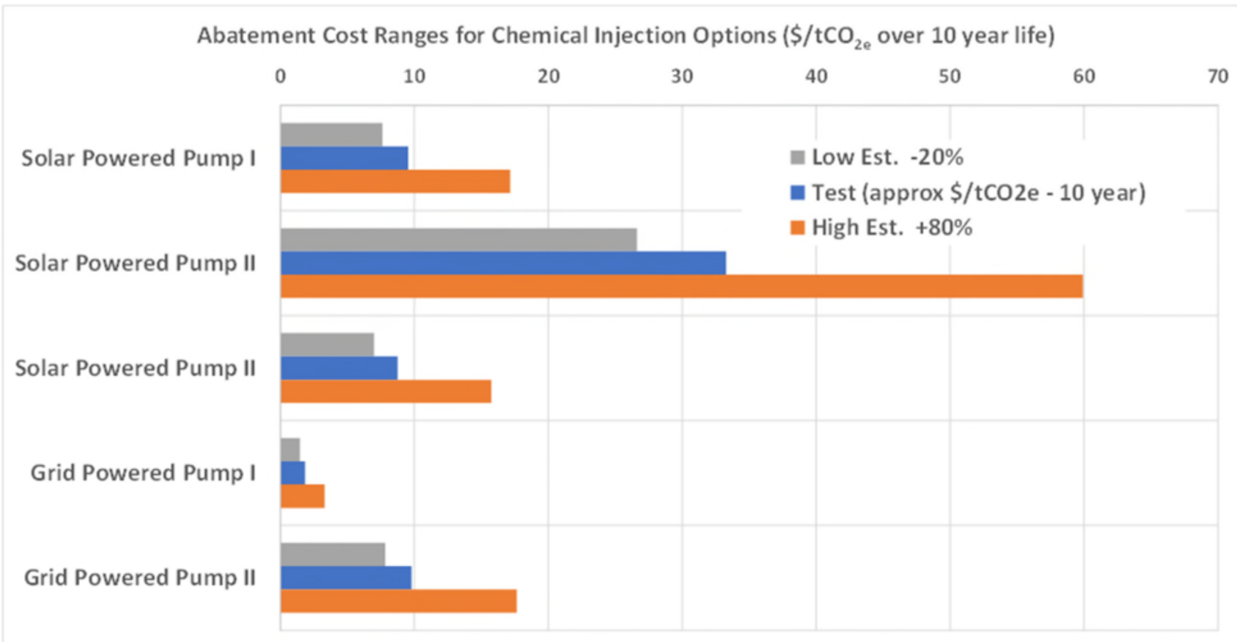

Figure 13 - Abatement Cost Ranges for STV Chemical Injection Pumps Based on An Assumed 10-Year Equipment Life

2. **Instrument Air Compressors** – Air compressors, replace the use of methane used as instrument gas and are used for several functions on a site such as powering pneumatic chemical pumps, instruments or controllers or even providing starting air for small gas compressors. Participants have found that some applications, such as those where some volume of starting air is needed for compressors, require more attention to air receiver sizing to ensure that other air users are not starved. Instrument air compressors seem to generally be sized so that average air usage is at about 10-20% of compressor capacity to allow for changes in air demand which can vary significantly over various time scales. In some cases, with higher short-term demands or lower capacity compressors compared to average load, participants noted a need for larger air receivers. This indicates a need for a solid understanding of the air demand profiles to ensure the right combination of compressors and air storage is selected. The main design factor is the method of powering the air compressors, which could be through a natural gas engine drive, onsite natural gas power generation, solar power, or line power if it is already available on the site for other

reasons. Converting from methane to air for pneumatic devices is straightforward and often does not require a change in the end devices but does require the addition of a separate air distribution piping system to segregate instrument air and fuel gas systems and may also require the retuning of some control devices. Compared to incumbent use of instrument gas, instrument air system result in major methane emissions reductions as the energy required to power a compressor (solar, grid or on-site ng generator) produce minimal GHG emissions (<1-3% of the emissions from methane). Shown below are abatement costs for the systems installed. As with chemical pumps the availability of power (either grid or solar) already on the site provides a cost advantage.

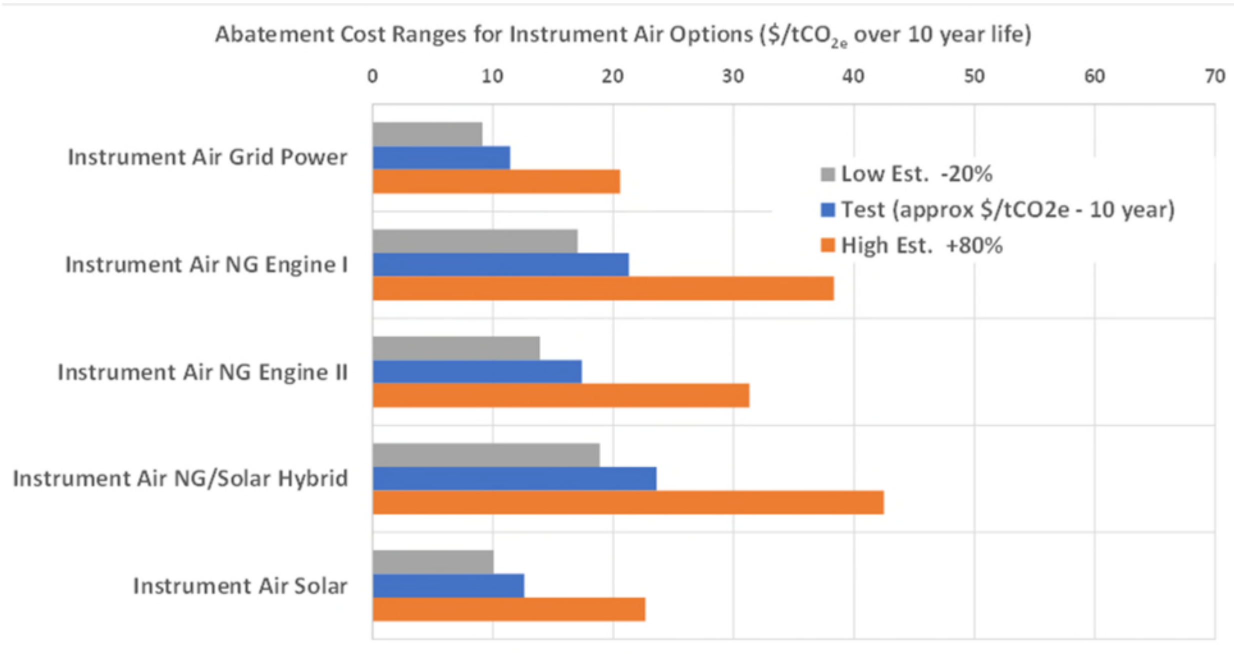

Figure 14 - Abatement Cost Ranges for STV Instrument Air Compressors Based on An Assumed 10-Year Equipment Life

3. **Enclosed Combustors** – Field applications included were more limited than originally planned, and only one type and model of combustor unit was installed at two sites. As expected, one site showed conversion of methane to CO_2, resulting in a significant GHG emissions reduction at a low abatement cost. Net emissions abated would be either 18 to 22 tCO_{2e} per tCH_4 converted and the GHG factor assigned to methane (i.e., 21 or 25). The abatement is not 100% as ~2.75 tCO_2 are generated for each tCH_4 converted, so the GHG reduction achieved is about 86-89%. While conversion is assumed to be high (over 97%), there may be some "slippage" of methane when the units are not operating at optimal combustion conditions, although much less than would occur with an open flare stack. The end-user was not able to assess slippage as it is extremely difficult to measure in the field. The fact that one unit was unable to operate due to a lack of gas production from the well pad selected shows a major challenge with justifying combustor installations despite the low abatement cost. Gas production from many venting wells may either be extremely erratic or stop altogether, which may require units to be relocated. This can be

managed by actively managing where units are located to maximize utilization of the available combustor fleet. For new pad locations, the pads could be laid out to allow easy combustor installation as required. The chart below shows the abatement cost for an enclosed combustor. As with the other charts the low to high estimate range is arbitrary at -20% to +80% but could be much larger for this technology as in the case of the unit where the gas production stopped so the abatement cost would be infinite at that site, but the unit can be readily moved to another site to recover the abatement value.

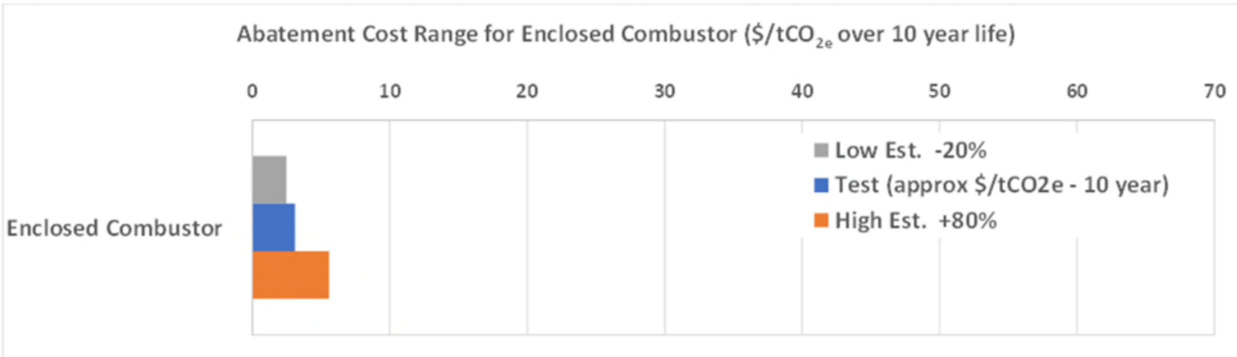

Figure 15 - Abatement Cost Ranges for STV Enclosed Combustors Based on An Assumed 10-Year Equipment Life

4. **Remote Power Generation** – This option allows for either installing an electric drive instrument air compressor or converting onsite devices from natural gas pneumatic to electronic actuation. There may be other uses for the power, such as communications for remote monitoring and operation, etc. which might enhance the justification for conversion. Participants evaluated pure solar, pure natural gas fueled, and hybrid systems. The main difference is the volume of combustion emissions emitted vs. unit price and abatement cost. The major emissions reduction comes from eliminating the use of methane as power gas which can be achieved at a much lower cost using natural gas fired power generators, which are slightly less emissions intensive than average grid power generation sources in Alberta. The additional incremental costs and emissions reductions resulting from implementing solar power (full solar or hybrid) should be assessed based on consideration of the incremental costs of going solar and any change in reliability. i.e., Decision #1 – eliminate methane venting by installing a natural gas power supply for, say, a 95+% reduction in GHG emissions; Decision #2 – higher incremental cost to go further and add some percentage of solar to eliminate all or some of the combustion GHG emissions. Natural gas-fired power generators are off-the-shelf and common for many remote applications in the oil and gas industry and other sectors. At oil and gas sites, natural gas as fuel produces lower GHG emissions than the same generators using gasoline or diesel fuel. Solar power systems have seen significant improvements since they were first introduced. Hybrid systems provide some solar capacity without requiring large investments in battery storage, battery replacements, and impacts of more northern locations on solar availability in winter. The chart below shows the abatement costs for the four test sites with the lowest cost being for a packaged mini-power generation system.

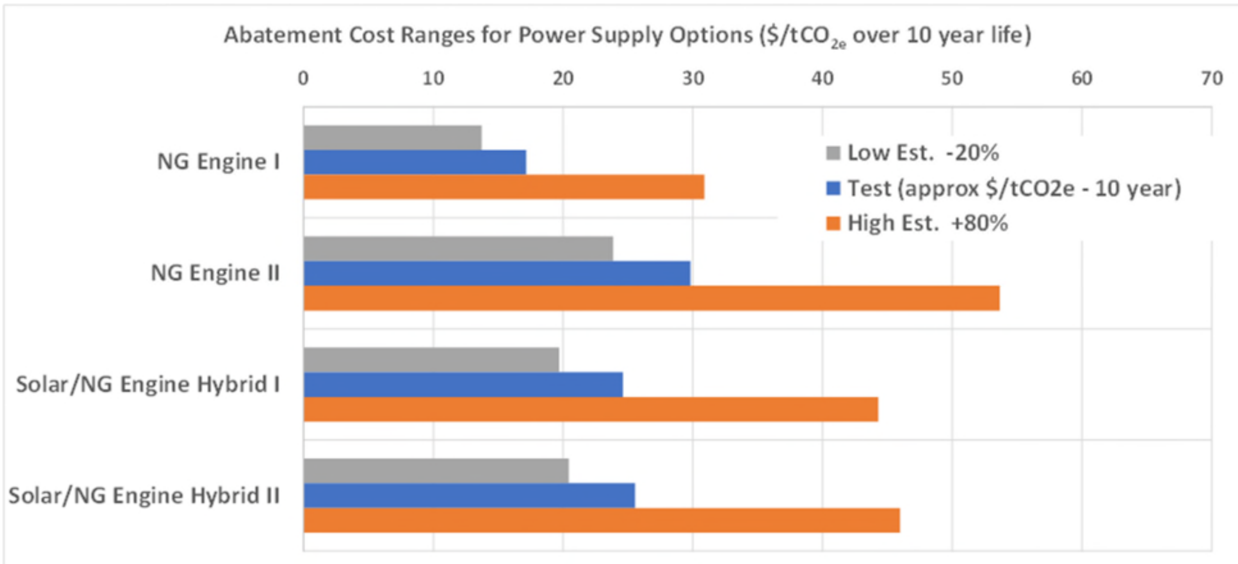

Figure 16 - Abatement Cost Ranges for STV Remote Power Generation Based on An Assumed 10-Year Equipment Life

High-level Analysis of Abatement Costs

Based on data provided by participants on emissions abated and costs, an assessment was made of the abatement costs for each sub-project test program, with results shown above. Some technology tests were single units pre site for power generation, air compression and combustors, while for chemical pumps the values show are averaged over a larger number of sites with the same technology. As tests only provide a single case out of a potentially wide range of sites where the technology could be applied, a rough range of abatement costs was estimated based on the potential emissions reductions of the same equipment at similar sites at different stages in their operational life, or different operational constraints/conditions. For simplicity, it is assumed that the sites selected for this project would be ones with higher venting rates, so the average site may have an abatement cost 80% higher with the same equipment with less abatement, while if there are higher emitting sites, those might have a 20% lower abatement cost with the same equipment because a slightly greater benefit is being achieved. So, a +80%/-20% range is applied to the field test abatement cost values for each project.

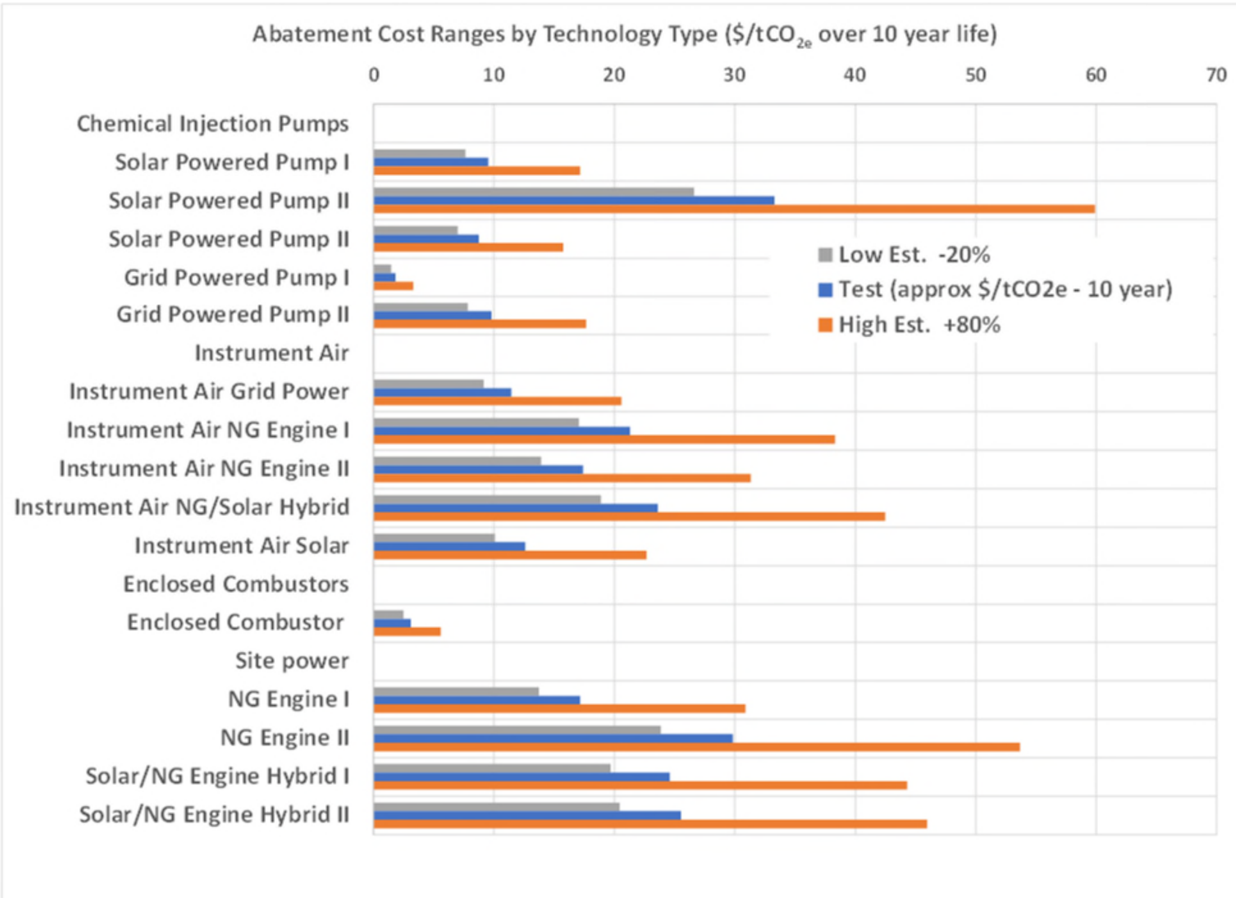

Figure 17 - Abatement Cost Ranges for STV Technology Types Based on An Assumed 10-Year Equipment Life

F. KEY LEARNINGS

Learnings and impacts

Retrofitting systems in the field is more costly, and these costs increase when there are more methane sources are on site. This is because the site layouts are not optimized for the alternate technology so more piping must be installed in the field. An example is where 3-4 single chemical pumps at a site are replaced by a single multi-head pump technology which requires installation of new piping to reach the required injection points in the system. "Plug and Play" packaged systems can partially overcome this barrier. For new facilities, including low-emitting devices in the initial installations will generally always be the best choice to minimize costs, environmental impacts, and the security of the facilities. Many companies have already implemented policies for only installing non-venting equipment at new sites. This policy should be adopted for all remote sites. Specific learnings/impacts for technologies tested include:

- **Chemical Injection Pumps** – Many newer pumps have multiple heads to handle multiple chemicals, which may require re-piping of the chemical injection lines increasing costs for retrofits but increasing benefits for "green field" or new installations. The major criterion for selecting a solar or grid pump is determined by what is available at the site. Grid power may often be more economical if the power is already available at a site. As touched on earlier, determining annual volumes of chemicals used at each site is not done in current operations as chemical use is tracked by operating area rather than individual sites. The methane benefit achieved at each site is proportional to the amount of chemical injection needed, which varies by chemical and over time as operating conditions change over its producing life. Some are continuous, and some are seasonal. Many replacement pumps allow for "smart" operation to allow remote rate adjustments, chemical tank level monitoring, and other features which can add to the economic benefits of making a technology change.

- **Instrument Air Systems –** Where there are many gas-driven devices, installing either solar, grid-powered, or gas engine-powered air compressors can economically reduce methane emissions. The major modification needed to the existing facilities is to separate the fuel and instrument air systems.
- **Enclosed Combustors –** These are viable solutions for vent streams that cannot be reduced by other means. However, due to the unpredictable nature of many of these sources, producers should implement programs to proactively manage a fleet of combustors to ensure they are installed at sites that best use the design maximum conversion capacity of each unit.
- **Alternate Power Systems –** For sites with larger remote sites with more diverse methane sources that need to be mitigated, preference will likely be for gas engine generators or solar/gas hybrid systems to minimize the need for battery storage and ensure that there is power for peak loads. Even though gas or grid systems still cause some emissions, the emissions from combusting natural gas fuel will only be 1-3% of the emissions from using methane gas to power devices, and then be vented.

G. OUTCOMES AND IMPACTS

Project Outcomes and Impacts

Field testing has confirmed the technical and economic suitability of these four technologies for installation in remote oil and gas sites, and the results should encourage a more rapid roll-out of the technologies to other operations, as it is already doing in the operations of the participating producers.

Clean Energy Metrics

- **Investment in Clean Technology –** The project invested a total of $1.9 million for field demonstrations. The commercialization/implementation target is $400 million, which should be achieved after ten years. The industry participants indicated near-term corporate plans to proceed with the installation of hundreds of site conversions. Many others have also already been completed.

- **Number of Field Pilots/Demonstrations** – The original plan was for 26 separate field installations, and it was grossly exceeded as the actual number of demonstrations of various technologies was at 46 different sites. This was due to actual costs of units being lowered than predicted, and a larger flexibility afforded to industry participants to choosing sites that made sense as test sites.
- **Number of Publications** – The publication target was 5. Publications were targeted in a variety of ways, and those include:
    - PTAC maintains a directory of methane emissions reduction technologies which included the technologies use in these tests.
    - PTAC features the STV project at regular methane mitigation and net zero conferences including a summary of results at PTAC's 2021 and 2022 Net Zero conferences.
    - The PTAC CRIN Innovation Showcase features many of these technologies. The Showcase is constantly shared with both PTAC and CRIN audiences all year round
    - PTAC hosts focused conversations, an event targeted to talk about emissions reduction technologies, where STV Vendors and results have been shared.
    - PTAC's Canadian Emissions Reduction Innovation Consortium (CanERIC) committee and events feature STV results
- **Number of Clients Selling Goods or Services Internationally** – Indications are that at least 5 of the vendors involved will now move to sell their products in international markets.
- **Number of Projected New Jobs Created from Future Deployment** – Will be determined from future deployment but is anticipated to be well over 200 with personnel from equipment vendors, contractors doing site installations, and end-user personnel.
- **Projected GHG Emissions Reductions from Future Deployment** – Projected to be 55 $MtCO_{2e}$ on a cumulative basis by 2030 to 2040, depending on the pace of deployment.

Program Specific Metrics

- **Number of Sector HQSP Trained** – Estimate of 70 Industry HSP employed during the project to support the manufacturing, installation, operation, and analysis of 46 field installations.
- **Cost Intensity Reduction on Commercial Development** – To be determined from future deployment. Estimated to be a reduction of at least 10% to 30% reduction due to lessons learned on retrofitting and design improvements on "plug and Play" equipment items.
- **Number of End-users Participating** – Due to corporate mergers, the number of direct industry participants dropped from 4 to 3. However, the number of sites controlled by participants remained about the same. Another 10+ producers were involved through their participation in PTAC's methane network.

Project Outputs

- PTAC held sessions at the 2021 and 2022 Net Zero Conferences, talking with STV participating vendors about their experiences with testing and deploying their solutions. The total attendance at the 2021 and 2022 Net Zero Conferences was 1,681 people. The 2022 session was titled "Session 20: Methane Mitigation • Part 2 • PTAC Success Stories." The Net Zero Conference occurs every year in October. This informative three-day event brought together stakeholders from government organizations, regulatory bodies, oil and gas producing companies, service and supply companies, research centres, and academic institutions to discuss and collaborate on various aspects of oil and gas methane emission detection, mitigation, and reporting. This includes, regulations, policies, research, technology development and deployment, and best practices within five streams: Methane, CCUS, Hydrogen, Electrification and Nuclear towards achieving Net Zero by 2050.
- PTAC has partnered with CRIN to rebrand the Innovation Showcase, an online exhibition space that lists vendors and their innovative technologies. The platform is available 24/7 and allows instant connections with innovators, allowing oil and gas industry audiences to understand better and view technologies that have participated in the STV program.

H. BENEFITS

Economic

The project resulted in direct investments of $1.9M in purchased equipment from Canadian vendors and innovators. Through the project, these suppliers learned about field applications and improved their designs which will increase market penetrations for the technologies. The project showed low abatement costs and, in some cases, economic payouts comparable to normal oil and gas investments, depending on the value placed on the emissions reduction on a $\$/tCO_{2e}$ avoided basis. The chart below shows the distribution of expenditures between the four technology areas. The previous chart showed the ranges of abatement costs for the technologies.

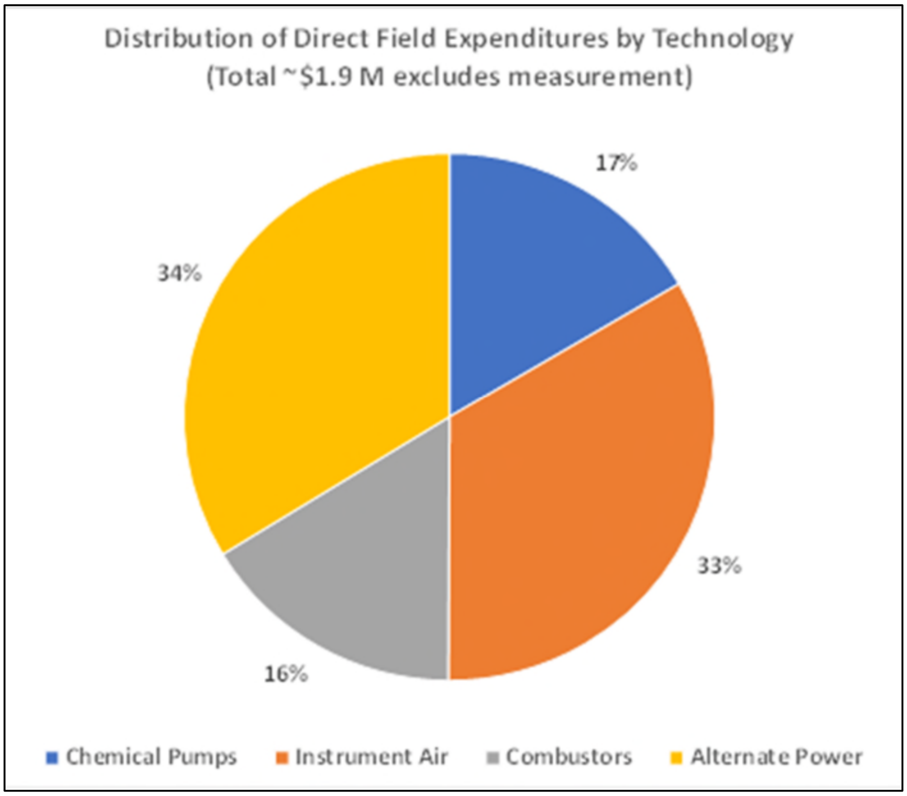

Figure 18 - Distribution of Direct Field Expenditure by Technology

Environmental

The chart below shows the distribution of emissions reduction by technology which were a direct result of the project. All technologies showed a significant reduction in emissions compared to incumbent technologies while being relatively easy to install and with minimal other environmental impacts.

Social

The project created jobs for vendors, producers, and installation personnel, and training to ensure they understood the impacts of the technical installations. Benefits were achieved without creating any significant new risks or hazards to the operations, operating personnel, or local residents (if any).

Building Innovation Capacity

Demonstrating these technologies and highlighting additional potential implementation benefits will motivate innovators to continue making their systems more flexible, versatile, and economically attractive to end users.

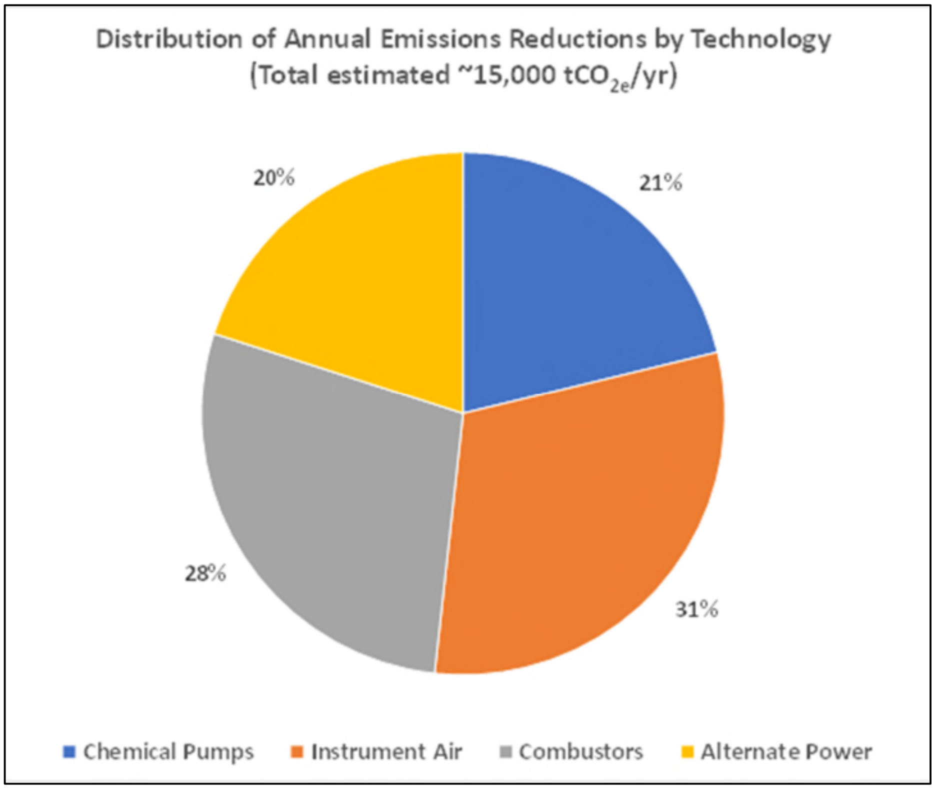

Figure 19 - Distribution of Annual Emissions Reductions by Technology

I. RECOMMENDATIONS AND NEXT STEPS

The project's objective was to generate field-based performance validations in Alberta for a cohort of methane emissions reduction technologies, thus providing operators with information to confidently purchase the equipment at scale and benefiting Alberta innovators with local market growth and a launchpad for exports. Since project inception in 2020, the innovation community has continued to offer novel products to the industry, and field-based performance validations of recently developed methane emissions reduction technologies are needed as new products enter the market. It is also important to note that the original impetus for the project was the policy target by the Alberta and Canadian governments to reduce methane emissions by 45%. There are now discussions about increasing the policy target to 75%, which strengthens the need for additional field testing of more efficient and cost-effective technologies.

With our understanding of this evolving knowledge gap, PTAC has secured additional funding from the Clean Resource Innovation Network (CRIN) to support the field testing of a smaller second, a net new cohort of novel technologies. The CRIN-funded scope is a net addition to the Alberta Innovates scope, and it started in June 2022 and will be completed by March 2023. PTAC continues to look for additional funding to onboard a third cohort of technologies in 2023-24.

Separately, PTAC has secured funding to support the deployment of field-tested commercial methane emissions reduction technologies through its Methane Consortia Program (MCP). However, this program will end in March 2023, and PTAC is also working to identify additional funding sources to support deployment initiatives.

Finally, PTAC supports increasing economic activity and prosperity simultaneously with reducing the environmental impact. A key opportunity is to grow the export of Alberta-developed methane emission reduction technologies to international markets, particularly the United States, as this country is starting to adopt policies to reduce methane emissions. In this context, PTAC has secured funding from Global Affairs Canada to support the update of its directory of methane emissions reduction technologies and to support a trade mission to Houston in March 2023. PTAC continues to seek additional financial support to expand its programming supporting Alberta exports of technologies developed with support from Alberta Innovates.

J. KNOWLEDGE DISSEMINATION

Throughout this two-year project, communications have occurred with participants and stakeholders via email, in-person meetings, webinars, and conference presentations. In particular, the project was highlighted in the 2021 and 2022 editions of the PTAC Net Zero Conference, as well as in the PTAC annual report. Several of the technologies field-tested by the project are also highlighted in video format on the PTAC-CRIN Innovation Showcase platform. Within the year, the showcase will also include successful deployments of these technologies on the field.

The project's public report focuses on technology types, issues to consider, features to be assessed, and overall cost-benefit assessments. PTAC intends to prepare and issue additional public reporting focused on end-users and vendors to assist them in using the project results to made decisions on their own plans to implement emissions reduction solutions in the four technology areas covered in this project.

K. CONCLUSIONS

Project Objective, Key Components and Results

The objective was highly appropriate to remove questions and potential concerns of end-users for the use of the four technologies addressed by this project. End-users involved in the field tests confirmed to themselves and their companies that reducing methane emissions can be achieved using these technologies at a relatively low cost, with minimum problems, and no major impacts on day-to-day operations.

The technologies targeted by this project were assessed based on a wide range of factors as the applications are also very wide with different site constraints (energy sources, number and type of emitting devices, stage of site producing life, and ranges of methane rates). Each technology was tested with suitable variations, and data was collected on key costs, environmental, maintenance, and other impacts.

End-users were involved in showing that the emissions could be effectively mitigated by the technologies used within the constraints of their various operating sites and corporate objectives. Vendors and innovators could demonstrate their products and receive feedback on enhancements to make their products more desirable and valuable in domestic and international applications.

Overall Learnings, Outcomes, Benefits and Next Steps

The main learning was in the development of guidance, as described in this report, showing the relative range of potential abatement costs for the technologies. This should allow end-users to prioritize their roll-out of technologies to achieve reductions in emissions from the largest sources at the lowest cost to accelerate industry-wide reductions.

There is now a solid basis for supporting the roll-out of these mitigation options in the industry. Major producers' results will help motivate those companies to rapidly deploy mitigation measures and encourage others to do the same.

Key benefits involved showing the ability of four different technologies to address a range of methane emissions from several different types of remote facilities.

The next steps include producing a visually appealing and engaging public report to provide other potential end-users, particularly smaller oil and gas producers, with the motivation and information they will need to adopt these technologies sustainably.