CCEME ID E100338

Installation of Air/Fuel Ratio Controllers and Vent Gas Capture on Engines

Final Report

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Total Project Cost	$7,710,426
Total CCEMC Contribution for Project	$2,676,715

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Disclaimer

Executive Summary

Cenovus Energy Inc. (Cenovus) with the assistance of the CCEMC participated in a project to reduce fuel usage and vented emissions of natural gas from engine driven gas compression facilities within Alberta. The project involved installing REMVue® computerized air/fuel ratio controllers onto 11 engines and 28 Slipstream® vent gas capture controllers tying in over 220 vent sources into engines and being used to offset fuel. The project cost $7.71 million with CCEMC funding of $2.68 million. As a result, Cenovus reduced greenhouse gases (GHG) emissions by an approximate 174,700 tonnes CO_2 equivalent CO2e over the estimated 10-year life of this project. The cost ratio is projected to $28.81 per tonne CO2e reduced. Depending on vent rates and the opportunity to install this technology upfront versus in-field retrofit costs has the potential to be below $15/tonne. These results are immediate on installation, verifiable, and sustainable reductions in fuel gas combustion (CO_2 emissions) and methane emissions that have a global warming potential of 25 (CO_2e).

The Cenovus installation of air/fuel ratio controllers (AFRC) and vent gas capture (Slipstream®) on engines project had mixed results. The AFRC results were better than anticipated and by using a site specific audit, the results can be estimated with fairly good certainty for what the energy efficiency / GHG benefits will become. The richer the base case situation the greater the potential savings and GHG reductions.

The Slipstream® portion of the project had other challenges. The Slipstream® system performed better than expected with minimal operational issues. Issues with respect to engine operation or reliability were more of a concern with adjusting set points or having operations staff get comfortable with the technology. The challenge with the Slipstream® was regarding the size and quality of the vent sources and how to economically capture them. Different vent sources have different characteristics and they responded differently to back pressure. Below are a few important aspects that need to be considered when evaluating AFRC and Slipstream® on engines projects:

1. If the engine chosen for AFRC is a rich burn engine, there are energy efficiency gains to be made in the rich to lean conversion.
2. If the engine chosen for AFRC is a lean burn engine, there are zero to minimal efficiency gains to be made.
3. The Slipstream® should be able to manage the incoming gas automatically with no changes to how an operator manages regular operation of the engine. However it does take time for operations staff to learn the system and get comfortable with the technology.
4. It is challenging to economically capture vents to bring into the Slipstream®. Ideal projects have vent sources near the Slipstream® or have an economic means to transport the vent to the Slipstream®.
5. Vent quality, rate and characteristics are unique to each facility and source and time should be taken to better understand them to feel more confident about expected project results.
6. Engine and compressor upgrades can add up costs significantly. It's important to consider those costs when considering the project economics.
7. Offset credits greatly benefit the project economics and can be achieved however it comes with greater administrative burden and record keeping.

The Slipstream® technology was shown to be "as advertised" with the issues around the cost of capturing and delivering the vents to the Slipstream® as well as better understanding the vent quality and characteristic.

Introduction and Project Overview

Cenovus with the assistance of the CCEMC participated in a project to reduce fuel usage and vented emissions of natural gas from engine driven gas compression facilities within Alberta. The project involved installing REMVue® computerized air/fuel ratio controllers onto 11 engines and 28 Slipstream® vent gas recovery controllers tying in over 220 vent sources into engines and being used as fuel. For the purpose of this report the following terminology is used:

1. AFRC – air / fuel ratio controller on an engine.
2. VGC – vent gas capture, also described as the system of vent sources and network of piping tying in all the various vents towards an engine air intake.
3. Slipstream® – controller, instrumentation and valve train that controls the amount of vent gas going into the engine air intake. The VGC and Slipstream® combination is often referred to as Slipstream® in this report.

The scope of the work included the installation of REMVue® AFRC on specific stationary engines (if an AFRC was not already present), plus a VGC and Slipstream® at various facilities. For Slipstream® to work, it must have an AFRC on at least one engine. One Slipstream® controller can handle multiple vent sources. Some of the sites modified already had AFRC installed and therefore just needed the Slipstream® and VGC installed.

In general, the REMVue® AFRC system modifies the engine controls and provides a rapid response control system that provides the proper amount of fuel for the combustion air taken in by the engine depending on engine tuning. load, process gas operating conditions and ambient air conditions. The net effect of the upgrade is an increase in fuel efficiency for the same amount of torque. Additionally, it reduced NOx, N_2O and carbon monoxide, all of which contribute to reduced greenhouse gases.

The VGC and Slipstream® system allows the gathering of low pressure vented gases from a number of compressors or other sources and using that as fuel. The primary vent source for this project was compressor packing vents. Typically packing leaks on sliprods and/or seals on rotating shafts are captured and vented to atmosphere. With VGC and Slipstream®, gases are collected and inserted into the fuel system on an engine controlled by a AFRC system. The AFRC makes the necessary adjustments to account for the additional fuel as the volumes may be variable. Because these vented compressor gases are typically methane rich, recovering small volumes can result in large CO_2e emission reductions. The sites chosen for this project had engines that can use the REMVue AFRC system, or have an existing AFRC. These were typically the Waukesha, White Superior and Caterpillar 3500 series engines larger than 600 Bhp. Then sites that had various vent sources that could be economically VGC'd to the Slipstream® engine.

Figure 1 shows a simplified process how a REMVue® AFRC manages a Slipstream® on a generic 6 cylinder natural gas driven turbo charged engine. It is important to note the metering and valving on the green fuel lines, as well as the waste gate, pressure, temperature transmitters and the REMVue® computerized control panel which operates, manages and controls the system. These distinguish a REMVue AFRC or Slipstream system from typical units.

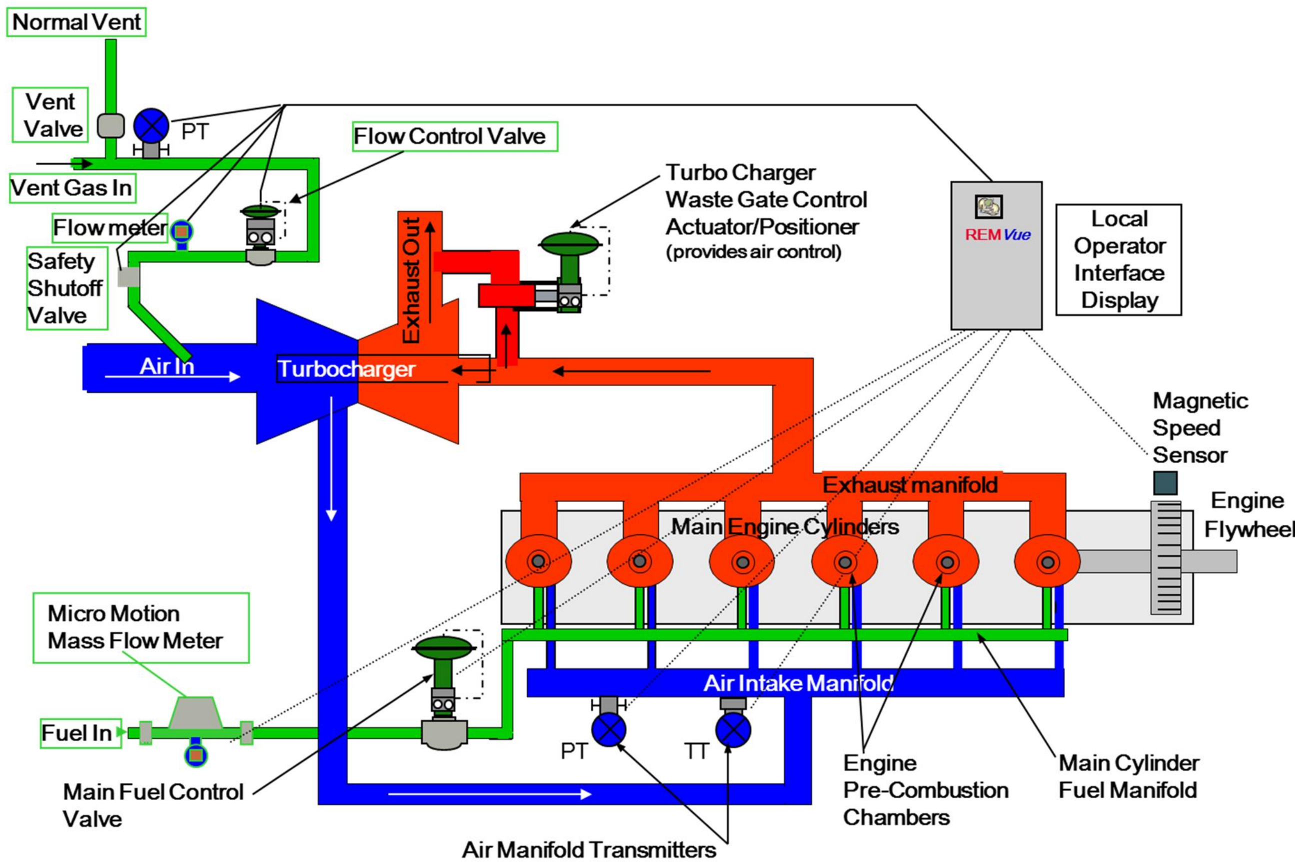

Figure 1: REMVue® AFRC and Slipstream® Process Diagram
(Courtesy of Power Ignition and Controls a division of Spartan Controls, 2014)

Project Goals

Project goals for the installation of AFRC and VGC on engines project were dependant on meeting various milestones and project objectives and proceeding forward (shown in more detail in Schedule A). The main deliverable was installing VGC and Slipstream® on a certain number of facilities. As the project progressed with time as more learnings were accumulated from previous installations and more facility information was acquired the number of facilities decreased.

Table 1: Final Project Outcome	Initial Estimate	01-2012 Forecast	07-2012 Forecast	01-2013 Forecast	07-2013 Forecast	Final
# of Facilities	37	33	33	33	28	28
# of REMVue® AFRC Upgrade Installations	29	20	11	12	11	11
# of Slipstream® Installations	37	33	33	33	28	28

Table 1 shows how the number of facilities for REMVue® AFRC and Slipstream® installations decreased with time. Reasons for the decline were mainly site conditions not being as expected or installation costs being greater than initially expected. The main factors were site layouts which didn't allow for all the economic piping of vent sources. For example, if there were no pipe racks between venting sources or if production declines meant compressor units (venting sources) were being shutdown.

Project Final Outcomes

Project final outcomes for the AFRC and Slipstream® project can be viewed as a whole or into their parts (AFRC and Slipstream®). For the performance analysis of this report, we will focus on AFRC and Slipstream® separately and for the financial analysis we will focus on the project as a whole per facility. The outcomes and results will be discussed in further detail below in the *Analysis of Results*, *Greenhouse Gas Impacts* and *Final Financial Reports* sections.

Literature Review

REMVue® AFRC and Slipstream® are "off-the-shelf" technologies from Power Ignition and Controls a division of Spartan Controls. The Alberta oil and gas upstream industry has quite a bit of experience with the use of the AFRC, however the Slipstream® is considered a less used technology in the industry despite it being quite advanced in it's development. Some key studies on the technology are shown in the following links below and the learnings were incorporated in the development of the project.

PTAC

Stationary Engines Air Emission Research Final Report (Clearstone Engineering Ltd., 2015)
Field Evaluation of the REMVue® LHP Technology (Brown, 2012)EPA
REM Technology Inc SlipStream® System: Industry Impact Assessment With Field Qualification Tests (Zahner, Picard, & Kostek, 2009)
Emissions and Efficiency Enhancements with REM AFR Systems (Zhaner, 2005)

EPA

REMVue Energy Optimization with SlipStream® (Gilbertson, 2008)

Cenovus considered the technology relatively low risk , however there were risks with understanding the various venting sources and their characteristics and how they will respond to being tied into a common header.

Equipment Manufacturing and Commissioning

As mentioned in the previous section, the REMVue® AFRC and Slipstream® are "off-the-shelf" technologies from Power Ignition and Controls a division of Spartan Controls. Manufacturing and commissioning was well defined from the equipment supplier. There were issues with commissioning on the operations side as they learn how to use the technology and operate. Issues were identified with the VGC of the various vent sources, the issues are better described in the *Experimental Procedures/ Results/Lessons Learned* section.

Analysis of Results

Results from the AFRC and Slipstream® project are mixed and will be discussed separately below.

AFRC - Results

As shown in Table 1 Cenovus upgraded 11 engines with REMVue® AFRC. The AFRC upgrade on an engine could have one or all three of the emission and energy efficiency benefits shown below:

1. Potential fuel efficiency with the AFRC upgrade.
2. Allows for Slipstream®, using captured vented gas as fuel.
3. Potential NOX and CO reduction – not reviewed in this report.

Depending on the engine chosen to upgrade there are different things to consider when installing an AFRC. The main consideration for the above benefits depends on where the engine is normally tuned and operated (i.e. whether the engine is a rich burn or lean burn engine). Figure 2 shows how engine tuning and the amount of excess air can effect engine fuel efficiency or emissions. A rich burn engine is considered in the stoichiometric zone or to the left of the stoichiometric zone and a lean burn is considered to the right of the stoichiometric zone.

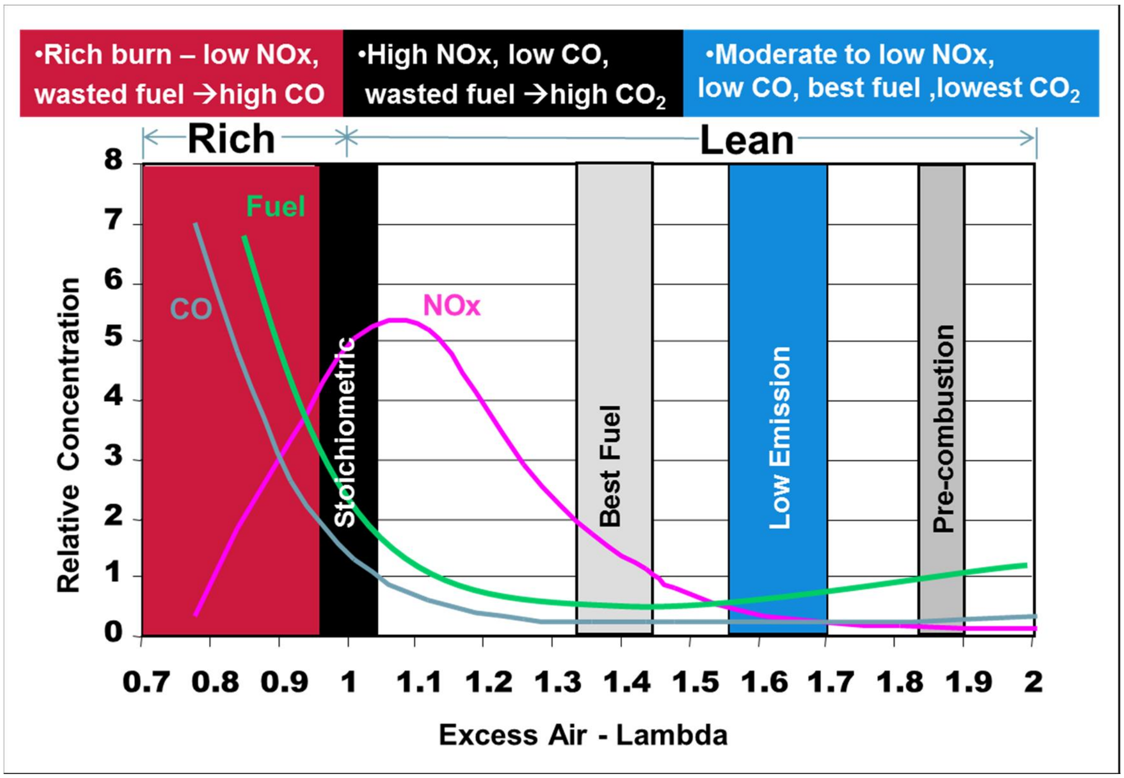

Figure 2: Air / Fuel Ratio and Emissions / Fuel Efficiency
(Courtesy of Power Ignition and Controls a division of Spartan Controls, 2014)

If the engine is a rich burn, the REMVue® AFRC addition allows for a rich to lean burn conversion which has energy efficiency benefits. Doing a rich to lean burn conversion showed nine to 24 percent efficiency gains where the AFRC on lean burn engines show zero percent as the efficiency gain. This is not unexpected since AFRC installations on lean burn engines were originally estimated at about two percent. The cost of the AFRC installation was justified by the installation of the Slipstream® system. The AFRC is needed to allow the Slipstream® system to operate. Theoretically efficiency gains of one to two percent could be expected over time with the engine being constantly tuned with an AFR control vs. manual tuning but it is difficult to show in a one day audit or a snap shot in time. As an example of longer term results, at Verger A, despite the lean burn engine operating very poorly, the engine improvements and modifications showed an improved efficiency by four percent from the audit.

Conversely, when rich burn engines are converted and tuned to lean burn operation, they easily show efficiency gains as shown in Table 2. Note that the results below are commissioning audit results. The continuous metered verified offset results are shown in the Greenhouse Gas Impacts section.

Table 2: Initial REMVue® AFRC Performance Results

	Original Estimate			Actual[1]		
Facility Name	% Efficiency Gain	Fuel Savings / day mcfd	GHG Savings Tonnes CO2E/Year	% Efficiency Gain	Fuel Savings / day mcfd[1]	GHG Savings Tonnes CO2E/Year[1]
Facility 8 K102	2.0%	3.5	67.6	NA	0.0	0.0
Facility 9 K103	2.0%	2.9	57.7	NA	0.0	0.0
Facility 11 K101	6.5%[2]	14.6	285.3	4.0%	26.7	632.3
Facility 13 K101	6.5%	11.4	224.4	10.3%	30.3	698.8
Facility 14 K101	6.5%	8.6	169.4	8.9%	51.0	1152.7
Facility 16 K201	6.5%	10.2	200.9	23.5%	28.1	677.0
Facility 17 K501	2.0%[3]	3.1	61.7	13.5%	5.3	137.1
Facility 18 3 K1	6.5%	5.8	113.4	24.0%	41.3	949.0
Facility 26 K101	15.0%[4]	26.3	545.8	14.8%	22.9	505.4
Facility 27 K710	2.0%	3.2	62.2	NA	0.0	0.0
Facility 28 K105	2.0%	1.8	35.3	NA	0.0	0.0
Total		**91.4**	**1,824**		**205.4**	**4,752**

[1] Savings are based on commissioning and or audit results. Verified offset volumes are shown in the Greenhouse Gas Impacts section.
[2] Initial estimate is high, the engine was actually a lean burn engine but was originally thought to be a rich burn.
[3] Initial estimate is low, the engine was actually a rich burn engine but was originally thought to be a lean burn.
[4] New site which had an updated higher expected efficiency gain for the economics. GHG and fuel savings higher than estimate because we used a pre-audit to better estimate the AFRC benefits.

VGC and Slipstream® - Results

For Slipstream®, the vent gas recovery results are lower than expected. Packing vent rates are variable by nature given packing installation procedure, condition and how they degrade over time. The results to date indicate packing vent rates are consistently lower than what was expected in the initial economics (a leak rate of 0.59 scfm/throw). The results show we are getting, on average, 0.29 scfm/throw. Units that have greater than 0.59 scfm/throw have additional vent sources attached to the system. Results are shown in Table 3. Note that the results below are average daily results (assuming no upsets and 8760 hr operation). The continuous metered verified offset results are shown in the Greenhouse Gas Impacts section.

Table 3: REMVue® Slipstream® Performance Results to Date

Facility Name	Fuel Savings / day mcfd[1]	GHG Savings Tonnes CO2E/Year[1]	# of Compressor Throws	Slipstream® Vent Rate / Throw scfm/throw
Facility 1	10.8	1,368.2	12	0.62
Facility 2	0.6	77.5	4	0.10
Facility 3	0.3	35.3	4	0.05
Facility 4	0.6	77.5	4	0.10
Facility 5	0.3	41.2	12	0.02
Facility 6	3.7	466.3	16	0.16
Facility 7	5.7	721.8	6	0.66
Facility 8	1.2	156.6	6	0.14
Facility 9	1.1	136.6	2	0.38

Facility Name	Fuel Savings / day mcfd[1]	GHG Savings Tonnes CO2E/Year[1]	# of Compressor Throws	Slipstream® Vent Rate / Throw scfm/throw
Facility 10	2.3	357.9	20	0.08
Facility 11	1.9	263.7	6	0.22
Facility 12	1.4	186.0	4	0.24
Facility 13	2.5	270.8	4	0.44
Facility 14	1.2	215.5	4	0.20
Facility 15	0.8	101.3	8	0.07
Facility 16	2.6	435.6	6	0.30
Facility 17	1.4	150.7	4	0.24
Facility 18	4.0	580.4	12	0.23
Facility 19	13.3	1,428.0	12	0.77
Facility 20	5.1	841.9	16	0.22
Facility 21	5.6	720.2	16	0.24
Facility 22	2.6	269.6	6	0.30
Facility 23	15.6	1,679.0	16	0.68
Facility 24	6.8	722.9	8	0.59
Facility 25	3.2	448.5	18	0.12
Facility 26	0.0	30.6	4	0.00
Facility 27	3.4	430.9	8	0.30
Facility 28	3.5	503.6	8	0.30
Total	**101.4**	**12,718**	**246**	**0.29**

[1] Savings are based on commissioning and or audit results. Verified offset volumes are shown in the Greenhouse Gas Impacts section.

It is believed that some of the vented gas is leaking into the crankcase and expect that the recoverable venting rates will increase with a new packing replacement/modification. Unfortunately it is not economic to shutdown units to replace packings given the small amounts of gas recovered from this work. New packings will have to be replaced upon failure of the current packings. Upon upgrade it is expected that initial rates will be low then increase over time as the packings degrade over time. It is important the packings have a pressure ring so vented gas does not just blow by into the compressor crankcase vs into the packing and into the Slipstream®.

It should be noted that packing vent gas is a mixture of oil and gas. Cenovus has taken steps try to knock out some of the oil but at some sites higher than normal oil deposits has been noted on the turbo compressor blades. Currently there has not been a significant amount of oil which would cause us to shut in a Slipstream®, however this is being monitored and evaluated should it become more significant. Other vent sources do not have this concern, it should be something to be considered for any new installations.

Cenovus spent a considerable amount of time investigating the low vent rates and looking for ways to optimize. It appears as though low pressure venting is more affected than previously expected by unexpected and dynamically varying back pressure from various control devices and tubing internal diameters.This is discussed more in the sections below.

Experimental Procedures / Results / Lessons Learned

Collecting vents has proven to be challenging and Cenovus looked for ways to improve vent collection. Problems usually arose in the following three categories:

1. Vent source equipment is not operating as designed.
2. Very low operating pressure of a piping and variable control gathering system reduces the vent rate for vents previously going to atmosphere.
3. Vent rate published emission factors are higher than actual.

As Cenovus tried to better understand the venting source issues were improved where economic during prescheduled shutdowns or regular maintenance. The sections below talk in more detail about the individual vent sources and considerations for optimization.

Compressor Packings

The design of compressor packings and the location of vent ports vary considerably for each compressor manufacturer and model. In addition, prior to the Slipstream® project if a compressor was venting gas out of the packing vent or the crank case vent, the gas volume was considered too small and difficult to recover. In sweet service applications, it doesn't matter if the packing vented out of the packing vent or the compressor crankcase, usually only being monitored in a failure condition.

Now that we want to collect the gas out of the packing vent, vent tubing design has become more important. What we found with this project is that, in some cases, a slight back pressure on the packing vent tends to decrease vent rates or force the vent gas into the crankcase. Venting natural gas into the crankcase is not considered a best practice and should be avoided.

If a packing does not hold any pressure it may have the ability to depressurize the entire VGC system into the distance piece or to the crankcase. At one site, one compromised compressor throw out of several actually reduced gas from going into the air intake. As the project progressed we started testing each packing's ability to hold pressure, making modifications if necessary. This increased modification costs.

Through a test method Cenovus and the vendor have developed, we tested each packing tied into VGC individually and found that a many of them leak into the crankcase and require replacement or some modification. Cenovus has replaced some of the packings where we have had the ability to do so. Unfortunately doing this work cannot be justified on its own merit and will be managed with existing maintenance. It is important that when connected to a Slipstream® packings have a pressure ring so vented gas does not just blow by into the compressor crankcase vs into the packing and into the Slipstream®. Cenovus is trying to upgrade packings on Slipstream® units as we replace packings in already scheduled downtime going forward.

Instrumentation Vents

Instrumentation vents have been a continuous source of vented emissions for Slipstream® when sites had instrument gas available versus instrument air. Vent rates to date have not been what was expected, so flow rates to the Slipstream® have been lower than the anticipated published rates. Cenovus recently had a fugitive emission study done at four sites looking at instrument vent gas. The fugitive emission study compared individual metered instrumentation vent rates to Slipstream® metered rates. The Slipstream® rates were found to be consistently lower than the sum of the individual vent sources. This would imply a back pressure or restriction in the instrument vent header and/or the VGC piping and controls.

Cenovus investigated this further to determine if the back pressure is causing instrumentation to vent less or if we are losing the gas elsewhere. The fugitive emission study seems to indicate that the gas is not being lost elsewhere, however the metering type does have an effect. Passive continuous metering versus instantaneous 'vacuum' metering (high flow sampler) is showing consistently different results with passive continuous metering showing lower flow rates that match with the Slipstream® meter. It could be that the back pressure is causing the instrumentation to vent less by choking at the instrument, or the vacuum is causing the instrument to vent more. A recent bench test that was done on some instrumentation to determine the effects of back pressure verified that venting was reduced but not significantly. From the bench test there were some instruments that are "bad actors" and do not hold pressure very well, venting through cracks in the casing. Cenovus will continue to monitor the integrity of the instrument vent system with its fugitive emission audits. Regardless of the results, the published vent rates seem to be conservative. These may be fine for emissions reporting and facility design but have the opposite effect for emissions reduction opportunities and GHG crediting.

Dehydrator Flash Gas

Tied-in flash gas is a significant source of fuel for the Slipstream® system that often is sent to the flare or vented. Cenovus has some Slipstream® sites that use dehydrator flash gas as a vent source, testing was done to see if reducing flash tank pressure has an increase in vent rates. Testing has shown that reducing flash gas pressures is not resulting in significant volumes of additional gas. Ninety-five percent of the gas is being recovered in the initial flash from high pressure to 350 kPag (50 psig). Dropping flash tank pressure below 50 psig does not increase vent rates significantly, that said it is recommended to have the flash tank pressure as low as acceptable from a VGC perspective.

Discussion

Results for this project have been mixed. AFRC rich to lean conversions have been better than expected but really are a function of how the engine was tuned in the base case. The more rich the engine was tuned (usually for best power and reliability) the greater the results from the audit. The benefits are considered real because the audited tuning point is the normal operating point. Having a base condition of an engine tuned at stoichiometric would result in lower savings from moving to a lean condition, this is expected and shown in Figure 2. Overall AFR results were positive and showed better than expected energy efficiency gains. AFRC on lean burn engines have not resulted in notable efficiency gains, however do offer more certainty in engine tuning vs carbureted engines.

VGC and Slipstream® results were also mixed. The Slipstream® system showed great results with respect to how it handled vents coming into the engine. No notable decrease in engine operation, maintenance or reliability were noted (with proper maintenance and operation). The issue was with respect to the vent rates, vent quality (ie. consistent rate and or composition) and bringing the vents to the Slipstream®. Vent rates were variable at each site. It has been shown in this project that estimating vent flow rates is difficult using emission factors or "snap shot" vent rate samples. It's important to estimate vent rates with some back pressure to better understand the venting characteristics and rates. Maximizing the recovery of vented gases in the future will require monitoring from operations and ensuring Slipstream® sources are properly maintained. Current optimization efforts show that whatever optimization is done (if the system is sealed and holds pressure) it shouldn't increase vent rates significantly.

As mentioned above there weren't any significant issues with an engine using a Slipstream®, the issues were with respect to vent rates and bringing the vents to the Slipstream®.

Scientific Achievements

As mentioned in the previous section, the REMVue® AFRC and Slipstream® are "off the shelf" technologies from Power Ignition and Controls a division of Spartan Controls. There was nothing to patent or publish, however project results and learnings were shared with the public. The following conferences were used to help communicate the project successes and learnings:

PTAC – Emissions Management, Energy Efficiency and CO2 Credits Forum – November 20, 2013 Calgary - Alberta – REMVue® Slipstream® Vent Sources and Optimization

AEEA – Alberta Energy Efficiency Alliance Conference – January 29, 2014 Calgary, Alberta - Cenovus Energy Inc. EE Case Study REMVue® AFR Slipstream® Air/Fuel Ratio Control and Vent Capture Project

CIPEC – Energy Summit – May 14, 2014 Niagara Falls, Ontario – Cenovus Energy Inc. EE Case Study REMVue® AFR Slipstream® Air/Fuel Ratio Control and Vent Capture Project

CPANS – CPANS Annual Conference – May 22, 2014 Edmonton Alberta - Cenovus Energy Inc. EE Case Study REMVue® AFR Slipstream® Air/Fuel Ratio Control and Vent Capture Project

Greenhouse Gas Impacts

The expected GHG impacts of this project vary and are expected to increase with time as packing seals degrade over time. Cenovus was successful in getting verified offset credits for these projects in 2011-2012 and is in the process of verifying 2013 and 2014. Table 4 below shows the 2011-2012 verified offset credits and their estimated reduction moving forward (please note the disclaimer with the forward looking CO2e annual savings).

Table 4: REMVue® AFR and Slipstream® Offset Credits and Anticipated Future reductions

Facility Name	2011[1]	2012[1]	2013[2]	Anticipated Future Annual Savings[3]
	Tonnes CO2E/yr	Tonnes CO2E/yr	Tonnes CO2E/yr	Tonnes CO2E/yr
Facility 1	0	0	433	1,368
Facility 2	0	0	0	77
Facility 3	0	0	18	35
Facility 4	0	0	0	77
Facility 5	0	0	84	41
Facility 6	7	67	296	466
Facility 7	0	0	480	722
Facility 8	0	0	86	157
Facility 9	0	0	27	137
Facility 10	0	0	141	358
Facility 11	0	98	606	896
Facility 12	0	27	129	186
Facility 13	83	45	959	970
Facility 14	137	1,191	2,053	1,368
Facility 15	0	23	101	101
Facility 16	0	842	1,138	1,113

Facility Name	2011[1]	2012[1]	2013[2]	Anticipated Future Annual Savings[3]
	Tonnes CO2E/yr	Tonnes CO2E/yr	Tonnes CO2E/yr	Tonnes CO2E/yr
Facility 17	18	266	236	288
Facility 18	0	1,189	1,129	1,529
Facility 19	0	0	517	1,428
Facility 20	0	565	874	842
Facility 21	0	290	597	720
Facility 22	0	0	48	270
Facility 23	0	774	1,495	1,679
Facility 24	8	268	751	723
Facility 25	449	327	312	449
Facility 26	0	0	8	536
Facility 27	0	0	227	431
Facility 28	0	28	425	504
Total	**704**	**5,999**	**13,169**	**17,470**

[1] Actual verified offsets.
[2] Based on actual data that has not been verified yet.
[3] This report contains forward-looking information prepared solely for the purposes of providing information about technology used by Cenovus Energy Inc. and is not intended to be relied upon for the purpose of making investment decisions, including without limitation, to purchase, hold or sell any securities of Cenovus Energy Inc. The information provided in this report about technology used by Cenovus Energy Inc. are estimates only and future vent rates or run times may vary. Readers are cautioned not to place undue reliance on forward-looking information as our actual results may differ materially from those expressed or implied. Additional information regarding Cenovus Energy Inc. is available at cenovus.com.

Table 4 shows varying GHG offsets throughout the year. The main explanation for the yearly variation is the project commission date or operators not turning the unit back on after an upset (whether for technical reasons or just a failure to turn the unit back on). The GHG reductions are estimated to be 17,470/yr going forward assuming the units and system is run 365 days of the year and process conditions stay constant. Over 10 years this is a reduction of 174,700 tonnes for the life of the project. The results are a combination of AFRC and Slipstream® GHG reductions. The AFRC reductions can be considered to be fairly constant, however the Slipstream® reductions are a result of vent rates which can vary greatly and rely on proper maintenance to ensure system integrity (VGC system hold pressure, no system leaks). Future reductions once verified will be registered with the Alberta Emission Offset Registry. Registering the credits has been a learning experience for Cenovus and the administrative and record keeping burden should be considered prior to applying for carbon offsets. With the offset credits obtained using the Alberta Offset Protocol system, the economics of this project was improved.

Overall Conclusions

The Cenovus installation of AFRC, VGC and Slipstream® on engines project had mixed results. The AFRC results were better than anticipated and by using a site specific audit can be estimated with fairly good certainty for what the energy efficiency and GHG benefits will become. The richer the base case situation the greater the potential savings and GHG reductions.

The Slipstream® portion of the project had other challenges. The Slipstream® system performed better than expected with minimal operational issues. Issues with respect to engine operation or reliability were more of an issue with adjusting set points or having operations get comfortable with the technology. The challenge with the Slipstream® was regarding the size and quality of the vent sources and how to economically capture them. Different vent sources have different characteristics and they responded differently to back pressure. If someone is considering a AFRC and Slipstream® on engines project one should consider all of the following:

1. If the engine chosen for AFRC is a rich burn engine, there are energy efficiency gains to be made in the rich to lean conversion.
2. If the engine chosen for AFRC is a lean burn engine, there are zero to minimal efficiency gains to be made.
3. The Slipstream® should be able to manage the incoming gas automatically with no changes to how an operator manages regular operation of the engine. However it does take time for operations to learn the system and get comfortable with the technology.
4. It is challenging to economically capture vents to bring into the Slipstream®. Ideal projects have vent sources near the Slipstream® or have an economic means to transport the vent to the Slipstream®.
5. Vent quality, rate and characteristics are unique to each facility and source and time should be taken to better understand them to get better confidence on expected project results.
6. Engine and compressor upgrades can add up costs significantly. It is important to consider those costs when considering the project economics.
7. Offset credits greatly benefit the project economics and can be achieved however it comes with greater administrative burden and record keeping.

The Slipstream® technology was shown to be "as advertised" with the issues around the cost of capturing and delivering the vents to the Slipstream® as well as a better understanding of the vent quality and characteristics.

Next Steps

The next steps for the AFRC, VGC and Slipstream® on engines project is to investigate other potential vent sources which can be taken into the Slipstream® ie. dehy still vent gas. Now that the Slipstream® technology is in place, it makes tying in other vent sources more economical.

Regarding the AFRC installed, Cenovus is looking at ways to incorporate this technology in maintaining future compliance for NOX emissions with respect to engine tuning. AFRC from rich to lean conversions is one of the only technologies which reduces NOX emissions while at the same time showing some energy efficiency benefits.

Technology / Process / Innovation

As mentioned in the previous section, the REMVue® AFRC and Slipstream® are "off the shelf" technologies from Power Ignition and Controls a division of Spartan Controls. Process improvements did not revolve around the technology as much as it revolved around improving methods to capture vents, best practices and econonmic carbon offset realization.

Commercialization

As mentioned in the previous section, the REMVue® AFRC and Slipstream® are "off the shelf" technologies from Power Ignition and Controls a division of Spartan Controls. The product is already comercialized and marketted.

Communications Plan

As mentioned in the previous section, the REMVue® AFRC and Slipstream® are “off the shelf” technologies from Power Ignition and Controls – a division of Spartan Controls. Cenovus has been communicating the project results and best practices to industry where applicable. Best practices and offset credit learnings are being shared with industry and suppliers to better improve the product and optimize technology performance and costs.

Final Financial Report

The costs for the AFRC, VGC and Slipstream® on engines project were significant and GHG reductions were not as high as initially anticipated. Table 5 shows the capital cost and $/tonnes CO2E reduced.

Table 5: Total Investment and Expected GHG Reductions

Project Cost	$7,710,426
CCEMC	$2,676,715
1 year tonnes saved	17,470
5 yrs tonnes saved	87,351
10 yrs tonnes save	174,703
$/tonne CO2E without CCEMC	$44.13
$/tonneCO2E with CCEMC	$28.81

Table 5 shows the economics of the entire project from initial engineering to construction, commissioning and offset realization. The cost of $44.13/tonne (without CCEMC support) is significant, however as the project went on, it is foreseeable to see a new project be less than $15/tonne depending on site conditions and venting opportunity. Costs for installation dropped with time as upfront engineering costs decreased the amount of engineering costs in the ladder projects. The initial cost to engineering and piloting the first Cenovus Slipstream® was approximately four times the cost of some of the ladder installations. The greatest cost efficiency would be realized by installing this equipment at the development stage of the project instead of going into existing facilities and retrofitting. Having a high quality large vent source would greatly change the cost per tonne as well. Cenovus’s experience was that the Slipstream® technology could handle larger vent sources, it was just that the sources we had were not as significant as expected. Significant costs were associated to fine tuning the system and attaining offset credits. As installations were advancing the learnings from previous projects were applied to the new projects and costs improved with time.

When reviewing the costs depending on the project, costs can vary significantly. In general projects can fall in four categories.

1. Slipstream/VGC only (chosen unit has an existing AFRC)
2. Slipstream/VGC and engine/controller upgrades (chosen unit has an existing AFRC)
3. REMVue AFRC and Slipstream/VGC
4. REMVue AFRC and Slipstream/VGC and engine/controller upgrades

Prices for the VGC and engine/controller upgrades varied however on average you could consider each component equal, for example a project type of 1 is 1/3 the price of a project type of four and a project type of two could be the same price as a project type of three. Income from the fuel savings and GHG offsets are not shown in this analysis, however one could take the analysis above and do economic calculations based on assumed fuel and offset prices.

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Schedule A

		Milestone
1	HAZOP	Choose one site with REMVue installed, conduct Hazardous Operations (HAZOP) Study on Slipstream and install Slipstream, modifying HAZOP results as required.
2	Surveys, Design, Install	Re-assess field locations to install combinations of REMVue and Slipstream System. Field survey and engineering design, drawings and approvals. Revise cost estimates. Prepare 3 locations for Slipstream to align with shutdown.
3	Approvals and Planning	Meet with operations and facility supervisors to organize installation downtime around turnarounds and maintenance requirements. Ongoing field work.
4	CCEMC Status Meeting	Meet with CCEMC to report on status. Ongoing field work.
5	Purchase 2011 Equipment	Purchase 2011 equipment and materials. Install 6 locations.
6	Pre-Purchase 2012 Equipment	Pre-purchase portion of 2012 equipment and materials.
7	Install	Complete engineering design, final procurement, and installation of 4 sites by mid 2012.
8	Final Install	Complete remaining engineering design, final procurement, and installation of 18 sites by end of 2013.
9	Testing and Data Collection	Final tune-up and system results testing and reporting, site by site as completed.
10	Final Reports	Final reports verification
11	Holdback	Receive holdback