TECHNOLOGY FOR EMISSIONS REDUCTIONS

COLD HEAVY OIL PRODUCTION WITH SAND (CHOPS) METHODS FOR REDUCTION OF METHANE VENTING

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Executive Summary

In Alberta and Saskatchewan, proposed legislation aims to reduce venting from Cold Heavy Oil Production with Sand (CHOPS) sites. The volumes venting to atmosphere are small. In some cases, there is incentive to reduce the emissions with Carbon Tax Credits for sites producing less than 500 m^3/d. The greatest challenge in reducing emissions is designing systems to capture and utilize the low flow volumes and intermittent flow from the surface casing and tank venting and the ability to measure these volumes. Additional difficulties encountered are designing for the low pressures experienced from the venting and the fact the gas is water wet and will freeze without heat tracing. Typically, there is no power on site to provide electric tracing which compounds the problem.

Numerous technologies were investigated, but none can be implemented easily with the exception of the Hexa-Cover solution. The solution reduces the tank vapours, but these vapours account for no more than 5% of the methane emissions from a typical site. Therefore, capture of excess casing gas is required to provide effective emission reduction at CHOPS sites. Since the design considerations tend to become complex, the solutions will involve proper engineering to solve the site-specific problem to ensure the sites can be safely operated. Additional challenges will be present at sites where pipeline and power infrastructure does not exist. In this case the Producer will find that combustion solutions are currently the best alternative.

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Sentio Engineering

PETROLEUM TECHNOLOGY ALLIANCE CANADA PTAC

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1.0 STUDY PURPOSE AND OBJECTIVES

The purpose of the study was to find solutions to reduce the Methane venting from Cold Heavy Oil Production with Sand (CHOPS) facilities in order to conserve Methane when possible. This study evaluates the various technologies currently being used to reduce emissions and identifies any new technologies with potential for reducing emissions. Recommendations are provided for the best technologies for the various applications.

The technologies selected for examination are listed below.

- VRU (Vapour Recovery Unit);
- Slip Stream Green Tank System (GTS) for CHOPS;
- T.O.P. Tank (Thermally Optimized Production);
- Hexa-Cover;
- Solution gas compression;
- Combustion - HY Bon combustors, Black Gold Industries combustor, flaring, “Cool” TCI (Total Combustion Inc.) Incinerator,
- New technology from a literature search.

A brief description of each technology will be provided. The report will detail:

- Key equipment components;
- Piping and control requirements;
- Process schematic;
- Operational challenges;
- Safety concerns;
- Costs for greenfield and brownfield installations;

2.0 DESCRIPTION OF CHOPS FACILITIES

CHOPS is the primary method of heavy oil production. The facility typically consists of a well equipped with a gas engine which drives a hydraulic power unit which in turn drives a Progressive Cavity Pump (PCP). The engine jacket water can be used as the heat medium for the heat tracing to prevent the collected gas from freezing. Alternatively, the engine skid can generate electricity which is utilized for heat tracing. Oil produced from the well flows from the wellhead to a heated, insulated tank. The tank vents to the atmosphere. Tank heat is required to maintain the appropriate viscosity of the oil for tank unloading. Typical tank temperatures are around 80°C. The tank temperature affects the amount of emissions being vented to atmosphere. In order to reduce tank venting it is recommended to keep the tank temperature as low as possible and still maintain an acceptable viscosity for trucking. Another consideration is to choose the chemicals used to treat the oil carefully to ensure they are not flashing and adding to the emissions on site. Oil is periodically trucked out of the tank to a plant for processing.

A typical CHOPS site is depicted in Figure 1.

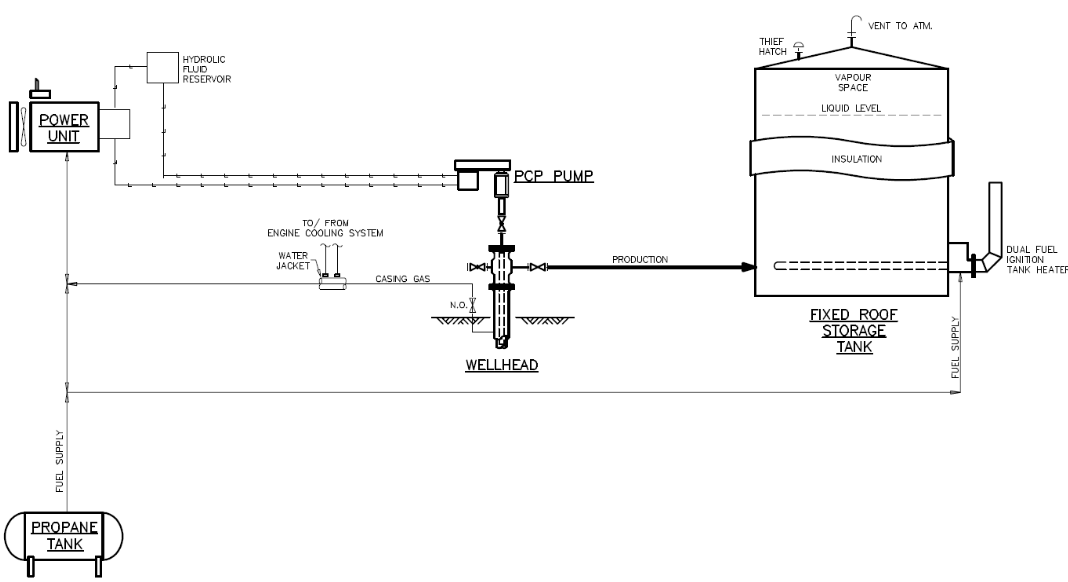

Figure 1: Typical CHOPS Components

Figure 2: Typical Small CHOPS Site (*Photo Courtesy of Spartan Controls*)

Sources of emission are from the well casing vent and the production tank on site. The maximum transient flow rates for this study are 2,000 m^3/d (71,000 scfd) of casing gas and 100 m^3/d (3,500 scfd) of tank venting. These represent 95% and 5% of the total emissions, respectively. Flow rates will vary significantly from zero to the maximum value. Most CHOPS sites emit less than 500 m^3/d as shown in Figure 3. For the purpose of this report, evaluations were completed for the following rates of venting:

- 0 – 500 m^3/d – carbon tax credits may be provided for emissions reductions;
- 500 – 900 m^3/d – this range of vented gas is required to be combusted or conserved. It is not allowed to be vented. No carbon tax credits are available for these sites.
- 900 – 2,100 m^3/d – this volume needs to be combusted or conserved. An economic test should be completed to determine if the stream can be conserved.

Equipment sizes and Greenhouse Gas (GHG) emissions are evaluated for these rates.

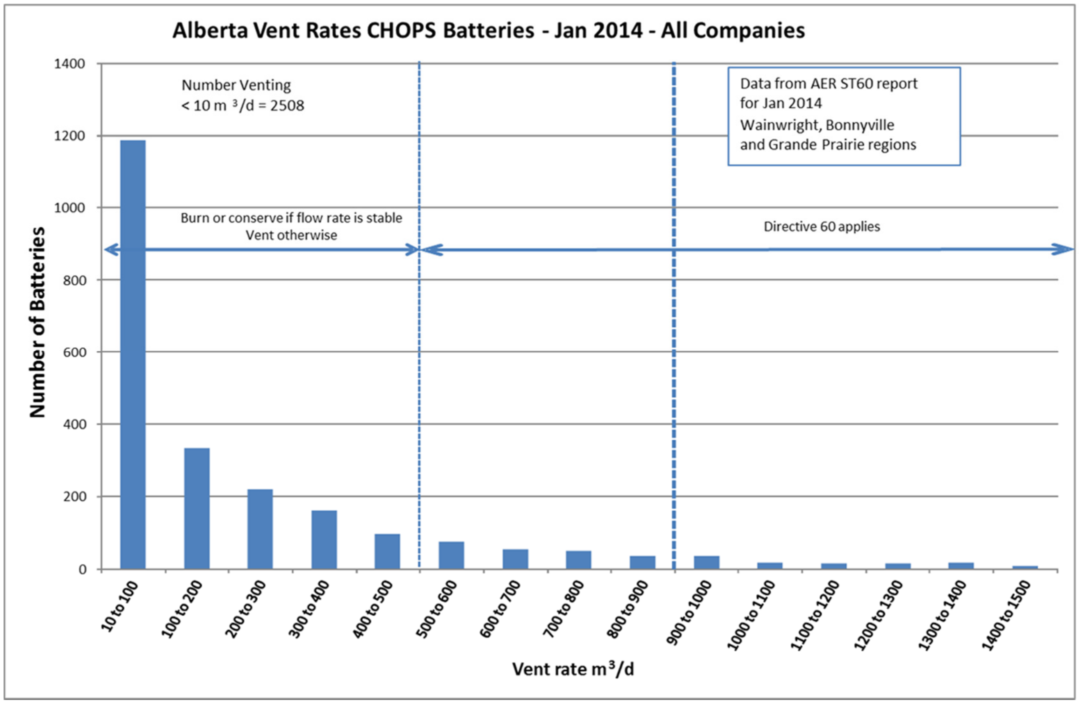

Figure 3: Vent volumes at CHOPS Site (*Graph Courtesy of Spartan Controls*)

Table 1 shows the expected emissions and the CO_2-equivalent for the flowrate ranges under consideration. For the purposes of this study, it is assumed that combustion is complete, i.e. all of the Methane is burned and converted to only CO_2 and H_2O. For each 1 kg of Methane, 2.74 kg of CO_2 and 2.25 kg of H_2O are released.

The CO_2-e value is obtained by multiplying the mass of the Methane by its Global Warming Potential (GWP) factor. The currently accepted value of GWP for Methane is 25.

For comparison, the outcomes of 100% recovery are shown in Table 1. This represents the case where all of the Casing Gas and all of the Tank Venting is combusted. The amount of CH_4 shown is the total amount of CH_4 in the gas for the corresponding flowrate. The values for CO_2 show the amount that would be generated by complete combustion of all of the gas. The CO_2-e value shows the equivalent value of the Methane if all of the gas is vented instead of being incinerated.

For example, at a combined flowrate of 900 sm^3/d (Casing Gas + Tank Vent), the flowrate of Methane in the gas is 611 kg/d (223 t/y). If all of this Methane is incinerated, the amount of CO_2 that would be generated would be 1675 kg/d (611 t/y). If the gas is vented instead of being incinerated, the CO_2-e of the Methane is 15,264 kg/d (5,571 t/y).

Table 1: CO2 Rates for Combustion versus Venting

Casing Gas + Tank Vent		100% Recovery Casing Gas + Tank Vent		95% Recovery Casing Gas Only	5% Venting from Tank
Flowrate	CH_4	CO_2	CO2-e	CO_2	CO_2-e
sm^3/d	tonne/annum				
500	124	340	3,095	323	155
900	223	611	5,571	581	279
2100	520	1,426	13,000	1,355	650

In the typical CHOPS configuration, the casing gas and tank emissions are vented to atmosphere. Considering a total flowrate of 900 sm^3/d is venting at a padsite, the amount of CH_4 venting to atmosphere is therefore 611 kg/d (223 t/y). If the casing gas is combusted, and it is assumed there is 100% efficiency (of 95% of the total emissions), this would generate 1591 kg/d (581 t/y) of CO_2. The remaining gas (Tank Vent) is emitted directly to atmosphere and the CO_2-e is 763 kg/d (279 t/y).

If the goal is to reduce the CO2 emissions, there is an advantage to combustion compared to simply venting the gas.

The ambient temperature has an impact on tank emissions – emissions increase with higher temperatures. This effect can be mitigated provided the tank is adequately insulated and its temperature controlled. It can then be assumed that all internal regions of the tank are at the same temperature and no change in vapor pressure of the fluid content occurs. When no change in vapor pressure occurs, tank venting is minimized. However, where there is inflow or outflow of the tank, emissions will be generated.

Emissions from the wellhead are also present in the form of casing gas. Oil production is maximized when the backpressure on the well casing annulus is minimized. Casing gas is vented through the casing valve on the wellhead. Closing the casing valve will cause build-up of gas in the annulus, which can push the liquid column down to the pump intake and risk gas being drawn into the pump intake. The presence of gas at the pump suction can cause the pump to run dry and cavitate with pump motor failure to follow. Therefore, it is imperative to maintain the backpressure in the annulus at the lowest possible pressure, which maintains a sufficient fluid column above the pump.

The PCP is normally engine-driven. Casing gas can be utilized as fuel for the engine. If there is insufficient casing gas or its flowrate fluctuates widely, then propane is substituted as the fuel. On many sites, the operational difficulty with using sporadic volumes of casing gas to power the site is very challenging. Often, operations choses to maintain maximum up time and therefore, propane becomes the primary fuel source. Propane has the added advantage of consistent quality with a constant flow rate which will improve pump reliability and optimize engine availability. There are systems currently operating with the switch between the casing gas and the propane being completed automatically. When the casing gas volumes or pressure falls below the predetermined set point, the site will automatically switch to propane as the fuel source. Casing gas is also used as fuel for the tank burner. Engine jacket cooling water is used for the heat trace required on the casing gas line to prevent freezing.

Operational challenges are presented by the nature of gas and the variable flow rate. The following aspects should be considered in the design of emission reduction measures:

1. Casing and tank vent gas are water-saturated. Gathering wet gas is problematic because water drops out. The presence of free water can lead to freezing and corrosion. Water condensation creates additional pressure drop in gathering systems. The solution to these problems is to reduce the water content by conditioning the fuel gas.
2. If the casing gas is used as fuel, the lines need to be heat traced and insulated to prevent freezing.
3. The high water content of the casing gas can provide challenges when used as fuel for the fired equipment.
4. Vented gas is a safety issue.
5. Intermittent flow from the casing gas at low pressures requires a wide operating range for venting and control components.

CHOPS facilities in the Lloydminster area do not typically include the pipeline gathering systems or infrastructure to capture the vented gas. Currently the only solution to venting gas at the CHOP sites is to conserve the gases, consume the gases or to convert the gases to CO_2. Each province has its own requirements. The Alberta regulations are currently more stringent than those in Saskatchewan, however, Saskatchewan will soon follow Alberta's lead.

3.0 REGULATORY REQUIREMENTS

3.1 ALBERTA ENERGY REGULATOR (AER) REGULATIONS

Any emissions from a CHOPS site totaling more than 500 m^3/d need to be combusted or conserved according to the AER D-60 regulations at single well sites or multi-well batteries. Any site with emissions volumes greater than 900 m3/d should have an economic test completed to determine if the gas needs to be conserved or if it can continue to be combusted. The AER has adopted the Clean Air Strategic Alliance (CASA) objective hierarchy for managing routine solution gas flares and has extended its application of the hierarchy to include flaring, incineration, and venting of gas in general. In accordance with the objective hierarchy, licensees, operators, and approval holders must evaluate the following three options:

1. Can flaring, incineration, and venting be eliminated?
2. Can flaring, incineration, and venting be reduced?
3. Will flaring, incineration, and venting meet performance standards?

The AER does not consider venting an acceptable alternative to flaring. If gas volumes are sufficient to sustain stable combustion, 500 m^3/day or even lower, the gas must be burned (or conserved). Combustion of solution gas in incinerators is not considered to be an alternative to conservation. For solution gas management and disposition reporting, incinerated gas must be reported as flared. Justification for volumes not combusted may be required. The solution gas flaring and venting gas management framework is presented below for reference.

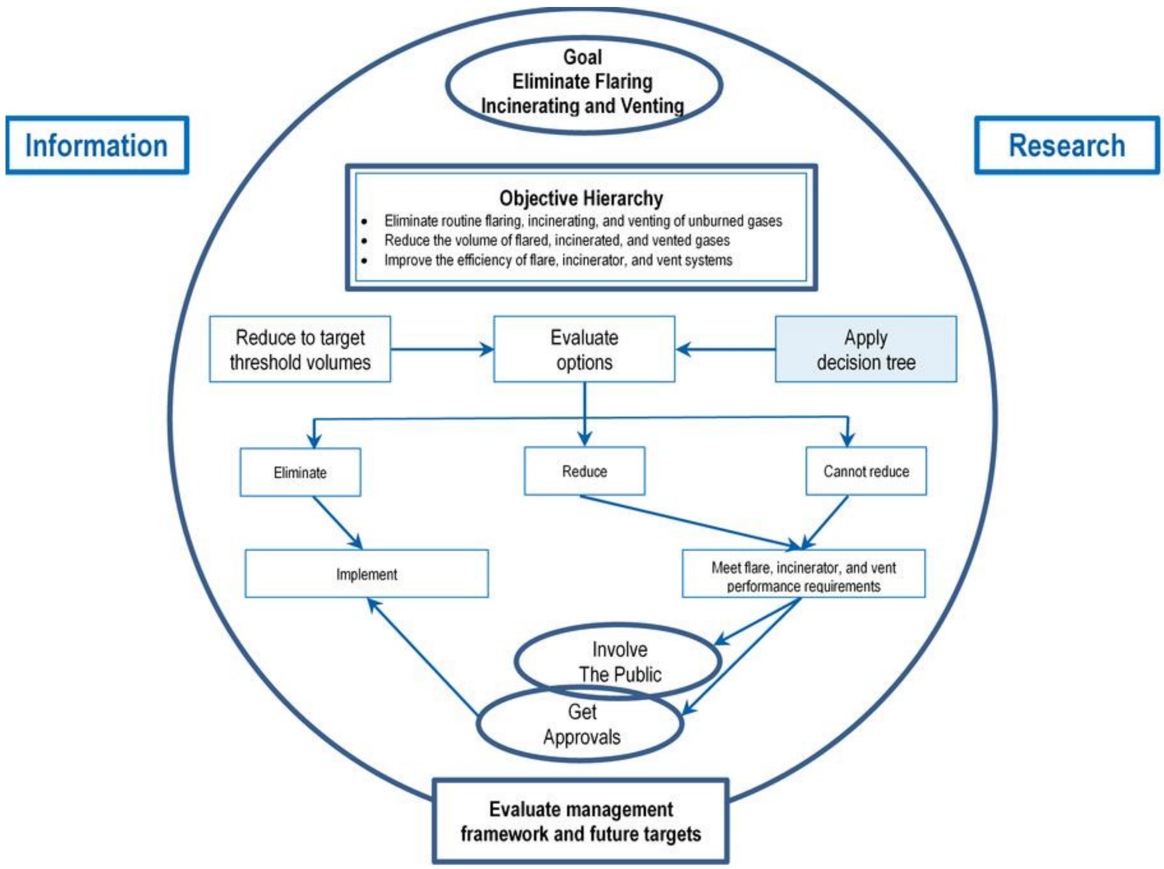

Figure 4: Solution Gas Flaring and Venting Management Framework

Conservation is defined as the recovery of solution gas for use as fuel for production facilities, for other useful purposes (e.g., power generation), for sale, or for beneficial injection into an oil or gas pool (e.g. pressure maintenance, enhanced oil recovery). Conservation opportunities are evaluated as economic or uneconomic.

The AER adopted the solution gas flaring/venting management framework and endorses the solution gas flaring and venting decision tree process as recommended by CASA. The licensee or operator must apply this decision tree to all flaring or venting of more than 900 m^3/day and be able to demonstrate how each element of the decision tree was considered, and where appropriate, implemented. The 900m^3/d is the minimum threshold to conduct the evaluation. The solution gas flaring and venting decision tree is presented below for reference.

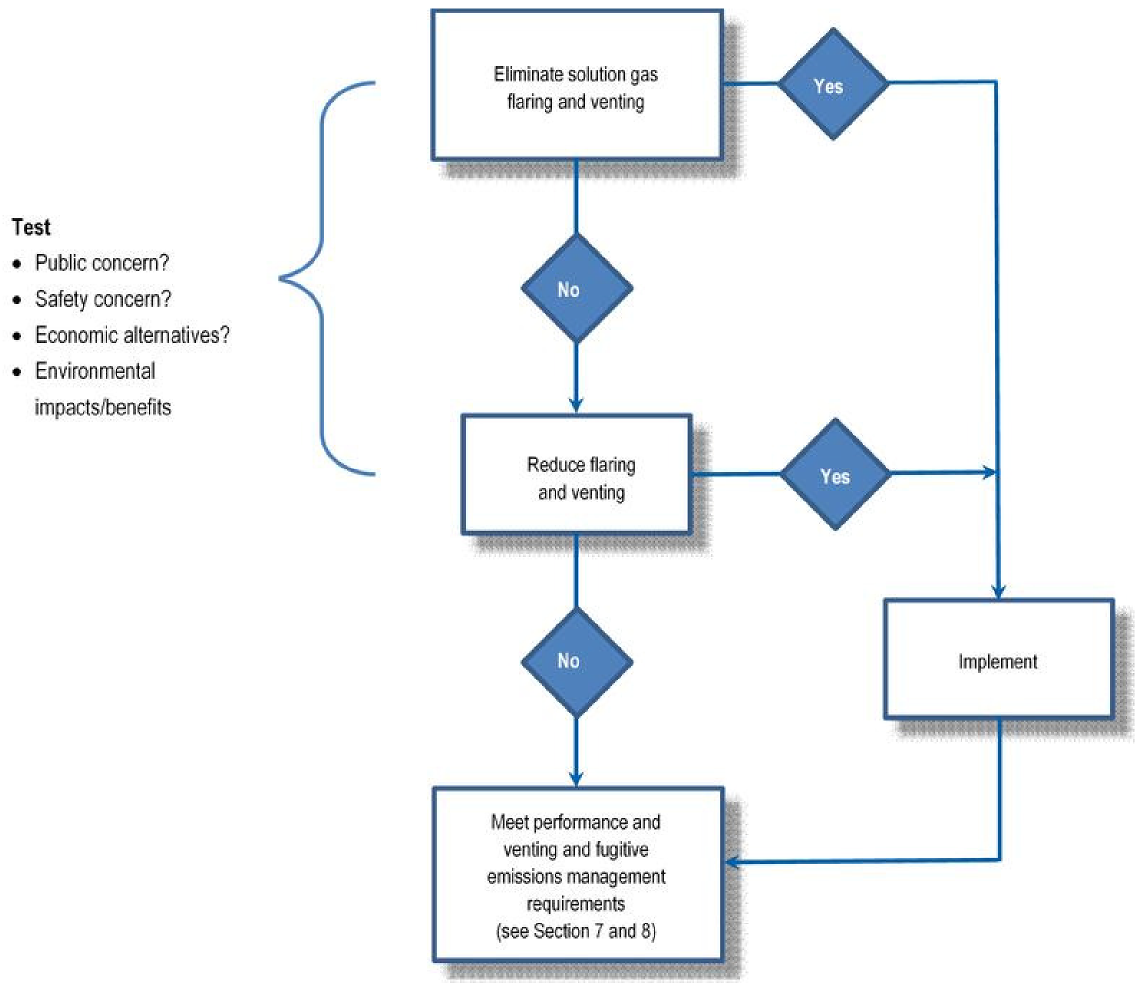

Figure 5: Solution Gas Flaring and Venting Decision Tree

Economic evaluations of gas conservation must use the criteria outlined in AER's Directive 60. The licensee or operator must consider the most economically feasible option in providing detailed economics. Conservation economics must be evaluated on a royalties-in basis (paying royalties) for incremental gas and gas by-products that would otherwise be flared or vented. If the economic evaluation results in an NPV less than – Cdn$55 000, the licensee or operator must re-evaluate the gas conservation project on a royalties-out basis (not paying royalties). If the evaluation results in an NPV – Cdn$55 000 or more, the licensee or operator must proceed with the conservation project and may then apply to Alberta Energy for an "otherwise flared solution gas" royalty waiver.

If the economics of gas conservation generates an NPV before-tax of more than –Cdn$55,000, the solution gas conservation project is considered economic, and the gas must be conserved.

If a solution gas conservation project has an NPV less than –Cdn$55,000 and is therefore considered uneconomic on its initial evaluation, the project economics must be re-evaluated annually (within 12 months of the latest evaluation) using updated prices, costs, and forecasts.

The AER also supports and encourages clustering which is the practice of gathering the solution gas from several vents at a common point of conservation. In some cases, this is applicable to CHOPS sites to reduce emissions.

3.2 SASKATCHEWAN MINISTRY OF ECONOMY REGULATIONS

Saskatchewan Ministry of Economy currently has legislation that a facility venting and/or flaring greater than 900 m^3/d of gas must not be constructed within 500 meters of an occupied dwelling, public facility, or urban centre. An exemption may be provided by the ministry and a copy of that exemption included with the facility licence application. However, the venting and flaring requirements will follow AER regulations in the near future.

4.0 TECHNOLOGY SOLUTIONS TO BE EXAMINED

4.1 EMISSION CAPTURED USING VAPOUR RECOVERY UNIT (VRU) COMPRESSORS

4.1.1 Description of the Technology

Vapour Recovery Units are comprised of compressors designed to boost gas pressure. In this case, they would be employed in low pressure applications. The system is typically comprised of the following components:

- Compressor
- Driver (electric motor or engine)
- Variable Frequency Drive (VFD)
- Inlet scrubber
- Heat exchanger (optional)
- Pressure transmitters
- Gas metering
- Control valves
- PLC or control system for safety and equipment operation
- Piping collection system

The following schematic illustrates how the components are normally arranged on site.

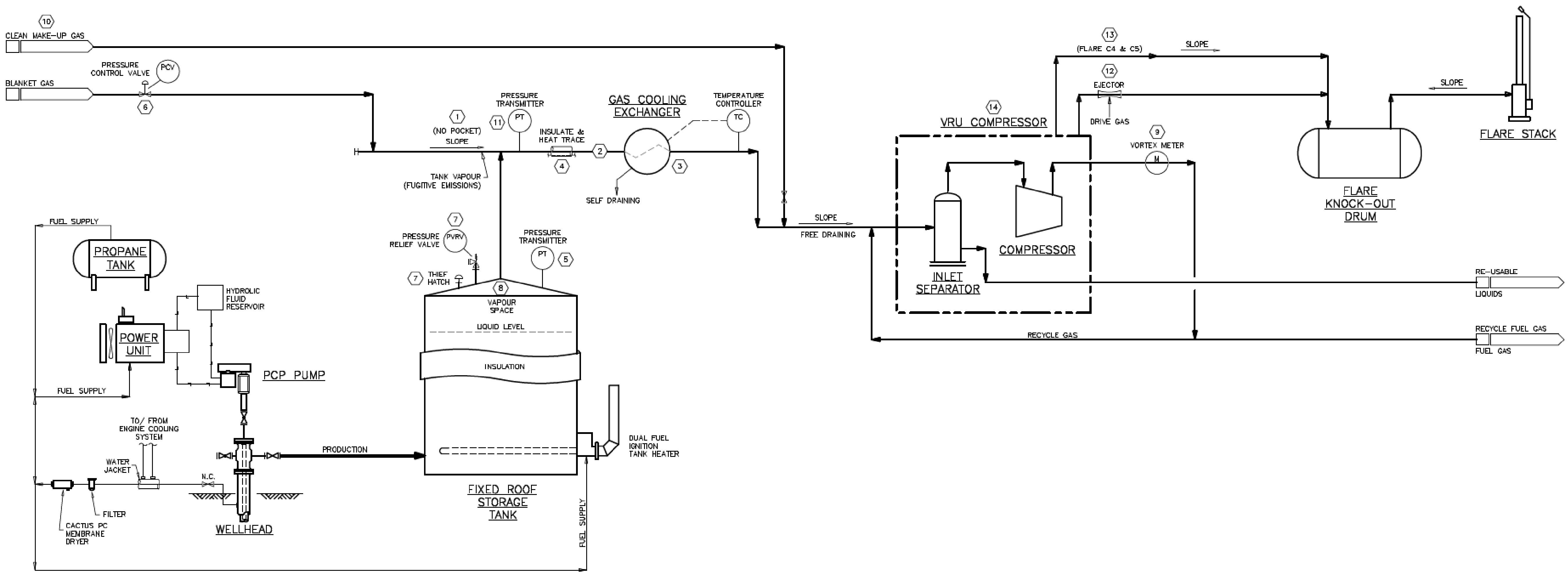

Figure 6: Typical VRU Components

Once the gas is compressed, it can be used as fuel in the engine of the PC pump. The gas may be produced into a storage vessel for later use or temporary collection or produced to a pipeline for further processing. In order for a VRU system to be effective, it should be installed on a grouping of tanks such as at a battery. *The VRU's presented below are for considerably more gas than would be generated from one (1) tank. These systems also require a gas blanket to ensure no oxygen enters the VRU compressor.*

4.1.2 Compressor Styles

The compressors must be designed with flexibility to handle variable flow rates and low suction pressures. Therefore a Variable Frequency Drive (VFD) installed on the motor along with recycle capability provides the most flexibility. Engine drivers are used where electric power is not available. Some form of power generation will be needed for the control systems.

The compression service is typically difficult as the gas is wet, sour, and contains asphaltenes. Compressors in the sizes used for these applications are small. They were originally designed for air or refrigeration service. As such, they are not built for corrosive service in materials or seals. A high maintenance or replacement service cycle should be expected with at least annual replacement. Some of the compressor types used with the best success in this service are reviewed in the following discussion.

4.1.2.1 Scroll Compressor

- A spiral cast into an elliptically rotating hub forces gas from the outside entrance of the spiral toward the center discharge to compress the gas. The rotating hub is nested in a matching, stationary spiral to trap the gas between the two.
- Some tolerance for liquid slugs or debris.
- Sub-100 HP projects, discharge pressure up to 2,379 kPag (345 psig).
- Positive displacement, oil flooded design.
- Low sound, virtually no vibration, no pulsations.
- Low cost.

Figure 7: Scroll Compressor Cutaway

4.1.2.2 Sliding Vane Compressor

- Eccentrically mounted rotor containing laterally sliding blades (i.e. vanes).
- Springs cause vanes to slide out while pressure on the compression chamber wall force the blades to slide in.
- Gas is forced into decreasing space as the rotor rotates thereby causing compression between the vanes, the rotor hub and the compression chamber wall.
- Works well with high volume and low differential pressures.
- Operates well in vacuum service.
- Limited discharge pressures – 1,000 kPag (150 psig).
- Pressure ratios of 6:1
- One manufacturer claims to have success in 80% H_2S service.
- Liquid will break blades.
- Capital cost, operational cost, and maintenance costs are low.
- High operational reliability.

Figure 8: Sliding Vane Compressor

4.1.2.3 Screw Compressors

- Twin helical rotors set inside a case, trap gas at the entrance and then move a pocket of the trapped gas towards the end of the rotors. The gas is trapped against the end wall of the case to compress it.
- Machines may be oil flooded or dry.
- Various configuration of gears, internal porting, and loading devices are available.
- A variety of sizes are available for different volumes and differential pressures.
- Operates well in vacuum service.
- Maximum discharge pressure as between 1,379 – 2,413 kPag (200 psig and 350 psig) depending on manufacturer.
- Pressure ratios of 10:1.
- Some tolerance for liquid slugs but not debris.
- Dew point control can be provided and is recommended to prevent dilution of oil in oil-flooded screw compressors with the forming of condensate in the compressor.
- Corrosive gas service requires purge after operation to preserve bearings.

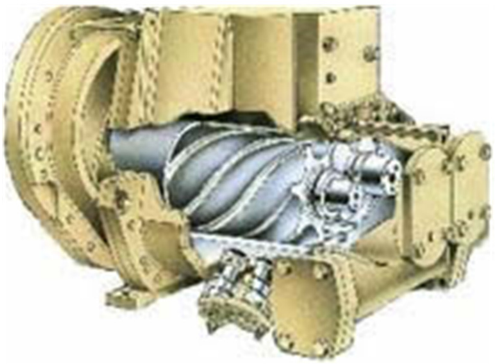

Figure 9: Screw Compressor

4.1.2.4 Liquid Ring Compressors

- Compress gas by rotating an impeller with vanes located eccentrically within a cylindrical casing. The impeller traps a pocket of gas and liquid against the case perimeter to compress the gas. The liquid forms the seal against the case wall and the vane tips.
- A high tolerance for liquid slugs and debris.
- Operates well in vacuum service.
- Pressure ratios of 4:1.
- Available in different materials. Typically stainless steel design.
- Difficult to service in the field.
- Best for lower compression ratio.
- Expensive and complex operation.

4.1.2.5 Reciprocating Compressors

- Compress gas by piston sliding in a chamber.
- Gas is compressed on one or both sides of the piston.
- Inefficient at low suction pressures.
- Suitable for corrosive gas applications if the frame size required can be suitably equipped.
- Multiple stages can be arranged to provide any final compression ratio. This compressor is often arranged in series with another compressor that is more efficient at low suction pressures.

Figure 10: Reciprocating Compressor

Table 2: Comparison of Compressor Styles for Groupings of Tanks

	Scroll	**Sliding Vane**	**Screw**	**Liquid Ring**	**Reciprocating**
Capital Cost	$140,000	$300,000	$300,000	$1MM	$400,000
Capacity Range	934 – 5,635 m^3/d (33 – 199 mcf/d)	1,274 – 3823 m^3/d (45 – 135 mcf/d)	2,958 m^3/d (105 mcf/d)	10.8 10^3 m^3/d (35.3 mcf/d)	3,600 – 4,056 m^3/d (127 – 143 mcf/d)
Minimum Suction Pressure	–51 kPag (–7.5 psig)	0 kPag (0 psig)	0 kPag (0 psig)	–10 kPag (–1.5 psig)	–48 kPag (–7 psig)
Maximum Discharge Pressure	1,310 kPag (190 psig)	1,000 kPag (150 psig)	1,724 – 2,068 kPag (250 – 300 psig)	346 kPag (50 psig)	2,410 kPag (350 psig)
Operating Cost	Low*	Low	Medium	Very High	Low
Maintenance Cost	Low	Low	Medium	High	Low
Reliability	Good	Good	Good	Low	Good
Maximum Compression Ratio	30:1	6:1	20;1	4:1	4:1

* A scroll compressor could also be utilized under the solution gas compressor technology.

Note: the comparison of styles is relative to each other

4.1.3 Expected Emissions and Greenhouse Gas (GHG) Reduction

Capturing the venting gases from the tanks and utilizing the gas as fuel for burners or engines will result in a reduction of GHG emissions. The expected reduction in Methane emissions from the site is approximately 5%.

4.1.4 Use of Emissions for Other Purposes

None other than those mentioned above have been identified at this time.

4.1.5 Overlap with Other Technologies

There are no overlaps with other technologies.

4.1.6 Limitations and Weaknesses

Vapour Recovery Units (VRU) are challenging to design and operate. The flowrates to these units are typically intermittent and highly variable. Good VRU design ensures that the following are taken into consideration:

1. VRU suction piping must be properly sized and must slope towards the suction scrubber. Proper sloping ensures that liquid slugs are less likely to develop in the suction line.
2. Cooling the tank vapours will help to ensure VRU volumetric efficiencies.
3. Installing an inlet separator to capture liquids will help protect the compressor. The liquids from the separator must be directed to a location other than a slop tank. Slop tank liquids are typically heavier than the VRU liquids, and the addition of the VRU liquids will often generate a butane – or pentane-rich vapour. This gas will tend to accumulate within the system and will require periodic venting or flaring. VRU liquids are often suitable for use as a bitumen diluent.
4. Appropriate location of the VRU suction pressure transmitter is important for optimal design and operation. This sensor is typically placed close to the VRU compressor and is used to admit make up gas to the VRU when rates and/or pressures are low. However, a better location for the pressure sensing point for make-up gas is to place it as close to the tank farm as possible. This ensures the make-up control valve is more responsive to fluctuations in tank pressure as opposed to fluctuations in the recycle gas flow rate.

The recommendations to minimize operational problems experienced with a VRU system include:

- Design the piping header to provide a positive slope towards the VRU for the entire gathering system header i.e. no pockets.

- Ensure the piping is large enough to handle the flow volumes while minimizing the pressure drop.
- The inlet heat exchanger must accommodate cleaning and must be self-draining. The heat exchanger most suitable for the application is a single pass, straight through design i.e. does not have U-tubes.
- Properly heat trace and insulate the gas gathering lines.
- Ensure pressure transmitters are provided at the top of each tank in the tank farm area and that they are tied into the control system.
- Ensure the blanket gas regulators or the pressure control valves are located on the top of the tanks to eliminate any liquid accumulation at the valve discharge.
- Check the thief hatches and Pressure Vacuum Relief Valve (PVRV)'s to ensure they are set to relieve at the appropriate set pressure.
- Ensure that none of the internal tank flanges on the tank vapour piping are leaking.
- Install a meter on the gas outlet line of the VRU for control and troubleshooting purposes. A vortex meter is a good choice because it provides good accuracy over a wide range and minimizes low pressure drop.
- Ensure clean make-up gas is provided to the VRU suction and not just recycled to maintain minimum flow.
- Ensure there is a pressure transmitter at the inlet to the VRU compressor which can be programmed to ramp up the speed of the VRU if one of the tanks starts to experience an increase in pressure.
- Verify the Programmable Logic Controller (PLC) programming is correct for the operation.
- Install an ejector in parallel with the VRU to send gas to flare in case the VRU fails or a large volume of gas is generated from the tank.
- A flare or combustor will be required if any C4's and C5's accumulate from the liquids collected at the inlet.
- Size the VRU appropriately; do not use flow rates suggested by API 2000 sizing as this methodology is overly conservative. Double the flowrates provided from simulation software such as HYSYS or VMGSim.
- Designing VRU's for sour service can be costly.
- Intermittent flow at low pressures requires a wide operating range and intricate control philosophy/implementation for VRU design.

- Appropriate equipment selection of the VRU is paramount. Gas composition, flow rate, suction and discharge pressure will dictate which compressor type is best suited to the site.

4.1.7 VRU's for Single Well Sites

VRU's have been successfully installed in the Peace River area. In order to understand the challenges in the Lloydminster area, the differences in the design parameters are outlined below:

Table 3: VRU Comparison for Lloydminster Area versus Peace River

	Lloydminster	Peace River
Power Available	No	Yes
Sour Service	No	Yes
Gathering systems to direct the gathered gas to	No	Yes
Large Volumes of Gas to be conserved per site	No	Yes (up to 10 wells per pad)
Fuel gas available for blanket gas	No	Yes
Complex Control system Required (electric)	Yes	Yes

Shell's VRU's design addressed several important design parameters;

- The production tanks typically operate at low maximum operating pressures (e.g. 16 ounces/square inch or 1 pound per square inch (psi))
- gas production rates can vary widely and in order to prevent a tank roof from blowing off or the tank itself blowing apart, the tanks have two (2) overpressure protection devices that relieve to atmosphere in the event of overpressure (thief hatch and PVRV)
- Shell install a pressure transmitter on the tank header system to shutdown all production if the tank experiences high pressures

The major challenge to install a VRU system to the single well sites in Lloydminster is the lack of blanket gas and the lack of power. One idea that could be investigated is to direct some or all of the casing gas into the tank and capture the gas off the tank with an engine driven VRU. Power would be required on site to control the panel, the transmitters, and the control valves. A high pressure shutdown would be required if the pressure in the tank reached design pressures, and a low pressure shutdown would be required to prevent oxygen ingress into the tank if the casing gas blanket did not have high enough pressure or volume.

Therefore, a Thermoelectric Generator (TEG) would be required or an alternator or generator installed on the PCP engine to generate power for the controls as well as the heat tracing and lighting. Since there is no gathering system to direct the collected gas to, a flare or combustor would need to be installed to combust any excess gas not consumed by the TEG, tank burner and engine on site.

There are several styles of compressors that may work for this application;

Table 4: Single Tank VRU Comparisons;

	Scroll	Screw	Sliding Vane	Go-Technologies
Flowrate	1982 – 2124 m^3/d (70 – 75 mscf/d at 0 psig suction)	500 m^3/d (20 mscfd)	500 m^3/d (20 mscfd)	815 m^3/d (however, experience shows the unit can do significantly less volumes with good results)
Cost	$140,000	$100,000	$140,000	$21,000

The costs presented here are for the capital cost of the compressor unit including the skid. Additional costs will be required for the TEG, the combustor, the controls system and the interconnecting piping and wiring to complete the project.

Please note that additional information is provided on the Go-Technology solution in section 4.5.1.3

4.1.8 Conclusion

The VRU solution is a complex solution for the single well site. Numerous pieces of equipment would be required to operate together to collect, consume and ultimately combust the gas.

4.2 EMISSION CAPTURED USING SLIPSTREAM GTS TECHNOLOGY FOR CHOPS

4.2.1 Overview

The SlipStream GTS (Green Tank System) for CHOPS is a proprietary system developed by Spartan Controls. The system is configurable in a variety of control schemes. First, it may be used to control the main burner in the tank, using either propane or casing gas. The switching between the two fuel sources is automated by the SlipStream GTS control system. Spartan has suggested that the automated fuel selector controls should improve reliability over the regulator controlled system. Second, an auxiliary burner installed in the exhaust stack is also provided to burn any gas not consumed by the main burner or the engine. The auxiliary burner will be operated when excess fuel is available after the main burner demand and pcp engine is satisfied. Spartan also predicts that the SlipStream GTS burner with the auxiliary burner should achieve 99.9% destruction efficiency. That is the same efficiency as an enclosed combustor (typical burner efficiency without air injection is 96% to 98%). The user of the technology should request data to validate the burner efficiency.

The AER advised Spartan Controls that the auxiliary burner may avoid the need for a flare stack if a special application is submitted by the Producer. It is not clear at this point if the combusted vented emissions burned in the auxiliary burner are to be reported as combusted fuel gas or flared gas. Finally, a glycol heat exchanger has been incorporated in the main burner vent stack utilizing the waste heat for a heat tracing system that is used to heat the oil and gas piping. The heat tracing system may improve energy efficiency if the oil is preheated prior to introduction to the tank.

The current design philosophy is directed at reducing up to 500 m^3/d of the vented emissions per SlipStream GTS system. On larger sites where more than one tank is employed, additional auxiliary burners may be installed on each tank. That way, several increments of reductions in vented emissions may be achieved.

4.2.2 Description of the Technology

The SlipStream GTS for CHOPS systems may be used to manage casing gas, tank vents or both. A sophisticated control system is required to manage the various gas streams if they are all captured and combined. The power for this control system is expected to come from an alternator or generator installed on the PCP engine. Since the control systems can become very complicated, the costs can also increase significantly with an increasing number of vent sources being captured and burned. The SlipStream GTS for CHOPS system has therefore been configured in three arrangements to help reduce the installed costs where that level of sophistication is not needed. The following configurations are currently available.

1. Auxiliary burner alone: The fuel supply is casing gas piped over from the main burner since it is very near. The heat tracing system is included.
2. Main burner plus the auxiliary burner: The main burner will need to be replaced with a SlipStream burner. This configuration is intended for sites with more casing gas capacity than the auxiliary burners may provide or if the fuel system requires an upgrade by code.
3. Tank vent capture: This configuration requires control to manage casing gas plus tank vents without causing an upset in either system.

The primary approach is to install the auxiliary burner and have it operate in conjunction with the PCP engine fuel system. The design allows the PCP engine to operate as it does now with the existing vent to atmosphere. That way the site system is restored to original condition if the SlipStream GTS for CHOPS system is disabled. Propane use should also be reduced because the allocation of fuel use is automated.

The auxiliary burner is sized for 500 m^3/d. This threshold was chosen to limit the radiant heat against the tank wall from the auxiliary burner. The auxiliary burner may also be fired even when the main burner is not in operation (i.e. no temperature demand). It is unlikely that tank vents will be captured since the volume of gas captured is small and the costs associated with the control systems are relatively very large.

Additional maintenance will be required for the controls and the various control systems. Additional automation means that the system should be self-regulating and increased reliability could be attained. All collected vents should be combusted.

4.2.3 Expected Emissions and GHG Reduction

All collected vents may be combusted.

4.2.4 Use of Emissions for Other Purposes

The site emissions could be collected and burned as fuel for engines or heaters.

4.2.5 Overlap with Other Technologies

There are no overlaps with other technologies.

4.2.6 Limitations and Weaknesses

Additional maintenance will be required for the controls and the various control systems. Additional automation means that the system should be self-regulating and increased reliability should be available.

4.2.7 Conclusion

The product is currently in development and the final configuration is likely to change once product testing is completed. A pilot project is being developed to test the auxiliary burner and the main burner controls. The technology, once proven, would be a viable alternative to installing a flare on site. Reliability may also be improved with the automated switching between propane and casing gas fuel sources. Plus additional heat tracing would reduce the additional heat input required to maintain tank oil temperature. It should provide a less expensive alternative both economically and with respect to space constraints on the lease.

4.3 Emission Reduction Using NEWCO T.O.P. Tank

4.3.1 Description of the Technology

In a traditional cold heavy oil production site the engine is housed in a small shack near the wellhead and a firetube burner is housed inside the production tank. Fuel is required to run the engine and to heat the firetube inside the production tank. Newco’s Thermal Optimized Production Tank (T.O.P) relocated the engine from the shack to the production tank and eliminated the need for a firetube burner by utilizing the engine glycol and exhaust heat that would normally be wasted on a typical heavy oil site and circulating it through the interior of the tank to heat the production tank.

Forty percent of the engine heat needed to heat the tank comes from the glycol (coolant), forty percent from the exhaust and twenty percent from the radiant heat from the engine. The design can put out 220 kW (750,000 Btu/hour) into the production fluid. The engine is designed to run the PCP with either captured casing gas or propane, similar to the current single well battery setups. The engine does not change its operation, it has just been relocated to inside the tank.

Two separate glycol loops are located inside the tank and serve as the radiator. The glycol lines are installed beside the engine room but below the oil/water interface. Two separate exhaust loops are also located inside the tank. Both the exhaust lines can be installed in the oil or the water zones inside the tank. If the tank upper set point temperature is reached, the shorter of the exhaust coils will automatically be bypassed to vent to atmosphere until the tank temperature drops below the lower set point. The exhaust lines are equipped with mufflers on the outside of the tank to reduce the noise pollution. Exhaust gas is vented to atmosphere. Placing the engine room inside the tank attenuates the muffler shell noise radiation by 50 to 100 dB according the manufacturer. The engine room displaces approximately 10 m^3 (60 bbls) of fluid.

The glycol coils are required to be submerged in either oil or water to disperse the heat and act as a radiator to cool the glycol as it circulates from the V8 engine into the tank. In the 1000 bbl tank design, Newco states that a sufficient submergence depth would be 9 – 10 feet.

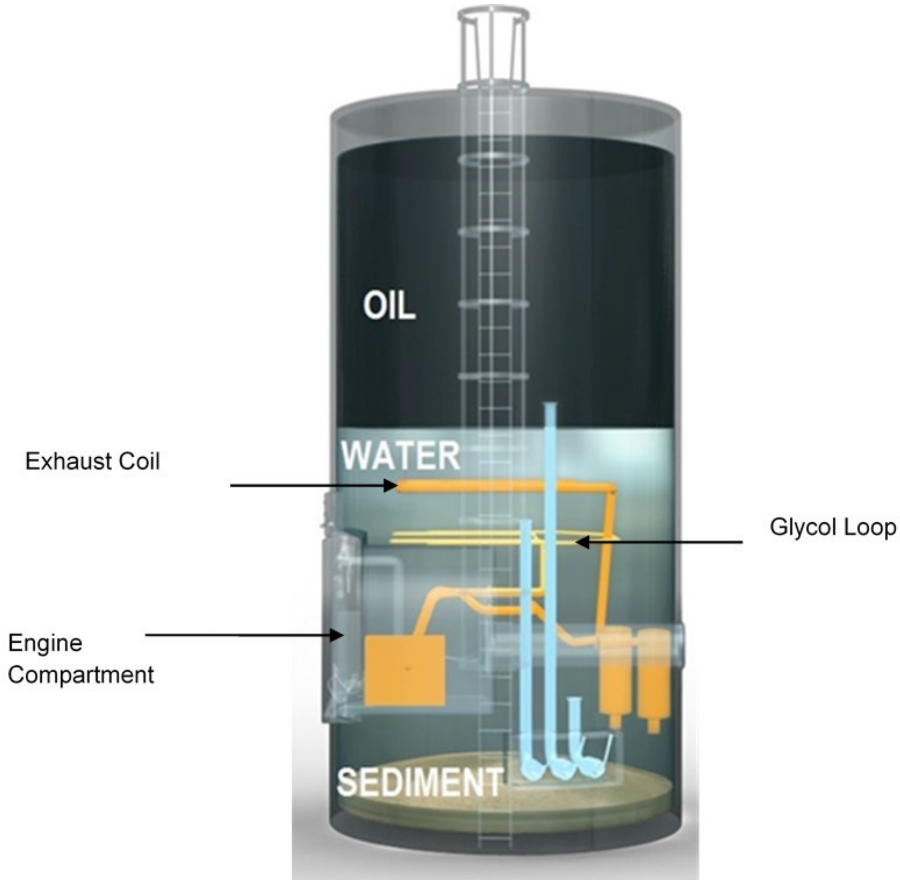

Figure 11: Newco T.O.P. Tank

4.3.2 Expected Emissions and GHG Reduction

A typical heavy oil storage tank temperature of 80°C is required to keep the fluid viscosity low and achieve a distinct water and oil interface. GHG emissions are reduced because the burner firetube inside the storage tank is eliminated from the production tank. Reduction of emissions would therefore be the amount of gas used to fire a 750,000 Btu/hr firetube or 784 m^3/d of gas or 2150 kg/d (785 t/y) of CO_2.

4.3.3 Use of Emissions for Other Purposes

Newco® has designed their T.O.P tanks to include a gas scrubber that is located in the engine room to allow wet gases such as the casing gas from the wellhead to be utilized as fuel. These engines are dual fuel rated. By harnessing the casing gas from the wellhead, the need for additional fuel sources such as propane is potentially eliminated, resulting in further operational cost savings.

4.3.4 Overlap with Other Technologies

There is no overlap with other technologies.

4.3.5 Limitations and Weaknesses

This system has eliminated one source of GHG emissions, but it still produces CO_2 as a result of the combustion process from the engine. This application has appeal for heavy oil production sites by utilizing the engine as a heat source. This product has been installed on eight sites for field trials but they are not currently operating. Testimonials from the Producers at the field trial sites advise that the technology provided benefit and functioned well during the tests. No evidence of long term testing was made available.

The technology does not enjoy widespread use in CHOPS production sites at the time of writing this report. The technology has not been tested on other sites such as gas plants or oil batteries. This is also not a solution to vented emissions reduction on sites with excess casing gas as the excess gas will not be combusted or conserved with the addition of this technology.

The vendor has hired an independent engineering firm to review and make recommendations regarding placing the engine inside the tank. Initially, it would seem that this could not be completed and still meet the design requirements of API RP505 to meet the Area Classification for electrical installations. This has been addressed by installing the engine in a sealed room inside the tank, thereby allowing the engine to be wired for general purpose. Other design requirements to ensure the installation meets the area classification are to have adequate ventilation of the space using a clean air source, and to monitor the sealed room with a fixed continuous combustible gas detector. The monitor will be wired to shut down the engine when it detects gas above 10% LEL (lower explosive limit). Using these design criteria, along with some operational requirements outlined in the third party review summary will, in theory, meet the electrical code to allow the engine to be installed in the tank.

4.3.6 Conclusion

This is one of the combustion solutions that is innovative. The engine for the wellhead pump is installed in the production tank and the waste heat from the engine is used to maintain the production tank temperature. A traditional firetube is not required. The casing gas is used as fuel for the engine and is therefore not vented. Propane that would normally be required to fuel the firetube is not required. This solution has the potential of still venting methane however, if there is more casing gas being produced from the wellhead than needs to be consumed and may therefore not be the complete solution. There are currently no operating sites and there are no third party peer reviewed test results available.

The Area Classification for the electrical design must normally be reviewed and approved by the electrical engineer stamping the installation drawings of the site. As well, the operating firm's QMP (Quality Management Plan) representative must review and agree with the stamping engineer's recommendation. The Newco T.O.P. Tank design will also be required to undergo this review and approval process.

4.4 EMISSIONS REDUCTION USING HEXA-COVER

4.4.1 Description of the Technology

Hexa-Cover® markets a floating tile system designed to minimize odours, emissions and organic growth on water ponds. The cover consists of individual hexagonal, plastic tiles approximately 25 cm across. The tiles are manufactured from an engineered polymer material. There is one formulation for water and another for oil service. Special manufacturing features like equidistant ribbing and shaped edges ensure the tiles are self-righting and self-locking to form a closed cover. The systems were developed to reduce odours and algae growth on outdoor water treatment lagoons but have been found to be useful for a similar application in oil and gas, particularly CHOPS tanks. The Hexa-Cover® tiles have been designed with anti-static material for oilfield applications.

The tiles are dumped into a tank through the thief hatch or other opening and can be installed whether there is liquid in the tank or not.

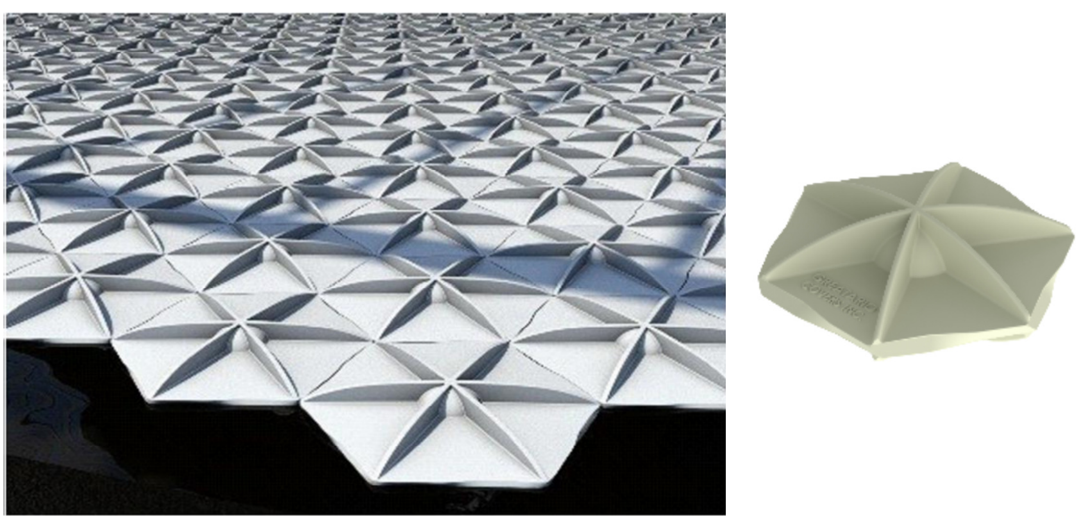

Figure 12: Hexa-Cover Interlocking Tiles

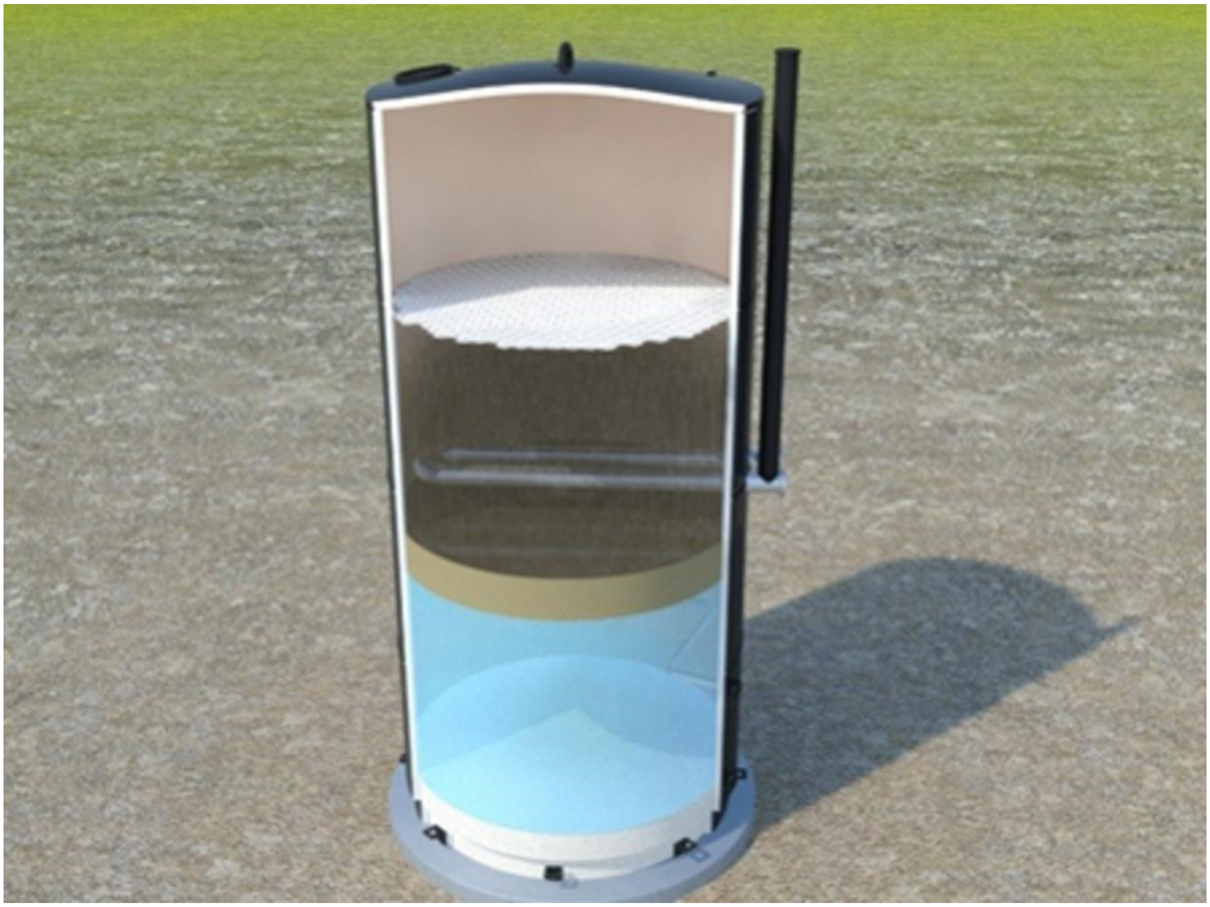

Figure 13: Typical CHOPS Tank with COVER Tiles

4.4.2 Expected Emissions and GHG Reduction

The Hexa-Cover® system has been tested in the field and in the lab. Laboratory tests conducted by Exova using toluene yielded 65% reduction of headspace vapour generation. Lehder Environmental Services conducted field tests at Mann Lake on a tank with 60 m^3/week oil production in it. The results showed 53% reduction in water content in the vapour space, and 93% reduction in C_6 content of the vapour. One company has reported a 20% reduction in burner fuel costs with an associated reduction of 27 kt CO_2e/year based on ten years of data however, these findings have not been qualified by peer review.

The emissions reduction for the Hexa-Cover sites will be realized through the use of less fuel gas required to be used as the Hexa-Covers provide an insulation to the vapour space of the tank. Less fuel will be required to maintain the minimum tank temperature.

An additional property of this system is the reduction, or elimination, of the requirement for chemical defoamers. These compounds are typically BTEX components and the rate of addition needed typically amounts to a greater source of BTEX emissions than naturally occurs in the heavy oil.

4.4.3 Use of Emissions for Other Purposes

The site emissions could be collected and burned as fuel for engines or heaters.

4.4.4 Overlap with Other Technologies

Utilizing a cover to minimize odours and emissions is a new approach.

A product with similar properties, called Hexprotect, is manufactured by Advanced Water Treatment Technologies (AWTT). This product consists of hexagonal elements which are designed to reduce emissions by forming a floating cover on the surface of the liquid. The elements are manufactured from High Density Polyethylene (HDPE). This product has been used in the chemical and oil industry, particularly in fracking to reduce evaporation and heating costs. The supplier has not confirmed whether the materials have anti-static properties.

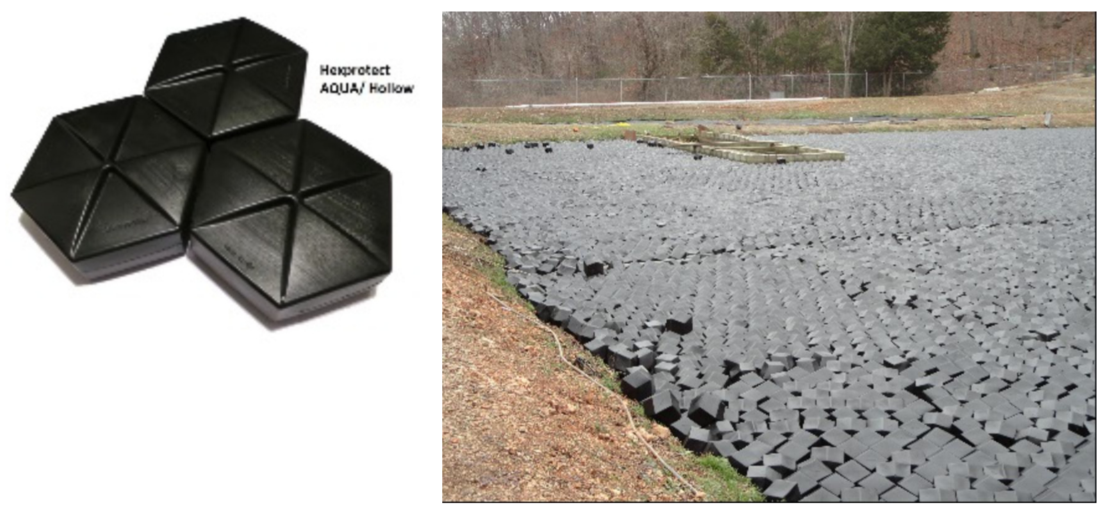

Figure 14: AWTT Hexprotect Installed Tiles

4.4.5 Limitations and Weaknesses

This system is currently undergoing field testing and any limitations or weaknesses will be identified at the conclusion of those trials.

4.4.6 Conclusion

The Hexa-Cover® solution appears to have the potential to reduce tank emissions. There are several studies underway to gather and quantify the claims for emissions reduction and reduction of fuel gas to maintain tank temperatures. The costs are low, the risk is small.

The procedure for removing the tiles for tank servicing has been developed and field-tested and can be undertaken within 3-4 hours. There is some hesitation from some operations staff to implement the Hexa-cover solution as cleaning of the tank can increase from a 1 day job to a 3 day job if they do not implement the proper procedure to clean the tank as these tiles do become fixated on the bottom of the tank with the bitumen and have to be shovelled off.

4.5 EMISSION CAPTURED USING SOLUTION GAS COMPRESSION

4.5.1 Description of the Technology

As stated earlier, it is important to maintain a casing head pressure as close to zero as possible. Often times, surface casing compressors are installed to capture the vented gas. These units can be scroll, centrifugal, rotary vane, rotary screw or small reciprocating compressors depending on the volumes of gas to be compressed. These units can be electric motor or gas engine driven.

It is important that these units be portable. Many units have been built to be extremely portable and with a minimal skid footprint. They frequently employ a “utilidor” concept with removable panels or doors to allow servicing.

These units can be installed with high pressure braided hoses for quick connects and a VFD, if used, can be mounted outside on a backboard panel using a NEMA enclosure.

For this type of application to work, the collected gas must be used on site as fuel or be collected and delivered as sales gas. It would be collected in pipelines or in a portable pressurized container on a trailer and transported to a gas plant or a pipeline.

Can-Gas have developed a system to compress, dehydrate and transport the compressed gas in a trailer. The gas is then delivered to a customer’s pipeline. The units are designed for a capacity of 5,097 m^3/d – 8,495 m^3/d (180 mcf/d – 300 mcf/d) based on a suction pressure of 138 kPag (20 psig) and a discharge of 13,790 kPag (2,000 psig). There is a line heater and pressure regulator to match the customer pipeline pressure restraints at the unloading point. The storage trailers have a capacity of 3,964 m^3 – 4,248 m^3 (140 msf – 150 msf).

4.5.1.1 SMD Centrifugal Compressor

The centrifugal natural gas compressors outlined below could be used for boosting low flow rate gas pressures in a variety of services. This could be achieved by increasing the impeller speed which in turn increases the kinetic energy/velocity of the gas. The rise in kinetic energy is converted to potential energy/static pressure in the diffuser section. By slowing down the flow of the gas, this pressure rise in the diffuser is directly proportional to the pressure rise in the impeller.

The SMD C-type compressor is a compact, efficient, high speed centrifugal compressor with maximum impeller speeds ranging from 90,000 rpm (C38 series) to 240,000 rpm (C8 series). These compressors can be belt driven from a variety of standard drivers and can be installed as a booster compressor. The maximum discharge pressure this compressor is capable of achieving is 350 kPag (50 psig). This is due to the limitations on the seals for the compressor drive spindle and the outer housing.

The compressor wheel standard material is made of aluminium and the housing is anodized aluminium. The C-type compressors have been developed and tested with SX100 traction fluid to maintain the level of performance and durability it was designed for.

The data sheets below depict the different models and ranges that the SMD compressors can achieve.

Characteristic	Symbol	C8-6	C8-8	C15-16	C15-20	C15-60
Max flow rate, 0.70 SG natural gas MMSCFD	V_{flow}	0.12 (1.38 CR)	0.162 (1.38 CR)	0.375 (1.75 CR)	0.362 (1.98 CR)	0.549 (1.63 CR)
Max compression ratio	CR_{max}	1.97	2.23	2.43	2.94	2.35
Max drive efficiency	η_{max}	95%		97%		
Unit weight	M	1.4 kg (3.1 lbs)		2.9 kg (6.4 lbs)		
Rotation direction (from drive side)	$Rin_{direction}$	CW	CW or CCW	CW		
Peak input shaft speed, rpm	Rin_{max}	19,170		15,900	14,207	11,840
Peak impeller speed, rpm	$Rout_{max}$	240,000		201,500	180,000	150,000
Min inlet oil temperature	$Toil,in_{min}$	-40°C (-40°F)				
Max inlet oil temperature	$Toil,in_{max}$	+80°C (176°F)				
Mounting torque Pulley bolt	M-	M6 bolt, 12.1 Nm (8.9 ft-lb)		M10 bolt, 50 Nm (37 ft-lb)		
Mounting torque Oil banjo bolts	M10x1	21Nm (15.5 ft-lb)				

Figure 15: SMD Technical Data Sheet for C8 & C15 Series

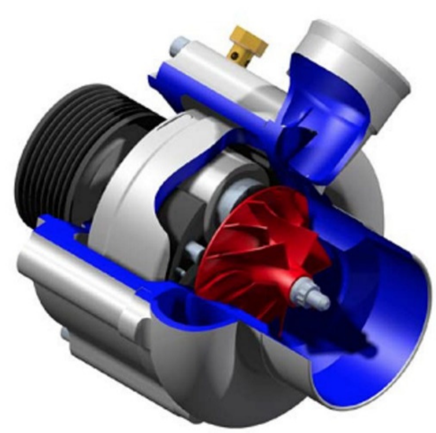

Figure 16: SMD Compressor

The compressor chart shows that even at low volumes this compressor can still produce positive discharge without the need to recycle like most compressors. The low end of the spectrum covers volumes as low as 0.003 g/s air (211 m^3/day) while achieving a 1.08 to 2.2 compression ratio. While this number may seem low, a typical low pressure system only requires ounces of pressure to satisfy the needs of a flare or a trailer system. The challenge will then be how to sell low pressure, wet gas.

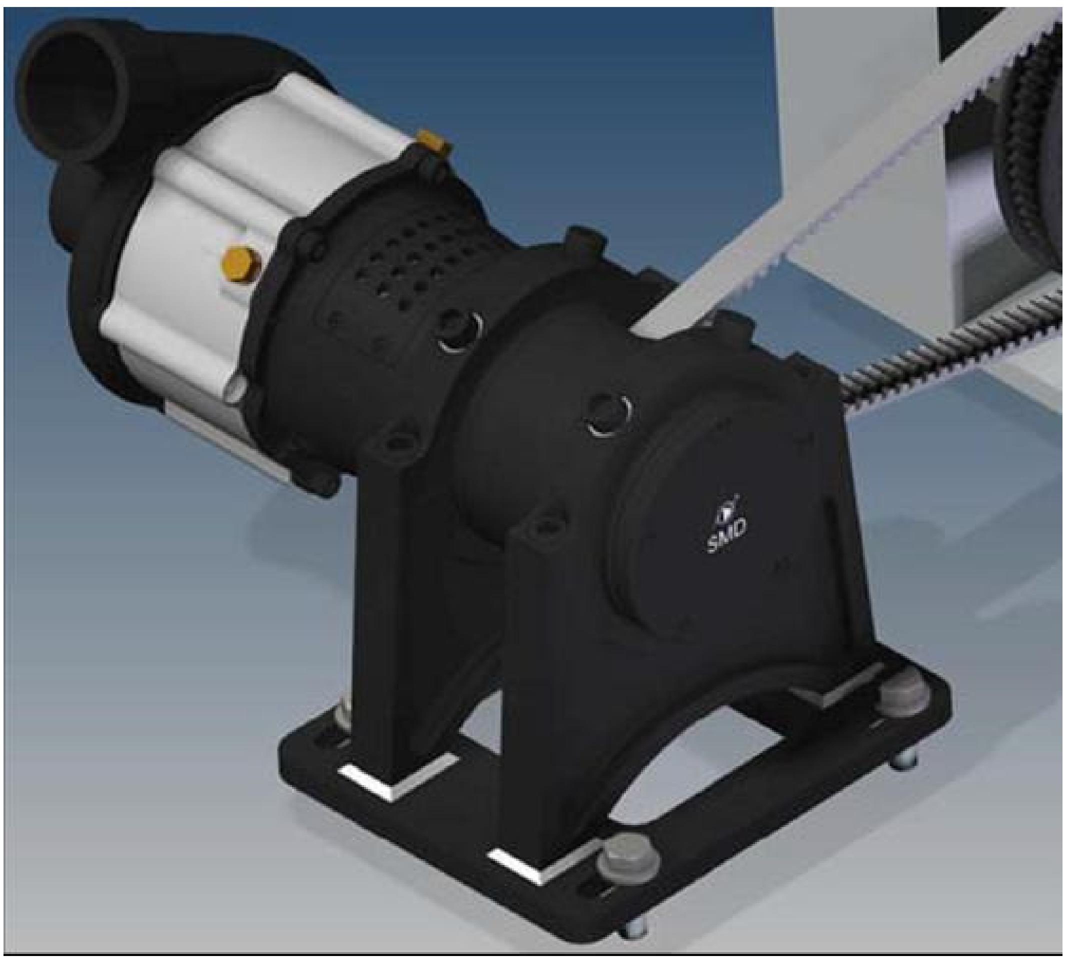

Figure 17: SMD Compressor Drive for C38 Series

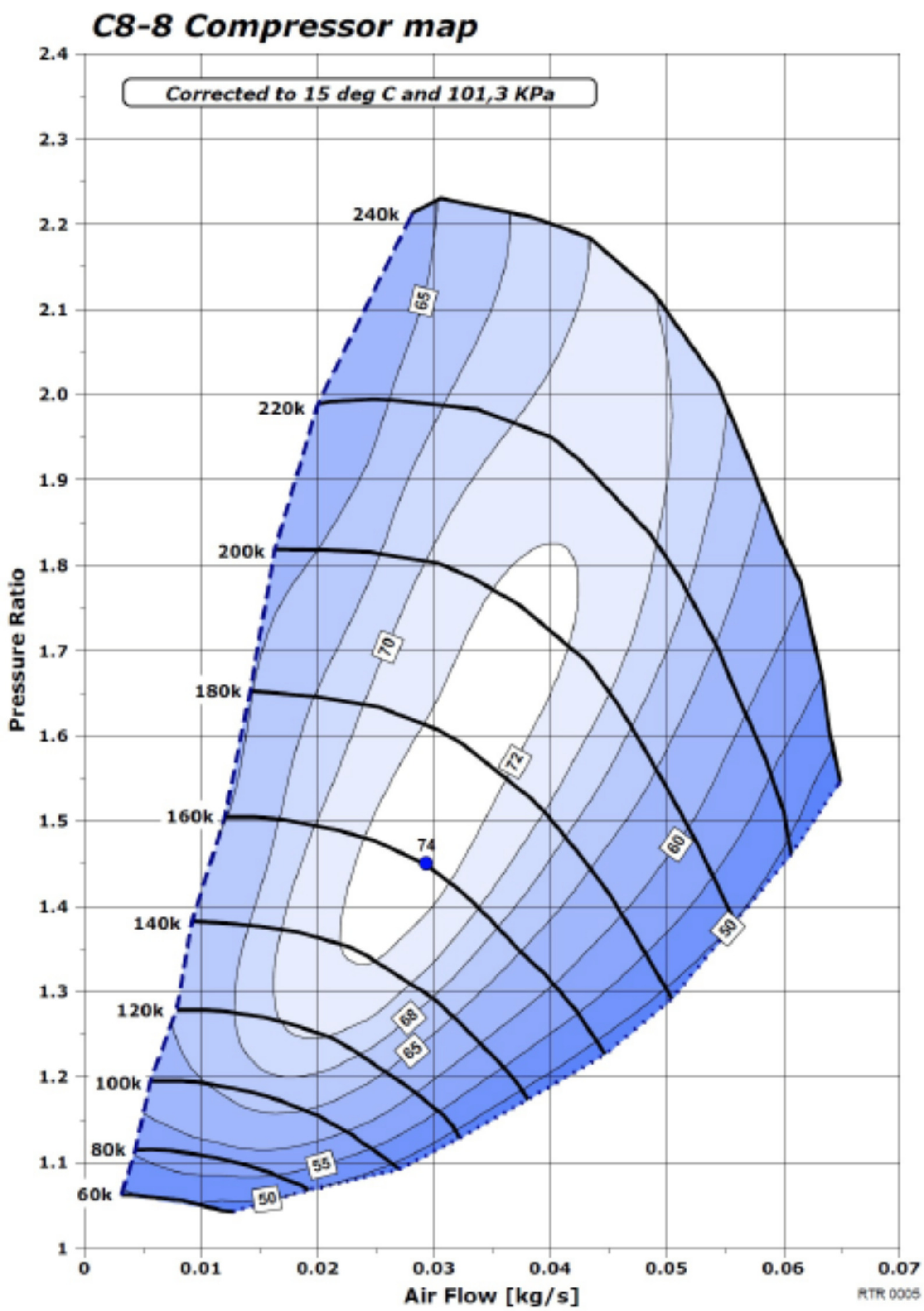

Figure 18: SMD Compressor Curve for C8-8 Model

4.5.1.2 Busch MM1144BP Compressor

A Busch Mink compressor is capable of compressing 2,324 m^3/d (82 mcf/d) of casing gas. The compressor is a rotary lobe pressure pump which is capable of compressing to 210 kPag (30 psig). It is single stage direct driven and air cooled.

The pump has two claw shaped rotors in the housing which will take in the casing gas as they rotate in opposite directions. The gas is compressed by the rotors and discharged through a silencer. There is a non-return valve in the inlet of the pump which prevents gas from back flowing through the pump when it is turned off.

The pump comes equipped with a high efficiency TEXP motor.

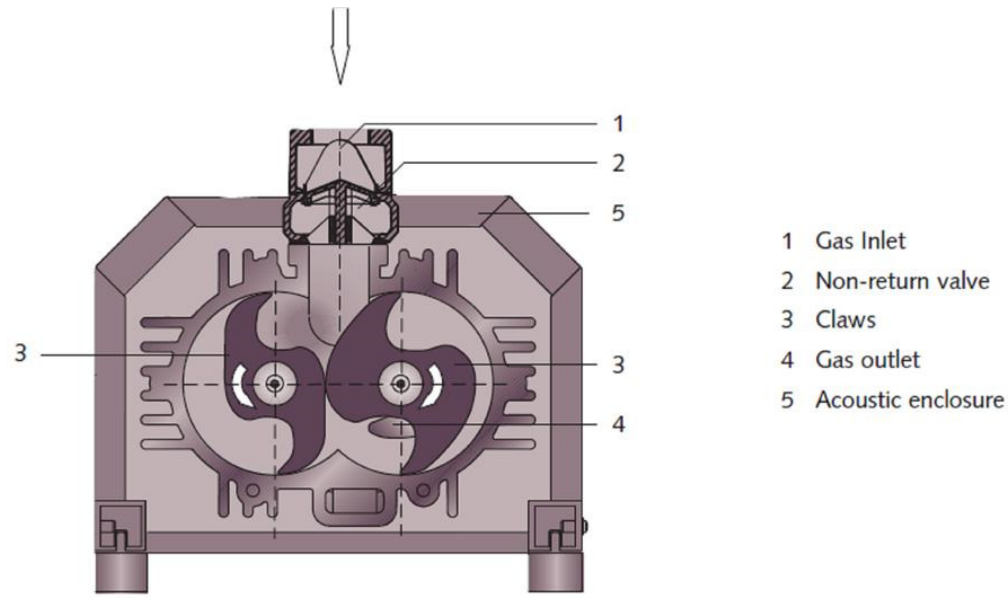

Figure 19: Busch Mink Compressor

4.5.1.3 Go-Technologies

Go Technologies have indicated they have successfully installed 20 casing gas collection systems on CHOPS sites and their units will compress from 500 m^3/d up to 14,000 m^3/d (18 mcf/d – 494 mcf/d). The system that would work for the CHOPS sites would be a 5 HP Gardner Denver 2MP Blower for the low to mid range volumes and the 5H Model for low to high volume, complete with a 35 cc hydraulic motor. The unit operates off the existing skid with either a hydraulic flow control, priority valve, or by adding a tandem pump. Therefore fuel consumption is kept the same and installation costs are kept low. The discharge pressure from the blower can be as high as 82 kPag (15 psig maximum for the 5H and 12 psig maximum for the 2M). These packages are small and mobile. The skids are 1.2 m x 1.2 m x 1.8 m high.

The gas compressed from the units can be utilized as fuel in the tank burners and hydraulic drives on site. Excess gas can either be vented or further compressed in a second compressor and delivered to a pipeline. The sites that have used this system have modified them to allow the burners and engines to run off the casing gas as well as propane. The equipment switches automatically between the two fuel sources. The blowers have been set up to automatically start when casing gas becomes available and to shut off when the pressure drops off. The packages are outfitted with desiccant dryers complete with a sight glass and drain. The suction piping to the blower can be heat traced off the hydraulic drive. These packages can also be set up to incorporate a call out system in the event the blower goes down.

Go-Technologies are set up to either lease or sell these packages.

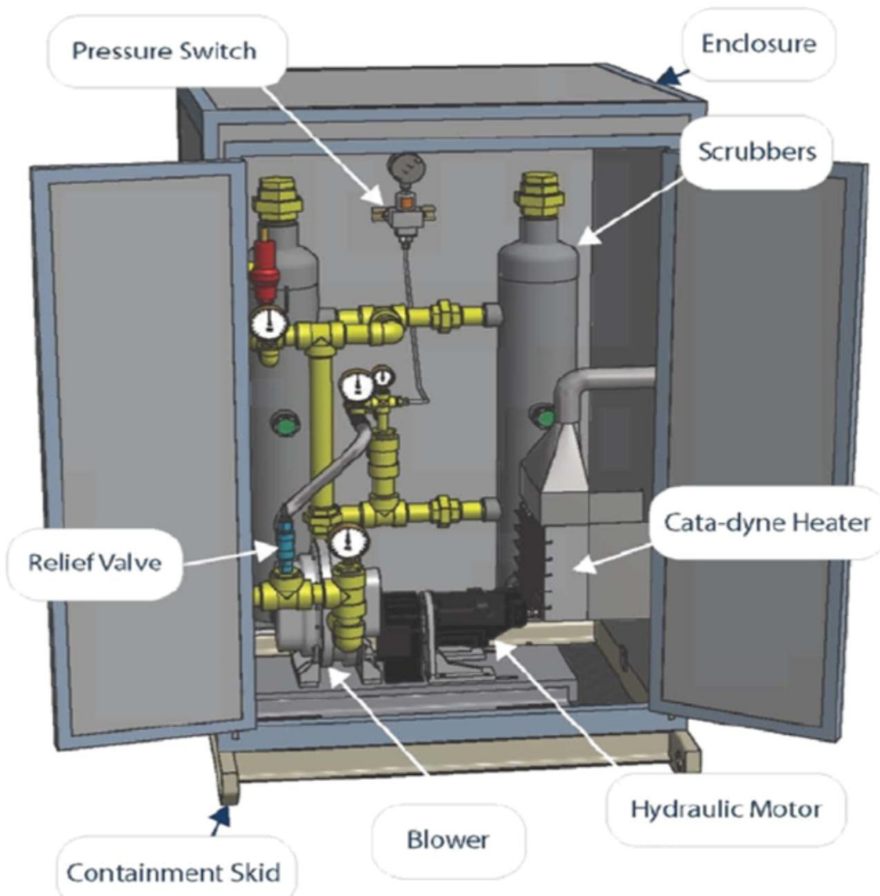

Figure 20: Go-Technologies Blower

4.5.2 Expected Emissions and Greenhouse Gas Reduction

It is expected that 100% of the surface casing vent gas is collected. As 95% of the methane emissions from a pad site are from the surface casing vent, 95% of overall methane emissions from a pad site will be captured. Burning the captured methane increases the CO_2 emissions from site. Table 1 identifies overall site emissions.

4.5.3 Use of Emissions for Other Purposes

Captured emissions could be used as fuel gas for other equipment, i.e. burners and generators. Proposals have been developed to tie into a municipal grid or pipeline, but that would be site dependent.

4.5.4 Overlap with Other Technologies

There is some overlap with the VRU technology as several of the compressor styles could be utilized as surface casing vent gas compressors, however, the size and implementation is different.

4.5.5 Limitations and Weaknesses

At this point in time, the challenge is to collect both storage tank emissions and surface casing gas due to the very low pressure parameters in which these gases exist and the spacing requirements needed between the wellhead and storage vessel. Detailed work would be required to combine both streams into the suction of the compressor. One very important design challenge is how to capture the tank vapours without a proper fuel gas blanket. *Without the blanket, oxygen will be drawn into the compressor suction.*

An additional challenge is how to handle any liquids that are knocked out in the suction scrubber. A small pump will be required to bring the liquids to the tank. Electricity may be required to run the compressor and the pump.

4.5.6 Conclusion

Due to the small and sporadic volumes of gas addressed in this study, there is only one proven solution using casing gas compressors to capture the gas. Go-Technologies have numerous casing gas compressor installations working for several clients. Some of the installations have been working for 3 years with very little maintenance required.

4.6 EMISSION REDUCTION USING COMBUSTION

4.6.1 Description of the Technology

Methane is over 25 times more effective at trapping heat in the atmosphere than carbon dioxide. Methane's role as a potent greenhouse gas (GHG), coupled with the fact that its average lifespan in the atmosphere is 12 years, means that activities to reduce methane emissions have great potential for reducing human impact on climate change in the near term. Therefore, it is better to convert vented methane to carbon dioxide by combustion to reduce the effects on the environment.

There are several types of systems that can be used to combust the vented emissions, namely flares stacks, enclosed vapor combustors and incinerators. The differences in the systems are found in the efficiency of the combustion process and the amounts of fuel required to obtain such efficiencies with fewer unburned hydrocarbons present in the exhaust as combustion efficiency increases. Flare stacks will emit more unburned hydrocarbons than the other two technologies. Casing vents can be captured for combustion by using large diameter piping to the inlet of the units to minimize pressure drop through the vent capture system.

The AER Oil and Gas Act specifies a spacing requirement for flame type equipment to be 25 meters from the wellhead and 25 meters from the tanks. This is due to the open flame generated by the flare.

The flare line will need to be traced and insulated to avoid liquids freezing in the lines. The tracing could come from the engine jacket cooling water, but there are limitations to the effectiveness with increasing distance to the engine. A small liquid knockout pot in the front of any of these systems is also required to ensure liquids do not enter the combustor system. The flare line (to any of the technologies presented) will need to have an in line flame arrestor installed as per the AER Directive 60 if there is not a constant sweep or purge of the line.

4.6.1.1 AER D-60 Backflash Control

Inadequately purged combustion systems may have enough oxygen present to support combustion. Backflash may occur when the linear velocity of the combustible mixture of gas and air in the system is lower than the flame velocity.

The licensee, operator, or approval holder must take precautions to prevent backflash using appropriate engineering and operating practices, including;

a. Installing flame arresters between the point of combustion and the flare or incinerator separator; or,
b. Providing sufficient flare header sweep gas velocities (i.e., purge or blanket gas) to prevent oxygen intrusion into the flare or incinerator system.

It is important to adequately trace the flame arrestor to prevent liquid freezing as the results can be catastrophic if allowed to freeze up. These CHOPS sites would require a flame arrestor as there would not be enough fuel to maintain the constant purge required to ensure a positive pressure on the flare piping system.

Flame arrestors prevent air from being drawn back into the flare system by blocking reverse flow. They also prevent explosions from occurring by absorbing the heat from a flame front traveling at sub-sonic velocities dropping the burning gas/air mixture to below its auto-ignition temperature.

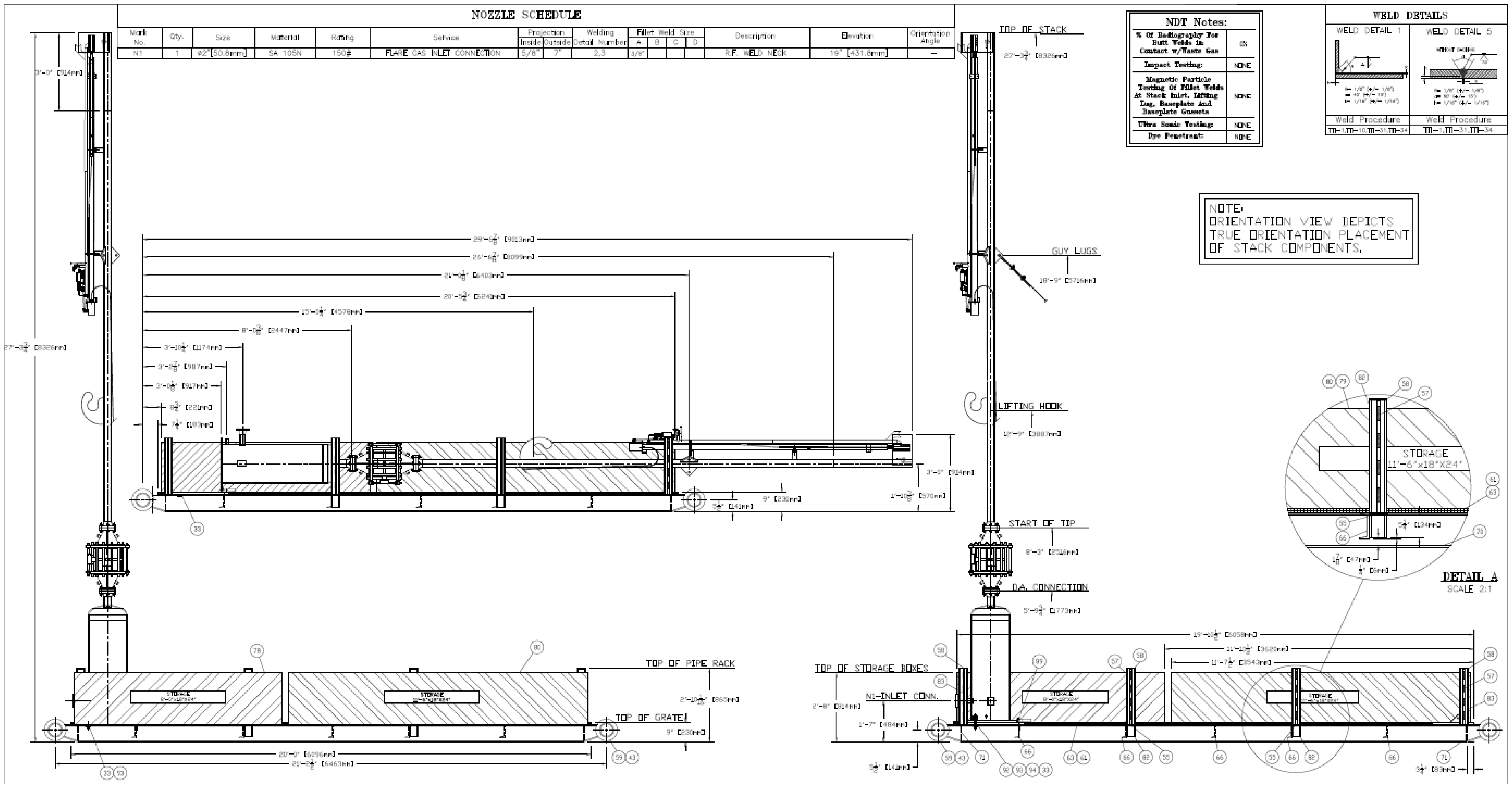

Figure 21: Skid Mounted Flare Stack (*Drawing Courtesy of Tornado Combustion Technologies*)

4.6.1.2 Flare Stack

A traditional flare has the flame at the top of the stack open to the environment using the process gas as fuel with the intent of burning as much gas as possible and not concentrating on the efficiency of the burn. Thus many flare stacks are seen emitting dark black puffs of smoke indicating incomplete combustion and particulate emissions. The flare system shown in Figure 21 is a skid mounted flare system for ease of portability. This flare is equipped with 3 guyed wires to support the stack and a flame arrestor. The efficiency of a non-assisted flare (one without an air assist to promote combustion) will be 96% to 98%.

Tornado has developed and markets a new flare ignition system called the Tornado Electronic Ignition System (TEIS). It is a stand-alone igniter and is not used as an ignition system for pilots. The system uses a solid state timer to initiate a high voltage spark every 40 seconds when the control panel is turned to “auto”. The TEIS is pre-set with optimal factory settings to arch for two seconds each cycle; these settings are not adjustable.

4.6.1.3 Enclosed Vapour Combustor Unit

An enclosed vapour combustor is differentiated from a traditional flare stack by relocating the flame from the visible open atmosphere into a non-visible controlled chamber within the stack itself. The Burner Management System (BMS) along with the design of the burner allows for an elevated combustion temperature which will achieve a 99% to 99.99% total hydrocarbon destruction. The stacks are usually wider and shorter than a traditional flare since thermal radiation is not as prevalent as with a traditional open flame flare. The pilot gas requirements can range from 0 – 84 m^3/day (0 – 3 mcf/d) depending on the composition of the waste gas being combusted. For waste gas that is dry and rich in lighter hydrocarbons (i.e., methane, ethane, propane) the pilot fuel gas volume requirement is reduced because the lighter hydrocarbons have a higher heating value and therefore tend to ignite and burn more readily than the heavier hydrocarbons such as pentane, hexane, or heptane.

The combustor can have its own designated low pressure (LP) burner located in the lower portion and can be equipped with a separate high pressure (HP) line in the upper section. The optional HP line, which runs up the outside of the unit and bends back inside the fire tube at the top, acts as a smokeless flare and allows for separate facility blowdown capabilities. This is achieved because it comes equipped with a dual ignition burner management system (BMS). For ideal combustion, an operating pressure of 1.4 kPag (0.2 psig) at the low pressure inlet should be maintained. Figure 22 shows an example of a patented enclosed vapour combustor manufactured by Black Gold Industries Ltd. Hy-Bon EDI Vent Gas Management also provide an enclosed vapour combustor unit which could be considered for the CHOPS sites.

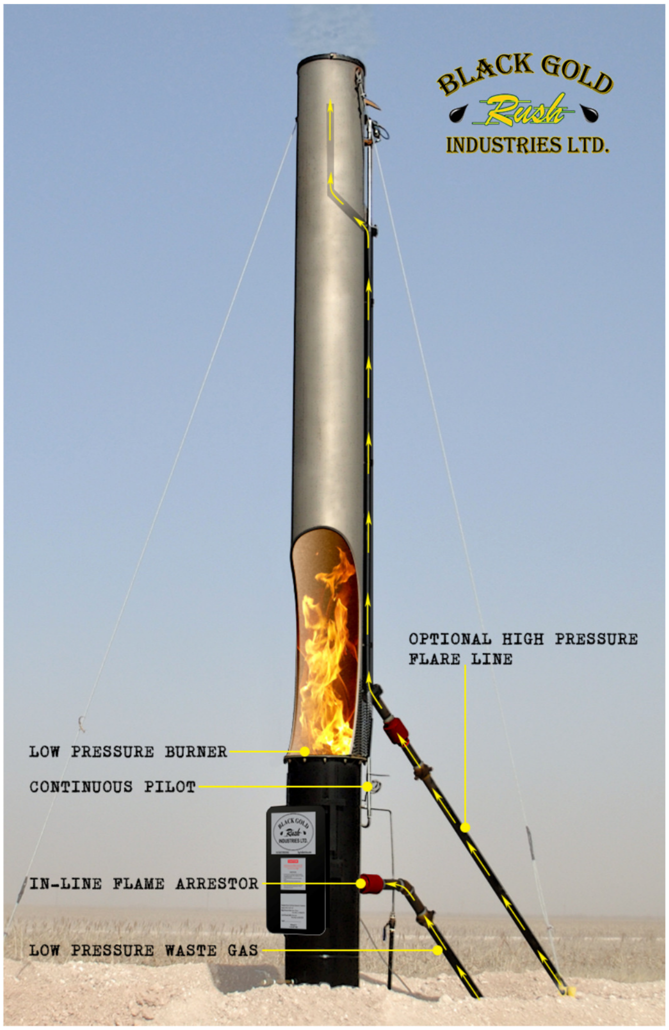

Figure 22: Black Gold Rush Combustor

4.6.1.4 Air Cooled Non-Refractory Lined Incinerator

Waste gas enters a header at the base of the unit and is then diverted to flow controlled burner trains (B149.3 compliant). Specially designed burners mix the vented gas with air and provide additional fuel as required.

TCI Air Cooled Non-Refractory Lined

Fuel is required for the flame failure ignition systems. The flame failure ignition systems come with control panels that provide alarm capabilities and continuous relight features. These units do require power to run the flame failure ignition system; however, the power can come from a solar panel. The product is robust, simple to use, and requires very little maintenance. Additional air is acquired through the concentric ringed stack. Air not used to complete combustion throughout the stack travels upward along the wall maintaining a protective barrier and a cool stack wall temperature. This is the reason why a refractory lining is not required.

The main components are 304 stainless steel stack, carbon steel body, piping, valves, regulators, tubing and venturi burners. They are typically installed on piles with guy wires or on trailers or skids for temporary service. The combustion efficiency is 99.8%, resulting in no smoke, no odour, and no visible flame during normal operations.

Most incinerators are designed with refractory in them. The refractory is subject to high temperature, thermal shock, chemical attack, abrasion, and erosion. Refractory breaks easily during transmission to site and will erode over time. Refractory also needs to be kept warm at all times to reduce the effects of thermal shock. The refractory lining is easily damaged by temporary over-firing events during system upsets. Therefore, refractory must be maintained at not less than 900°C. This requires supplementary fuel.

The cost to transport the Air Cooled Non-Refractory Lined incinerator is much less as it does not have refractory in it.

Figure 23 shows a schematic for a TCI Air Cooled Non-Refractory Incinerator. This incinerator can combust two streams. The two different streams are introduced at different locations within the stack itself. The tank vent stream would be introduced at a different location than the main waste gas stream.

The pilot requires 0.5 m^3/hr (19 scf/hr) of a dry, clean fuel source such as natural gas, propane, or any other fuel. The maximum allowable waste gas pressure is 102 kPag (14.9 psig).

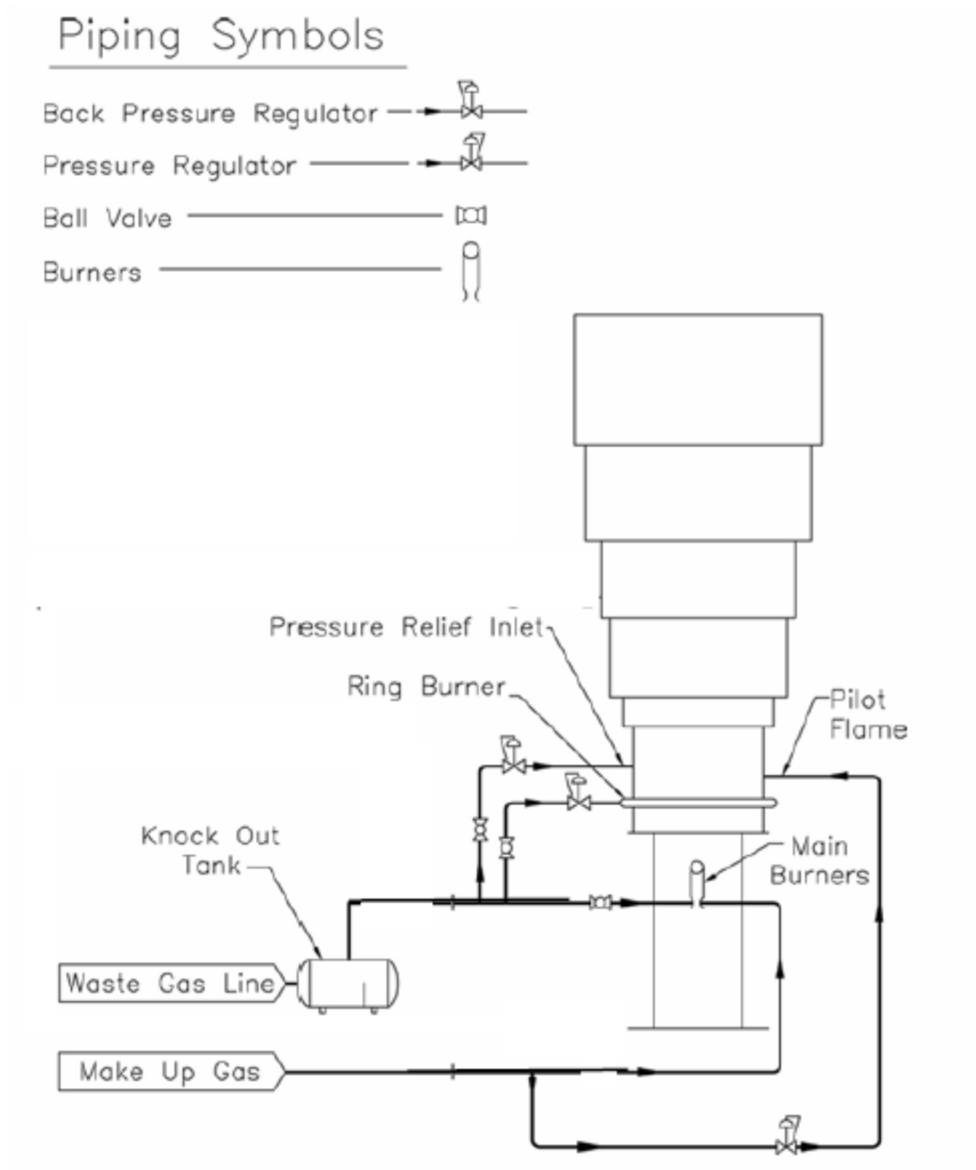

Figure 23: TCI Air Cooled Non-Refractory Lined Incinerator P&ID

4.6.2 Expected Emissions and GHG Reduction

It is expected that 100% of the surface casing vent gas is collected. As 95% of the emissions on a pad site are from the surface casing vent, 95% of overall emissions from a pad site will be captured. The remaining 5% is comprised of tank venting. If tank venting is also collected, a separate, dedicated burner train would be required depending on the technologies chosen. This second burner train would be operated by its own BMS.

Black Gold Rush Industries Ltd has a combination low pressure enclosed combustor and a high pressure flare unit. This style unit could be operated with a single BMS as it would handle both the casing gas burner as well as the tank vent gas burner within the same consolidated control device.

4.6.3 Use of Emissions for Other Purposes

The site emissions could be collected and burned as fuel for engines or heaters.

4.6.4 Overlap with Other Technologies

There is no unique overlap with other technologies.

4.6.5 Limitations and Weaknesses

Combustion is initiated in flare stacks or enclosed combustors, incinerators using a constantly lit pilot or an automatic ignition system. Constantly lit pilots can blow out in windy conditions as a result of a malfunction in the fuel control (which floods the pilot with gas) or insufficient gas being vented from the pad site to sustain the pilot.

An automatic igniter avoids the problems with the pilot. The automatic ignition systems use a sparking device. Spark plugs in combustor systems can eventually build up with carbon and close off the spark gap preventing proper operation. Another industry problem is the overheating of ignitor probes. This results in distortion and widening of spark gaps which the generated signals eventually are unable to bridge.

Tornado has patented a floating electrode (Arch-Light and V-Design) to avoid carbon build up on the spark gap. The floating electrode allows back and forth movement of the electrode while maintaining a constant spark gap. This self-cleaning, self-aligning feature is unique to Tornado. Tornado addressed the problem of overheating ignitor probes by pioneering their own shroud and gas stripper. This development allows the igniter and pilot head to be positioned below the actual flare tip so that it is not exposed to the highest heat area. This replaces the constant pilot and auto-relight system. It would be recommended to use this new system only in waste gas streams that contain very little H_2S.

The use of an open flare with flare stacks can have poor optics with the area residents. Often, an enclosed flare stack or incinerator is chosen as an option to minimize area resident concerns.

A reliable, clean, dry pilot gas supply is required for the Air Cooled Non-Refractory Lined incinerator or the enclosed vapour combustor. It could be propane or natural gas and is required in order to achieve the design combustion efficiency. Ensuring a continuous, consistent supply may be a challenge for remote well-sites but can be managed with an adjacent propane storage bullet. The level in the bullet would be required to be monitored and maintained, incurring an additional maintenance step.

Free liquids cannot be permitted to enter any of the combustion devices; therefore, if liquids are present, a knockout pot will be required and any accumulated liquids must be removed. The combustors must also be 25 m from the wellhead and the tank. The flare line will need to be insulated and heat traced.

4.6.6 Conclusion

Combustion, if a stable flame can be kept, is one of the easiest and most cost-effective solutions to reduce emissions from a CHOPS site. The installed costs are relatively low, the design is not complex and it has a positive impact from a GHG perspective as kilogram for kilogram, the comparative impact of methane on climate change is over 25 times greater than CO_2. The challenge will be to not create more GHG emissions if a pilot is required on the design of combustor chosen.

4.7 LITERATURE SEARCH FOR NEW TECHNOLOGIES

4.7.1 Description of the Technology

From the research, it would appear that there will be two potentially viable alternatives in the future; conversion and power generation. There are a number of options to produce power, which are outlined below. All of these options will require that the gas be conditioned.

A membrane system could be used for the removal of contaminants; however, there is a requirement for pressure drop for contaminant reduction.

The table below identifies some single well, low pressure vent gas clean-up methods as well as key considerations.

Table 5: **Single Well Considerations**

Vent Gas Dehydration	**Overview**	**Concerns**
Calcium Carbonate (Absorption)	• Gas Flows through bed(s) of solid $CaCO_2$ pellets • Water is adsorbed onto the pellets • $CaCO_2$ is consumed and must be replenished	• High Disposal Cost • Oil contaminates pellets and reduces capability • Expensive solution
Hydrate Inhibition using Methanol or Glycol solution	• Solution is injected into the production casing or into the pipeline • Multiple wells can be combined to optimize capital and operating costs	• Chemical is consumed and must be replaced • Dehydration by Glycol absorption may be more economically viable for multiple wells
Solid Desiccant	• Gas is conditioned with respect to water and hydrocarbon dewpoints	• Contaminants will foul the desiccant so pre-treatment is required • Process requires compression and/or heat, leading to higher capital and operating costs

4.7.2 Options

Possible vent gas applications include the following:

- Small scale Steam reforming is at, or close to, commercial demonstration. Using CHOPS vent gas for supply will require substantial gas clean-up and compression costs. There will be a requirement for local use of the products, H_2 and CO_2. Potential suggestions for use are possibly CO_2 for enhanced oil production (CO_2 flood) and/or H_2 fuel cells for electricity or fuel.
- Fertilizer Generation.
- Employing Liquefied Natural Gas (LNG) for truckers is at the commercial demonstration phase in Western Canada. Using CHOPS vent gas for supply will require substantial gas clean-up and compression costs.
- Power Generation;
  - Solid Oxide Fuel Cell technology is evolving. There is a pilot in the works to be designed to generate approximately 2 kW of electricity.
  - Thermopiles are mature technology; however, energy conversion efficiency is relatively low. Vent gas clean-up required.

- Microturbines are a relatively new distributed generation technology that are being used for stationary energy generation applications but would be very costly to implement on CHOPS sites.

4.7.2.1 Steam Reforming

Steam reforming is a process used for producing hydrogen, carbon monoxide, or other products from natural gas. This is accomplished in a reformer where hydrocarbons and steam react at high temperature.

By using a newly developed type of reformer, it is now possible to process ranges of 50 - 200 Nm3/h (1.8 mcf/h – 7 mcf/h) economically by compact, small-scale hydrogen generation plants based on steam reforming of natural gas.

Pre-Treatment

The vent gas used for the feedstock will require desulphurization (activated carbon filters, pressurized and either preheated and mixed with process steam or directly injected with water into the reformer). The water needs to be softened and demineralized.

Steam Reforming and CO-Shift Conversion

At approximately 900°C, methane and steam are converted within the reformer in the presence of a nickel catalyst to a hydrogen rich reformate stream. The heat required for the reaction is obtained by the combustion of fuel gas and purge/tail gas from the Pressure Swing Absorption system. Following the reforming step, the synthesis gas is fed into the CO conversion reactor to produce additional hydrogen.

Gas Purification – PSA System

Hydrogen purification is achieved using pressure swing adsorption (PSA). The PSA unit consists of vessels filled with selected adsorbents. The PSA reaches hydrogen purities higher than 99.999 % by volume and CO impurities of less than 1 vppm (volumetric part per million) fulfilling the specifications set by the fuel cell supplier. Pure hydrogen from the PSA unit is sent to the hydrogen compressor, while the PSA off-gas from recovering the adsorbents, called tailgas, is fed to the reformer burner.

The small scale steam reforming plants can either be built on skids or in sea containers (2 – 20 foot containers). The only interfaces needed are natural gas, water and electricity supply. The plants can be designed for automatic and unattended operation.

4.7.2.2 Conversion to Fertilizer

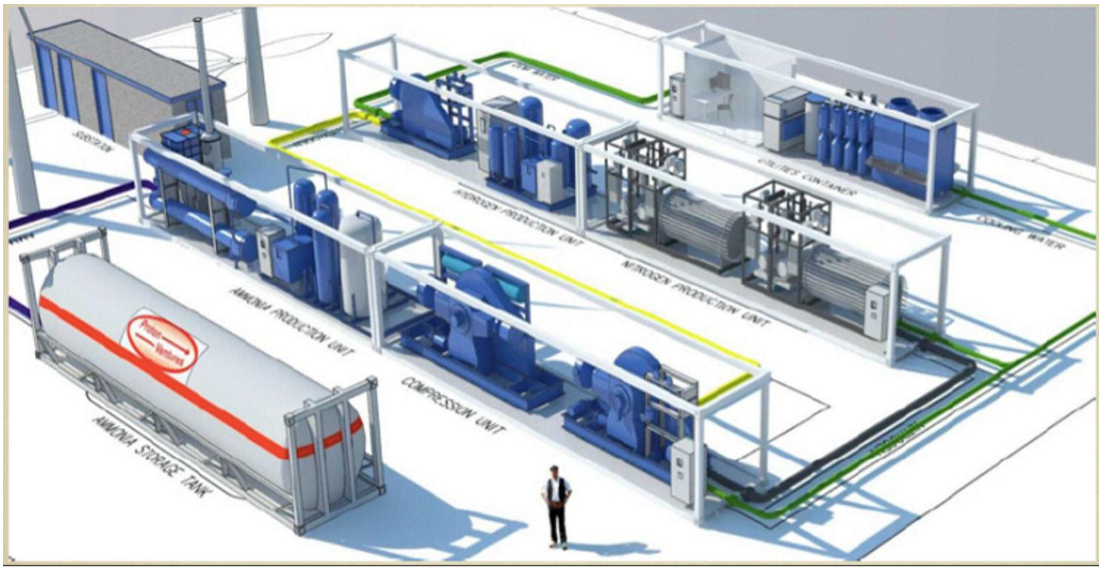

Figure 24: GE Mobil FLEX Generator

The GE MobilFLEX generator produces power from waste gas right at the wellhead to power the “ELF” system and the wellhead pump. The “ELF” system produces fertilizer.

No additional information could be found on this topic.

4.7.2.3 Creation of LNG (Liquified Natural Gas) for Truckers

LNG can be used to generate electricity, heat buildings, power drilling rigs, and fuel ferries and marine vehicles. The main impediment to using LNG in Canada has been the lack of liquefaction infrastructure. Without nearby plants to liquefy natural gas, LNG must be shipped via truck over long distances, increasing the cost for consumers.

Estimates by the National Energy Board (NEB) suggest that trucking LNG 1,000 kilometers can increase its cost by $1.88 – $3.10 per million British thermal units. Recent and proposed construction and expansions of small-scale liquefaction facilities would decrease trucking distances for many prospective adopters of LNG as a fuel.

An example of a small-scale LNG plant is the first Canadian merchant LNG facility, built in Elmworth, Alberta by Ferus Natural Gas Fuels and opened last October 2014. The 190 m^3/d (1,200 bbl/d) plant – designed to be expanded up to 250,000 gallons per day, produces high-quality LNG fuel for engines used in drilling rigs, pressure pumping services, water heating for well fracturing and heavy-duty highway and off-road trucks.

To support the entire LNG supply chain, Ferus NGF designed and built specialized mobile storage and dispensing equipment to provide a full service fuelling solution.

4.7.2.4 Power Generation

Various technologies currently exist for power generation.

4.7.2.4.1 Small Scale Solid Oxide Fuel Cell

A new, small-scale solid oxide fuel cell (SOFC) system could be used in the future for site power generation. There is a smaller system currently being developed at the Department of Energy's Pacific Northwest National Laboratory. Fuelled by methane, the system achieves an efficiency of up to 57%, improving on the 30% to 50% efficiencies seen previously in SOFC systems of similar size.

Like batteries, fuel cells use anodes, cathodes, and electrolytes to produce electricity. But unlike most batteries, fuel cells can continuously produce electricity if provided with a constant fuel supply. Fuel cells are characterized by their electrolyte material, which in the case of SOFCs, is a solid oxide or ceramic. Ceramic materials also form the anode and cathode which, along with the electrolyte, form a total of three layers.

Air is pumped up against the cathode, which forms the outer layer, with oxygen from the air becoming a negatively charged ion where the cathode and the inner electrolyte layer meet. The negatively charged oxygen ion then moves through the electrolyte to reach the final anode layer where it reacts with a fuel to create electricity, as well as steam and carbon dioxide by-products. SOFCs can run on different fuels, including natural gas, biogas, and hydrogen.

Because they are more efficient than other methods of electricity generation, including coal power plants, SOFCs consume less fuel and create less pollution to generate the same amount of electricity. Small-scale SOFCs also have the advantage of being able to be placed closer to where the electricity generated is consumed, reducing the amount of power that is lost when sent through transmission lines.

Solid oxide fuels cells are a promising technology for providing clean, efficient energy. Current research shows that smaller solid oxide fuel cells that generate between 1 and 100 kilowatts of power are a viable option for highly efficient, localized power generation.

Steam Reforming for the SOFC (see Diagram above)

Steam reforming involves mixing steam with the fuel to create carbon monoxide and hydrogen, which in turn reacts with oxygen at the fuel cell's anode. This process is endothermic and the additional heat required can cause uneven temperatures on the ceramic layers, leading to weakening and breakage of the fuel cell. A heat exchanger external to the fuel cell is required to permit the initial reactions between steam and the fuel to be completed outside of the fuel cell. This process is known as external steam reforming.

Heat Exchangers

Heat exchangers for this process consist of a wall made of a conductive material that separates the two gases. The hot exhaust that is expelled as a by-product of the reaction inside the fuel cell is located on one side, while a cooler gas that is heading toward the fuel cell is located on the other. Heat from the hot gas moves through the wall to warm the incoming gas to temperatures needed for the reaction to take place inside the fuel cell.

New research has shown that creating multiple walls using a series of tiny looping channels, narrower than a paperclip, is more effective than a single dividing wall. These microchannel heat exchangers increase the surface area to allow more heat to be transferred, thereby increasing the efficiency of the system. The microchannel heat exchanger was also designed so that the gas moves through the looping channels with very little additional pressure.

Steam Recycling

One of the current systems also recycles the exhaust coming from the anode, consisting of steam and heat by-products, to maintain the steam reforming process. Not only does this recycling negate the need for an electrical device to heat water and create steam, it also means that the system is able to consume unused fuel.

The efficiency of the combination of external steam reforming and steam recycling and use of microchannel heat exchangers allow the system to use as little energy as possible with the end result being more net electricity production.

4.7.2.4.2 Thermopiles

A thermoelectric generator (TEG) converts heat directly into electricity. As heat moves from a gas burner through a thermoelectric module, it causes an electrical current to flow.

The thermoelectric generator is comprised of a hermetically sealed thermoelectric module (thermopile) which contains an array of lead-tin-telluride semi-conductor elements. This durable module provides a chemically stable environment for the thermoelectric materials which ensures a long service life. On one side of the thermopile, a gas burner is installed, while the opposite side is kept cool by aluminum cooling fins or a heat pipe assembly. An operating generator maintains a temperature of approximately 540˚C on the hot side and 140˚C on the cold side. The heat flow through the thermopile creates steady DC electricity with no moving parts.

TEGs range in output size from 15 watts to 550 watts, and can be used in applications requiring power up to 5,000 watts. Uses include power for remote control and monitoring of oil or gas production facilities, telecommunications systems and cathodic protection of well casings.

TEGs produce power by the direct conversion of heat into electricity without any moving parts. This feature offers significant advantages, particularly for remote applications.

TEG Features

Thermoelectric Generators are highly reliable and easy to install and operate on methane gas. The solid state design ensures trouble free operation and provides reliable power. The system can be installed and commissioned within a day.

The burner system is equipped with an automatic spark ignition system and is constructed from high temperature nickel alloys, with stainless steel cabinets.

The maintenance requirement for these units is low, perhaps one to two hours annually.

Capital and operating costs are competitive for systems of up to 500 watts.

The generators are hermetically sealed and have a proven life capacity of 20 years in continuous operation.

4.7.2.4.2.1 Expected Emissions and Greenhouse Gas Reduction

There would be no methane emissions if the entire site could use the power generated. See Table 1 for expected emissions from the site.

4.7.2.4.2.2 Use of Emissions for Other Purposes

The site emissions could be collected and burned as fuel for engines or heaters.

4.7.2.4.2.3 Overlap with Other Technologies

There is currently no overlap with other technologies identified.

4.7.2.4.2.4 Limitations and Weaknesses

The site can generate electricity from the combustion of the venting gas; however, the volumes are not consistent and there are generally no sites where electricity can be sold back onto the grid. The gas used to create the power needs to be continuous because, without a steady flow, the chemical reaction can be disrupted and cause a faulty charge to occur. The gas itself also requires a 37.3 MJ/m^3 (1,000 btu/scf) heating value to maintain power charge for these TEG units.

4.7.2.4.3 Microturbines

Microturbines are a simple form of gas turbine, usually featuring a radial compressor and turbine rotors, and often using just one stage of each. They typically recover exhaust energy to preheat compressed inlet air, thereby increasing electrical efficiency compared with a simple-cycle machine. The air-to-air heat exchanger is termed a "recuperator," and the entire system is typically called a recuperated cycle.

Microturbines provide high electrical efficiency compared with traditional gas turbines in the same size class. The efficiency advantage is derived when a portion of the exhaust energy is returned to the energy conversion process.

The strength of the microturbine option lies with combined heat and power (CHP) or combined cooling, heat, and power (CCHP), where the clean exhaust heat can be recovered and re-used.

Microturbines work as follows:

- Fuel is supplied to the combustor at approximately 630 kPag (90 psig);
- Air and fuel are burned in the combustor, releasing heat that causes the combustion gas to expand;
- The expanding gas powers the gas turbine that in turn operates the generator; the generator then produces electricity;
- To increase the overall efficiency, microturbines are typically equipped with a recuperator that preheats the combustion air using turbine exhaust gas. A microturbine can also be fitted with a waste heat recovery unit to heat typically water, but for these sites, they could be retrofitted to heat a medium that could be used for heat tracing.

4.7.2.4.3.1 Expected Emissions and Greenhouse Gas Reduction

It would be expected that the microturbine would be able to capture all the vented casing gas. Therefore, there would be a 95% reduction in methane emissions. See Table 1 for a summary of expected emissions from the site.

4.7.2.4.3.2 Use of Emissions for Other Purposes

The site emissions could be collected and burned as fuel for engines or heaters.

4.7.2.4.3.3 Overlap with Other Technologies

Compression is required to be added to the inlet of the microturbine.

4.7.2.4.3.4 Limitations and Weaknesses

With the small vented volumes at the CHOPS sites, the project is not economic. A compressor to boost pressure would be required.

4.7.3 Conclusion for New Technologies

Steam Reforming, Fertilizer Generation, and LNG for Trucks require a steady flow of natural gas and an abundance of infrastructure. These would not be viable solutions for a single well battery site.

Power generation is not a viable option due to the low and sporadic flowrates coming from the sites. Even if there were enough gas to create electricity, there is generally no ability to sell the power generated back to the grid as most of these sites are not near power lines. TEG's have been used successfully on small sites in the past, however, the difference between the sites that they have been used successfully and a CHOPS site is the need to have a continuous steady flow of natural gas.

5.0 STUDY CONCLUSION

PTAC has initiated a study with support from;

- Devon Energy,
- Husky Energy,
- Canadian Natural Resources Limited and
- Alberta Innovates – Energy and Environment Solutions

to investigate potential solutions for CHOPS sites that are venting casing gas and tank vents to the atmosphere in the area of Lloydminster.

Numerous technologies were investigated including;

- VRU (Vapour Recovery Unit);
- SlipStream GTS for CHOPS;
- T.O.P. Tank (Thermally Optimized Production);
- Hexa Cover;
- Solution gas compression;
- HY Bon combustors, Black Gold Industries combustor, flaring, "Cool" TCI (Total Combustion Inc.) Incinerator;

New technology from a literature search which includes;

- Steam Reforming
- Fuel Cell Technology
- Conversion to Fertilizer

- Creation of LNG for Truckers
- Power Generation
  - Thermo piles
  - Micro turbines

In almost all cases, the operation will require some form of clean up as the gas is water wet. This adds a level of complexity as there will be an associated pressure drop and water that drops out of solution will need to be addressed. Freeze protection will also always be required. Most of the solutions require a significant amount of equipment to make the process work.

Of all the technologies investigated, the viable alternatives that have proven themselves in the field are the Go-Technology solution gas compressor, combustion of the vented gas and Hexa-Covers® floating tiles. Tank emissions alone account for only about 5% of the total site emissions. Therefore the floating tiles on the tanks and vapour recovery compressors will not provide a comprehensive solution. Solutions focusing on capture and use of casing gas will offer the most effective method of reducing vented emissions. The typical CHOPS site vents less than 500 m^3/d and that low flow rate will impose a limit the choice of technology.

Regions where access to power or pipelines is not available will not permit conservation of gas in pipeline networks or allow electric motors to be powered by the grid. The selection of technology will thus be influenced by the availability of infrastructure in the area. The choices of technologies that will be suitable for these "stranded" sites will be floating tiles in the tanks and combustion of excess casing gas. The SlipStream GTS system also shows promise as a viable alternative but it has not been proven with a field trial at the time of this writing. Of the proven combustion technologies, the Producer has a choice of flare stacks, enclosed vapour combustor units or Air Cooled, Non-Refractory Lined incinerators.

Works Cited

"Compressor Types." *Compressor Types*. N.p., n.d. Web. 18 May 2015.

Dowler, Cameron. Spartan Controls Ltd. Personal correspondence and technical data on the SlipStream GTS System.

"Enclosed Vapor (Vapour) Combustors." *Black Gold Rush Industries RSS2*. N.p., n.d. Web. 18 May 2015.

"Ferus Natural Gas Fuels Opens Canada's First Merchant LNG Facility." *Environmental Leader RSS*. N.p., n.d. Web. 18 May 2015.

"Green Car Congress: Ferus Natural Gas Fuels Commissions 1st Merchant LNG Facility in Canada." *Green Car Congress: Ferus Natural Gas Fuels Commissions 1st Merchant LNG Facility in Canada*. N.p., n.d. Web. 18 May 2015.

"Hexa-Cover – Greatario." Hexa-Cover – Greatario. N.p., n.d. Web. 20 May 2015.

"Home – Black Gold Rush Industries." *Black Gold Rush Industries RSS2*. N.p., n.d. Web. 18 May 2015.

"HY-BON." *HY-BON*. N.p., n.d. Web. 18 May 2015.

"Membrane Air/Gas Dryers." *Air Products Cactus Membrane Air and Gas Dryers*. N.p., n.d. Web. 18 May 2015.

"Microturbine Technology Matures – POWER Magazine." *POWER Magazine*. N.p., n.d. Web. 18 May 2015.

"Power Where You Need It." *Welcome to Gentherm Global Power Technologies*. N.p., n.d. Web. 18 May 2015.

"Record Setting Small-Scale Solid Oxide Fuel Cell Could Power Neighborhoods." *Record Setting Small-Scale Solid Oxide Fuel Cell Could Power Neighborhoods*. N.p., n.d. Web. 18 May 2015.

"Rules of Thumb for Chemical Engineers." *Rules of Thumb for Chemical Engineers*. N.p., n.d. Web. 18 May 2015.

"Solutions." *RSS*. N.p., n.d. Web. 18 May 2015.

"TCI Incinerators / Thermal Oxidizers: Engineered Solutions for Combusting Waste Gas." *TCI Incinerators / Thermal Oxidizers: Engineered Solutions for Combusting Waste Gas*. N.p., n.d. Web. 18 May 2015.

"The Unique and Patented Hexa-Cover® Floating Cover Is Perfect on Almost Any Form of Fluid Surface." *Hexa-Cover® Floating Cover Is Used on All Forms of Basins, Lagoons, Reservoirs, Containers, Ponds and Tanks*. N.p., n.d. Web. 18 May 2015.

"The User Cost of Capital Under Neo-Classical Technology. Part 2. Taxes Included." *Taxation, Technology and the User Cost of Capital Contributions to Economic Analysis* (1989): 95-120. Web.

"Welcome to NEWCO Tank Corp. – The Environmentally Friendly Oil Tank." *Welcome to NEWCO Tank Corp. – The Environmentally Friendly Oil Tank*. N.p., n.d. Web. 18 May 2015.

Engineered Solutions For Combusting Waste. *TCI USA, INC.* (n.d.): n. pag. Web.

Black Gold Rush Industries Ltd. BGR-HP/LP Combustor Model: BGR-36. Sundre: Black Gold Rush Industries, n.d. Print.

Black Gold Rush. BGR – LP Combustor Model: BGR-24. Sundre: Black Gold Rush, n.d. Print.

Busch Vacuum Technics Inc. Dry Rotary Claw Pressure Pump. Boisbriand: Busch Vacuum Technics, n.d. www.busch.ca. Web. 10 June 2015.

Combustor Tear Away Rendering V2. Digital Image. Black Gold Rush Industries, 15 April 2015. Web. 15 April 2015.

Dallas Rosevear. Black Gold Rush Industries Enclosed Vapour Combustors. Sundre: Dallas Rosevear, 2015. Print.

Environmental, United States, Protection Agency, Office Of Air And Radiation, and (6202J). *POWERING MICROTURBINES* (n.d.): n. pag. Web.

Fraser, Don. PTAC Flare Gas Conservation. Calgary: Cangas Solutions, 2014. Print.

Gasstar, Epa. *Scroll Compressors for Vapor Recovery –A Case Study* (n.d.): n. pag. Web.

Global Thermoelectric. Model 5100 Thermometric Generators. Calgary: Global Thermoelectric, 2013. www.globalte.com. July 2013. Web. 09 June 2015.

Global Thermoelectric. Model 8500 Thermometric Generators. Calgary: Global Thermoelectric, 2013. www.globalte.com. January 2013. Web. 09 June 2015.

Going, Curtis, and Kevin Clarke. Toptank The New Standard in Heavy Oil Storage. 11 October 2014. Power Point Presentation. Alberta, Lloydminster.

Kohuch, Rob. Findings Report. Rep. no. H1004-1. Lloydminster: QPS Evaluation Services, 2014. Print.

Kolb, Hans. "Methods for Reduction of Methane Venting." Message to the author. 17 March 2015. E-mail.

Lare. *U.S. FLARE MANAGEMENT What Is the Definition of "Truly Stranded" Wells?* (n.d.): n. pag. Web.

"On-site Steam Reforming." *HyFLEET:CUTE*. N.p., n.d. Web. 14 Sept. 2015.

Outer, Gas Enters An, Opening As One Scroll, and Orbits The Other. *Emerson Vapor Recovery Solution How Does Scroll Work?* (n.d.): n. pag. Web.

Pituch, Dominic. "Budgetary Estimate on TEG for PTAC." Message to the author. 11 June 2015. E-mail.

Rosevear, Dallas. "Methods for Reduction of Methane Venting." Message to the author. 19 May 2015. E-mail.

Saxinger, Jeff. SMD Technical Data Sheet C8 and C15 Series Vol. 5.0. Calgary: SMD, n.d. Print.

Saxinger, Jeff. SMD-PTAC Report Requirements Summary Response. Calgary: SMD, 2015. Print.

Simard, Catherine. "Proposal for a Busch MM1144BP Compressor." Message to the author. 11 June 2015. E-mail.

Solutions, Energy And Environmental. "Fuel Cell Handbook, Fifth Edition." (2000): n. pag. Web.

Tysowski, Jeff. Capital Cost Analysis Newco Tank Verses Old Technology. Saskatoon: Research and Development Process Management, 2015. Print.

Tysowski, Jeff. New Technology K2A-HOPT Oil Production Tank. Rep. Saskatoon: Research and Development Process Management, 2009. Print.

Zahner, Frank. Report content on SlipStream GTS systems.