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## **Increasing Sales Gas Output from Glycol Dehydration Plants**

Trina Dreher, SPE, Courtney Hocking, Michael Cavill and Adam Geard, Process Group Pty. Ltd.

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### **Abstract**

Natural gas contains significant amounts of water that must be removed. A common way to dehydrate gas to low water levels is via a liquid desiccant such as tri-ethylene glycol (TEG) and the use of stripping gas in the regeneration system.

The patented GLYNOXX® recycle stripping gas process offers a solution to obtaining enhanced gas dehydration without wasting valuable product. In this process a small amount of stripping gas is introduced into the stripping column, which once it passes through the column is cooled to condense and separate the majority of water. The stripping gas is then recycled to the stripping column via a blower. The stripping gas used is preferably flash gas, although if sufficient quantities are not available then fuel gas may be used. Regardless of the type of stripping gas employed, the recycle process ensures that only very small make-up quantities are required on a continual basis thereby decreasing the amount of fuel gas consumed during operation. An additional advantage of the GLYNOXX process is that it reduces the amount of gas vented from a TEG dehydration plant thereby reducing the carbon emissions liability of the plant.

The GLYNOXX process may be integrated into a new TEG dehydration plant or retrofitted to an existing TEG dehydration plant. This paper details the GLYNOXX design and how it is integrated into both new and existing plants. It then compares the operation of an existing TEG dehydration plant that employs standard stripping gas operation with that of the GLYNOXX process following a retrofit, including the required plant modifications. A simplified economic analysis is presented for a retrofitted GLYNOXX process to illustrate the significant advantages of the technology for TEG dehydration plant operators.

### **Introduction**

For over 35 years Process Group has been designing and fabricating glycol dehydration packages as a major part of its business. Each package is customised for the client's particular specifications and needs, meaning although the basic design is consistent the detailed design of each package can vary greatly. Many of these plants have been for Queensland coal seam gas (CSG) developments. In recent times, our clients have demanded packages that are more energy efficient with lower emissions so we developed a retrofit solution for our standard gas dehydration package design in order to offer glycol plant operators more favourable outcomes in terms of stripping gas usage and plant emissions for existing plants. In particular, the solution has been developed to be applicable to both gas-fired and electric reboilers and only require relatively minimal additional capital investment and operating costs for its implementation.

Raw natural gas is saturated with water vapour that must be removed before the gas can be commercially used for several reasons including; (i) to prevent the formation of hydrates, (ii) to meet the water dew point specification, or (iii) to reduce corrosion rates. The use of liquid desiccants is an established and proven method utilised by the industry with tri-ethylene glycol (TEG) the most common liquid desiccant employed, although other glycols and desiccants may be used. Figure 1 illustrates a typical TEG dehydration process. The water saturated gas is contacted with lean TEG in the contactor (1) where the counter-current flow path and high contact surface area enhances water absorption into the TEG from the gas stream resulting in relatively dry gas and water-rich TEG exiting the contactor. Before the rich TEG can be recirculated to the contactor it needs to be regenerated by boiling off the absorbed water in the reboiler and still column (6).

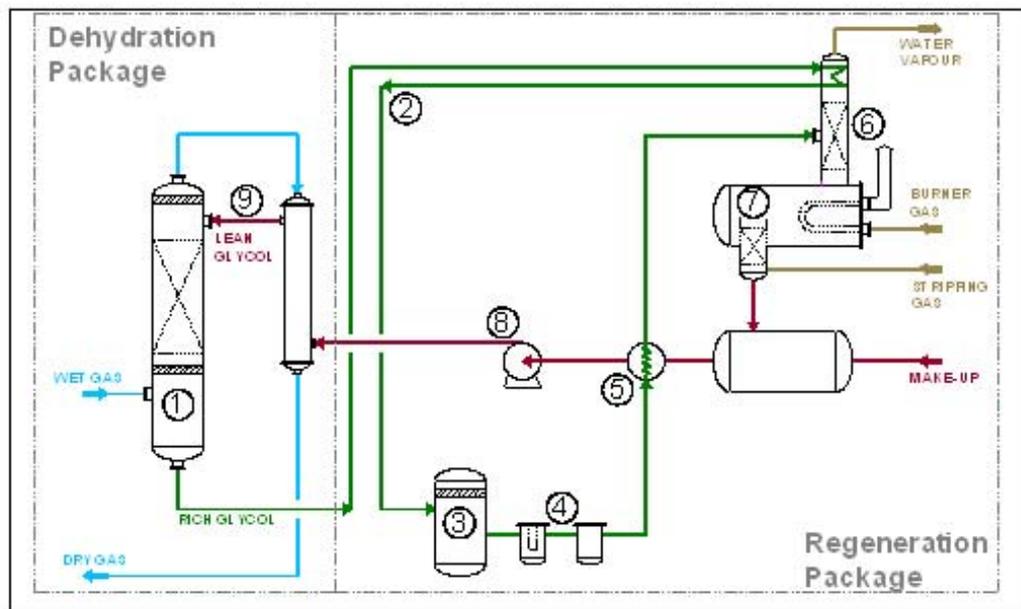


Figure 1: Typical TEG gas dehydration process

The required concentration of the TEG that enters the contactor and contacts the wet natural gas is determined by the specified water content of the dried gas. This TEG concentration is typically in the range 95-99.99 wt% (balance water) and the operational conditions in the reboiler and stripping column are adjusted to regenerate the TEG to the desired concentration. The reboiler typically operates at approximately atmospheric pressure and 204 °C which results in a maximum TEG purity of approximately 98.6 wt%<sup>1</sup>. There are several methods available to obtain a higher TEG purity and each method is based on the principle of reducing the effective partial pressure of water in the vapour space of the reboiler allowing a higher TEG concentration at the same temperature. The stripping gas process, vacuum regeneration, azeotropic processes (*e.g.* Drizo™) and condenser bundle processes (*e.g.* Coldfinger®) are examples of processes that can increase the TEG concentration. Stripping gas is the most common method largely due to its simplicity and low cost.

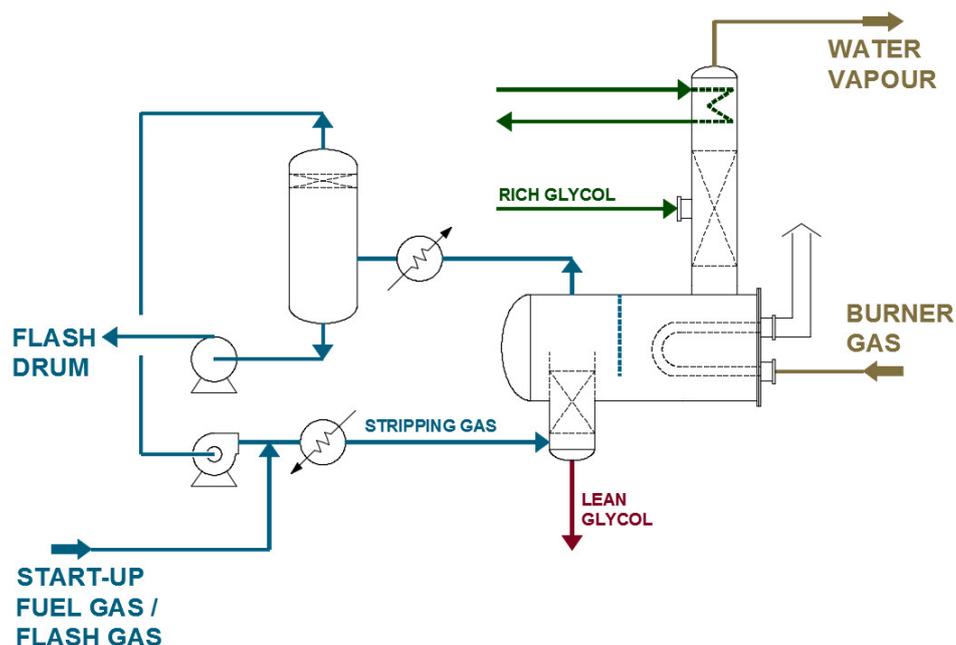
As shown in Figure 1, for the stripping gas method a small stream of gas is usually injected into the stripping column, which is a small packed column located at the lean TEG discharge of the reboiler (7). In the stripping column the stripping gas contacts the hot lean TEG and strips an additional small amount of water from it into the gas thereby increasing the purity of the lean TEG. The wet stripping gas then passes into the reboiler, through the still and exits the process at the still overheads from where it is usually either sent to flare or vented. As such, the use of stripping gas adds directly to the dehydration plant gaseous emissions and particularly the carbon emissions when natural gas is used as stripping gas. It is possible to condense the still overheads to remove the water and recover the stripping gas however, as the vapour stream can be in the order of 40-80% water and the flow rate is relatively small it is usually not economic to do so. Typically either fuel gas, flash gas or a mixture of both are used as stripping gas. Flash gas, which is the overheads from the flash drum (3), can also be used as fuel for a gas-fired reboiler rather than being sent to flare.

### The GLYNOXX® Process

The GLYNOXX process was developed to reduce the stripping gas usage and vented emissions from a TEG dehydration plant. The process virtually eliminates the venting of stripping gas thereby reducing the amount of make-up fuel gas required for stripping and the plant emissions. In the GLYNOXX process stripping gas is continually recycled from the stripping column vent, reconditioned and returned to the stripping column. As such, once the stripping gas circuit is charged there is very little gas make-up or venting during operation. Figure 2 shows how the GLYNOXX process integrates into the reboiler and stripping column. The vapour spaces of the stripping column and reboiler are separated via a baffle so the hot vapour, at approximately 200 °C, containing stripping gas, water and TEG from the stripping section exits the vapour space and is cooled via a heat exchanger to 55 °C. The 2-phase stream then passes into a separation vessel from where the condensed water and TEG are pumped to the flash drum for recovery. The pressure of the vapour stream exiting the separation vessel is increased

via a blower before being injected into the bottom of the stripping section. The pressure increase across the blower is typically in the order of 20 kPa to account for pressure losses in the GLYNOXX circuit however, it may be higher or lower depending on exchanger and piping design. Similarly, the reboiler operating pressure is typically in the range 0-10 kPag but may be higher or lower depending on the exchanger, blower and piping design. At start up the GLYNOXX circuit needs to be charged with stripping gas, which could be fuel gas, flash gas or nitrogen, the latter from an external source. A small amount of stripping gas make-up is required during operation as small losses result from the reboiler baffle weep holes, which are required to maintain pressure equilibrium.

Figure 2 illustrates the basic GLYNOXX process however, it should be noted that several variations in design can be implemented depending on client specifications and if GLYNOXX is to be retrofitted or incorporated into a new plant. Specifically the stripping gas can be fully or partially recycled, it may be pre-heated downstream of the blower via a coil that runs through the reboiler and the stripping column may be integral or separate to the reboiler.



**Figure 2: The GLYNOXX® process**

The maximum theoretical TEG concentration achieved with GLYNOXX is 99.85 wt%, which although slightly lower than that reportedly achieved with Drizo and similar azeotropic systems the GLYNOXX advantage is that the process does not require the presence of azeotropic components such as BTEX (benzene, toluene, ethylbenzene, xylene). If the raw natural gas does not contain any aromatics, as is the case with coal seam gas, then azeotropic systems require not only their introduction but also result in their continual venting, which can present potential health and safety concerns around plant operation. In contrast, there are no such concerns around a GLYNOXX plant as it does not require any aromatics to be present and has very low emissions compared to other methods of increasing the lean TEG concentration.

The GLYNOXX process can be easily retrofitted to existing TEG dehydration plants as the equipment footprint is small and requires minimal modifications to existing equipment. For the 100 MMscfd plant discussed in this paper the footprint of a GLYNOXX unit is approximately 3x3x4 m (LxWxH) and would be located near the reboiler to minimise line losses. Where an air cooler is used to cool the hot vapour then an additional 1.4x1x1.7 m (LxWxH) should be allowed. The GLYNOXX process largely uses existing pipework in the stripping gas circuit so only minimal changes are required, although a small nozzle on the top side of the reboiler would need to be added if none existed. The reboiler requires the installation of a baffle to separate the stripping gas and reboiler sections. The baffle is simply a plate that contains weep holes and can be bolted in place with appropriate supports. This avoids any welding and the associated costs of re-testing the pressure vessel.

## Results and Discussion

Analysis was conducted for the dehydration of gas from a typical coal seam well in Queensland, Australia. Details of the simulated plant investigated are given in Table 1 and the maximum ambient air temperature was assumed to be 45 °C.

Inlet Conditions	
Gas Flow Rate (MMscfd)	100
Gas Pressure (kPag)	7500
Gas Temperature (°C)	55
Lean TEG Circulation Rate (USGPM)	21.9
Lean TEG Concentration (wt%)	99.7
Lean TEG (USG/lb H <sub>2</sub> O removed)	2.5
Gas Composition (mol %)	
	H <sub>2</sub> O Saturated
	CO <sub>2</sub> 2.0
	Nitrogen 3.0
	Methane 95.0
Outlet Conditions	
Gas Flow Rate (MMscfd)	99.97
Gas Pressure (kPag)	7440
Gas Temperature (°C)	59-60
Outlet Water Content (lb H <sub>2</sub> O/MMscf)	4

**Table 1: Specifications of the TEG dehydration plant used for simulations**

Eight design cases for the 100 MMscfd standard plant were investigated, as given in Table 2, and reflect those typically employed by the industry. In effect, each Case “A” is a retrofit of GLYNOXX on the corresponding Case “B” without any major changes to existing equipment. Traditionally gas dehydration plants have employed gas-fired reboilers that are fuelled by fuel gas although more recently there has been growing interest in the deployment of electric reboilers. On a typical plant the flash gas is either vented or used as stripping gas, with fuel gas making up any short fall in flow. Fuel gas may also be used as the sole source for stripping gas. As noted in the table below, where GLYNOXX is installed either flash gas or fuel gas is used as the initial charge of stripping gas and the stripping gas circuit may be run in full or partial recycle modes. For Cases 2A and 4A the GLYNOXX process is run in partial recycle mode where part of the stripping gas is vented rather than being fully recycled in order to fully utilise the flash gas.

It should be noted that consistent operating conditions were used for all cases for ease of comparison rather than fully optimising each individual case. Each design case was modelled via Aspen HYSYS® using the Peng-Robinson equation of state. The results at steady state operation are given in Table 3.

Case	GLYNOXX installed?	Reboiler type	Flash gas usage	Stripping gas source	Reboiler fuel
1A	Yes	Gas-fired	Vented	Full recycle (Fuel gas charge)	Fuel gas
1B	No	Gas-fired	Vented	Fuel gas	Fuel gas
2A	Yes	Gas-fired	Stripping Gas	Partial recycle (Flash gas charge)	Fuel gas
2B	No	Gas-fired	Stripping Gas	Flash gas / Fuel Gas	Fuel gas
3A	Yes	Electric	Vented	Full recycle (Fuel gas charge)	Electricity supply
3B	No	Electric	Vented	Fuel gas	Electricity supply
4A	Yes	Electric	Stripping gas	Partial recycle (Flash gas charge)	Electricity supply
4B	No	Electric	Stripping gas	Flash gas / Fuel Gas	Electricity supply

**Table 2: Design cases investigated**

Case	1A	1B	2A	2B	3A	3B	4A	4B
<b>Stripping Gas</b>								
Stripping Gas Flow Rate (kg/hr)	110	55	110	65	110	55	110	65
Flash Gas Used for Stripping (kg/hr)	-	-	30	30	-	-	30	30
Fuel Gas Used for Stripping (kg/hr)	1	55	0	35	1	55	0	35
<b>Total Stripping Gas Make-up Flow Rate (kg/hr)</b>	<b>1</b>	<b>55</b>	<b>30</b>	<b>65</b>	<b>1</b>	<b>55</b>	<b>30</b>	<b>65</b>
<b>Energy Usage</b>								
Fuel Gas Used for Stripping (kg/hr)	1	55	0	35	1	55	0	35
Fuel Gas Used as Reboiler Fuel (kg/hr)	46	40	46	40	0	0	0	0
<b>Total Fuel Gas Used by Plant: Flow Rate (kg/hr)</b>	<b>47</b>	<b>95</b>	<b>46</b>	<b>75</b>	<b>1</b>	<b>55</b>	<b>0</b>	<b>35</b>
Equivalent Energy Usage (kW)	648	1,320	639	1,043	13	764	0	482
Reboiler Duty (kW)	335	282	334	287	335	282	334	287
<b>Total Electric Power Usage (kW)</b>	<b>25</b>	<b>15</b>	<b>25</b>	<b>15</b>	<b>360</b>	<b>297</b>	<b>359</b>	<b>302</b>
<b>Vent Gas</b>								
Vent Gas Methane Flow Rate (kg/hr)	21.6	70.5	21.1	52.3	21.6	70.5	21.1	52.3
Total Vent Gas Flow Rate (kg/hr)	278	332	277	312	278	332	277	312

**Table 3: TEG dehydration plant simulation results**

As the results given in Table 3 indicate, retrofitting GLYNOXX to a typical TEG dehydration plant will decrease the stripping gas make-up flow rate as well as the overall quantity of fuel gas required to operate the plant. So regardless of whether fuel or flash gas is used as stripping gas or whether the reboiler is gas or electric-fired a GLYNOXX retrofitted dehydration plant will result in more fuel gas being available to sell, either as gas or Liquidified Natural Gas (LNG). On the other hand, a GLYNOXX retrofit will increase the overall stripping gas flow rate compared to a conventional plant. This is because the recycled stripping gas contains some water and is therefore, less efficient at stripping water from the TEG than dry fuel gas. In the case of flash gas, even though flash gas is also a wet gas, it contains less water than recycled stripping gas so is more efficient than the recycled gas although less efficient than dry fuel gas. A GLYNOXX retrofit will also increase the reboiler duty due to the recycling of the aforementioned water in the stripping gas to the flash drum of the TEG dehydration plant. It should be noted that optimisation of the lean/rich glycol heat exchanger will reduce the reboiler duty however, for this analysis the performance of the exchanger was not optimised as it was assumed that the existing exchanger would not be modified during the retrofit. If the lean/rich exchanger was modified or replaced in order to optimise the GLYNOXX process then the reboiler duty would be closer to, although still higher than, the conventional process. Given that the lean/rich exchanger is commonly a plate type then its modification would be relatively inexpensive although the economic benefit of doing so is greatly dependent on the cost of the reboiler fuel source, as discussed in the following section.

As shown in Table 3 the GLYNOXX process significantly reduces the vented emissions of a TEG dehydration plant compared to conventional plants. Moreover, it also more than halves the amount of methane emitted via the vent stream, which significantly reduces the carbon emissions of the plant as discussed in a later section. The lower vent stream flow rate and methane emissions are due to the recycle of stripping gas. The use of nitrogen as stripping gas would also cause a significant reduction in amount of methane emitted via the vent stream. In addition, the quantity of nitrogen required would be lower than that for a conventional plant however, the overall cost of generating nitrogen on site would have to be taken into consideration to determine if its use would be beneficial.

Alternative gasses to fuel or flash gas, such as nitrogen or carbon dioxide, are equally effective in the GLYNOXX process. Although the analysis of different types of stripping gas is out of the scope of this paper we can say that the type of stripping gas has an effect on the stripping gas flow rate however, the effect is usually not significant enough to alter the equipment design or cost. As such, the stripping gas may be easily changed during the life of a GLYNOXX plant.

As previously mentioned, Cases 2A and 4A employ a partial recycle GLYNOXX process in order to fully utilise the flash gas. For the plant investigated there is little difference between the operation of GLYNOXX in full or partial recycle modes however, for plants where the flash gas flow rate is high relative to the stripping gas flow rate then operating in partial recycle mode decreases the stripping gas rate relative to the full recycle mode and consequently decreases the reboiler duty and vented gas stream flow rate compared to full recycle mode.

## Economic Analysis

The cost of retrofitting the GLYNOXX process to an existing TEG dehydration plant and the economic benefit that it may bring are dependent on various site specific factors such as the existing plant size, configuration, location, and the price of gas, LNG and electricity. As such, we have only performed a simplified payback analysis for retrofitting the GLYNOXX process for each design case in order to provide an indication as to the economic value of such a retrofit. The results are given in Table 4 where for each design case we have also considered the situation where (i) the fuel gas is sold as natural gas and (ii) the fuel gas is converted and sold as LNG. The assumptions used in the calculations are given below and commodity prices have been obtained from published data over recent time periods.

- Retrofit equipment capital expenditure (CAPEX) excludes installation and commissioning costs as these are site specific and can therefore, vary significantly
- Fuel gas sell price (AEMO) = \$3 /GJ
- Cost of electricity (AGL) = 11 c/kWh
- LNG sell price (Platts Japan/Korea Marker) = \$7.70 /M BTU = \$11 /M BTU less 30% gas to liquid conversion cost (assumes infrastructure is in place)
- Electricity operational expenditure (OPEX) includes all electric power required by the TEG dehydration plant
- The cash flow figures given are the differential (rather than absolute) values between a conventional and GLYNOXX retrofitted plant
- Payback is based on cash flows; no discounting or risk factors are applied
- Annual operation = 330 days
- All figures are given in Australian dollars

Case	1A	2A	3A	4A
Retrofit equipment CAPEX (\$)	\$280,000	\$280,000	\$280,000	\$280,000
<b>Sales gas sold as natural gas</b>				
Δ Revenue from sales gas (\$ p.a.)	\$57,475	\$34,511	\$64,621	\$41,264
Δ Electricity OPEX (\$ p.a.)	-\$8,712	-\$8,712	-\$54,886	-\$49,658
Overall Δ cash flow (\$ p.a.)	\$48,763	\$25,799	\$9,736	-\$8,394
Payback (years)	5.7	10.9	28.8	N/A
<b>Sales gas converted and sold as LNG</b>				
Δ Revenue from LNG (\$ p.a.)	\$140,143	\$84,148	\$157,568	\$100,616
Δ Electricity OPEX (\$ p.a.)	-\$8,712	-\$8,712	-\$54,886	-\$49,658
Overall Δ cash flow (\$ p.a.)	\$131,431	\$75,436	\$102,682	\$50,958
Payback (years)	2.1	3.7	2.7	5.5

**Table 4: Economic comparison of a TEG dehydration plant GLYNOXX® retrofit**

Table 4 clearly indicates where the sales gas of a TEG dehydration plant is converted to LNG product then due to the high selling price of the value added LNG product the revenue and therefore, payback time obtained from the GLYNOXX process is highly favourable. In all cases where the final saleable product is LNG then the payback time for retrofitting the GLYNOXX process is between 2 and 5.5 years. In comparison, if the sales gas is sold as natural gas then the economics are only favourable for a plant with a gas-fired reboiler where the payback is in the order of 6 and 11 years for the cases where fuel or flash gas are used as the stripping gas respectively. In both cases the additional revenue resulting from not using saleable sales gas as stripping gas is significantly greater than the costs associated with the small additional amount of fuel gas required for the reboiler and the small increase in power usage. In contrast, where an electric reboiler is installed the cost of the additional power to account for the higher reboiler duty required by the GLYNOXX process largely outweighs the additional sales gas revenue.

Although a rigorous sensitivity analysis has not been performed, it should be noted that the economic return of the GLYNOXX process is highly dependent on the cost of the fuel used to power the reboiler. In particular, it is dependent on the gas, LNG and electricity prices, all of which could vary greatly according to the plant location and negotiated supply contracts. In our analysis we have used conservative pricing values so believe that there is scope for economic improvement depending on a client's individual circumstances.

As mentioned previously, the analysis performed here is for a simple retrofit of the GLYNOXX process and therefore, the process is not fully optimised. An improvement in the payback time could be achieved by implementing enhancements such as optimising the lean/rich exchanger to reduce the reboiler duty and replacing random packing for high efficiency structured packing in the stripping and still columns. As such, for a new build TEG dehydration plant with the GLYNOXX process the economics would be better than the retrofit cases shown here.

## Carbon Emissions

One of the original impetuses for the development of the GLYNOXX process was the introduction of a carbon tax by the Australian government however, at the time of writing this legislation was in the process of being repealed. Even so, analysis of the emissions from a TEG plant is still beneficial to determine where improvements can be made. The greenhouse gas emissions of the TEG dehydration plant were calculated using the Australian guidelines<sup>2</sup>, which closely follows that published by the American Petroleum Institute<sup>3</sup>. Emissions are reported in terms of tonnes of carbon dioxide equivalent (CO<sub>2</sub>-e), which is the conversion of all greenhouse gasses to an equivalent basis relative to their global warming potential. It should be noted that the global warming potential of methane is 25 times that of carbon dioxide so a reduction in the amount of methane emitted from a plant has a significant effect on the plant's carbon emissions. As per the guidelines emissions are categorised as follows:

- 1 Reboiler combustion
- 2 Fugitive emissions other than emissions that are vented or flared
- 3 Fugitive emissions that are vented or flared:
  - 3.1 Vented gas streams
  - 3.2 Vented gas from non-routine activities (*e.g.* maintenance)
- 4 Purchase of electricity

The calculations for categories 2 and 3.2 as listed above are dependent on the package inlet gas flow rate and are therefore, constant across all cases. In contrast, the emissions resulting from reboiler combustion, electricity usage and the gas vented from the still column depend on the operation of the particular plant, which can greatly affect the plant's overall emissions. Emissions from the purchase of electricity are calculated for a plant located in Queensland however, it should be noted that due to the difference in power generation methods across Australia and the World, this figure can vary greatly according to the plant's location.

Case	1A	1B	2A	2B	3A	3B	4A	4B
1. Reboiler combustion	980	891	980	891	-	-	-	-
2. Fugitive emissions other than emissions that are vented or flared	803	803	803	803	803	803	803	803
3 Fugitive emissions that are vented or flared								
3.1 Vented gas streams	4,781	15,914	4,873	11,857	4,987	15,914	4,866	11,857
3.2 Non-routine vented gas	3,190	3,190	3,190	3,190	3,190	3,190	3,190	3,190
4. Purchase of electricity	150	102	150	102	2432	2023	2425	2060
<b>Total (CO2-e tonnes)</b>	<b>9,904</b>	<b>20,900</b>	<b>9,996</b>	<b>16,844</b>	<b>11,410</b>	<b>21,922</b>	<b>11,283</b>	<b>17,907</b>

**Table 5: TEG dehydration plant estimated CO2-e emissions**

Table 5 indicates that the main source of carbon emissions from a TEG dehydration plant are from the vented gas streams from the still column and flash tank. For a conventional plant configuration the emissions from these streams are very high because the stripping gas is continually vented once it passes through the reboiler and still column and therefore, a significant quantity of methane is released into the atmosphere. In contrast, the GLYNOXX process greatly reduces the vented emissions as the stripping gas is recycled rather than vented thereby greatly reducing the quantity of methane vented. An alternate way to reduce the carbon emissions vented from a TEG dehydration plant is to replace the stripping gas with a non-greenhouse gas such as nitrogen however, a thorough analysis would need to be performed to determine if this use of nitrogen negated the additional emissions produced via its generation.

For each case investigated, the carbon emissions using a gas-fired reboiler are lower than the equivalent case using an electric reboiler, partially due to the fact that producing energy on site via gas combustion is more efficient than purchasing electricity that has been generated off site and transmitted possibly hundreds of kilometres.

## Conclusion

In response to client demands for more energy efficient glycol dehydration plants with lower emissions Process Group developed the GLYNOXX process, which offers glycol plant operators more favourable outcomes in terms of stripping gas usage and plant emissions compared to conventional stripping gas or azeotropic processes. In the GLYNOXX process stripping gas is continually recycled from a stripping column vent, reconditioned and returned to the stripping column so once the stripping gas circuit is charged there is very little gas make-up or venting during operation.

Via a series of process simulations we have shown that the GLYNOXX process decreases the stripping gas make-up flow rate as well as the overall quantity of fuel gas required to operate a typical TEG dehydration plant. Therefore, regardless of whether fuel or flash gas is used as stripping gas or whether the reboiler is gas or electric-fired a GLYNOXX retrofitted TEG dehydration plant will result in more fuel gas being available to sell, either as natural gas or as LNG. On the other hand, a GLYNOXX retrofit will increase the overall stripping gas flow rate and reboiler duty compared to a conventional plant as the recycled stripping gas contains some water and is therefore, less efficient at stripping water from the TEG than dry fuel gas.

A simplified economic analysis was performed to determine the payback time for retrofitting the GLYNOXX process on a TEG dehydration plant. Where the sales gas is converted to LNG the payback was between 2 and 5.5 years for all cases investigated. In contrast, where the sales gas is sold as natural gas then due to the lower selling price of natural gas compared to LNG, a GLYNOXX retrofit was only beneficial for a gas-fired reboiler configuration with a payback time in the order of 6 and 11 years for the cases where fuel or flash gas are used as the stripping gas respectively. This non-rigorous analysis is based on conservative assumptions and as the payback figures are dependent on the gas, LNG and electricity prices and the exact configuration of the GLYNOXX retrofit the economics will vary according to the circumstances surrounding an individual plant.

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